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NATIONAL ACADEMY OF SCIENCE AND ENGINEERING

eit Knowledge & Innovation Community

EIT ICT Labs

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Future Energy Grid

Migration to the Internet of Energy

acatech STUDY

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EIT ICT LABS

EIT ICT Labs is a Knowledge and Innovation Community (KIC) supported by the European Institute of Innovation & Technology (EIT). Our mission is to turn Europe into a global leader in Information and Communication Technologies - ICT innovations. Sustainable energy supply, intelligent traffic management and increasing the quality of life are just some of the challenges that society, business and politics will face in the future. Innovative ICT technologies offer new ways of giving a much needed boost to finding alternative solutions. Education, Research and Business are three elements in the EIT ICT Labs "Knowledge Triangle" and key drivers of the knowledge-based society. EIT ICT Labs aims to create a new breed of innovators and entrepreneurs that can develop breakthrough ideas - supported all the way to the market.

EIT ICT Labs Co-location centres in Europe play a vital role as virtual and live meeting places for project members, students, entrepreneurs, SMEs and start-ups as well as major industrial partners searching for new talents and new innovative opportunities. Mobility is a key factor – we bring people together across geographical and organizational borders. EIT ICT Labs – Bringing ICT Innovations to Life.

The action line Smart Energy Systems drives European innovation for future energy systems. Meeting the EU's climate change and energy policy objectives for 2020 and beyond will require a major transformation of our electricity infrastructure. The paradigmatic change from fully controllable power plants in the classical power grid to distributed area sources of alternative energy such as wind and solar calls for new qualities in the system-wide capture, aggregation and processing of data. Thus, the power grid becomes ICT-integrated – a convergence which is of technical, conceptual and economic nature. ICT is the key enabler for innovation and new business in the smart grid resulting in fast growing markets in Europe, U.S. and Asia for new ICT-based Smart Energy products, services and solutions. The action line Smart Energy Systems focuses the programmatic challenges of the smart grid and mobilizes a strong network of European partners from industry and academia to innovate on user involvement, business models and ICT-enabled technical infrastructures.

For more information, please see www.eitictlabs.eu

acatech – NATIONAL ACADEMY OF SCIENCE AND ENGINEERING

acatech represents the German scientific and technological communities, at home and abroad. It is autonomous, independent and a non-profit organisation. As a working academic institution, acatech supports politics and society, providing qualified technical evaluations and forward-looking recommendations. Moreover, acatech resolves to facilitate knowledge transfer between science and industry, and to encourage the next generation of engineers.

The Academy counts a number of eminent scientists from universities, research institutes and companies among its Members. acatech receives institutional funding from the national and state governments along with third-party donations and funding for specific projects. It organises symposiums, forums, panel discussions and workshops to promote new technologies in Germany and to demonstrate their potential for industry and society. acatech publishes studies, recommendations and statements for the general public.

The Academy is composed of three bodies, the Members, organised in the General Assembly, the Senate, whose well-known figures from the worlds of science, industry and politics advise acatech on strategic issues and ensure dialogue with industry and other scientific organisations in Germany, and the Executive Board, which is appointed by the Members of the Academy and the Senate, and which guides the work of the Academy. acatech's head office is located in Munich while offices are also maintained in the capital, Berlin, and in Brussels.

For more information, please see www.acatech.de

FOREWORD

BY DR PHILIPP RÖSLER

DR PHILIPP RÖSLER, FEDERAL MINISTER OF ECONOMICS AND TECHNOLOGY

Establishing the path towards a new energy era represents one of the great challenges of the 21st century. In Germany, we have already set our course with the 2011 Energy Package. The central challenge is now to integrate the fluctuating feed-in from wind and solar power with stable and affordable energy services.

The fruits of wind and solar power are not always available everywhere. Electricity generated from renewable sources has to be transported from the north to the south, and as a result we need new grids. Moreover, the power must be available when consumers – citizens and companies – need it. So we need to expand our electricity storage capacities, too. In addition, we have to be able to control consumption, so that the power load can adapt to fluctuations from renewable energy sources. Smart systems ensure a high degree of profitability and reliability of supply by monitoring, directing and regulating the power supply. The underlying basis for this is provided by modern information and communications technologies (ICT).

Our E-Energy flagship project in 2007 gave the green light for the intelligent electricity supply system of the future – the smart grid. Interdisciplinary research projects into new ICT-based procedures, applications, infrastructure and smart grid frameworks have been developed and tested in six model regions. Real-life examples are demonstrating the major contribution that ICT can already make to modernising the energy sector.

Now it is time to look further into the future. Alongside the activities of the E-Energy model regions, we are also incorporating acatech's Future Energy Grid project into our E-Energy support programme. This project is analysing the technological, economic, political and social factors required to ensure the successful construction of smart grids by 2030. International developments are also taken into account. The findings of this project are revealing the key factors for development of innovative ICT concepts and software systems in order to achieve the successful conversion of the energy supply system. This is also helping to find answers to current problems, and to develop a framework of regulation that promotes growth.

The next step is to ensure that this new expertise can flow rapidly into further progress across a broad spectrum. The publication of this study will assist in the task of distributing this knowledge. I would like to thank the publishers for their initiative, and wish everyone reading this report much success in their work on innovative energy systems.

Yours faithfully,

Philipp Rösler
Federal Minister of Economics and Technology

FOREWORD
BY GÜNTHER OETTINGER

GÜNTHER OETTINGER, EUROPEAN COMMISSIONER FOR ENERGY

The 2020 Agenda of the European Union contains a key message, namely that economic growth and employment in Europe will depend increasingly on innovation in products and services. Among these innovations are smart grids, which serve to make more efficient and sustainable use of natural resources. In April 2011, the European Commission published a Communication entitled "Smart Grids: From Innovation to Deployment". If existing grids are not fundamentally modernised and upgraded, the generation of electricity from renewables will stagnate. Moreover, opportunities to achieve energy savings and improve energy efficiency will be missed.

Smart grids form the backbone of a carbon-free electricity system of the future. Their development also represents an opportunity for us to support the competitiveness and global technology leadership of European providers. We are at an early stage of deployment. In the past ten years over 5.5 billion euros have been invested in around 300 smart grid projects in the EU. Smart meters are currently installed in around 10 percent of all households in Europe, and they have already helped consumers to reduce their power consumption by as much as 10 percent.

The EU can contribute toward the deployment of smart electricity grids by developing a relevant legal framework, directing investment and issuing standardisation mandates. The development of uniform technical standards for a pan-European smart grid represents a challenge, but it is not insurmountable if we are able to bring about the internal market for energy by 2014, and incorporate the final "energy islands" in the EU into the interconnection grid by 2015. The European Commission has asked European standardisation organisations to develop European standards for smart meters, electric vehicle charging equipment and smart grids. In order to ensure that the standards are agreed in time by 2012, the Commission will monitor the standardisation development process and if necessary will take care of the process of developing network codes.

However, we must also take advantage of the opportunities that arise outside the borders of the European Union. For this reason, the Commission is supporting projects such as the development of renewable energy in the southern Mediterranean. An example of these is the DESERTEC industrial initiative, which aims, by 2050, to cover 15 percent of the EU's demand for electricity, as well as the local requirements, from sustainable, climate-friendly generation located in the North African desert. To enable this, on 24 November 2011 representatives of DESERTEC and MEDGRID signed a cooperation agreement. As these two initiatives together form a very impressive cluster of expertise and enterprise around the Mediterranean, I am extremely pleased to see that they now wish to combine their forces for the good of all sides.

I am certain that acatech, under its guiding vision of sustainable growth through innovation, will also contribute to the realisation of the EU's energy policy objectives. Supported by its network of excellent scientists in many different disciplines, it provides industry, politicians and the general public with advice, thus helping to resolve global challenges, not least those surrounding competitiveness, reliability of supply and sustainability in Europe.

Günther H. Oettinger
European Commissioner for Energy

FOREWORD

BY PROFESSOR DR HENNING KAGERMANN

PROFESSOR DR HENNING KAGERMANN, PRESIDENT OF acatech

In contrast to other, traditional academies, acatech – Germany's National Academy of Science and Engineering – brings together experts from science, industry and other parts of our society. Against the backdrop of this unique composition of experts, however, just like many other academies around the world we seek to address global challenges. After all, energy efficiency and efficient use of resources are joined by demographic change in demanding new, key conditions for the success of innovation. And it is on innovation, rather than reinvention, that our work focuses.

So it was no surprise when, during a survey of over 60 experts conducted in autumn 2011, every single one of the future topics that was raised could be fitted in to one of the five action areas of the Research Union: climate/energy, health/nutrition, mobility, security and communication. What was noteworthy, however, was the massive importance attached to information and communication technologies (ICT) in their role as key technologies and enablers.

The main drivers of future-oriented developments are the Internet, embedded software-intensive systems and the technical and economic convergence of the physical world with cyberspace to create cyber-physical systems (CPS). CPS use sensors to gather data from the physical world, which they then process and convert into information that they provide in the form of networked services for a range of applications. The feedback loop to the physical world is provided by actuators, which convert electronic signals into mechanical actions for direct impact. Physical processes are coordinated and optimised in what are currently unique methods, and new potential for exploitation is being discovered. Humans encounter CPS everywhere – in the form of smart cars, smart factories or smart grids. They represent a key step on our journey towards a global Internet of Things, Data and Services. acatech has only recently published two documents on this topic, with "Cyber-Physical Systems. Innovationsmotor für Mobilität, Gesundheit, Energie und Produktion" describing how CPS represent an engine for innovation in mobility, health, energy and production, and "Internet der Dienste" explaining the Internet of Services.

The trend for networked services has been evident for years. When we were seeking an overarching motto at the first IT Summit in 2006, we agreed on "Plattformen für vernetzte Systeme" or Platforms for Networked Systems. The Internet of Things was established as a flagship project, alongside the Internet of Services and the most important application of these concepts, the Internet of Energy, which was later piloted in the various model regions as part of the E-Energy funding programme. The development of E-Energy as a path towards the Internet of Energy has proven to be very successful for two other reasons, as well. First, findings from the programme have transferred to other cable/pipe-based infrastructures, such as the gas and water grids. Second, the programme has opened doors for other innovations, such as electric mobility.

As early as 2009, acatech, together with the Leopoldina National Academy of Sciences and the Berlin-Brandenburg Academy of Sciences and Humanities, presented an integrated programme of energy research that placed particular emphasis on the "no-regret measures": energy efficiency, storage and smart grids.

For the first time, this final report of the acatech "Future Energy Grid" project identifies the technologies and functionalities required in order to establish the migration paths towards the Internet of Energy. It demonstrates that the convergence process between energy technology and ICT can succeed.

It has produced a broad, new reference work of facts and data. In June 2011, the initial interim findings and recommendations from this project found their way into the final report of the "Sichere Energieversorgung" (Secure Energy Supply) ethics commission, meeting with a good response.

The analysis has confirmed that information and communications technologies are a significant enabler for the energy revolution. The increasing requirements for metering and regulating the generation, transmission, storage and consumption of electricity can only be met by means of intelligent convergence of ICT and energy systems. The recommendations that have been derived from these findings are published in parallel, in the acatech POSITION PAPER series bearing the title "Future Energy Grid. Information and communication technologies for the path towards a sustainable and economical energy system". The core message is that there are no major obstacles that will make it impossible to deploy and expand smart grids. Nevertheless, if it is not possible to implement an integrated overall strategy in which the key action areas are matched against each other, the energy revolution may be delayed by many years, or, in the worst case, may even fail entirely. Smart grids are not simply a desirable future dream, they are a necessity. The current electricity infrastructure is just not designed to cope with the future increasing levels of electricity produced from fluctuating renewable energy sources such as the wind and the sun.

The restructuring of the electricity infrastructure presents massive challenges to industry, science, politicians and society as a whole. The recently published report on the popular consultation on energy technologies for the future conducted by the Ministry of Education and Research clearly indicates the need for measures. Moreover, the consultation confirms that citizens cannot simply be viewed as passengers on the journey towards the energy supply of the future, but must be involved actively in these processes from an early stage.

I would like to thank the Federal Ministry for Economics and Technology for its support of the project as part of the E-Energy programme. This analysis reveals once again that the successful completion of the energy revolution will depend on combining the right amount of technological innovation with social changes and innovative business models. The complexity of systems all around us is increasing, and that is equally true of the energy supply. Only by ensuring coordinated cooperation of all participants and lean monitoring will we succeed in avoiding the "Complexity trap" scenario described in this study and establish a full smart grid in line with the energy policy objectives of the energy revolution.

Yours faithfully,

Henning Kagermann
President of acatech

EXECUTIVE SUMMARY

The objective and pace of the energy revolution have already been decided. Germany intends to cease nuclear generation of electricity by 2022. It has long been planned that electricity generation from fossil fuels such as gas and coal will be stopped by 2050, in a staged process, and replaced by renewable energy sources. Politicians, the economy, science and the population at large face immense challenges in relation to the "energy revolution". For the successful integration of wind and solar power into the energy system, along with the new processes, market roles and technologies this entails, information and communication technology (ICT) is a key enabler. The German electricity system is already in a state of upheaval. For a number of years, it has been adapting to significantly different energy policy and environment policy conditions. Since 2000, the Renewable Energy Act (EEG) has promoted and guaranteed the priority usage of electricity from renewable sources. Mandatory participation by industry in the emissions certificates trading market and the Federal Government's objective of reducing greenhouse gas emissions are contributing to improved energy efficiency. At the same time, alongside these state interventions in the market, there have been attempts to strengthen competition on the energy market. The course has already been set for the transformation from a centralised structure of conventional generation to a distributed one in which renewables play a major role.

RENEWABLE, DISTRIBUTED AND FLUCTUATING – THE CHALLENGES OF THE ENERGY REVOLUTION

The transformation to renewable energy sources entails a mostly fluctuating pattern of power generation. The supply of power, which will fluctuate far more markedly due to the increasing proportion of wind farms and photovoltaic (PV) systems, must be kept in harmony with the equally fluctuating demand. In addition, there is the problem that most of this supply relies on distributed feed-in, or plants that feed in directly to the distribution grid. While the flow of electricity was previously from the top down, from high voltage to low voltage, there are now increasing levels of reflux from lower voltage levels. The grid infrastructure must be adapted to cope with this bidirectional power flow. For example, greater numbers of local smart substations will be constructed so that the distribution grid is equipped to coordinate bidirectional load flows. Throughout the distribution grid, the demand for high-time-resolution metering, regulation and automation of the electricity flow is growing. In addition to the current developments on the generation side, consumption characteristics will also change in the future. Electric mobility, heating pumps and other consumer appliances will create a new dynamic in the distribution grid and will be integrated into the smart grid. Variable tariffs may also lead to increased grid load. As the switchover to renewable energy sources progresses, it should be anticipated that electricity will be used increasingly to provide heating and to power mobility.

To integrate renewable energy sources, the grid infrastructure must be adapted at all levels. The electricity system of the future will appear different, not only because of the addition of major lines for long-distance transmission, but also in terms of the distribution grid. To balance out supply and demand, storage will play an increasingly important role. A variety of technologies will be used, depending on the timescale (from the sub-second range up to seasonal balancing). In parallel to the technical changes, new developments are also reaching the energy market. While competition will increase significantly, there will also be a need for greater direct intervention in the market in order to achieve climate protection goals and protect consumers.

In conjunction with the technical changes, therefore, the market structures will also have to undergo significant adaptation, and end users and micro generators will have a much greater direct influence on market activities. New sales and business models that rely on the increased use of ICT will create incentives for consumers to modify their energy usage patterns. The large installed capability of renewable energy sources for generation will regularly lead to situations in which the overall system produces more power than is currently needed. New markets or market rules must be created for this situation, to realise the triumvirate of energy sector objectives.

The security and commercial viability of the energy supply are vital for a highly technologised industrial country on the way to achieving a sustainable energy supply. ICT and the corresponding communication standards can contribute to overcoming these challenges. The use of ICT should improve the integration of the distributed energy resources (DER) and help match generation to supply and achieve a higher level of customer benefit. The basic challenges are known both in the energy sector and politics. In many places, work on a solution has already started. This can be seen in the example of the six model regions participating in the E-Energy Initiative of the Federal Ministry for Economics and Technology (BMWi).

METHODOLOGY AND COMPOSITION OF THE STUDY

This study describes the migration path that must be followed to achieve the "Future Energy Grid" (FEG) by 2030.

To do this, the investigation considered which potential future scenarios could be affected by this migration path. To produce the scenarios, significant key factors were determined, namely the expansion of the electricity infrastructure, availability of a system-wide ICT infrastructure, greater flexibility of consumption, energy mix, new services and products, costs for end consumers, standardisation and the political framework.

These eight key factors are combined together in a variety of ways to form the three consistent scenarios for 2030:

1. "20th century": The energy supply system is based on bulk non-fluctuating generation, which permits load-based operation as in the 20th Century. There are very few new ICT-based services on the market. In general, variable tariffs are not used. Legislation has implemented this path consistently and reinforced competition.

2. "Complexity trap": Despite there being strong social and political will for the energy revolution, it has not been possible to implement this operationally in a uniform body of legislation. The main actors have been unable to agree on a single way forward or to get behind a single set of standards. This also results in problems with the expansion of the electricity infrastructure. The supply of new energy services is limited to just a few basic functions. The lack of uniformity in these developments is reflected in high costs for the energy supply system.

3. "Sustainable & economic": The transformation of the energy system by 2030 has been successful. Smart grids have made a major contribution to this. By reaching agreement between energy policy, society, energy suppliers and technology providers, the transformation was concluded according to a long-term plan. The supply of electricity is based primarily on renewable energy sources. The system-wide ICT infrastructure and the requirements-based expansion of the transmission grid and distribution grid form the backbone for the efficient operation of the power supply and the platform for a range of new services that act increasingly as drivers for new business models. Competition on the energy market has intensified.

The next step is to respond to the question as to the type of technological progress necessary for each scenario. In general, each relevant, ICT-related technology area can be assigned to three (ICT) system layers: the closed system, which is primarily controlled by the grid operators, the networked system layer, which has a range of actors, and the ICT infrastructure layer, which ensures the exchange of information.

The potential development of each technology area can be divided into up to five development stages progressing to 2030. For each of the scenarios, the degree of development required by the technology area before the overall system described in the corresponding scenario is realised must be identified. A major challenge is presented by the mutual logical interdependencies of the technologies as they develop. To determine the migration path, all dependencies between the development stages were calculated. This produced an overview for each scenario, with the dependencies allowing a sequence of the necessary developments to be drawn up.

THE PATH TOWARDS THE FUTURE ENERGY GRID

The "Sustainable & economic" scenario corresponds most closely to the objectives of the energy revolution, and was therefore analysed in particular detail. It has been found that the development up to 2030 will cover three phases:

1. During the Concept phase (2012-2015), the course will be laid for further development in the closed system layer in particular.

2. The Integration phase (2016-2020) is characterised by the systems in the closed system layer requiring increasing access options to components in the networked system layer. The rapid development of the ICT infrastructure layer is a key trigger in this process.

3. During the Fusion phase (2021-2030), the closed and networked system layers merge, as do the electrotechnical systems and ICT system. The now high mutual dependency between closed and networked system worlds requires, in particular, a high level of development among the cross-cutting technologies and ICT connectivity. Major importance is attached to security.

In each phase, there are critical dependencies in the development of technology. Particular attention must be paid to these critical points.

Alongside the necessary technological development stages, the successful transformation of the energy grid also requires political, economic, social and international supporting conditions. A Future Energy Grid will not only offer a solution for the energy revolution. It is also linked to economic prospects for Germany. In order to assess Germany's options as a pioneer and exporter of smart grid technologies, the development of the energy system here must be ranked in comparison with selected countries around the world. Germany has the opportunity to take technological leadership for smart grid technology. Ongoing demonstration projects for smart grid technologies, for example the model regions of the E-Energy Initiative of the BMWi, are helping Germany to access international markets. Nevertheless, a lack of sufficiently trained specialists may impact on this. Some countries are investing significantly more in smart grids and have established a technology advantage in some areas.

Legislation needs clear revision in respect of the changes that are occurring, to promote both competition and renewables feed-in, so that a large amount of value creation can be enabled by using smart technologies. Measures to integrate renewable energy sources into a market design that also takes account of the needs of the distribution grid are described here. A broad roll-out of digital meters is seen as critical, from both technical and market perspectives.

The redesign of the energy system must carry consumers with it. Even though the core topic of this study is technological migration paths, acceptance issues are considered in detail. Consumers are integrated into the development of the smart grid and are actually at the focus of many developments. "Consumers" are not a single, homogenous mass, but differ considerably according to the values they hold, their income levels and preferences, etc. Therefore, "milieus" are used to investigate the form of integration and to determine which milieus may play a leading role. For the topics under consideration, the Liberal-intellectual and High achievers milieus are important. These are milieus with high income levels that are open to innovation. Open communication about costs, benefits, risks and design options is of great importance for the other groups of consumers. A key factor in establishing acceptance is cooperation in development. If attractive products gain market penetration in the Future Energy Grid environment, the issue of acceptance will no longer arise.

The aim of this study is to help place this often opaque combination of topics in a structured context, and thus to participate meaningfully in the debate on the best way to achieve the ICT-supported energy supply system of the future.

Due to the necessary convergence of ICT and energy systems in the Future Energy Grid, and the broad range of topics, this study has taken the form of an interdisciplinary project in which technical experts from a range of disciplines and sectors were involved, along with experts in the economy and social sciences.

PROJECT

The original German version appeared under the title *Future Energy Grid. Migrationspfade ins Internet der Energie* and was published as part of the acatech STUDY series.

This study also formed the basis for the acatech POSITION PAPER *Future Energy Grid – Information and communication technologies for the path towards a sustainable and economical energy system (acatech 2012).*

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1 INTRODUCTION AND OBJECT OF THIS STUDY

The objective and pace of the energy revolution have already been decided. By 2022 Germany's exit from nuclear generation of its electricity supply should be complete. By 2050, the production of electricity from renewable energy sources should have weaned the country off its traditional reliance on coal, nuclear fuels and natural gas one step at a time, and thus made a major contribution to the Federal Government's climate protection goals. The path to obtaining these goals still remains unclear for all involved, however. Many questions relating to technology, cost, legislation and society are still unanswered and are impairing the vision of a clear strategy to achieve energy policy objectives. Politicians, the economy, science and the population at large will face complex tasks and immense challenges in relation to the mammoth "energy revolution". Information and communications technology, or ICT, is a key enabler in the successful integration of wind and solar power, and for new processes, market roles and technologies. This is where this study comes in.

– How can ICT contribute to a successful energy revolution?[1]
– What forms might the technological migration to a future energy system take?
– What can and must be done in parallel to the technological developments, to ensure that the energy revolution has a successful outcome in Germany as a highly industrialised nation, providing a role model for other countries?

The analysis, concepts and visions presented in this study in response to these questions are focused on the contribution to be made by ICT, as well as on the necessary and potential developments in this area. The overlap between ICT and energy systems (electricity grid infrastructure, storage, power generation and consumption technologies) plays a key role.

The study has considered the current state of research and development, and documents the current changes in the electricity system. On the basis of assumptions about the future development of technology, the markets and politics, it takes a constructive bird's-eye view of the path towards the Internet of Energy (IoE) taking us up to 2030. In Chapter 3, 19 system-defining technology areas are identified for three scenarios that outline the utopic vision. Chapter 4 then builds up corresponding detailed technological paths for migration to the electricity system of the future. In addition, as well as providing an international comparison illustrating developments in other European and non-European countries, Chapter 5 describes the benchmark for current developments as set in Germany, stating the potential points for optimisation and learning. Alongside the technological issues, selected aspects relating to the options and limitations of the legislative and regulatory framework (Chapter 6) and the acceptance of the technology by the population (Chapter 7) are also addressed.

The aim of this study is to help place this often opaque combination of topics in a structured context, and thus to participate meaningfully in the debate on the best way to achieve the ICT-supported energy supply system of the future.

THE ORGANIC EVOLUTION OF THE POWER SYSTEM IN GERMANY UP UNTIL THE START OF THE 21ST CENTURY

The starting point for the energy revolution is a reliable, proven electricity system that has evolved over decades. The infrastructure and growth of the German power system can be outlined as follows:

The structure of electricity generation in Germany is characterised, for systemic reasons, by a directed load flow (generation – transportation – distribution – usage) from central core generators, such as nuclear and coal-fired power plants. These central, major power plants feed in electricity at the EHV (extra high voltage) level of between 220 to 380 kV. While the high voltage (110 kV) grids are used as a feed-in grid for smaller power plants, and are nowadays mainly for use by larger wind farms, they were intended in the original plans for use as a redistribution system to provide the electricity over medium voltage (10 to 40 kV) grids. In close proximity to the consumer (for example on the periphery of towns and cities), the power is stepped down by transmission substations first to medium voltage level and then in local distribution substations to low voltage level (230 to 400 V) before being supplied to the consumer.

1 An overview of the research questions can be found in Appelrath et al. 2011.

As an alternative to this subdivision into four voltage levels, the grid may also be divided into a transmission grid and a distribution grid. Long-distance transportation, for instance between northern and southern Germany, uses the transmission grid, which is formed entirely of EHV grid components. The transmission grid is characterised by mostly above-ground suspended cables with visible electricity pylons. There are currently four transmission system operators (TSO) in Germany. The distribution grid is used to carry the electricity close to consumers or over short distances; it comprises high, medium and low-voltage grids. In these cases, the electricity is normally carried via underground cables. In comparison with the number of TSOs, the number of distribution system operators (DSO) in Germany is much higher, at around 866. Of the total 1.73 million km length of the German grid in 2009, around 35,000 km (or some two percent) could be classified as part of the extra-high voltage transmission grid. With 76,800 km (around four percent) of high voltage cable, 497,000 km (around 29 percent) of medium voltage cable and 1.12 million km (65 percent) of low voltage cable, the total share of the distribution grid in the overall German electricity system is therefore around 98 percent.[2] The various grid sections and voltage levels are connected by transfer points, switchgear and some 550,000[3] transformers.

In the past, the flow of electricity through the grid has always been directed from the major generating companies to the consumers. Bi-directional flows never formed part of the original supply role, and in the past only occurred on the transmission grid, i.e. for the purposes of long-distance transmission. In the distribution grid, the electricity flow has always been strictly one-way. Electricity generation followed demand – the electricity usage. In many areas this remains the case today. When electricity usage rises, the output of individual power plants increases or additional power plants are brought online. When the demand falls, the reverse happens. Therefore, in Germany, as in every other country, we have a demand-led electricity system. Consumers can take as much electricity out of the grid as they wish, at any time, or at least as much electricity as the physical characteristics of the grid infrastructure will permit. The obligation imposed by legislation to provide a grid infrastructure that is appropriate for these conditions, in other words to create and maintain the grid infrastructure and to guarantee its availability, is borne by the DSOs in the case of the distribution grid and by the TSOs in the case of the transmission grid.

The supply of consumers (domestic households and commercial customers consuming less than 100,000 kWh per annum) with electricity from the grid is based on the standard load profiles, which are derived from past experience of electricity usage and are updated at regular intervals. According to these profiles, every 15 minutes the power generating companies feed specific amounts of electricity into the grid without actually knowing the real level of usage by end customers at that point in time. Discrepancies between the estimated load profile and the actual usage are regulated at short notice. The existing grid infrastructure has been designed and constructed with this conventional form of generation and supply in mind (see Figure 1).

In addition to having technological expertise, a knowledge of the market is also needed to understand the German electricity system. In 2009, around 83 percent of the electricity in Germany was generated by four major energy utility companies (EUC).[4] Alongside these generating companies, there are some 300[5] municipal utilities or regional generating and supply companies with generating capacities of greater than 1 MW electric output. Combined with a highly volatile number of additional small and micro generating companies, these contribute the remainder of Germany's domestic electricity generation capability. Until the mid-1990s, the grids were owned and operated largely by the EUCs. As a result, the entire value chain from generation and sale through to supply was mainly tied up within one group. In 1998, the German Energy Economy Act (EnWG; Energiewirtschaftsgesetz) regulated the unbundling of ownership of electricity production and distribution. Since then, the market has undergone a substantial change. The introduction of unbundling as part of energy policy came about through the EnWG (by the German Federal Government) and through the Internal Market in Electricity Directive (by the EU), in order to avoid

2 BNetzA 2010a, pp. 84-85.
3 BDEW 2011a.
4 BNetzA 2010a, p. 19.
5 BDEW 2011b.

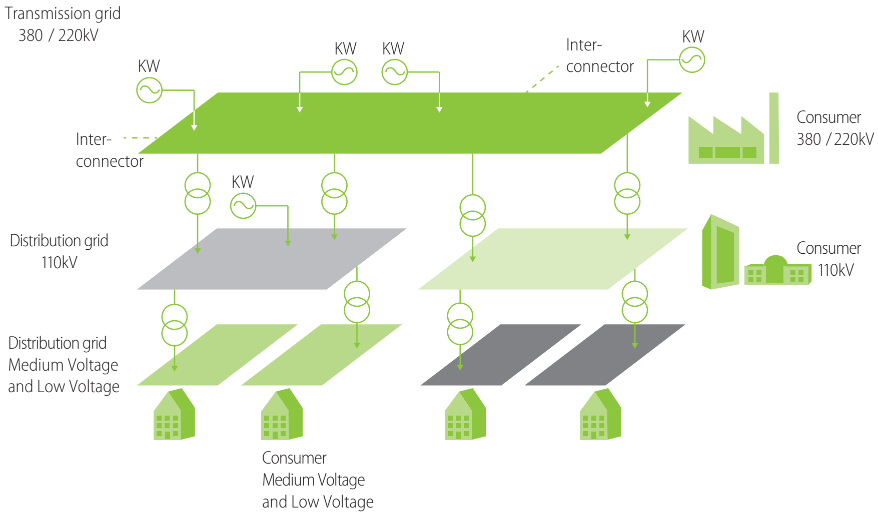


Figure 1: Composition, components and tasks of the electricity infrastructure (according to RWE, with modifications)

monopolies and guarantee greater competition among electricity suppliers. This process is still underway and the market and provider structures it has created have come to characterise the current energy economy landscape.

The use of ICT within this grid infrastructure has grown consistently over the past decades as the technology has moved on. However, where ICT is used in the electricity system it is limited to internal, largely uncommunicative isolated solutions for measurement and governing, as done by the EUCs and grid operators. In respect of the grid infrastructure, ICT deployment has been focused on the transmission grid (two percent of the total grid) since this is where bidirectional power flows occur regularly, requiring regulation and monitoring. In contrast, the distribution grid has largely been a blind spot in terms of ICT usage to date.

CURRENT CHANGES WITHIN THE GERMAN ELECTRICITY SYSTEM AND THEIR EFFECTS

Triggered by changes in energy policy and environment policy, the German electricity system has already been continually adapting to new technical opportunities and requirements for many years. Since 2000, the German Renewable Energy Act (EEG; Erneuerbare-Energien-Gesetz), as the successor to the Electricity Feed Act (SEG; Stromeinspeisegesetz), has required and guaranteed that the use of electricity generated from renewable sources be prioritised. It has therefore ensured a constant and substantial reconfiguration of the system through to the current day. In addition, the mandatory participation by the energy industry in trading in emissions certificates, combined with the Federal Government's objective of reducing greenhouse gas emissions, is contributing to a further increase in the proportion of renewable energy in the energy system. In summer 2011, Germany decided on an accelerated exit strategy from nuclear power by 2022, thus triggering yet another fundamental change in the energy system that will make a further contribution to achieving the energy policy objectives of the Federal Government's energy programme[6]. The course has therefore been set for the increased expansion of distributed generation based on renewable energies.

The energy policy objectives of the Federal Government's energy programme and the currently applicable package of measures point the way from a predominantly centralised structure to a predominantly

6 BUND 2011.

decentralised structure, from a system of electricity generation by conventional means to a system of generation from renewables. This will entail a change from a constant generation pattern to a fluctuating pattern, and from a load-led system to one that is led by generation. As a consequence, the known and constantly repeating generation and usage patterns will change in favour of very dynamic and flexible patterns with increasing need for regulation. The fluctuating supply of current from distributed generation, for example from wind farms and photovoltaic (PV) installations, must be matched against demand which fluctuates as much, in order not to compromise the stability of the grid and very high levels of power supply reliability in Germany. The increasing level of generation in the distribution grid will mean that more power is generated than used at a local level, and the load flow will thus be reversed. As a result the grid infrastructure will be placed under increased demands. This will entail a greater requirement for metering, regulation and automation of the power flow, and for high-resolution regional monitoring and control throughout the grid.

When it comes to guaranteeing the reliability of supply, the outlined developments will represent an enormous economic as well as a major technical challenge. The ongoing technical alterations needed currently comprise expansion and upgrading of the grid infrastructure, as well as addition of storage capacity and the introduction of ICT-based feed-in management.

The grid expansion measures currently being presented in Part Two of the German Energy Agency (dena; Deutsche Energie-Agentur) Grid Study have clarified the need to bridge the large geographical distances between the key wind power generating regions in the north of Germany and the major usage centres in the south. The requirement for transmission lines is estimated to come to around 850 kilometres by 2015 and around 3,600 kilometres by 2020. The primary focus is on the EHV system, that is the two percent of the grid infrastructure that is used for long-distance transmission.[7] However, optimum usage and integration of renewable energy sources also requires increased action in the downstream grid levels. The combination of ICT and energy technology may help reduce the need to expand the grid, by allowing more intelligent use to be made of the existing infrastructure.

Storage technologies play a key role in balancing supply and demand. A range of technological options are available in this respect, such as batteries, compressed air energy storage (CAES), pumped-storage power plants and the conversion of electricity into hydrogen as well as the potential for further synthesis to methane (power to gas technology). At the present time, these options are either not yet technologically mature (take the example of adiabatic CAES), uneconomic or not sufficiently profitable, or the potential locations are greatly restricted (for example the lakes or reservoirs required for pumped-storage power plants). Further development is therefore necessary in the field of storage technologies. This development must take account of the fact that the aforementioned potential storage solutions must feed the grid at various levels, while also supporting a range of different system services or supply roles. All of them require mutually adapted IT architectures and communications protocols.

The demand for increased ICT in the grid rises significantly in parallel with the need for measurement and regulation. The use of ICT should allow distributed generators to be integrated, achieving a balance of generation and usage. With ICT-based feed management, the DSOs are starting to react to the changing patterns and characteristics of generation, and therefore also adjusting to the technical requirements being made of the grid infrastructure.

In parallel to the technical changes, new developments are also reaching the energy market. The prioritisation of power from renewables leads to occasional situations in which there is an over-supply of electricity in the system overall. In these cases, the storage capacities must be topped up or generation capacities must be taken offline or powered down, to the extent that this is legally permissible for systems that are designed to use renewable energy. There was even a recent case on the Leipzig electricity exchange where over-production of electricity led to a short period of negative electricity prices. Actually buying electricity provided a revenue. Even though the reasons for these extreme events are certainly complex, they can just as accurately be traced back to the current, extremely dynamic changes in the energy system and the fact that the market has not yet fully adapted. In conjunction with the technical changes, therefore, the market structures

7 dena 2010a.

will also have to undergo significant adaptation, and end users and micro generators will have a much greater direct influence on market activities.

Along with the technical adjustments, the forecasting tools for fluctuating energy sources will be improved in order to facilitate planning. The accuracy of the forecasts of the duration and intensity of wind and sunshine will make a major contribution to ensuring the integration of renewables into the energy system is as easy as possible.

All of the technical and non-technical solutions outlined here are already helping to form a better understanding of the overall system and the inherent inter-relations of elements in the complex energy system. However, this understanding must be developed substantially if the success of the energy revolution is to be ensured and sustainable solutions are to be implemented.

THE USE OF ICT IN THE ENERGY SYSTEM – THE "INTERNET OF ENERGY"

Responding to the outlined changes and challenges through energy technology will affect both the design and construction of the grid infrastructure and the monitoring and control of the grids or electricity flows. The rising requirements for measurement, regulation and communication between system components (energy generation, distribution and usage technologies, storage, markets and trading rooms) can be met successfully if these components are merged to form functional, communicative entities. ICT will thus assume the function of a key enabler for the technical restructuring of the German energy system. The convergence of ICT and energy technology as they develop will therefore make a decisive contribution to the success of the energy revolution. The phrase "Internet of Energy" neatly describes the new quality of adaptation and interconnection exhibited by these two spheres of technology.

As the examples of largely internal and closed-loop ICT concepts for measurement and regulation in generation plants or discrete grid components demonstrate, the integration of ICT into the distribution grid and communication between system components is already gradually gathering pace. Photovoltaic and wind power systems (in excess of 100 kW) already have to be deactivated at short notice in emergency situations. This means these systems must communicate with the responsible DSO, which must be able to control them remotely. Information from smart electricity meters is already flowing from consumers to the appropriate electricity providers. Increasingly, local substations are also being equipped with the functionality to communicate. Growing numbers of communicating system components are being incorporated into the infrastructure. Generators, grid operators, electricity providers and consumers have to be given greater opportunities to communicate in real time.

In this study, we apply a concept of the Future Energy Grid (FEG) that focuses on the various layers of ICT usage options (see Figure 2). The concept takes the currently existing ICT infrastructure, as used by EUCs and grid operators as isolated solutions – mostly internal or corporate – (referred to here as the "closed system layer"), and adds an additional ring of additional ICT such as intelligent domestic devices, electric vehicles or distributed generation facilities (referred to here as the "networked system layer"). As a result, bidirectional communication is required between the various isolated systems and the new ICT ring, referred to as the "ICT infrastructure layer". Particular importance is now attached to the public communications network. Another key aspect will be which connections between the components are subject to the free market and which will be regulated. Issues of information security and data protection also play a major role.

PROCESS PARTICIPANTS AND PROTAGONISTS ALONG THE PATH TOWARDS THE "INTERNET OF ENERGY"

The energy revolution and the construction of an intelligent, or smart electricity infrastructure require the involvement of a great many partners. Generators, grid operators, consumers, market participants, research and development, training facilities for the technicians, engineers and scientists of the future, and of course the government, must all work closely together to find sustainable solutions to the issues and challenges raised by energy policy.

The power generation side, with the major EUCs, the municipal utilities, the local providers and the many micro and private electricity generators, must supply the required amounts of renewable power.

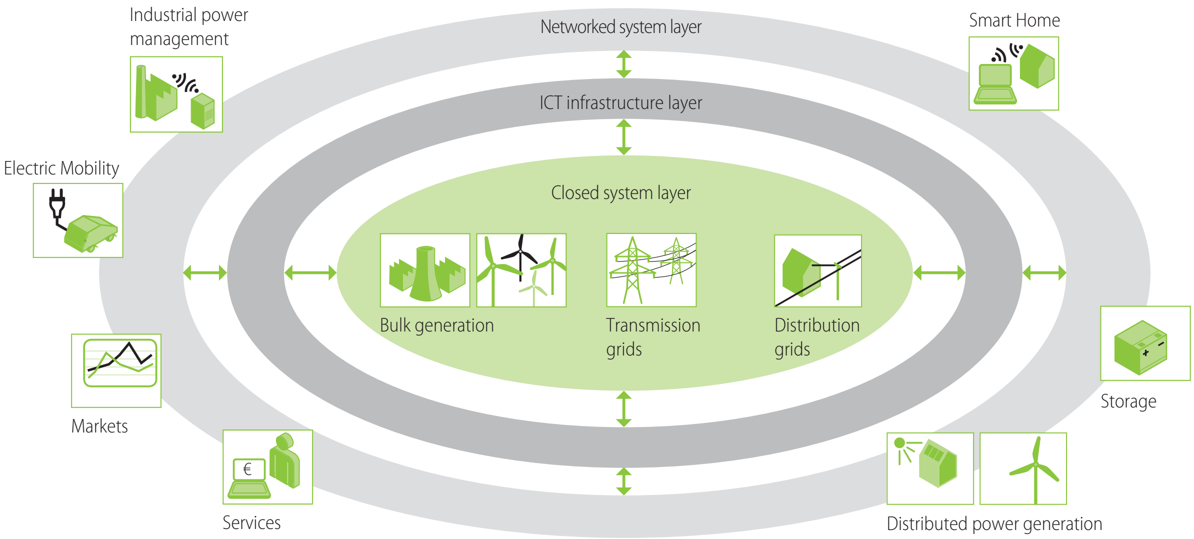


Figure 2: Composition and components of the abstract and simplified system model with selected underlying technologies, functionalities and application areas

Achieving these aims will tie up immense amounts of investment, not least since alternative generation capacity – back-up power plants – must be maintained and operated in order to balance the fluctuating levels of power generated from wind and PV installations. The German Energy Agency dena states that the investment required for expansion of the grid and connection of offshore wind farms will be between around €1.0 billion and €1.6 billion every year between now and 2020.[8] Renovation of the European distribution grid will entail investment of around €400 billion from 2010 to 2014. After additionally considering the investment required in the transmission and supra grid, the European Commission estimates that the investment volume will total €600 billion by around 2020.[9]

The grid operators must meet their obligations to maintain grid stability and the reliability of supply while at the same time ensuring that they prioritise and manage the feed of power from renewables. These are two obligations that can currently only be met thanks to a further rule – namely the exception rule that gives permission for fluctuating generation sources to be deactivated in the event that they pose a risk to grid stability. As with the generators, the grid operators are also facing high levels of investment in infrastructure and line technology, which will represent a significant economic challenge.

If the power generators are located at the start of the value chain, the opposite end is occupied by the consumers. In contrast to the generation and distribution side, very few consumers have so far responded to change. Usage patterns are largely unchanged compared with past decades. Consumption patterns throughout the day and the volume of consumption, or demand for electricity in domestic households and industry, have barely changed. Still today, the consumption of electricity by households during the course of the day registers three usage peaks, in the morning, at lunchtime and in particular in the evening. The anticipated changes will affect consumers directly more frequently in the future, whether via the continuing rise in electricity prices that will be the inevitable result of the aforementioned investment in the system infrastructure, or via the supply and usage of new services. Moreover, consumers, or the population at large, will also be challenged by the changes introduced by

8 dena 2010a, p. 13.
9 Oettinger 2011; EKO 2010a.

measures such as increased line expansion or the technological and functional revolutions occurring within their households. Ideally, the public must be informed in advance, and where possible should be involved in the decision-making and planning processes. Since mid-2011, the Federal Ministry of Education and Research (BMBF; Bundesministerium für Bildung und Forschung) has been taking steps in the right direction with its "Bürgerdialog" (Citizens' Conversation) initiative.[10] Ultimately, if the technology revolution is to succeed it needs consumer backing.

In the context of the changes afoot, the current framework of legislation governing the market and generation/distribution of electricity in Germany also merits revision. Legislators have to rethink and redefine roles, responsibilities and obligations in the light of the recent changes. Statutory provisions for data protection are also needed, with the expected increasing levels of data transmission making this area all the more urgent. Inconsistencies between individual measures and specifications must be ironed out with the aim of creating a functioning marketplace.

Research and development (R&D) can provide significant impetus for refining the technology as well as understanding of the system, and is thus a vital component of the process of change.

Education policy and training institutions are responsible for supplying the labour market with qualified tradesmen, technicians and academics of the future. Conventional study programmes must be expanded and new programmes introduced where necessary.

The Future Energy Grid – a glimpse into the challenges of the future
The initial steps towards a smart energy system are already being taken. However, further steps will still be required. In order to be prepared for the changes to come, it is vitally important to take a forward look and also consider the shape of electricity supply and therefore of the Future Energy Grid. The challenges facing politicians, businesses and science in the development of a smart grid include:

- Development and adaptation of new technologies
- Creation and establishment of ICT standards (e.g. uniform protocols)
- Establishment of a practical framework of regulation to ensure a capable, working market
- Maintenance of very high levels of power supply reliability
- Management of data and information security
- Data protection
- Investment in infrastructure, generation systems and storage systems
- Cost-benefit analysis for specific technologies (e.g. smart meters) as a priority
- Involvement of the population and increasing acceptance for changes in the system and technology
- Further development and integration of storage technologies
- Integration of electric mobility
- Increased levels of understanding of the system (collaboration between technology and participants)
- Affordable electricity
- Liaison with other European countries on domestic developments

The latest changes in power generation must be taken into account in all analyses of what the future holds. The use of wind power will be extended, with the additional capacity focused on offshore wind farms in the medium term. The use of PV solutions will also grow significantly. In contrast, the potential of biofuel is rather moderate, despite the technology's existing base-load capacity meaning that no major adjustments would have to be made to grid infrastructure. According to the objectives of the Federal Government at the moment, the proportion of gross electricity consumption generated from renewable sources should grow from around 17 percent currently[11] (2010) to 35 percent in 2020, 50 percent in 2030, 65 percent in 2040 and finally to 80 percent by 2050.[12] In the medium term, imports of renewable power from North Africa[13] will become possible, helping to meet the objectives. The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU; Bundesumweltministerium) expects the long-term sustainable usage potential of renewables in power generation in Germany to be around 780 TWh/a[14], of which 280 TWh/a will be produced by offshore wind power, 175 TWh/a from onshore wind power, 150 TWh/a

10 BMBF 2011a.
11 BMU 2011a, p. 16.
12 BMWi 2010a, p. 5.
13 Cf. DESERTEC 2011a and 2011b.
14 BMU 2011a, p. 53.

from PV, 90 TWh/a from geothermal power, 60 TWh/a from biomass and 25 TWh/a from hydroelectric sources. In 2010, gross electricity consumption in Germany was around 608 TWh[15], which means that if consumption remains at the same levels, renewables could cover the entire demand in the long-term and Germany could become a net exporter of renewable power.

In the upper voltage levels, the use of ICT in the closed system layer is already high. This usage will continue to be developed and will remain at these high levels. Communications here are largely between the transmission system operators. In comparison, communication with the distributed generation facilities via ICT interfaces in the distribution system can be expected to expand significantly.

In contrast to current developments, which are focused on the side of the generators, a significant change on the consumer side is anticipated for the future. On the consumer side, increasing volumes of electric mobility solutions, smart electricity meters and distributed consumption systems such as thermal pumps will operate with communicating ICT interfaces. The future grid must therefore be able to fulfil its role as a middle-man between the consumer and the producer. Increased use of ICT can also be expected in respect of future grid operations. For example, greater numbers of local smart substations will be constructed and equipped to coordinate bidirectional load flows.

The electricity system of the future will appear different, not only because of the addition of major lines for long-distance transmission, but also in terms of the distribution grid. The FEG will need to have a "highway code" to govern bidirectional power flows in the low and medium voltage ranges. These rules will have to be defined technically, but also through legislation and regulation.

Additional storage capacity will also be a feature of the grid of the future. The gas grids can be used to store methane and in some cases also hydrogen, obtained from renewable power using corresponding technologies and converted back into electricity on demand. German pumped-storage power plants can also be used to store energy, as well as those in other European countries (such as Austria and Norway). In the long-term, the batteries of electric vehicles will be used as mobile storage facilities. The technical solutions in the future grid will be complemented by new sales and business models that can only actually be implemented with increased use of ICT. These will result in greater incentives to adjust generation and consumption. Demand-side management (DSM), namely the management of load and incentives for load shifting, particularly among industrial users, will make a major contribution. These challenges have been recognised by both the energy industry and by politicians, and both camps are working hard to come up with solutions and concepts, some of which are already being tested in pilot projects. One example of this relates to the six model regions that are participating in the E-Energy initiative launched by the Federal Ministry for Economics and Technology (BMWi; Bundesministerium für Wirtschaft und Technologie).

In part, there is a choice between either using ICT, i.e. investing in "smart" solutions, or expanding the primary technology including interconnects, switchgear, transformers, etc. In general, therefore, the expansion of the ICT infrastructure should be contrasted with the expansion of the electricity supply infrastructure by simple copper and iron. It can be expected that the energy system of the future will, in all cases, require the best technical solution to be balanced against the most economic, in a mixture of the two technical alternatives, the ratio of which has yet to be defined. After all, with all of these transformations and adaptation measures, the electricity must remain affordable in order for Germany, in its capacity as an industrialised country and economic centre, not to experience any disadvantages while maintaining a high standard of living.

In view of these very varied factors, it should be pointed out that irrespective of the extremely dynamic growth in renewable power generation all forecasts are indicating that at least for the next two decades, power generation from brown coal, hard coal and natural gas, as well as from nuclear fuels (until 2022) will form the backbone of the German electricity system. In contrast to the generation systems such as PV installations and wind farms that feed in fluctuating levels of power, the constant-level renewable power generators and energy sources such as biogas plants and solid biomass installations are associated

15 Derived from BMU 2011a, p. 16.

with significantly lower technical barriers. For many decades, hydroelectric power has been a constant source of power generation. The forms of generation that are currently still considered as exotic, such as deep geothermal energy, are slowly increasing in popularity in Germany, but are still at very low levels of exploitation and have only been recorded in the statistics for the past few years.

QUESTIONS TO BE TACKLED BY AND OBJECTIVES OF THE STUDY

Against the backdrop of these expected developments, the study tackles the following ICT-related questions in respect of a secure, reliable, economical and sustainable energy supply for Germany:

- What are the major technological steps towards the Future Energy Grid?
- What legislation is needed in the energy sector in order to enable these technologies to achieve penetration that is as market-based as possible?
- What role do issues of acceptance have to play in the context of these developments?
- In which areas does it make sense to look to international developments?

The aim of this study is to answer these questions and to produce a contribution to the discussion on these and related topics that is based on an analysis of the situation. It will investigate and reveal how the transformation of the energy system can be supported by the development and targeted deployment of ICT, and which conditions (energy technology, framework legislation, consumer-side) must be met in order for the massive potential of ICT to realise the IoE to be exploited.

There are many difficulties, especially with regard to the first question:

i. A smart grid has no tangible form and is not an objective in itself, rather it improves the technical and economic efficiency in a defined target scenario.
ii. So far, there is no general understanding of which ICT-related technology areas belong to a smart grid and how these fit together.
iii. A single migration path comprises many different individual paths for each technology area. The technology areas exhibit complex mutual dependencies.
iv. What conclusions can be drawn from complex relationships?

A multi-step, methodical procedure is needed in order to achieve the stated objectives; this procedure is outlined below.

i. The ambivalent nature of smart grid technologies
To overcome this challenge, the space occupied by future relevant options and opportunities must be recorded in as much detail as possible, and a migration path established to each option. This is done by applying a system of scenarios. In the first instance, the major key factors that are relevant to the formation of the future smart grid in Germany must be established. The properties of each of these key factors must be defined and described. It is then possible to define scenarios that depict the potential future situation, using consistent combinations of these properties. The methodology, procedures and findings are described in Chapter 2.

ii. Structure, selection, description and development of the technology areas
As a basis for the structure and selection, two complementary models were selected and adapted – the system layer model used by the EEGI[16] and many other groups, and the IEC[17] architecture model. All ICT-related technologies were then sorted into the technology areas and described. Development stages were then established (Chapter 3) to move from the current state of development to the state of development described in the vision papers.

iii. Dependency of developments
In principle it is possible to analyse several thousand dependencies between the individual development stages of the technology areas. However, to limit this task to what is strictly necessary and investigate only those dependencies that are relevant for one of the scenarios, the

16 EEGI 2010.
17 IEC 2009.

development stage for the corresponding technology area that could be allocated to each of the three scenarios was investigated. This produced the "technology view" of the scenarios (Chapter 3.5).

Once this view had been established, the dependencies were determined (Chapter 4.2). At this stage, therefore, a complex migration path will have already emerged for each scenario. What conclusions can now be drawn from this? To determine this, the web of relationships must be analysed.

iv. Analysis of the complex relationships

Two questions assist in the attempts to disentangle the complex web of relationships.

- Does a development stage for a technology area have a particularly large number of prerequisites in the given scenario?
- Is a development stage for a technology area a prerequisite for a particularly large number of further developments in the given scenario?

The first case consists of investigating whether or not the development stage has a key role to play in the scenario. If so, then this represents a risk to be managed since the technology area is very liable to interruption and could therefore delay the development of the scenario. In contrast, if a development stage for a technology area is a prerequisite for a particularly large number of further developments, it is seen as an enabler. As such this technology area must categorically be pushed forward with a great deal of force (see Chapter 4.3). Furthermore, analysis is required of whether there are any other specific factors that affect the migration path.

Since one of the scenarios, i.e. the scenario entitled "Sustainable & economic", is particularly close to the current political objectives, this is investigated in even greater detail.

In summary:

Procedure:

i. Create scenarios on the basis of key factors to create a comprehensive picture of the theoretical options for the future.
ii. Establish the technology areas of the smart grid and allocate them to the smart-grid system layers. Establish the development stages of the technology areas.
iii. Establish the corresponding development stages that are required for each of the three scenarios. Establish the dependencies between the development stages.
iv. Analyse the web of relationships for each scenario.

The figure below illustrates the procedure more clearly:

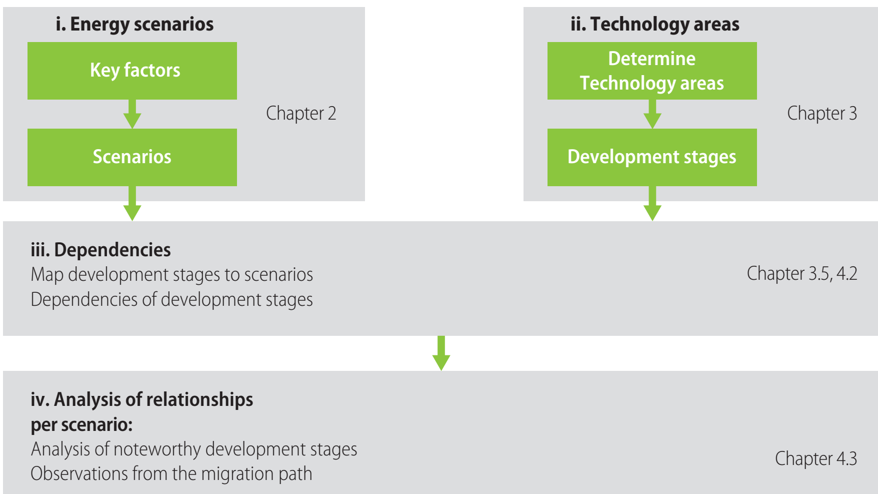


Figure 3: Composition and sample components of the abstract and simplified system model

Building on the analysis done in the study, recommendations will be formulated for the realisation of an optimum ICT migration path towards the IoE, to be published in parallel in the acatech POSITION series under the title *Future Energy Grid – Informations- und Kommunikationstechnologien für den Weg in ein nachhaltiges und wirtschaftliches Energiesystem*[18].

INVESTIGATIVE FRAMEWORK

The geographical extent of the study is focused on Germany. The analysis period of the study runs from 2012 (the base year) through until 2030. In terms of content, the focus is on the potential and necessary changes to the ICT infrastructure and the power grid infrastructure (both transmission grid and distribution grid, concentrating on the distribution grid). The core emphasis is on developments in ICT. The study's objective is to take the most comprehensive, thorough overview of the potential way forward and process of migration to the Internet of Energy, and then to reflect on the results in light of the corresponding necessary developments in the ICT sector. This objective also includes the intention to describe and categorise the assessed technologies and functionalities in as much detail as possible. In total, 19 technology areas (TA) have been identified, and a variety of future development stages have been defined for each. The interdependencies of factors along each migration path are established and described.

Three further key analyses complement the main lines of argumentation of the study in terms of content and methodology. The first analysis compares activities in Germany with those in selected European and non-European countries, identifying potential learning points and establishing an international benchmark. Questions that arise here primarily include:

- What technical, political and legislative prerequisites are in place in other countries?
- What technologies are other countries using and supporting?
- What can Germany learn from other countries?

Finding a response to these questions does not require the services of a crystal ball – rather, they are firmly focused on the current stage of developments. The current regulatory framework and unanswered questions relating to framework legislation will be analysed in a further layer of detail. Moreover, the future requirements for regulating a successful path toward the IoE will also be described. A specific question that needs to be answered here includes:

- What shape will the new markets take, and what will be the corresponding market regulatory mechanisms and the prerequisites for new services and business models?

The "Sustainable & economic" scenario, which corresponds to the government's current energy policy objectives, will be used to describe the necessary framework measures that will be required by 2030. In this instance the focus will be on Germany.

Following this, the current levels of technology acceptance in domestic households will be addressed, and questions relating to the methods and processes for improving this situation will be investigated. Questions arising in this context include:

- Where are the barriers at the moment?
- What barriers are anticipated for the future?
- How can these barriers be dismantled?
- What do promising communication concepts look like?

In a detailed view of consumers and their distribution in a variety of milieus, differentiated and categorised both according to social situation (e.g. income and education) and basic attitudes (e.g. traditional, modern, pragmatic), quantitative statements will be formed on the level of technology acceptance and specific options for communication to individual milieus.

This overview will not be particularly forward looking; rather the statements will relate to the current state of consumer opinion, with an outlook over developments in the next few years. The reason for this is that, in contrast to the smart grid technologies, there is no long-term road map for resolving questions of acceptance. Instead they can only be addressed in a conversation about the "here and now".

18 acatech 2012.

Comparisons will be made with the work in the E-Energy Model Regions, in which local surveys will be conducted to discover the attitudes of consumers in relation to specific technologies.

The current debate on the composition of the electricity system of the future is characterised by two further topics – storage technologies and electric mobility. The authors also attribute a key future role to these topics. Despite their major importance, both topics have only a large influence on the ICT concept for the smart grid indirectly and for that reason crop up among the ICT-related aspects in several place (e.g. in various key factors, a range of technology areas and in detail in chapter 6). In the scope of the 19 Technology Areas, storage technologies or their function are subsumed into Technology Area 13 "System Communication and Control Modules", which also considers consumers and generators as "functions" to be controlled. From this perspective, electric mobility is considered as one of several specific application options. Both of these technology forms are therefore discussed and highlighted at the positions in which they or the functionality they deliver make specific requirements of other system components.

DELINEATION FROM RELATED ISSUES

The following paragraphs outline the related topic areas that have not been investigated within the context of this study, in order to clearly delineate the scope and methodology that has been applied.

FORECASTS

This study aims to establish migration paths independently of any specific developments. Therefore, it is not the intention of this study to produce a forecast of the form that ICT will take in a future energy system. The purpose of the scenario system is not to identify the most likely development or most likely migration path towards the IoE. Rather, the development corridor must be expanded by locating the actual developments expected with a high degree of probability in order to enable the development of a robust migration strategy.

EXPANSION OF GRIDS, GENERATION AND OTHER TECHNOLOGIES

dena is currently conducting a study into the requirements for expansion of the distribution grid. Moreover, the German Association of Energy and Water Industries (BDEW; Bundesverband der Energie- und Wasserwirtschaft)[19] has commissioned a study on the expansion work needed through to 2020. The expansion of transmission grids at national and European levels is also the subject of investigation elsewhere.[20] Furthermore, there are various studies into the context of renewables feed-in and the associated pool of power plants that will be required in connection with this.[21] Equally, the analysis of technologies that do not have any reference to ICT, such as storage technologies, energy system technology, etc., falls outside the compass of this study. Electric mobility has already been investigated in detail in other plates.[22] The topic of storage is dealt with in many studies.[23]

BUSINESS MODELS

Even though new technical and market-specific functionalities and how they interact are considered, any guess regarding which new ICT-based business models will become established at a point in time so far into the future really makes no sense. However, key aspects of the development of future business models, such as establishing the correct format for the technology bases, are discussed in chapters 4 and 6.

COSTS AND BENEFITS OF SMART GRIDS

In view of the great uncertainty in terms of data and potential realisation options, there appears little point in preparing any serious

19 E-Bridge 2011.
20 dena 2010b.
21 For example, Matthes/Harthan/Loreck 2011.
22 acatech 2010; Hüttel/Pischetsrieder/Spath 2010; Mayer et al. 2010.
23 VDE 2009; Rastler 2010.

estimation of the costs and benefits of smart grids in 2030. To arrive at any robust statements on these combinations of topics would require the use of complex models and the identification of a robust set of data, as well as higher levels of knowledge about the deployment of smart grids. Nevertheless, a preliminary calculation – as prepared, for example, in the analysis by the Electric Power Research Institute (EPRI)[24] on the basis of the parameters of this study – would also be very useful for Germany too. The macroeconomic benefit in the next few years up to around 2020 is in urgent need of assessment (see chapter 6).

GUIDE FOR READERS

Depending on individual areas of interest, it is recommended that readers of this study focus on specific chapters. The table below should serve as a starting point for where to focus. The introductory parts of each chapter that are concerned with the methodological procedure that was applied may be ignored without hindering the reader's understanding of the remaining content.

CHAPTER INTERESTS	2	3	4	5	6	7	8
Key factors for the development of a future ICT-based electricity supply system	×						
Scope of possibilities for development of the supply of electric energy in Germany up to 2030	×	(×)					
Overview of the FEG Technology Areas that have ICT relevance		×	(×)				
Development paths of the Technology Areas that have ICT relevance		(×)	×				
Technological contexts and frameworks required for the realisation of an ICT-based energy supply system	(×)	×	×				
International comparison of smart-grid developments in representative countries				×			
Migration paths towards the smart grid	×	×	×				
Germany's position in relation to the electric energy supply from an international perspective				×			
Influencing factors on the distribution and acceptance of energy management systems in domestic households						×	
Regulatory framework (status quo and potential developments) with a focus on the shape of the market and changes in the distribution grid					×		
Overview of the use of ICT in the supply of electric energy in 2012		×					
Methods for developing scenarios	×						
Layers in the electricity supply system		×					
Outlook for the use of ICT in the future electricity supply system							×

24 EPRI 2011a does, however, carry out a cost/benefit analysis of a specific realisation, and has developed a method that is transferrable for use in Germany.

2 SCENARIOS FOR THE FUTURE ENERGY GRID

In order to deal with the uncertainties associated with future developments, this chapter describes the range of future relevant opportunities for the Future Energy Grid in as much detail as possible, and maps these to three clearly differentiated scenarios.

First of all, the methodological procedure is described. Then, the key factors and their future capacities, the "projections" are established. Consistent scenarios are finally prepared on the basis of these projections. It is apparent that three scenarios are sufficient to fully describe the range of future possibilities. In the subsequent chapters, these three scenarios are used to establish the suitable technological migration paths in each case, which form the core findings of the study and are described in detail in chapter 4.

2.1 METHODOLOGICAL PROCEDURE

The primary objective of the project is to describe migration paths for information and communication technologies (ICT). In order to achieve this, scenarios must first be developed. These scenarios are composed of a range of key factors. In relation to scenario-based research techniques, there are various methods of creating the scenarios. This project has adapted a procedure that has been described in detail by Gausemeier[25]. The current chapter explains the methodological procedure, which is split into five phases (see Figure 4).

2.1.1 SCENARIO PREPARATION

The first phase comprises the project description and forming-field analysis steps.

Gausemeier defines the terms scenario field and decision field, which are of key importance in the subsequent process, as follows[26]:

"The main goal of a scenario project is to support entrepreneurial decisions. This process always focuses on a particular object, for example an enterprise […], a product […], or a technology […]. This property of

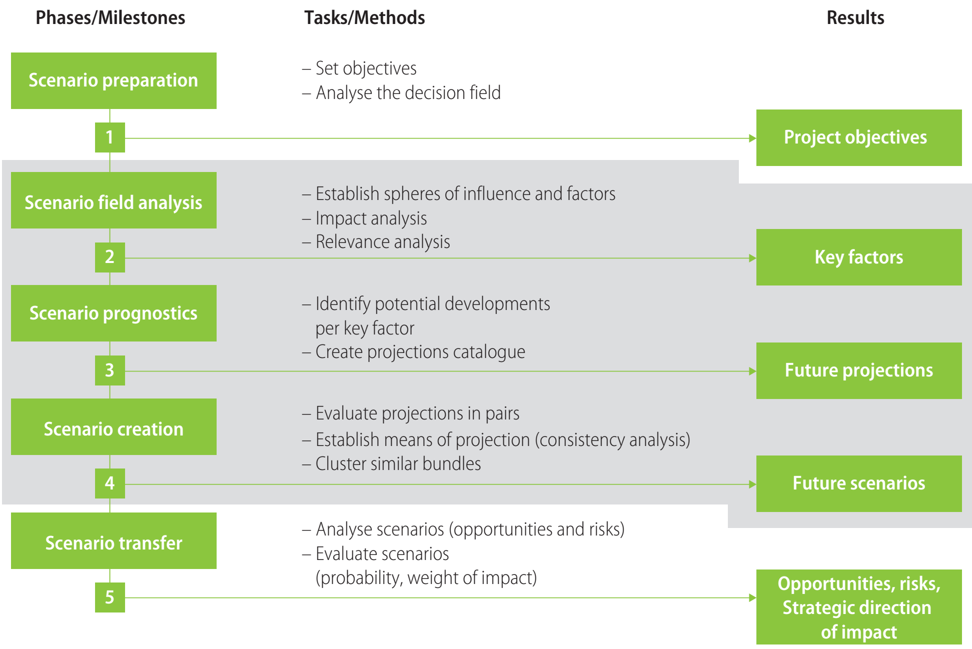


Figure 4: The five phases of scenario development, according to Gausemeier et al. 2009

25 Gausemeier et al. 1996 and 2009.
26 Gausemeier et al. 1996, pp. 99-100

a scenario project is referred to as a decision field. The decision field describes the subject of the scenario project."

"[. . .] The scenarios do not normally describe the possible futures of the decision field, but the development possibilities of a special vision segment that we call a scenario field. The scenario field describes the subject of what is to be explained by the created scenarios."

Project description

At the beginning of the project, the purpose of the scenario project must be defined. In practice, a distinction is made between four typical decision fields: corporate, product, technology and global scenarios Each of these four basic types can be used either for goal planning or resource planning purposes.

- In relation to goal planning, the future goals of the decision field are defined. Results may be robust future models (long-term development of the decision field taking account of several development opportunities) and robust future goals (goals that can be realised within the time horizon that are as resistant as possible to other influences).
- In terms of resource planning, the goals of the decision field are already known; the scenarios are then used to determine the resources required to achieve the goals. Potential results are futureproof strategies[27] and futureproof decisions[28].

The next step is to define the scenario field. The typical base forms of scenario field are external, decision field (internal) and system scenarios. The distinctions between the three base forms largely lie in their steerability. For example, external scenarios only contain environmental variables that cannot be controlled, while decision field or internal scenarios only contain controllable variables and are therefore fully steerable. System scenarios contain both steerable and external variables and are therefore partially steerable.

As a result, it is possible to arrive at twelve potential forms for scenarios, each of which can be used for each resource or goal planning.

In terms of organisation, four typical forms are identified: these consist of the academic, consultant, workshop and internal approach. Each of the four approaches offers different advantages and disadvantages for the corresponding scenario forms. Accordingly, a specific decision must be reached for each project.

Decision field analysis

The decision field analysis forms the second part of the scenario preparation phase. There are two steps to analysing the decision field in its current form. First, the decision field components (DFC) that comprise the decision field are identified. Then, the strengths and weaknesses of the components are investigated.

- The DFC are selected separately for each project and differ according to the form of scenario. Their purpose is both to describe the current state of the decision field and to create a vision of future development of the decision field.
- A SWOT analysis is then conducted for the DFC, the results of which can be a SWOT profile or portfolio. Since this part of the methodology is strongly related to enterprise growth scenarios, it is not further considered for this project as it cannot be adapted.

2.1.2 SCENARIO FIELD ANALYSIS

Formation of spheres of influence

The scenario field analysis phase commences with the formation of spheres of influence. First, the scenario field is viewed as a single system from which subsystems are then formed to create a system hierarchy over several levels. These levels are then described in greater detail via partial systems using suitable aspects. Partial systems that are of greater importance for the scenario field are identified as spheres of influence and can be differentiated into steerable spheres (for system and decision field scenarios) and environmental spheres (for system and external scenarios). Furthermore, it is possible to group together partial systems that are situated at different system levels to form crosscutting areas.

27 Well-coordinated measures and programmes in terms of a targeted action that takes account of future developments.
28 Decisions between potential actions with the aim of selecting the most successful action for the future.

Formation of influencing factors

The next step is concerned with the formation of influencing factors. For each sphere of influence, influencing factors are identified and their current state, future development and interaction with other spheres of influence are described. This process may be supported by discursive processes such as a systemic investigation, intuitive processes such as brainstorming or surveys of experts, or the use of additional sources such as checklists. The influencing factors are then prepared by being described in as neutral a manner as possible and being allocated to a sphere of influence in order to examine the key elements.

Identification of key factors

In order to reduce the volume of influencing factors and make them easier to handle, the key factors are identified from their number. This process commences with an effects analysis that evaluates the relationships between the influencing factors. A distinction is made at this point between the interdependency analyses (selection of key factors that best characterise the entire scenario field) and impact analyses (selection of key factors that exert the greatest effect on the decision field).

- The underlying data for each analysis are impact matrices for direct and indirect impacts, which identify the relationships between influencing factors.
- In addition to the impact analysis, it is also possible to carry out a similarity analysis with the aim of identifying and grouping similar influencing factors. This is based on the impact matrix and calculates a differential for all pairs of influencing factors.

Finally, a set of key factors is selected on the basis of the impact and similarity analyses. This is done using established selection criteria that are derived from the impact analysis, such as impulse index, activity, dynamic index or passivity. When selecting the criteria, the underlying form of the scenarios is taken into account. The desired number of key factors is then established and they are summarised into a key factor catalogue, with a degree of human correction in some circumstances.

29 Gausemeier et al. 1996.

2.1.3 SCENARIO PROGNOSTIC

At the start of the scenario prognostics or forecasting phase, fundamental decisions must be reached on three dimensions. These concern:

- The content orientation (extreme or trend projections)
- The plausibility (use of probability of occurrence/non-occurrence),
- The future time horizon (short term, medium term or long term).

In addition, it is recommended that the following quality criteria be taken into account when creating future projections:

- Credibility
- Differentiability
- Completeness
- Relevance
- Information content

Preparation of key factors

The next step is to prepare the identified key factors. For each key factor, characteristics are identified that describe both the current state of affairs and future development. By limiting the vision to two dimensions, it is significantly easier to use a quadrant-based visualisation. Moreover, according to Gausemeier[29], selection of more than two characteristics per key factor only makes sense in a handful of situations. Therefore there is a description of the actual state – a consensus-based description of the current situation – of the individual key factors.

Formation of future projections

On conclusion of the preparatory step, the next step is to draw up future projections of the key factors. First, the potential future projections are identified. This requires both analytical and creative capacities. This process may include:

- The exploration of developments
- The overstating of developments and their characteristics
- The deliberate acceleration of developments
- The deliberate inclusion of environmental developments
- The extrapolation of future developments from processes

In the sections below, a distinction is drawn between the critical (more than one future projection affected) and the non-critical (exactly one future projection affected) key factors. In the case of critical key factors, just a few future projections must now be selected from a potentially very large set. It should be ensured that all future projections have their own development opportunities and therefore do not attenuate or amplify any other future projections. In extreme scenarios, the future projections should be selected such that they cover the widest possible range of development opportunities. With trend scenarios, the future projections that have the highest degree of plausibility should be selected.

As an optional step, it is possible to identify the probability of occurrence. This step can be skipped for extreme scenarios since it is usually barely possible to determine the probability of occurrence here. It is rather more possible to carry out this step for trend scenarios, but it is by no means a necessity. According to Gausemeier[30], the probability of occurrence and other factors that can be derived from this, such as probabilities and plausibility of scenarios should instead be used as rough guidance.

The final stage of the scenario prognostic phase is to formulate and justify the future projections. A concise summary and detailed description should be prepared for each future projection. Care should be taken to formulate the descriptions in such a way that they can be understood by a lay audience. Illustrative formulations, diagrams, source citations and references are all examples of how to achieve this.

2.1.4 SCENARIO DEVELOPMENT

The scenario development phase is divided into the creation of projection bundles, the creation of prescenarios, future mapping and prescenario interpretation or description.

Projection bundling

A projection bundle describes a group of future projections that contain exactly one projection for each key factor. At this stage, these are then identified and evaluated. Two options for doing this are available.

- First is the possibility of deductive projection bundling, in which certain combinations of projections are preferred and thus evaluated intuitively as being suitable. They are then not verified any further.
- The alternative is to take an inductive approach. All potential combinations are considered, and using consistency analysis, plausibility analysis and reduction of the projection bundles, a projection bundle catalogue is created.

The consistency (lack of contradictions) within scenarios is key for their credibility. Therefore, the consistency analysis occupies an important position. First, all future projections are compared in pairs, and their relationships are evaluated. The relationship may be classified along a spectrum from completely inconsistent to very strong mutual dependency. The resulting matrix forms the basis for the continuing process of creating the scenarios. For each projection bundle, the matrix provides the consistency value, the average consistency value, information on existence of total inconsistency and the existence of partial inconsistency. Non-critical key factors are considered separately, since they have only one future projection. The result is a provisional projection bundle catalogue, which contains all projection bundles and their key factors that indicate no total inconsistencies.

If probabilities of occurrence were determined as part of the scenario prognostics or forecasting phase, a plausibility analysis must be undertaken for the provisional projection bundle catalogue. This analysis may comprise either

- A simple plausibility analysis (assuming that the consistency and probability of occurrence of a projection bundle are independent of each other)
- A cross-impact analysis (taking account of the inter-relations of probabilities of occurrence). There are three types of cross-impact analysis: correlated[31], static-causal[32] and dynamic-causal[33].

30 Gausemeier et al. 1996.
31 Cross impacts are represented as conditional or shared probabilities.
32 Cross impacts are represented as causal relationships for a time horizon.
33 Cross impacts are represented as causal relationships for several time horizons.

Since the provisional projection bundle catalogue still contains a large number of projection bundles at this point in time, four methods to reduce this number are described here:

- Reduction via the consistency value uses an expanded consistency scale in order to improve the recognition of partial inconsistencies. First, the total number of projection bundles to be included in the result must be defined. These are then selected according to their consistency value.
- Moreover, it is possible to reduce the number by looking at partial inconsistencies. The projection bundles that indicate large numbers of partial inconsistencies are identified and removed. This can be done by setting maximum values in either absolute or percentage terms.
- Another method is concerned with reducing the candidates by selecting representatives. As well as considering consistency, this method also reflects the differentiability of the projection bundles. The projection bundles are distributed into segments on either a linear or progressive basis (the number of segments is half the number of desired projection bundles), and representatives are selected for each segment. The representatives may be either the most different bundles in a segment, or the bundles in each segment may be grouped into two similarity-based clusters, from each of which the bundles with the highest consistency values are selected.
- The final method consists of reduction by means of full, manual scanning of the projection bundles. This method has the advantage of allowing all theoretically possible combinations to be considered. It is possible to conduct either a simple scan of the projections[34] or a complex scan of combinations[35].

All of the reduction methods result in a projection bundle catalogue that forms the basis for creation of the prescenarios. Values relating to the distribution and frequency of projections can also be identified from this catalogue.

Creation of prescenarios

It is possible to keep the next step extremely simple, just by selecting a few bundles from the projection bundle catalogue on the basis of suitable criteria and interpreting these directly as scenarios. Alternatively, prescenarios can be derived from the similarity values. The process of creating prescenarios comprises two phases:

- First, a cluster analysis is conducted to group projection bundles into partitions on a step-by-step basis
- Then, one partition is selected and its projection bundles are grouped into a prescenario catalogue

Internally, the contents of the clusters should be as homogeneous as possible, while the clusters themselves should be as heterogeneous as possible. An agglomerative, hierarchical clustering approach is used to achieve this. With this method, each bundle is first viewed as a cluster. The clusters are then grouped together two at a time according to their proximity, which is calculated from the similarity and dissimilarity. This process is repeated until just one cluster remains. The distance measurements must be recalculated for each repetition. The composition of the clusters can be affected by using different methods (complete, single and mean linkage methods). The following data are recorded in an agglomeration log for each repetition in the clustering process:

- The clusters that have been grouped together
- The earlier repetition in which these two clusters were generated
- The subsequent repetition in which the new cluster is handled
- The number of projection bundles
- A unique identifier for the cluster
- The plausibility

Now, just one partition is selected, the prescenarios of which are grouped into a prescenario catalogue. A partition is suitable only if the content of the individual prescenarios is as homogeneous as possible and the prescenarios themselves are as heterogeneous as

34 The three most consistent bundles are selected for the projections of the first key factor.

35 Each of the three highly consistent bundles are selected, each containing one projection of the first key factor in combination with a projection of another key factor, whereby all key factors and combinations are taken into account.

possible. In order to identify a suitable partition, either a simple measure of qualify (use of a partition level that relates only to internal homogeneity) or an expanded measure of quality (both internal homogeneity and external heterogeneity are considered) can be applied.

Future mapping

The next step is mapping of the future-space. The purpose of this is to obtain a rapid glimpse of the future situation. The future-space contains the future projections of the key factors, the projection bundles and the prescenarios that have been created. These elements and the way they inter-relate are visualised graphically by the mapping process. The graphical visualisation may take the form of a projection map, projection bundle map or combined maps:

- Projection maps are used to visualise the relationships between future projections and prescenarios. First, the graphical formation of prescenarios can be used to arrange all future projections in a single level, with similar projections located close together and dissimilar projections further apart. In addition, a subdivision is made into neutral zones, secure zones and intermediate zones. Second, projection biplots[36] are used to visualise the distribution of future projections over the prescenarios in ring form. A distinction is drawn between scenario-specific projection biplots and future-space oriented projection biplots.
- The projection bundle mapping is the most important mapping process since it offers the opportunity to visualise and test the prescenarios. This uses a multidimensional scaling instrument that takes account of both consistency and plausibility.
- In the case of combined mapping, the relationships between all of the objects in the future-space are visualised. Either a combined biplot or combined future-space map can be used for this. A combined biplot enhances the projection biplot by adding the option to visualise projection bundles and prescenarios in the internal space, thus allowing projections and bundles to be linked. In contrast, combined future-space mapping represents all objects in a single level by means of a correspondence analysis.

Scenario description

The scenario creation phase is concluded by the scenario description step. First, lists of properties are developed, containing the properties of a scenario. These may be unique (exactly one projection per key factor) or alternative (several projections for one key factor). The properties lists are developed in a process involving three consecutive steps.

- Identification of exact and fuzzy projections
- Identification of ambiguous projections
- Classification of ambiguous projections

Once the properties lists have been created, they serve as a scaffold around which the scenarios are fleshed out. An important aspect in formulation of the scenarios is the title, since it draws the reader in. Overall, the aim is to produce a creative and visionary scenario that places the reader in the future world. In addition, it should be possible to understand the scenarios without knowledge of the future projections for the key factors. However, references to future projections may be made and in some situations may be useful.

2.1.5 SCENARIO TRANSFER

The final phase, scenario transfer, is concerned with transferring the scenarios over to the decision-making processes at strategic enterprise management level. This phase does not apply in the context of this project, since the scenarios themselves represent the final result. The scenarios form the basis for the migration paths for the information and communication technologies. Nevertheless, the following section provides a brief explanation of the scenario transfer process.
Initially, an impact analysis is carried out. The purpose of this is to establish the consequences of the scenario for the decision field. A matrix is created to take account of the developments of the individual DFCs allowing their opportunities and risks to be established. This is followed by a round of contingency planning and futureproofing. The contingency planning process arrives at specific measures on the basis of the identified opportunities and risks. During the futureproofing

36 "A projection biplot provides an overview of the strength of representation of specific future projections in individual prescenarios." (Gausemeier et al. 1996.).

stage, the resulting contingencies are bundled to form futureproof plans. These represent a combination of measures, applicable to multiple scenarios, for a single DFC. The DFC futureproof plans can then be assembled to form a futureproof strategy, for example.

2.1.6 APPLICATION

The application of the scenario system was supported by the scenario software from UNITY AG[37]. For this scenario project, the electricity supply in 2030 was selected as the global decision field, ensuring that *global scenarios* would be created. Furthermore, the project is concerned with a *resource plan and future-robust strategies*, to help identify suitable measures. As both environmental and control variables are contained within the project, the scenario comprises a system scenario and the scenario field comprises the decision field together with the environment as an overall system. An academic approach was selected for the project organisation, in order for the scenarios to be derived from studies conducted by experts and academic institutions.

As the project has a strong ICT focus, the selected *decision field components* comprised the three layers described in section 3.3. (networked system layer, closed system layer and ICT infrastructure layer), since they appropriately describe the decision field and its development. *The SWOT analysis* is not expedient in this project and has therefore not been conducted. The scenario field is split into two *system layers*: energy supply and the supply environment. The energy supply layer is split into the following *spheres of influence*: infrastructure, consumption and generation. The spheres of influence in the supply environment layer are: market/economy, society, technology and politics. *Influencing factors* were identified for the seven spheres of influence in a moderated workshop. *Intuitive methods* such as team-based brainstorming and expert questionnaires were used. The result is a list of 32 influencing factors that are distributed evenly over the seven spheres of influence.

In the next step, the *key factors* were established from the set of influencing factors. These are described in detail in section 2.2 along with their future projections. The other influencing factors, such as the development of electric mobility, reliability and quality of supply, remain extremely important, but are not disruptive as long as the objective is to extrapolate the development of the electricity supply to extreme levels. The eight key factors were developed on the basis of expert opinions gathered in workshop. Finally, an *impact analysis* was conducted in order to test the selection that had been made. This involved the application of an *interdependency analysis*, since all influencing factors have to be equally evaluated. The evaluation of the impact matrix confirms the selection that has been made. In addition, from each of the seven spheres of influence at least one influencing factor is incorporated as a key factor in the further process of creating the scenarios.

At this point, a range of dimensions must be defined for the planned scenarios before the key factors are prepared. In terms of the content type, a decision was made to consider *extreme scenarios* since one of the aims of the project is to look at the potential developments for ICT in the energy sector, and not just those that are highly likely to come to fruition. For this reason, *probabilities of occurrence* are not considered, as according to the literature[38] it is very difficult to determine these in extreme scenarios. As a consequence of this, it is not then possible to conduct *plausibility analyses*. The selected *future horizon* is long term, given that the target scenarios relate to 2030 and are therefore more than five years into the future.

Once the framework for the target scenarios has been laid out, the current state of affairs and future projections of the key factors are described. The primary focus in this process is on the following five quality criteria: Credibility, Differentiability, Completeness, Relevance and Information content. Where possible, two attributes were selected for each key factor, describing the key factor's development. As a result, initially the current status and between two and four future projections were recorded for each key factor. These were then discussed in the context of additional expert workshops, to ensure that all resulting descriptions were consensus-based. When it came to developing the future projections, both analytical and creative approaches were taken. In addition, as recommended in the

37 UNITY 2011.
38 Gausemeier et al. 1996.

literature[39] for extreme projections, the development of the attributes was exaggerated. All eight key factors are considered as critical, since each one has more than one future projection. In selecting the future projections, explicit care was taken to ensure both the broadest possible coverage of the spectrum of development options and that none of the future projections is simply a stronger or weaker variant of another future projection. When formulating these, care was also taken to ensure they could be understood by a lay audience.

Another workshop was staged for the next step, which involved the development of a *consistency matrix* to identify the subsequent scenarios using a *deductive* process. All of the projections were compared in pairs and allocated a consistency score between one and five. A total of 317 projection pairs were therefore evaluated. The process produced 13,824 potential *projection bundles* (one projection per key factor). After removing all projection bundles that contain an inconsistent projection pair – i.e. a value of one in the consistency matrix – just 397 projection bundles remain, from which the *prescenarios* are formed. Since the number of projection bundles to be considered was not too large, it was decided to forego the process of *projection bundle reduction*. A clustering process was undertaken to formulate the prescenarios, using the *single-linkage method*, which is most suitable for producing extreme prescenarios[40]. Furthermore, the metric used to measure the bundle distances was the *squared Euclidian distance*. A *scree plot* was used to determine the number of scenarios. This indicates the way in which the quality (internal homogeneity and external heterogeneity) of the clusters changes with their number. Since the aim is to produce a set of scenarios that is as distinct as possible, three prescenarios were selected for the project. A potential fourth scenario would differ only marginally from each of the other three. By *mapping the pro*jection bundles on a multidimensional scale, it was then possible to visualise the prescenarios in the future-space.

The final step in creating the scenarios consisted of describing all three scenarios in detail (see sections 2.4 to 2.6). First, however, a list of properties of the key factors was created for each scenario. In most cases, this ensured that exact projections could be identified for the key factors. Fuzzy projections also occurred, however, and in some cases these were treated as ambiguous projections (for example in the case of the key factor "Standardisation"). The key factor projections used in the scenarios are linked in the descriptions so that the composition of the scenarios is obvious. When writing the descriptions of the projections and scenarios, care was taken to ensure the reader had a clear view of the envisaged future.

Experts were invited to participate in the various workshops alongside the members of the project group, specifically in order to take account of additional points of view. Moreover, the results were presented and discussed at relevant national and international conferences and congresses, as well as with a range of associations and government departments and academic institutions. For reasons of simplicity, this text refers merely to "scenarios" rather than "extreme scenarios".

2.2 KEY FACTORS

2.2.1 KEY FACTOR 1 – EXPANSION OF THE ELECTRICITY INFRASTRUCTURE

Definition

The task of the grid is to convey and distribute electrical energy between generators, consumers and storage facilities. The electricity infrastructure consists mainly of primary systems such as transformers, switchgear, suspended lines and cables, and of secondary systems comprising active protection and conducting system components as well as a range of functions that are required for operational reasons.

Explanations

The grid infrastructure is of key importance for ensuring the reliability of supply. Up until a few years ago, it was possible to describe electricity transportation as a top-down hierarchy. With the changes in production and consumption, the role of the grid has become more of a bidirectional and multidirectional connection between

39 Ibid.
40 Gausemeier et al. 1996.

producers, consumers and storage facilities. The expansion of the electricity infrastructure will determine what physical capabilities the grid will have in the future, and what intelligent, or smart, functionalities it can support.

In particular, the modified patterns of load transport in and in-feed to the medium and low-voltage ranges, the reversal of the flow of deliverables and the wide-area balancing requirement for fluctuating sources of power generation all represent new challenges for the capacity of the grids to perform as needed.

Current state of affairs

- Characteristics of the electricity infrastructure that comprises the transmission grid

The transmission grid consists of extra-high voltage grids operating at 220 kV or 380 kV grid voltage. Power plants producing in excess of 400 MW feed directly into the extra-high voltage grid at 380 kV, while those that produce around 150 MW to 400 MW feed into the 220 kV grid.

The extra-high voltage grid was designed to be purely a transport grid. This grid level takes care of the transportation of electrical energy over large distances. Through the European ENTSO-E association of transmission system operators, it also offers increased resilience since the cross-border networking permits the implementation of balancing measures to handle individual power plant failures. In addition, the transmission grid is subject to increased requirements in terms of operational safety of components. Even today, the transmission grid is already highly automated and there are specific rules governing traffic management that have the aim of ensuring rapid reaction to new situations. A future task is to introduce the transportation routes from major renewable power generators (offshore wind farms, solar power plants, such as DESERTEC) into the Association. In conjunction with this, there are also plans for high voltage DC (HVDC) transmission systems supporting up to around 800 kV.

- Characteristics of the electricity infrastructure that comprises the distribution grid

The distribution grid comprises all voltage levels up to 110 kV (inclusive) and is split into a high-voltage grid (110 kV), a medium-voltage grid (>0.4 kV to 60 kV) and the low voltage grid operating at 0.23 kV and 0.42 kV.

The medium-voltage grid is supplied by the high-voltage grid, which in turn is supplied by the transmission grid. The medium-voltage level is designed in the form of a ring or mesh grid with open gaps. Each ring line is typically supplied from between five and ten local substations. While the voltage used in rural areas is frequently 20 kV, in cities and towns the shorter distances mean that 10 kV can be used instead. The low-voltage level substations and substations used by large industrial consumers are connected to the load side of this grid. Larger CHP (combined heat and power plants) and wind farms also feed into the medium-voltage grid.

The low-voltage grids are connected to the medium-voltage grid via local grid transformers. In Germany, the low-voltage grids normally take the form of star or mesh grids. The latter are designed so that the fault point can be isolated and the electricity supply has to be interrupted only in a limited area until the fault has been corrected. All domestic customers are connected to the low-voltage grid. Alongside the consumption of electrical power, the expansion of distributed power plants also means that there is increasing feed-in at this voltage level. With greater use of PV (photovoltaic, or solar) power generation and CHP systems, there have already been cases of major problems in grid operations, especially in terms of voltage control.

In contrast to the transmission grid, there are currently no transportation rules that apply to the distribution grid. Medium-voltage and low-voltage levels are operated today without the system operators having knowledge of the grid status. Previously, there was no need to measure the exact status of the medium and low-voltage level grids since the directed load flow was easy to estimate in this top-down topology. Nowadays, however, the lack of information on the grid status creates increasing problems for grid management. In particular, feed-in from distributed generation systems to the medium and low-voltage grids can cause the voltage range to be breached.

Properties for the projections of the electricity infrastructure

The electricity supply system is split into the transmission grid and the distribution grid. These two grid formats differ greatly in respect of the requirements made of them in terms of resilience, response times and maintenance intervals.

Description of the properties of the transmission grid

- In the case of no or merely modest expansion:
  The extent of the transmission grid basically remains its 2012 level, and any expansion is extremely slow to progress. Negotiations on a European overlay grid have failed and only a few HVDC links have been implemented. It is therefore at times not possible to transfer power from renewable sources to the consumption centres or even across borders. As a consequence, wind farms must have their output reduced on a regular basis. This results in higher costs for the economy as a whole, since according to the EEG the farm operators must be "paid" for the reduced output, while increased capacity must be retained for the operating reserve and the operating reserve itself must also be used.
- In the case of major expansion of the transmission grid:
  The German domestic transmission grid has been expanded in line with demand. Domestic transmission systems (such as HVDC links, new three-phase AC transmission grids for voltages of 750 kV and higher transmission capacities and low-frequency three-phase AC grids that exhibit lower levels of loss) have been integrated into a European Overlay Grid. This overlay grid enables a flexible response to the fluctuating provision from renewable energy sources within Germany and across Europe. This means that long-term, seasonal fluctuations from renewable energy sources (such as wind power) can be balanced out across Europe and even beyond.

Description of the impact on the distribution grid

- In the case of an unsuccessful attempt to convert to a system of smart grids:
  The rules governing the distribution grid have not been changed. As a result, the system operators are being forced to undertake massive expansion of the grid, since the high level of synchronicity required by DSM and the cumulative distributed feed-in would otherwise overload the existing resources. This grid expansion makes high demands on the public purse in terms of costs. In some circumstances it results in reduced reliability of supply (except for selected customers in the scope of a special tariff) with the aim of delaying or avoiding grid expansion work.
- In the case of a successful attempt to convert to a system of smart grids: (well developed distribution grid with ICT components):
  Germany's densely meshed distribution grid is able to integrate distributed power plants intelligently with the distribution grid. Rules in force at the distribution grid level ensure low synchronicity of the power drawn from DSM systems and enable successful realisation of supply-demand matching concepts in individual sections of the grid. These rules allow the distribution grid to be operated efficiently at a higher load level. The grid expansion can thus be optimised. By controlling the loads, brief fluctuations in renewable energy sources in the distribution grid can be balanced out.
- Greater account is taken of variable grid charges for those feeding in and those with special contracts (consumption of over 100,000 kWh/a) when it comes to local planning. Solutions with optimised cost structures (ICT, network expansion, DSM) ensure lower grid charges. Grid charges, along with other variables such as connection options, are taken into account by feed-in generators and consumers (industrial and commercial) when carrying out local planning, so that these can be integrated into the existing electricity infrastructure in an appropriate way.

Projection A: Standstill

A European overlay grid has not been realised. Therefore, pan-European trading in energy is being made more difficult and fluctuations cannot be balanced out beyond large regional borders using the existing hydroelectric power plants and storage facilities in some countries. The result is the mass deployment of back-up power stations for the new generation sources. At the level of the distribution grid, the capacity for integration of distributed energy sources quickly hits the limits of economic and technical feasibility. The frequent shutdown of distributed power plants and the resulting high grid charges (caused by the high compensation payments due when the plants are shut down) continue to delay the switch to the new era of renewable power sources.

Projection B: Optimised locally – no expansion at interregional level

The distribution grids in Germany are capable of integrating a large number of distributed power plants into the existing infrastructure. However, it has not been possible to prioritise and carry out the necessary expansion of the transmission grid for the offshore wind farms built in the north of Germany so that the generated energy can be transported to regions with greater demand (for example the south of Germany). The potential of bulk generation plants that use renewable sources (such as offshore wind) cannot therefore be fully utilised. The transfer points to neighbouring countries are permanently at full capacity and offer no potential for additional trading activities. Local components are unable to balance out long-term fluctuations caused by renewable energy sources, such as seasonal summer/winter variances. In the winter this leads to increased feed-in from wind power, so that small distributed energy storage facilities are largely well stocked. As a consequence, the output of these power plants will be reduced since it is not possible to transport the power not required locally at any given time over to other consumption areas. In contrast, during the summer months when there is significantly less feed-in from wind power, back-up power plants must provide sufficient capacity levels to be able to supply the required power. This situation has a negative effect on end-user prices, since many power plants must be kept in stand-by mode in order to replace the renewable energy sources on a large scale when required.

Projection C: Inter-regional expanded, local grid operating under today's rules

Expansion of the grid has been driven forward within the transmission system. A European overlay grid allows the regional differences in wind power across Europe to be offset. However, at the level of the distribution grid it has not been possible to introduce transport rules or the necessary ICT infrastructure. Modern DSM measures such as electric vehicles and virtual power plants are increasing the synchronicity of demand in the distribution grids, which are not designed to cope. To prevent overloading the distribution grids, the DSOs are being forced to undertake massive investment in expanding their systems. They cannot permit larger DSM systems such as charging stations to be integrated into the distribution grid until the grid and the upstream grid levels have been adapted to the new patterns of demand. Attempts to incorporate a local distribution grid with inter-regional trading activities at German and European levels have failed. The efforts to spread the use of electric vehicles and other new loads are being thwarted by the lack of grid expansion and the lack of a smart grid at the level of the distribution grid.

Projection D: Free flow

In line with the plans to expand distributed and fluctuating feed-in, the grid expansion work is being driven forward rapidly. At a European level, the existing AC extra-high voltage grid is being expanded and a parallel DC transmission grid is being created in the form of the HVDC overlay grid, which makes energy storage facilities usable for Germany (for example those located in Norway). The load-centres of southern Germany are connected to this HVDC grid and can therefore also make use of the offshore wind power, as well as other sources. In addition, thanks to smart grid concepts, new expansion rules and control mechanisms, the distribution grids are able to receive a high proportion of energy from renewable sources.

2.2.2 KEY FACTOR 2 – AVAILABILITY OF A SYSTEM-WIDE ICT INFRASTRUCTURE

Definition

"The term 'ICT infrastructure' comprises all of the hardware and logic that permits the use of application software."[41]

According to this general definition, information technology (ICT) infrastructure enhances the traditional power grid infrastructure by enabling the realisation of adapted and new applications alongside the transport of electrical energy. In the context of this document, the ICT infrastructure supports the exchange of information between all of the actors in the smart grid, and allows them to access the data, services or devices available in the power grid. Access must be ensured, free from discrimination, enjoy secure and reliable protection, and comply with data protection requirements.

Explanations

The presence of an ICT infrastructure that is available throughout the enter power system provides the basic support for applications that far exceed the current provision of electricity. The ICT infrastructure is not an end in itself, but rather should be seen as a cross-cutting function. The properties of the ICT infrastructure thus have an impact on the characteristics of the power grids, extending a long

41 Kurbel et al. 2009.

way beyond the mere provision of a communication interface. The ICT infrastructure also provides opportunities for responding to energy-specific queries, with the creation of plant directory services, the development of role-based concepts and the provision of quality of service (QoS), to mention just a few potential applications.

The following are examples of opportunities that are dependent on the provision of a system-wide IT infrastructure:

- Integration of renewable energy conversion[42]
- Peak shaving (adaptation of the load profile) for DSM-capable plants
- Transformation into a multi-directional supply structure[43]
- Dynamic pricing within the energy market (for all participants)
- Realisation of new services and products (e.g. electric mobility)

The IT infrastructure integrates participants in the energy market, resulting in greater interaction. The data that it contains can be categorised as technically or commercially relevant, and must be handled accordingly. In this context, technically relevant means all data that are required to govern the operation of the power grid, and are therefore necessary to ensure reliability of supply. In contrast, commercially relevant data comprise information that serves the market mechanisms attached to the power grid, such as the aforementioned dynamic pricing or new services and products. Whether or not the energy data are stored centrally is of no importance here.

Current state of affairs

As shown in the discussion of the key factor "Expansion of the electricity infrastructure", the supply of electricity currently follows a top-down principle. In this context, ICT systems are primarily used by system operators. When it comes to substation automation, functions such as control, measurement and protection in the transmission grid in particular are realised using IT[44].

On the side of the electricity consumer, however, there is a difference between large industrial customers[45] and domestic customers. The energy requirement of domestic customers has long been sufficiently well predicted using standard load profiles[46]. The actual energy requirement is calculated on a yearly basis by reading the electricity meter[47]. Larger consumers have deployed digital metering solutions that offer the option of load-based remote reading. Even today, the data that are recorded combined with a corresponding pricing structure[48] offer an incentive for peak shaving in industrial contexts.

The increasing volume of distributed feed-in from sources such as wind power or photovoltaic systems means that additional grid status information is also required for the distribution grid. The distribution grid is being transformed from a uni-directional supply grid to a multi-directional structure that enables electricity to both be taken out of and fed into the system. In order to ensure the stability of the grid without locking down the fluctuating power plants consumption must be adjusted in line with fluctuating levels of power generation, where possible using automated systems. Therefore, a corresponding ICT infrastructure is also required here to collect and use the required information.

A potential approach for IT-based solutions that measure the state of the power grid more accurately is the selective use of high-resolution smart meters. Used in the right way, further possible applications for electronic meters include:

42 For 2020 the Federal Government has planned to increase the contribution of renewable energy sources to gross electricity generation to 30 percent (according to BDEW the contribution in 2009 was 16 percent).

43 Historically, the supply of electricity has followed a top-down approach from the extra-high voltage level (transmission grid) to the high, medium and low-voltage levels (distribution grid). With the expected increase in distribution of generation, a paradigm shift is anticipated resulting in a bottom-up supply in which the electricity is fed in to the distribution grid by small distributed generators.

44 For example, Supervisory Control and Data Acquisition (SCADA) stations, Remote Terminal Units (RTUs) and Intelligent Electronic Devices (IEDs) that are connected to each other via communications systems.

45 "Special contract customers" with an energy requirement of >100,000 kWh/a.

46 Standard load profiles contain historical data for average domestic customers. They achieve on average a high stochastic accuracy.

47 Normally an analogue electromechanical meter.

48 Thus the price for grid charges for these customers also depends on the annual peak output.

- Preparation of consumption data for the customer and analysis of own consumption patterns (and analysis of savings opportunities)
- Remote reading of meter levels at high time resolutions (real time if necessary), remote activation and deactivation of customers (savings in staffing)
- Improvement to consumption profiles and forecasts derived from them
- Use of dynamic tariffs to adjust customer consumption patterns to the current state of generation
- Support for DSM

According to Section 21 of the EnWG (revision of 26 July 2011), corresponding measurement systems that "[. . .] reflect the actual energy consumption and actual time of usage" (Section 21d) are mandatory in new builds and fully renovated buildings used by "[. . .] end users with an average usage of over 6,000 kWh" and for "[. . .] system operators as defined in the German Renewable Energy Act or the Combined Heat and Power Generation Act of new systems with an installed power of over 7 kW" (Section 21c).

In the long term, electric mobility is also a driver for provision of an ICT infrastructure in Germany. The use of electric vehicles to store power is a target.[49] To control energy storage and the return of power to the grid, detailed information on the grid status is required and must be communicated to the vehicle or charging station. In addition, market aspects such as billing of electricity at charging posts or crediting feed-back into the grid must be replicated. Alongside the provision of an electricity infrastructure that can provide power for electric vehicles, the ICT infrastructure is therefore primarily needed in order to realise data management for electric mobility systems.

The creation of an ICT infrastructure with components and motivators such as smart meters, electric mobility and renewable power plants is currently being tested in Germany and abroad. However, system-wide provision is still pending.

Properties of the projections for the availability of a system-wide ICT infrastructure

Some form of the ICT infrastructure will emerge on the basis of the need for sensors and actuators in the distribution grid. Depending on whether this development follows a long-term planning process with corresponding support from politicians or whether the development is event-driven, the two extremes will be either a range of incompatible isolated solutions or a comprehensive plug and play infrastructure that meets all requirements.

Projection A: Isolated solutions

The government and policymakers provide no leadership for development. Equally, there are no discussions on common standards among the providers of communication solutions for the power grid. Instead, they are attempting to force through their own, proprietary market standards. As a result, systems that are not fully interoperable are emerging in parallel. This is slowing down the process of system-wide dissemination of corresponding solutions, as uncertainty is generated about which will be the "winning" technology. For this reason, both consumers and the vendors of technical equipment are slow to adapt to developments.

Projection B: Plug & play

A system-wide ICT infrastructure is established that supports plug & play functionality and all required QoS attributes. Consumers and the vendors of technical equipment benefit from a high degree of planning certainty for their investment. This encourages expansion of the infrastructure and the range of services and devices offered to make use of it. Such expansion requires a high level of dissemination, which is increasing the potential of the smart grid and therefore its usefulness for providers and customers. This type of system is being created either through the development of market-compliant standards with corresponding political leadership or through the market leadership of a single market player, whose solution will be established as the de facto standard in this way.

49 Also referred to as V2G (vehicle to grid).

2.2.3 KEY FACTOR 3 – FLEXIBILITY OF CONSUMPTION

Definition

The factor "Flexibility of consumption" describes the opportunities for adapting the usage of electricity, i.e. the load on the power grid, according to the generation conditions. This is in direct contrast to the current load-driven form of operation, in which the supply of power follows consumption. Drivers for improving the flexibility of consumption in Germany are the increasing integration of distributed and fluctuating power plants, such as wind power and photovoltaic systems, while retaining the reliability of supply and increasing energy efficiency.

Explanations

The stability of the electricity grid depends on factors including the time-critical synchronisation of the provision of energy and actual consumption. There are two paradigms for matching these two variables.

1. Load-driven operation – the generation of electricity follows demand.
2. Generation-led operation – the demand for electricity follows generation.

In the demand-led form of operation, electricity is provided on the basis of consumption levels. This means that electricity generation must be planned according to demand for power. Forecasts are used alongside the meter readings to estimate the power requirement or load in the electricity grid. Fluctuations in consumption are balanced out by adjusting the output of the electricity generating power plants, in some cases also by means of load shedding. The opportunities for governing the output of power plants are dependent on the type of power plant in question. A distinction is drawn here between base, medium and peak load. While the foreseeable base supply is provided by base-load and medium-load power plants (such as nuclear power or coal) according to corresponding timetables[50], short-notice fluctuations are balanced out by peak-load power plants (pumped storage and gas-fired power plant). Due to their low capacity, operation of these forms of power plant is more cost-intensive than that of the base-load and medium-load power plants.

The second method of matching generation and consumption is known as demand-side management (DSM) or load control. The aim of this principle is to adjust energy consumption to match the less easily planned, fluctuating supply. If low amounts of power are available, some consumers may be temporarily disconnected from their power supply or have their power consumption reduced. During phases of high energy supply, consumers may, in contrast, experience advance supply in the form of front loading.

The load-control approach is particularly relevant when it comes to balancing out the fluctuating feed-in of power from renewable sources. In order to ensure the most efficient possible form of supply, there is a need to shift the load to a period in which there is sufficient power supply. New forms of automated governance control will be required in order to actively manage load in relation to short-notice changes in energy consumption.

Current state of affairs

The current power supply system mainly follows a load-led approach. In conjunction with the supply grids, the German system of power plant management ensures that the supply of electricity is as constant as possible[51]. The principle relies on the availability of adjustable power plants that are able to contribute power in line with the demand at any given time.

Within the EU, there is an emphasis on increasing the use of renewable energy sources, both in view of reducing CO_2 emissions and given the decreasing availability of fossil fuel resources. The growing expansion in renewable power generation systems requires additional measures in order to ensure the stability of the grid and achieve the desired levels of energy efficiency.

DSM or load control offers methods of supporting grid stability and improving the efficiency of the transmission and distribution grids.

50 The ability to adjust these power plant types is not excluded in principle, however. Thus, nuclear power plants could mainly balance out fluctuations. They can deliver a regular contribution of 10 GW. This achieves power gradients of 2 percent per minute per power plant (ATW 2010).

51 In 2009, the 14.63 minutes average interruption per end user represented a new high in the reliability of supply (BNetzA 2010a, p 273).

Potential grid expansion measures and rapidly rising grid charges can be avoided by achieving better utilisation of the grid. The proportion of electric load that would be suitable for load shifting is referred to as the load shift potential.[52] Off-peak storage heaters were an early attempt to shift the timing of the electricity grid load for domestic customers. By charging the heaters overnight, additional demand is generated when the demand for energy is normally low, in order to balance out the differences in demand between daytime and night. This method results in an increase in the base load.[53] The technique used to shift load and realise peak and off-peak tariffs is called ripple control. In fact, the system used is a form of audio frequency ripple control. Newer systems use Power Line Communications (PLC). This technology is generally suited to remote control of devices that are equipped with appropriate receivers, allowing additional consumer devices, such as warm water storage tanks, to be controlled. The switching between various tariffs is also implemented by controlling the meter systems.

The current understanding of DSM at the level of the private household describes a more in-depth approach. This proposes controlling household appliances that can be switched off temporarily according to the load situation in the power grid. A general approach within a smart home requires corresponding control mechanisms, which are being tested in pilot projects. The measurement of control-related variables and the control itself is done using ICT. Examples at this point include digital smart meters, corresponding controllable consumer devices (smart appliances) and the provision for data exchange via broadband communication tools such as Digital Subscriber Line (DSL), cable broadband, wireless local area networks (WLAN) and even Bluetooth or Zigbee.

Industrial customers also offer great potential for load shifting. In this segment there are already many opportunities and products for shifting load to times when there is lower demand for electricity. The incentive for this is created by variable tariffs for special customers that have an annual power consumption of > 100,000 kWh. In addition, major consumers can achieve considerable reductions in electricity costs via the unit price by adjusting their consumption, since the grid price is related to the annual peak load. The basis for these tariff structures that differ from those available to domestic customers is created by, among other factors, the greater distribution of digital meters in the industrial segment. Major consumers are also able to trade in energy volumes on the energy exchange. For example, they can sell temporary surplus energy on the spot market. The E-Energy Study[54] gives examples of situations in which load shifting is viable, such as the chemicals, paper and metal industries. As the load shift potential grows, the development of ICT is less important than it is for smaller consumers, since the available infrastructure already provides much of the required information for controlling the power consumption in a (semi) automated manner.

A range of factors is therefore key in encouraging more flexible consumption. First, data are required within the electricity grid, providing the necessary information to all parties participating in the flexible consumption scheme. Second, new consumer devices and appliances are required that are able to act as a load-shifting tool. In domestic households such devices include electric heating instead of oil or gas-fired heating in well insulated buildings, smart appliances in combination with smart meters, and electric mobility solutions that can potentially use the vehicle as a means of storing power. With their cold storage facilities, swimming pools and large energy-intensive buildings, industrial consumers offer a range of starting points for virtual storage in use as load shifting tools. The opportunities for both customer segments are currently being tested in the E-Energy model regions.

Properties for the projections relating to consumption flexibility

The properties for consumption flexibility relate to the levels at which load shifting is possible. A distinction here should be drawn not only between domestic and industrial customers[55], but also between power and energy. The participation of customers has a long-term impact on the characteristics of the power grid. Poor integration of consumers with the smart grid will result in massive efforts being needed in alternatives (grid expansion, etc.) in order to ensure the further integration

52 The dena- II Grid Study (dena 2010b) has quantified the load shift potential for Germany in 2020 at 6 GW.

53 Used frequently in such countries as France.

54 BMWi 2011d.

55 Here in the sense of large or special contract customers. These are characterised by potentially high adjustment capacity.

of fluctuating feed-in from renewable energy sources into the electricity supply.

Effects of participation by industrial customers

- High level of participation
  All industrial production processes provide an input into the energy planning process of a company. Large buildings, cold storage and other major consumers for which load shifting potential has been identified make their load shifting capacities available.[56] The available capacity for adjustment is high. The high level of participation among industrial customers will also result in a more dynamic development of products and services, in particular for that customer segment, which itself will further encourage additional participation.
- Low level of participation
  Industrial customers provide only low levels of load shifting capacity to the grid. This means that a large proportion of the adjustment potential of the smart grid is unused.

Effects of participation by domestic customers

- High level of participation
  By using smart meters and adjustable consumer devices, it is also possible to achieve load shifting for domestic customers. Variable tariffs represent an initial option for an incentive-based approach. Without automation, however, these will entail a drop in usability for domestic customers. It is a further encroachment on customers' autonomy. In terms of deployment, therefore, a high degree of automation for consumer appliances is targeted, with the aim of limiting any reduction in usability. New electricity-consuming devices such as electric vehicles, heat pumps and potentially future off-peak electric storage heaters offer additional options for load shifting and for offering corresponding products and services. Moreover, distributed power plants can be integrated more efficiently into the general grid by domestic customers.
- Low level of participation
  Private households decide not to participate in load shifting. This will result in a loss of adjustment capacity in the domestic customer segment, and restricts the opportunities to open up new markets for products and services in this area.[57] With the reduced options for the smart grid to affect voltage quality at distribution level in residential areas, the capacity for distributed power plants to be integrated into individual grids will soon be limited. Options for integrating any power generated by domestic customers into the smart grid are restricted.

Projection A: Low participation (low participation of industrial and domestic customers)

Industrial and domestic customers play only a very limited role in making consumption more flexible. Both large potential storage capacities (mostly among industrial customers) and some of the potential for new products and services (mostly private households) are lost. The expansion of distributed power plants and fluctuating feed-in is only possible to a limited extent and by incurring high costs to meet grid expansion requirements.

Projection B: Only industry (low participation by domestic customers, high participation by industrial customers)

Industrial customers make a large contribution to load shifting. Large buildings, cold storage facilities, swimming pools and even production processes can be incorporated into the load shifting schemes. This realises large storage options for use as energy containers. However, large-scale participation among domestic customers is not realised, and their adjustment capacity is lost. It becomes harder to introduce new products and services to this segment.

Projection C: Only domestic customers (high participation by domestic customers, low participation by industrial customers)

Large numbers of domestic customers contribute to making consumption more flexible. Smart appliances allow consumption to be controlled by (semi) automated processes. Customers are able to take advantage of variable tariffs. New markets are created in terms of products (smart meters, smart appliances, electric vehicles) and services (distributed marketplaces for trading electricity).

56 The adjustment capacity characteristic (capacity, time available) is dependent on the processes of the customers under consideration. For examples see the E-Energy Study, cf. BMWi 2011d.

57 This does, however, permit the use of energy services that are not based on DSM.

Projection D: Smart grid (high level of participation by both industrial and domestic customers)

Both industrial and domestic customers contribute to making consumption more flexible. While the industrial customers offer large volumes of load for shifting, grid controls for smaller generators and consumers can be realised at domestic-customer level. These also provide potential for new products and services (energy markets, electric mobility, etc.). As a result, the power grid achieves a high degree of flexibility when it comes to integrating new consumers and generators. The overall efficiency of the grid increases greatly.

2.2.4 KEY FACTOR 4 – ENERGY MIX

Definition

The term "energy mix" (used here only in respect of electricity) refers to the proportionate use of different sources of primary energy in order to generate electricity. A distinction can be made between primary energy from fossil fuels (oil, coal, natural gas), primary energy from uranium and primary energy from renewable energy sources (wind, sun, biomass, hydroelectric power). Depending on the form of primary energy, different types of power plant are used to generate electricity: Coal, oil and gas-fired power plants for processing fossil fuels, nuclear power plants, onshore and offshore wind farms, hydroelectric power plants, photovoltaic (solar) power plants, CSP (concentrating solar power) power plants and biomass power plants. As well as conventional power plants, biomass and fossil fuels can also be used in CHP (combined heat and power) plants. Bulk electricity generation is the term used for major power plants with high generating output (generally from several hundred MW up to a few GW) feeding electricity directly into the extra-high voltage or high-voltage grid. In contrast, distributed generation of electricity relates to the provision of lower outputs (from around 1 kW to several hundred kW), for feed-in to the distribution grid or for own consumption, by small generation facilities distributed geographically.

Explanations

The use of different primary energy forms for electricity generation also means differing feed-in characteristics by the power plants. In the case of power plants that operate using fossil fuels, biomass or uranium, the generation of electricity is dependent on ensuring a functioning supply chain for raw materials, but is largely independent of changes in the weather. Schedules for the amount of electricity to be generated in a given time period that are agreed and planned long in advance can normally be adhered to reliably. This supports the load-led operation of the electricity grid, in which the total level of generation is always based on the consumption (load) which varies over time. In contrast, the output of power plants that generate electricity from wind power or solar power is dependent on the current weather conditions (wind, sun, cloud) and is also subject to wide climatic and seasonal fluctuations. This results in a fluctuating feed-in with partially stochastic characteristics. It may be possible to forecast this feed-in within certain limits, and also to adjust it by controlling output, but it cannot be timetabled. These forms of power plant are initially only suitable for a generation-led form of operation, in which consumption is based on the amount of electricity that is generated (supply-dependent consumption). However, when used in conjunction with storage, controllable consumer devices and generators as virtual power plants, load-led operation is possible here too.

The various forms of electricity generation are also associated with different levels of environmental impact. Even just the exploitation (deep and open-cast mining) and extraction (oil rigs) and the transportation (oil tankers) of fuels are associated with a heavy environmental footprint and hazards. In addition, generation of electricity by burning fossil fuels leads, depending on the type of power plant, to various levels of CO_2 emissions. The extraction of uranium ore and the enrichment process and storage of radioactive waste from nuclear power stations are also damaging to the environment. In respect of CO_2 emissions, the use of renewable energy sources to generate electricity is largely neutral, and therefore does not contribute to climate change, except for the CO_2 emissions during the construction and dismantling of the plant.

Current state of affairs

The energy mix in Germany has changed over the past 20 years. This change is down in part to the depletion of natural resources in terms of fossil fuels. However, it is also due to an increasing use of renewable energy sources. The proportion of electricity generated from each primary energy source in Germany in 2010 can be seen in Figure 5. A large share of the renewable energy sources is taken by wind power,

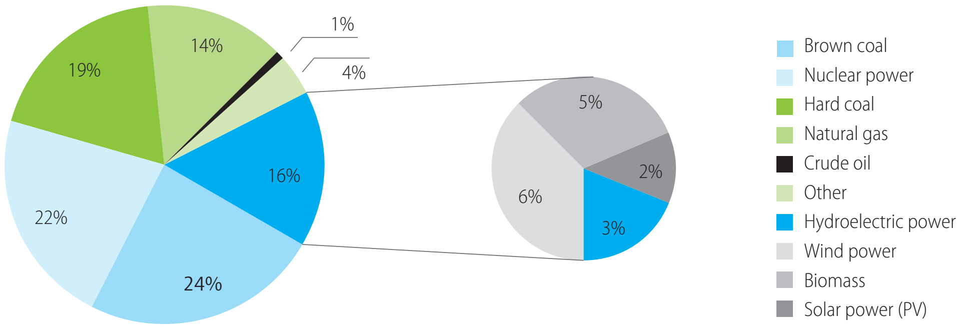


Figure 5: Share of primary energy sources in electricity generation in Germany in 2010[59]

biomass and hydroelectric power[58], while solar power is registering high growth rates.

In its Energy Concept published in 2010, the Federal Government emphasised that "renewable energy sources should occupy the main share" of the "energy mix of the future".[60] One of the major goals is to reduce greenhouse gases and therefore reduce the emissions of CO_2 into the atmosphere in the electrify supply process. For example, the share of electricity generated from renewable energy sources is set to rise to at least 35 percent[61] by 2020 and to at least 80 percent by 2050.

With its current energy mix, Germany, as also the EU as a whole, is a net importer of primary energy sources. This means that the current pool of power plants has less economically feasible, usable primary energy available to it than it needs in order to generate the required electricity. Therefore, both Germany and the EU are reliant on importing primary energy sources from other regions of the world.

Properties for the projections relating to the energy mix

The projections of the energy mix key factor consider two dimensions: environmental compatibility and capacity for planning

Projection A: Traditional

The generation of electricity requires fossil fuels, possibly also nuclear power[62] and hydroelectric power. Pumped-storage power plants, coal-fired power plants and nuclear power plants represent the state-of-the-art deployed technology. Gas-fired power plants are used to provide additional power during peak and medium-load periods. The amount of distributed feed-in, including of electricity from renewables, is limited. The consequence of this trend is that a minimum amount of investment is required in grid expansion since the load flows in the grid remain largely unchanged. In addition, further economic benefits are obtained by avoiding comparably cost-intensive investment in distributed power plants. This results in a comparably lower price of electricity for industrial and domestic customers. CO_2 emissions remain relatively constant, since the rising demand for electricity offsets any efficiency gains from developing power plant technology.

Projection B: Low CO_2 and predictable

The energy mix comprises mainly low CO_2 coal, solar power (CSP) hydroelectric power, wind farms that are capable of delivering base load, and biomass and geothermal sources. Only power plants with predictable output are used, which means electricity production can be controlled according to load. For reasons of technology and efficiency, mainly bulk

58 BMWi 2011g.
59 Own visualisation after AGEB 2011.
60 BUND 2011.
61 The national action plan for renewable energy published in August 2010 talks about 38.6 percent as the expectation for generation from renewable energy sources in 2020 (see BMU 2011b).
62 As of the time of writing in 2012, the possibility of continued use of nuclear power in 2030 in Germany is excluded. However, developments that would justify this projection are conceivable. The primary energy source does not in any case play a direct role in the topic of the smart grid. Only the capacity for influence, fluctuation and the feed-in level are relevant.

power plants are used. The "base-load capable" wind farms generate electricity on the one hand and use gas (such as hydrogen) to store excess energy during weak-load phases on the other hand.

The generated gas is fed into gas-fired power plants, for example, in the event of shortages. The coal-fired power plants use carbon capture and storage (CCS) technology, while solar-thermal power plants with storage facilities (e.g. thermal energy stores) located in sunny areas around the world transform solar energy into power. Hydroelectric power from Norway is also used. Power plants that use location-independent, easily transported primary energy sources use the existing structure and technology of the transmission and distribution grids. The supply of electricity from solar-thermal power plants and large hydroelectric power plants requires the expansion of extra-high voltage transnational transmission grids. Biomass power plants and smaller hydroelectric power stations also provide distributed feed-in.

Projection C: Renewables, but fluctuating

The contribution of fossil fuels and nuclear power to the nation's electricity generation is reduced on a continual basis, while the share of renewable energy sources in electricity generation rises at the same rate. Large, technology-dependent bulk power plants are replaced by medium-sized and small distributed power plants and offshore wind power facilities. Gradually, all potential locations for offshore wind farms are used and due to their combined power these can be seen as large bulk power plants. The construction of solar power plants is driven forward. Due to the high proportion of fluctuating feed-in, the consumption-oriented generation of electricity by electricity generators alone cannot be guaranteed in all locations at all times. To counterbalance this, smart grids and load management are introduced, with grid expansion and the integration of storage at all levels of the grid also necessary. Where these offsetting measures are insufficient, electricity must be provided from storage or via imports. Overall, the potential to become a net exporter rises. The CO_2 emissions and environmental impact are low. Nevertheless, there is a need for a great amount of investment in electricity generation, distribution and energy storage.[63]

2.2.5 KEY FACTOR 5 – NEW PRODUCTS AND SERVICES

Definition

The phrase "new products and services" refers to services and products that utilise the new options provided by the smart grid, by combining information and the functions provided by enhanced sensors and actuators to make a product, potentially complemented by additional services.

Explanations

New services and products[64] offer market opportunities and openings for traditional energy suppliers and for new participants in the marketplace. The new services that are offered are characterised by innovation in terms of the market, process or product based on energy information.

The new products and services are not only related to energy, but could also comprise new bundled products offered in conjunction with other service areas. While a provider that only sells energy can only differentiate itself via its price, new services in combination with energy offer unique selling points thanks to the increased customer benefit.

The "New products and services" area can be considered at two levels. First, new products can be established both for industrial and other commercial consumers as well as for domestic customers. At the same time, new services will develop that are primarily targeted at utility companies or grid system operators. With increasing options for communication between energy suppliers and grid system operators on the one side and end customers on the other, it is even possible to realise new services that create value added for both the energy supplier or grid system operator and the end customer, as well as in many cases several other participants. Such business models are already quite typical in other sectors and are discussed under the title Co-creation of Value[65]. The role of the customer in this situation has changed from being simply passive recipients and consumers to being active "prosumers"[66] who may even operate their own generation equipment and who are

63 See also chapter 6 for a discussion of the options of balancing fluctuating feed-in.
64 It is already estimated that the global market for smart domestic appliances will reach 26 billion US dollars by 2019, cf. Pike 2011.
65 Prahalad/Ramaswamy 2000.
66 McLuhan/Nevitt 1972.

(indirectly) participating in maintaining the stability of the electricity supply system.

Services and products for end customers

The supply of electricity on the basis of tariffs that vary over time or dynamic tariffs that depend on the amount of energy available or the grid capacity is a simple example of a new product. Alongside the supply of power, products may also be offered in relation to the operation of meters and metering services. Services include services and applications that the electricity customer may use and that do not necessarily have to be offered exclusively by electricity utility companies.

The line between products and services may be fluid. For that reason, no further distinction is made below. The information and control functions that are available in a future smart grid and that form the basis for new products/services for end customers are wide ranging, for example:

- With the growing levels of use of digital electricity and gas meters expected in the future, smart metering services may be set up to analyse and compare energy consumption information, for example. They may help consumers visualise consumption or offer automated advice on energy matters.
- Any domestic and industrial electricity customers that have their own generation equipment, such as a mini CHP system or backup batteries, may make this available as part of a virtual power plant. An aggregator can then direct these controllable distributed generation facilities with a view to maximising profit and thus provide balancing power.
- Heat contracting offers for CHP systems sell "heating" to the customer as a product, while an aggregator sells the generation of power and controls the times at which the CHP is running on the basis of electricity prices and taking account of restrictions imposed by the customer.

Services and products for energy utilities and grid system operators

The increasing availability of information and control options in a smart grid allows energy utilities to offer services, for example:

- The aggregation of load profiles for specific groups of consumer or specific regions supports energy consumers in optimising their procurement
- With high resolution consumption data that can be linked with additional information about the customer, variants of revenue management[67] can also be offered in the sale of electricity
- New forms of procurement are possible alongside full delivery, for example cooperative models, structured procurement, tranche-based procurement or full procurement with coverage by a main utility
- Backup generators can offer their potential on the market. Backup generators are found in agriculture, data centres and in hospitals, among other situations. There are already providers on the market that are developing services to aggregate the output of such facilities using communications technologies and offer the power to the reserve market.
- The direct marketing of generator output (all or just a share) as permitted thanks to Section 17 EEG can be supported for operators of distributed renewable energy generation plants.

Current state of affairs

Products that go beyond the scope of supplying energy have not yet penetrated the market for domestic end customers. Experiments such as the Google PowerMeter have been abandoned. For industrial customers there is a wide range of offerings for contracting, participation in the balancing power market, and other services. Virtual power plants are operated in a few isolated cases.

Properties for the projections relating to the development of new services

The establishment of new products and services assumes a number of properties. While it is dependent on the technical capabilities, it is affected more by the paradigms that already exist in the energy market and that are influenced to a significant extent by legislation and regulation.

Projection A: Traditional services

This projection transfers the current concept over to the smart grid on a 1:1 basis. New services are limited primarily to the automation

67 Cross 1997.

that is required in the distribution grid. Where it is economically feasible or necessary in order to maintain the role of the distribution grid, monitoring and control functions are installed, in a similar way to the norm for today's transmission grid. This means that overload situations, as could occur given the greater use of new electrical consumer devices such as electric vehicles or heat pumps, can be detected at an early stage and avoided. Techniques that are already in use for off-peak storage heaters, such as ripple control, may be applied here. Just as peak and offpeak tariffs are offered in some regions today, this concept could be extended in the future to help shift the load of new consumers into off-peak hours. Dynamic tariffs linked to an automated form of power management are not forced on customers, however.

Projection B: Basic services

In this projection, the opportunities of the smart grid are primarily used to make the existing business processes of energy companies more efficient. In particular, Outage Management and Asset Management processes are provided with greater volumes of information at shorter intervals, and, given the increased opportunities for remote control, can react more rapidly to problems and correct faults. Digital meters that can be read remotely will primarily be installed when the savings in meter reading costs and subsequent processing and correction by staff exceed the costs of providing and installing the meters. In instances where detailed sequences of customer consumption data are available, revenue management methods can also be applied to increase revenue. If the customer indicates a corresponding willingness to pay, smart metering services are offered and the consumer is sent a monthly bill on the basis of the measured consumption. As in other sectors, the functions provided by the Internet will be put to greater use so that customers can manage their own master data (information such as bank account, and possibly the ability to change consumption forecasts if, for example, the number of occupants in the home changes). Other functions to be supported by the Internet include standardised processes such as moving house, complaints, requesting a bill or viewing bills online. These functions allow the utility company to make savings in its customer care operations.

Projection C: Killer apps

If customer demand for specific products increases strongly, this creates a self-amplifying system and new markets that will enjoy a large boom thanks to the smart grid. Customers take greater interest in their own electricity consumption and take advantage of opportunities to analyse their usage thoroughly. Vendors of white goods offer automated energy advice that highlights the benefits of their energy-saving devices and makes the benefits easy for customers to understand. Services such as "light contracting" and similar, for commercial users, are made possible since the energy consumption of individual departments as a proportion of the entire usage becomes visible and the company's overall awareness of its energy consumption rises. Household management or smart home systems also increase in popularity, as many household appliance vendors are now building in compatibility with corresponding gateways and affixing a "Smart-grid Ready" label to help sell their refrigerators and washing machines. The availability of grid-related pricing with bonus systems for customers make it more attractive financially to install these devices. With an ambitious programme of standardisation and economies of scale and scope, many smart grid applications will be economically viable and offer those customers who are willing to pay the corresponding premium the opportunity to enjoy value added. The existing economically feasible potential of DSM[68] will therefore be completely exhausted by these developments and contribute to stabilising the power grid, with a simultaneous increase in the proportion of fluctuating generation.

68 For Germany, for example, dena 2010b.

2.2.6 KEY FACTOR 6 – COSTS FOR END USERS

Definition

End-user costs are the costs incurred by domestic customers for the volume of electricity they consume in comparison with their household income.

Explanations

End-user costs differ according to quantity supplied, region, customer flexibility and maximum output consumed. Input factors on the supply side include, in particular, the purchase price or generation price, grid charges and state charges in the form of the EEG surcharge (or reallocation charge) and the Kraft-Wärme-Kopplungsgesetz (KWK-G; Combined Heat and Power Act) surcharge, taxes and concession levies. The quantity supplied may change considerably in the future, for example if the use of electric vehicles proliferates or heat pumps replace gas-fired heating systems.

Current state of affairs

The initial results of the smart meter pilot projects conducted in Germany reveal that domestic customers currently have only a very limited interest in finding out more about the price of electricity and potential savings,[69] even though the costs of electricity in Germany are the second highest in Europe.[70] This is reflected in the previous switching patterns of German domestic customers, 90 percent of whom continue to fulfil their energy requirements using their regional energy utility company.[71] Rising energy costs[72] and the ever increasing liberalisation of the energy markets have led in the past few years to constant growth in the domestic customer churn rate.[73] While this rate was 1.7 percent in 2006, it rose to over 3.4 percent in 2007 and to 5.25 percent in 2008.[74]

Major consumers already enjoy more complex electricity products and the opportunity to purchase the electricity they need from a range of component products as and when they need it. The price charged to major customers is currently around 50 percent below the price charged to domestic customers[75]. Compared with prices for domestic customers these prices are subject to fluctuations according to time of day and load. The prices contain an output component[76] that significantly dominates the grid charges.

Since the end of 2010, energy companies have also been required to offer variable tariffs to domestic customers.[77]

Properties for the projections relating to end-consumer costs

The key factor end-consumer costs is considered in two dimensions. First, the effects of different levels of cost for end consumers are described. The second dimension is then price volatility. The level of costs has a greater impact on end consumer decisions than volatility.

Impact of the level of end consumer costs in terms of household income

- In the case of high costs for end consumers:
  Spending on electricity rises to a level of household income at which the customer becomes highly motivated to make efforts to improve energy efficiency and energy sufficiency. There is great willingness to take advantage of time-based flexible tariffs, and even to accept lower usability levels as a result. The churn rate of domestic customers has risen rapidly, resulting in massive competition among electricity suppliers.
- In the case of low costs for end consumers:
  In the long term, the end-consumer costs for domestic customers remain at 2012 levels. Customers have little interest in either time-based variable tariffs or in a smart meter or smart grid.

Impact of volatility over time in prices for end consumers

- In the case of high price volatility:
  Time-based price fluctuations in the European energy market or

69 VZBV 2010, pp. 39 et seq.
70 EKO 2010b, p. 584.
71 BNetzA 2009a, p. 156.
72 From April 2008 to April 2009 electricity costs for domestic customers with a basic supply contract rose by 7.3 percent, BNetzA 2009, p. 161.
73 The annual churn rate defines the percentage of customers who change provider, by dividing the number who switch by the total number of customers.
74 Calculated from the number of households (40.2 million) and the number of customers having switched electricity provider, Destatis 2010; BNetzA 2009, p. 157.
75 In 2009: household customer price: 21.08 cents/kWh, industrial customer price: 11.89 cents/kWh, BNetzA 2009, p. 160.
76 Power price: This is calculated from the annual peak power usage by a large customer and forms the basis for the power component of energy costs.
77 More accurately: Tariffs that encourage energy saving or controls. However, there is as yet no clear answer to the interpretation of Section 40 para. 3 EnWG.

other volatile prices are communicated to domestic customers via their smart meter in near real time. The price fluctuations that occur are so volatile, however, that manually adapting consumption patterns would lead to a great loss of usability and activities would become difficult to plan. However, price fluctuations offer opportunities for making cost savings through the use of smart grid applications (as in electric vehicles, freezers, circulator pumps, etc.) that have the objective of automating when and how the devices are used, where possible with no loss of usability.[78] The cost-saving opportunities then become a significant driver for the adoption of smart grid systems at domestic-customer level.

– In the case of low price volatility:
  Primarily, the energy utilities offer simple tariffs (just peak and offpeak tariffs in addition to the fixed price per kWh). Flexible tariffs are barely offered at all, and are only used by a few customers. Domestic customers are not particularly able to affect their energy costs by changing consumption patterns and in some circumstances must reckon with loss of usability as a trade-off. When the loss of usability is too great, domestic customers are able to select another tariff from another energy utility that better matches their consumption patterns. This option heavily restricts the opportunities for an energy utility to introduce DSM for domestic customers.

Projection A: High costs, low volatility
With the price-based incentive of simple tariffs, there are hardly any opportunities for domestic customers to actively modify their consumption patterns to take advantage of the tariff structure. The only option available is to switch provider to an energy utility that has a tariff system that is a better match for the customer's usual consumption patterns. However, the tariff selection of domestic customers has a negative impact on the desired effect of some providers' tariff policies to encourage load shifting at domestic customer level. Customers are unhappy since they are also unable to reduce their high energy costs in the long term due to the complexity of differentiating the various energy products and adjusting their energy consumption.

Projection B: Low costs, high volatility
Only a handful of customers react to the availability of variable tariffs. In contrast, many more customers experience frustration at the constant price fluctuations and the constant flow of new information from this system. Customers find that the effort needed in terms of time to understand the tariffs is disproportionate to savings that can be achieved, which are relatively low. The price level does not offer the desired price savings effect that would encourage customers to learn about DSM and smart grid applications.

Projection C: Low costs, low volatility
Electricity costs remain comparably low and variable tariffs are used to only a very limited extent. This means that for domestic customers there is barely any incentive to adjust their consumption patterns to take advantage of variable tariffs. Value-added services that are based on electricity price information therefore find it difficult to gain any level of penetration. The situation remains largely as it was in 2012.

Projection D: High costs, high volatility
Significantly higher electricity make customers more inclined to use their own distributed electricity generation options, and also make them more willing to take advantage of variable tariffs. At the same time, these intelligent incentive-based systems engender greater levels of acceptance of DSM and of smart grid applications among domestic customers. The high degree of automation of smart grid applications means that customers notice barely any decrease in usability. Distributed storage (for example in electric vehicles) is used to decouple electricity purchasing from demand, to the extent permitted by the storage capacity.

78 Cf. for example the new range of products from Miele. Whether such tariffs and the associated intervention in device control will be accepted is considered in chapter 7.

2.2.7 KEY FACTOR 7 – STANDARDISATION

Definition

Standardisation creates a unified framework for communication in the smart grid at both syntactic and semantic levels, to enable the ICT infrastructure that is superimposed over the grid to be plug & play (in terms of interoperable). Alongside standardisation of communication technologies, the general concept of standardisation also refers to a unified range of ICT components, energy data semantics and also unified processes for the smart grid. Standardisation is a cross-cutting topic for the various layers of the smart grid ICT architecture. By extension, industrial standards are also identified as standards here.

Explanations

The interfaces of the interacting ICT components and the way they interact with each other must be implemented in the ICT system in a standardised manner. Security standards for smart grid data and systems must also form part of the standardisation process (data protection for personal data/high-level encryption).

Standardisation must be distinguished from the separate property of interoperability (i.e. the capability of two systems to exchange information that is semantically and syntactically correct). The aim of standardisation in the context of the smart grid is to unify ICT and energy to form an Internet of Energy (IoE). The objectives include the interoperability of all ICT systems offered by market participants, standardisation on an Internet-based protocol (Internet protocol – IP), plug & play capability of new components for the entire system, uniform architecture and QoS requirements. In addition to interoperability, standardisation must also take account of data security and system security.

Current state of affairs

When it comes to standardisation it is necessary to differentiate between national and international initiatives. In addition, there are certain de facto standards, or industry standards, that have become established due to market forces. This means that a solution takes precedence on the basis of the actual distribution of the technical solutions from one firm or consortium, without these ever having been submitted to a standardisation process (with all of the associated consequences). An example of this in the energy sector are smart home or home automation implementations such as KNX[79] and Zigbee [80]. In addition to the technical standards dimension, which will be discussed in further detail below, there are also various technical and statutory requirements for data exchange on the energy market that are stipulated by the regulator and often identified as standards. These are generally national in nature, and while they may be based on international solutions this need not, however, always be the case. In Germany, a solution is in use in the area of market communications based on the EDIFACT (Electronic Data Interchange For Administration, Commerce and Transport) standard with modified semantics and exchange processes (business processes for the supply of electricity to customers – GPKE, with market rules for accounting grid billing – MaBiS, and the business processes for switching gas supplier – GeLi Gas, etc.).

Standards in the energy sector are conceived at various levels and developed in a variety of committees and organisations. The International Electrotechnical Commission (IEC) is an international standardisation committee in the field of electrotechnology. Alongside the International Standardisation Organisation (ISO) and the International Telecommunication Union (ITU), it is the most important standardising body for electrical and electronic systems and equipment. The scope of the IEC comprises all electrotechnical systems and equipment including generation and distribution of energy, electronics, magnetism and electromagnetism, electroacoustics, multimedia and telecommunication, as well as general disciplines such as specialist vocabulary and symbology, electromagnetic compatibility, measurement and operating behaviour, reliability, design and development, security and the environment. The IEC is a non-governmental organisation (NGO) with a strict hierarchical structure. At the top level are the national committees (NC) of the member states. Each NC represents the national electrotechnical interests of the corresponding country within the IEC. In most countries, interest is created by the market, politics, associations and national standardising bodies.

At international level there are numerous roadmaps and initiatives that have been established to deal with the challenge of standardisation in

79 The aim of KNX is mature, globally available intelligent networking of modern home and building systems in line with EN 50090 and ISO/IEC 14543.
80 Radio network standard.

the smart grid [81,82]. By way of example, these include the IEC SMB SG3 Roadmap[83], the NIST Interoperability Roadmap[84], the German Smart Grid/E-Energy Standardisation Roadmap[85] and the Strong and Smart Grid China Roadmap[86]. The various roadmaps make statements concerning specific standards issued by different organisations. Common to all, however, are the standards issued by the IEC Technical Committee (TC) 57.

IEC TC 57 is a system committee that has the task, in addition to considering individual components such as switches and protective functions, of also considering the upper levels of system networking, such as monitoring, control, internal information exchange and external interfaces. So far, 63 standards have been issued in this field. Another 20 projects are currently being worked on by 11 working groups.

At European level the main recognised standardisation organisations are the European Telecommunications Standards Institute (ETSI), the Comité Européen de Normalisation (CEN) and the Comité Européen de Normalisation Electrotechnique (CENELEC). CENELEC mirrors the work of the IEC at European level. It is responsible for European standardisation in the field of electrical engineering. CENELC, ETSI (standardisation in the field of telecommunications) and CEN (Comité Européen de Normalisation; standardisation in all other technical fields), together make up the European system for technical standards. CENELEC is a non-profit organisation under Belgian law, based in Brussels. Its members are the national electrical engineering standardisation bodies from most European countries.

At national level in Germany, the work of the IEC is mirrored and brought together in the scope of the standards to be considered by the Verband der Elektrotechnik Elektronik Informationstechnik (VDE; Association for Electrical, Electronic & Information Technologies). The Deutsche Kommission Elektrotechnik Elektronik Informationstechnik im DIN und VDE (DKE; German Commission for Electrical, Electronic & Information Technologies of DIN and VDE) is the responsible organisation in Germany for developing standards, norms and safety provisions in the fields of electrical engineering, electronics and information technology. It is a body composed of the Deutsche Institut für Normung (DIN; German Institute for Standardisation) and of the VDE, and is supported by the latter.

The DKE is the German member of European (ETSI and CENELEC) and international (IEC) standardisation organisations.

DKE 952, Network Control Technology Group, is the German mirror committee of IEC TC 57 and replicates the work of TC 57 in the body of national standardisation.

Technical Report (TR) 62357: Power System Control and Associated Communications - Reference Architecture for Object Models[87], Services and Protocols was published in 2003 and is used by IEC TC 57 to set its various standardisation projects and families of standards in context with each other. The aim is to establish a Seamless Integration Architecture (SIA) for the supply of electricity and to document and subsequently rectify certain inconsistencies in relation to the application of the various standards in an overall context. The TR therefore describes all existing object models, services and protocols produced by TC 57 and documents their dependencies. These standards and the architecture represent the state of the art in terms of standardisation for smart grids. At European level there are currently three mandates that have a direct reference to smart grids: Smart Meter Mandate M/441[88], which is currently quite delayed, due to differing ideas about the required functionality scope, the E-mobility Mandate M/468[89] and the Smart Grid Mandate M/490[90], which is of the greatest importance for

81 Rohjans et al. 2010.
82 Uslar et al. 2010.
83 SMBSG3 2010.
84 NIST 2010.
85 DKE 2010.
86 SGCC 2010.
87 IEC 2009.
88 EC 2009.
89 EC 2010a.
90 EC 2011.

smart grids and is quickly developing the set of consistent standards necessary for rapid implementation.

Properties for the projections relating to the key factor

The standardisation projection can be discussed in two dimensions - degree of interoperability and type of standardisation (market-led or policy-led).

As a result, four projections have been identified.

Projection A: Standardisation is delayed for political reasons

In this projection, the regulator has exercised an influence on the standards. These have not become established in expert meetings or directly on the market. While regulation and its associated processes are able to introduce standards, these are more or less poorly implemented on the market due to transitional rules and protectionism. Some vendors and suppliers implement their own proprietary solutions and no longer engage in standardisation committees, since these do not move sufficiently quickly for them. Innovative developments are no longer brought forward for standardisation, and standards remain at a technical standstill.

Market players are extremely reticent when it comes to implementing and developing ICT. This can happen when no standards come to the fore and the market reacts by standing still rather than backing the wrong solution. As a result, the projection becomes innovation-unfriendly and is characterised by a lack of speed.

Projection B: Market players do not cooperate

Since no consensus could be reached among the vendors, monolithic solutions from individual full-service providers dominate in this projection. This leads to a high degree of interoperability, albeit with little competition, as without standards the barriers to entry to the market are higher. However, if suppliers wish or have to bring together full-service providers in order to achieve greater functionality in the smart grid, additional higher integration costs are to be expected. The market players do not collaborate on the development of a uniform standard, but each develops its own solution with the aim of rapidly taking a dominant market position and so oust other incompatible products and competitors from the market. Each of the developments involves large amounts of duplicated work, generating higher costs for the market players. The parallel development of proprietary ICT systems can be expected as a result.

Projection C: Policy enforces standards

The regulator takes an effective, speedy and targeted stance on standardisation. In order to ensure rapid progress, the parties agree on simpler, less innovative solutions, some of which are tailored to specific requirements of the German market and cannot, therefore, be used internationally. The forced implementation for the German market means that manufacturers miss out on development capacity, integrator capacity and investment funding. As standardisation takes place largely without recourse to technical experts, through the medium of regulation, the solutions that are put in place are immature and minimalistic. They are often too rigid to allow further innovation. Overall, this scenario offers a high degree of interoperability, but the standardisation is not accepted by the market, and the benefits for services or opportunities to internationalise the work and products are limited.

Projection D: Consensus in the industry drives standardisation

This projection represents an ideal vision: Within the standardisation process, key market players have organised themselves and established consensus-based, capable, innovation-friendly solutions that are harmonised at an international level. This unity provides the companies with security for their planning and allows them to invest in their standards-compliant solutions and in the expert knowledge of their employees. This will ensure fast penetration of the market and thus will deliver the expected increased levels of interoperability of technical ICT systems and processes. There is a high level of interoperability, which is enforced by the market. The market players quickly implement the technology in their products. In terms of interoperability, the market players agree a uniform standard that is mutually enforced and introduced to the market. In comparison with projection B, it can be assumed in this case that early cooperation between the market players will avoid high costs of adaptation due to a lack of interoperability.

2.2.8 KEY FACTOR 8 – POLITICAL FRAMEWORK CONDITIONS

Definition

The political framework comprises primary[91, 92, 93] and secondary legislation, as well as supporting measures and even the actions of the ministerial departments and public offices that directly or indirectly relate to the energy supply sector. Primarily these comprise EU legislation[94] and Federal legislation, but also include state-level and local laws.

Explanations

In general, political framework measures react to current developments or anticipate them, supporting specific future (desired) developments or attempting to prevent undesired developments. Promising measures are selected in line with the scope and effective range of the objective and are also designed to match and integrate with other measures. An example of the effect of political leadership in the area of energy efficiency is the energy consumption of electric motors, which comprises around 45 percent of the world's electricity consumption. According to a working paper published by the International Energy Agency (IEA), major efficiency improvements could be achieved in this area that would pay for themselves. Nevertheless, progress is usually only achieved if politicians are committed.[95]

Policymakers are able to access a broad spectrum of tools such as supporting or restricting competition, direct or indirect financial support, or placing obstacles in front of investment, promoting R&D, etc. Alongside energy legislation – i.e. the entire body of statutory texts that govern the markets and regulatory environment for the energy sector – the smart grid is also affected by other laws such as, within Germany, the Bundesdatenschutzgesetz (BDSG; Federal Data Protection Act), the Gesetz über das Mess- und Eichwesen (EichG; Act on Measurement and Verification), the requirements of the Bundesamt für Sicherheit in der Informationstechnik (BSI; Federal Office for Information Security) and, in the medium term, possibly also the Telekommunikationsgesetz (TKG; Telecommunications Act).

The principal current primary and secondary legislation that relates to the smart grid comprises the EU Directives 2009/72/EC, EnWG, EEG, KWK-G, the Anreizregulierungsverordnung (ARegV; Incentives Regulation Ordinance), the Stromnetzzugangsverordnung (StromNZV; Electricity Grid Access Ordinance), the Stromnetzentgeltverordnung (StromNEV; Electricity Grid Charging Ordinance), Konzessionsabgabenverordnung (KAV; Concession Levy Ordinance) and BDSG. These are accompanied by the Guidelines and Decisions of the Bundesnetzagentur (BNetzA; Federal Network Agency) and the state regulatory bodies (for example on data formats, deadlines, etc.) that relate to these laws and ordinances. Political measures may result in social investment for socially desirable outcomes (e.g. by amending grid charges or a reallocated surcharge such as the EEG surcharge), or may also provide direct funding, for example by investment in an infrastructure that supports innovation or through grants paid to private projects using funds from general taxation. In addition there are measures to support research and development such as the Federal Government's E-Energy programme. Even before legislating or drawing up secondary legislation, the government already decides on the form of initiatives and consultations as well as strategic positioning to determine how the framework conditions will evolve.

Political will also generally reflects the acceptance of citizens. In some cases, however, political measures may differ from the majority view. No further detail is explored here, and reference is made to chapter 7.

Current state of affairs

In view of the wide range of topics, the current state of affairs can only be mentioned in broad, illustrative terms here. A more detailed treatment of this topic can be found in chapter 6.

Irrespective of their stance on nuclear power and coal, all political parties in Germany currently state in their manifestos that the long-term

91 BMWi 2010b.
92 BMWi 2006a.
93 BMWi 2010c.
94 This is evident, for example, from the Third Internal Market Package (Electricity Directive 2009/72/EC of 13 July 2009) which establishes a new basis for the regulation of the transmission grids. This has yet to be transposed into German law.
95 SGN 2011.

achievable aim is to have low-carbon energy without needing to resort to nuclear generation. An energy concept was formulated by the Federal Government on 28 September 2010.[96] Without going into details, there are some fundamental contradictions in the changing electricity supply that are related to the expansion of a smart grid. In the area of German legislation, mention should be made of the rules relating in particular to the feed-in from CHP systems and plants covered by the EEG, unbundling and rules on metering, the combination of which has not resulted in an optimum situation today from the perspective of the system as a whole. There are also problems in the expansion of power transmission lines and in expansion of the distribution grids.[97] Even though there is no final consensus on the extent and method of expansion of the transmission grid, especially in relation to the transportation of offshore wind power, there is no argument that the expansion of the electricity grids lags severely behind the planned expansion of renewable energy.[98] Delays can be expected in the near future, since "[…] with the continued expansion of renewable energy, there is a risk that the level of security will fall in terms of system stability. As a consequence, intervention by the system operators in line with Section 13 EnWG will become increasingly necessary in order to avoid critical situations in system operations." [99]

The desired state of affairs is a situation in which there is an effective mechanism motivating the market players to coordinate their activities a great deal more than they do today. Currently this is being breached in certain segments and in relation to certain sub-sections of energy policy (for the main part deliberately). It applies, for example, to:

Electricity generation according to EEG and KWK-G

Currently, feed-in from all EEG systems attracts payment at rates that do not vary according to grid utilisation or market price fluctuations. In cases of power output in excess of 100 kW, Section 6 EEG stipulates that the plant must allow grid system operators to intervene with information and regulation options in the case of faults. In addition, Sections 9 to 11 EEG govern the obligation for the DSOs to expand their grid capacity (their grid power capability as defined in Section 19 para. 3 clause 2 ARegV) and the conditions under which the DSOs are exceptionally permitted to regulate plants that have generation output of more than 100 kW (known as feed-in management). Furthermore, Section 64 para. 1 EEG contains a provision allowing secondary legislation, which the government has already implemented in the context of the Verordnung zu Systemdienstleistungen durch Windenergieanlagen (SDLWindV; Ordinance on System Services from Wind Power Plants)[100], with the aim of improving the integration of wind power systems into the distribution grids for the purpose of providing grid services. No further options for allowing grid system operators to influence smaller plants are currently provided for in EEG.

Direct marketing is permitted according to Section 17 EEG, although as a rule direct marketing for solar power and offshore wind power is not worthwhile, and is only partially worthwhile for onshore wind power. Electricity storage is only regulated insofar as interim storage is permitted (in Section 16 para. 3 EEG). The KWK-G contains corresponding provisions. In addition, the policymakers have also attempted to make investment in storage more attractive by "exempting pumped-storage power plants that have been built after 31 December 2008 and other plants used for storage of electricity that will enter into operation by 31 December 2019 from payment of grid access fees for a period of up to ten years following commissioning in respect of the receipt of the electricity to be stored."[101]

Generation of electricity by large power plants

Since this topic does not play a role for the smart grid until the medium or long term, i.e. the mechanisms for large power plants will not change until later, it is not considered here.

Supply of electricity by vendors

Competition on the energy market should be further stepped up thanks to several initiatives. Measures include unbundling (Sections 6

96 BMWi 2010a.

97 This applies in particular to onshore wind power, the transportation of which frequently demands high capacity in the 110 kV grids.

98 BMWi 2011a.

99 BMWi 2011e. p. 8.

100 Systemdienstleistungsverordnung (SDLWindV; Ordinance on System Services from Wind Power Plants) of 3 July 2009 (Federal Gazette I p. 1734); most recently amended by Article 1 of the Ordinance of 25 June 2010 (Federal Gazette I. p. 832).

101 Cf. Section 117 para. 3 EnWG.

et seq. EnWG), primary and secondary legislation on measurement (including Section 21b EnWG and the Messzugangsverordnung (MessZV; Measurement Access Ordinance) and also the requirements of BNetzA (especially GPKE). Against this backdrop, customers, including and especially the smallest among them, will be more and more likely to switch supplier. Suppliers have no reason to worry about the concerns of the grid. The reduction in annual peak loads will only be of benefit to large-scale customers.

Electricity consumption

In order to make the consumption of electricity more flexible for end customers, Section § 40 EnWG attempted to introduce a provision requiring energy utility companies who supply end customers, i.e. the suppliers, to offer load or time-dependent tariffs from 30 December 2010. Furthermore, in an initial step to transpose the Energy Services Directive into German law, Section 21b EnWG was formulated so that in new builds and major renovation projects, meters must be installed that provide end customers with more information about their current consumption and that therefore either promote energy efficiency and/or provide incentives for load shifting. Due to a lack of further provisions, standards, norms and other market incentives, it is dubious[102] whether or not DSM can be used on this basis as a typical smart grid process. Further inconsistencies with the smart grid concept still exist in the verification legislation, the grid charging ordinance with standard load profiles and unanswered questions relating to data protection[103]. EU Directive 2009/72/EC does require smart meters, however, where economically feasible.

Electricity transportation

Due to the aforementioned unbundling provided for in StromNEV and EEG, there is no incentivisation in respect of (renewable energy) generators and/or consumers to make any contribution to grid stability. While grid charges are already largely output-related (see Section 17 StromNEV) these are non-dynamic and do not, therefore, take account of the current grid status. Nevertheless, the "g function" does guarantee a reference to the contemporaneous and therefore capacity-determining peak load.[104] Grid system operators are only permitted to take action (Sections 13 & 14 EnWG) that could affect generators and/or consumers if there is a risk of fault or massive danger. However, a smart grid that permits integration of large quantities of electricity from renewable energy sources requires proactive participation from as many players as possible. For more information on the topic of grid expansion, see key factor 1.

Government initiatives

Some of the lack of cohesion has, in the meantime, been recognised. For example, the E-Energy Initiative supports R&D in ICT and smart grids. Recommendations for the legislative framework have been developed by groups of experts including representatives of the model regions. Additional Government initiatives with relevance for the political framework also include: The "Zukunftsfähige Netze" (Future-proof Grids) platform formed by the BMWi at the start of 2011, which also provides a home to "Fragen der Systemsicherheit sowie der Themenkreis Smart Grids/Smart Meter im Fokus" (Questions of System Security and the Smart Grids/Smart Meters in Focus Topic Group)[105] and, at European level, the "Task Force Smart Grids"[106] expert group launched by the European Commission and the Energy Directorate, which is to develop the steps to be taken by politicians and policymakers to implement a smart grid.

Properties for the projections relating to the key factor

From the point of view of the FEG scenarios, there are two dimensions relating to key factor 8, with corresponding extreme properties. The first dimension defines the targets set by politicians. Even if the current work is certainly in the "ecological direction"[107, 108], developments that could lead to a change of direction in the long term and take greater consideration of economic aspects are certainly conceivable. Obviously, either of the two possible directions would

102 BMWi 2011b.
103 At the time of writing the ongoing discussion on the BSI draft of a "protective profile" should also be considered.
104 This is naturally perfectly sufficient for today's electricity supply without the synchronicity factor influenced by DSM.
105 BMWi 2011b.
106 ECE 2011a.
107 BMWi 2010a.
108 EKO 2010 c.

only make sense if the approach was harmonised among all of the Member States of the European Union. In each direction, therefore, it is assumed that liberalisation will continue and that the principal objective will remain a market-based system of "self-control" of the electricity system.

The second dimension defines the consistency of the political framework. In view of the complexity of the overall system, the in some cases contradictory interests of the groups of participants, the many acts of legislation affected and not least the incomplete knowledge of the best solution as well the dependency on many physical conditions, finding the correct or at least a suitable single framework proves to be a Herculean effort. The one extreme would mean that the relevant body of legislation and political action are inconsistent and incoherent. In the other case, all measures are logical and perfectly matched in terms of their timing.

Projection A: "Traditional policy"

Following one specific revelatory moment[109] politicians have focused on a system of energy based principally on the generation of power from core fossil fuels. With CCS and nuclear power, this could even be largely carbon free. The applicable legislation has been modernised in order to herald the emergence of increased competition in the energy market. Expansion of distributed and fluctuating generation enjoys neither subsidy from reallocation charges nor any other form of concerted support. Competition policy makes it easier for customers to switch supplier. Monopolies in the generation of electricity are dismantled.

Projection B: Complexity trap

While lofty aims were (and continue to be) striven for at European level[110], contradictory national interests among the Member States have meant that the legislation has been unable to consistently push the restructuring of the energy system forward. The individual parts of energy legislation are not integrated with each other to a sufficient extent to promote the planned future for energy. Despite there being great political will, the legislation has created obstacles, or has not cleared existing barriers adequately out of the way.[111] Even the change to generation-led operation, planned as early as 2010 (see above), has only been driven wearily forward, as the regulations required to ensure the energy market can work with flexible loads have failed to materialise. This has also been due to the fact that work on many changes, such as the modernisation of the standard load profile to incorporate greater flexibility, has started too late. As the support for R&D in the many affected disciplines (engineering and natural sciences, as well as law and social sciences) has been poorly coordinated, it has been difficult to share findings and in some sensitive points the information simply arrived too late for implementation in products or in the political framework.

Projection C: Political leadership

A vision for energy has been formulated, and is being discussed in depth and communicated. Politicians (in government and ministerial departments) are taking the lead in shaping the implementation without entering into dirigisme. Instead, efforts are building on the creativity of the market. Primary and secondary legislation complement each other and produce a market-based implementation. The "basic contradictions" that were defined in 2010 have been resolved. Market roles have been formed so that the electricity supply system, including the needs of the grid, is operated a single entity, as was the case before the unbundling process.[112] Energy legislation allows tariffs to be designed freely, both for grid charges and the supply of electricity. To prevent the formation of local monopolies or even too close a relationship with an electricity service provider, the BNetzA and the European regulator have created a body of rules that assists end customers in switching supplier easily, even within the European Economic Area. Monopolistic structures have been strictly regulated or dismantled. Support for feed-in from renewables is not paid at a flat rate according to the supplied quantity of energy as in 2010. Instead, plants can generally only be operated profitably if the parties that are responsible for grid system operation are permitted a certain level of control authority and a form of energy recycling is operated by combining other feed-in, storage or variable consumers. Only then does any promotion of renewable energy occur.

109 The scenarios illustrate how that could arise.

110 EC 2010 b.

111 A path leading to this unexpected development is described in the scenarios.

112 The opportunities for this are discussed in chapter 6. They could also include political opposition from individual interests that hinder development.

The exchange of real-time information and many other planning and operating data among grid operators is governed by energy legislation. The precise rules have largely been defined by the parties themselves, however. The government has only imposed precise requirements at a few key points. As the electricity infrastructure is largely based on ICT in 2030, the approaches started in 2010 have been pursued and extended consistently so that there are now comprehensive requirements built into the energy legislation.[113]

2.3 DEDUCTION OF THE SCENARIOS

Section 2.1.6 already described how the adapted scenario process has been applied in the scope of this project. As the scenarios form the key starting points for the subsequent process and are therefore of particularly great importance, the next sections explain in more detail just how they have been derived from the key factors.

The first step was to develop a consistency matrix. All properties of the eight key factors were compared in pairs, to identify the relationships between them. A consistency score was calculated for each pair, on a scale from 1 to 5 as follows:

- 1 = Totally inconsistent
- 2 = Partially inconsistent
- 3 = Neutral, or not mutually dependent
- 4 = Mutually favourable
- 5 = Strong mutual support

In total, 317 assessments were made. Figure 6 shows an excerpt of the consistency matrix for the first four key factors, from which it can be seen, for example, that all properties of the key factors "expansion of the electricity grid infrastructure" and "system-wide ICT infrastructure" are neutral in relation to each other, and that a renewable, fluctuating energy mix (key factor 4, projection C) and a high overall participation in making consumption more flexible (3D) provide each other with strong mutual support.

	1A	1B	1C	1D	2A	2B	3A	3B	3C	3D
1A										
1B										
1C										
1D										
2A	3	3	3	3						
2B	3	3	3	3						
3A	4	3	4	3	4	2				
3B	1	4	2	4	3	3				
3C	1	4	1	5	2	5				
3D	1	4	1	5	2	5				
4A	3	2	3	2	3	3	4	2	5	2
4B	1	2	2	4	3	3	2	5	2	2
4C	1	2	2	5	1	5	2	4	3	5

Figure 6: Excerpt from the consistency matrix

The next step was to consider all potential projection bundles. A projection bundle is a set of properties, with exactly one property per key factor. This meant that there were 13,824 different projection bundles with eight properties each. The consistency matrix can, however, be used to restrict this set, by rejecting all projection bundles that contain at least one "Totally inconsistent" score. This is identified by a relationship between two properties in the matrix being rated 1. Once this was done, 397 projection bundles remained for the creation of the scenarios. In view of the relatively small number of projection bundles, it was decided to forego a reduction process, and to continue instead with clustering in order to form the prescenarios.

The objective of the cluster analysis is to group the projection bundles in such a way that the group members are as similar as possible (internal homogeneity) but the groups themselves are as different as possible (external heterogeneity) The cluster analysis involves the formation of clusters on the basis of distance measurements. In the first stage of this process, each of the projection bundles represents a distinct cluster in the agglomerative, hierarchical cluster

113 See also key factor 2, for example.

method. By calculating the distance between the projection bundles, a distance matrix is created. In each repetition of the clustering process, two clusters are joined to form one new cluster, and the distance matrix is thus reduced. When reducing the distance matrix, the single-linkage method was applied, since, according to Gausemeier[114] this is best suited to the task of identifying and representing extreme prescenarios. This means that before each clustering iteration, the distance measurement of the new cluster must be selected by taking the lowest measurement of the clusters that have been used to form it. This step is repeated until just one large cluster remains. The result is a list of partitions that contain differing numbers of clusters. In this project, the most granular partition contains 397 clusters (the 397-cluster partition) and the least granular partition contains one cluster (the 1-cluster partition).

A decision must now be made regarding the number of desired scenarios. When this is established, the corresponding partition number is selected. For example, select the 3-cluster partition for three scenarios and the 4-cluster partition for four scenarios. A quality benchmark is used to assess the suitability of the partitions. As already explained, the internal homogeneity and the external heterogeneity of the clusters in a partition is taken into account. For the FEG project, the squared Euclidian distance was used to calculate the proximity measurement. The decision on the suitable number of scenarios can now be supported by a scree plot. This maps the number of prescenarios and also shows the information loss that arises from grouping the projection bundles. Typically, a characteristic kink can be identified, known as the "elbow point"[115], which indicates the most suitable number of scenarios. The number of scenarios selected for the project on the basis of this plot was three.

Figure 7 maps the projection bundles showing the result of the clustering process using multidimensional scaling (MDS). The diameter of the circles, each of which represents a projection bundle, indicates the consistency of the respective bundle. The axes of the MDS visualisation do not have any meaning in terms of content and are therefore not considered further. They are used to express the similarity of the projection bundles through the distance between the projection bundles. All of the circles with the same colour or number belong to a single prescenario. They form the basis for creation of the three final scenarios, by selecting a list of properties for each scenario on the basis of the frequency of occurrence of properties of the eight key factors. Figure 8 indicates which properties were actually identified for the three scenarios.

As can be seen in Figure 8, the scenarios contain both exact projections and fuzzy projections. An exact projection is one in which exactly one property of a key factor is used, such as is the case for the key factor "energy mix". Fuzzy projections are those that are not unique, i.e. either one of the possible properties can be selected or they are treated as ambiguous projections and therefore more than one property is permitted per key factor in a scenario. In the case of the key factor "standardisation", for example, an ambiguous interpretation is applied for all three scenarios.

Finally, the scenarios were described using creative and visionary language (see sections 2.4 to 2.6). Briefly, the resulting scenarios can be described as follows:

- **Scenario "Sustainable & economic":**
  The "Sustainable & economic" scenario transports the reader into a future consisting of an economically sustainable energy supply system, as laid out in part in the Energy Concept of the Federal Government[117] and the Technology Roadmap of the European Strategic Energy Technology (SET) Plan[118]. The proportion of electricity generated by wind power and photovoltaic installations has increased significantly (4C). Distributed feed-in from renewable sources is subject to fluctuations. A range of technological measures and market-based rules have been implemented (8C) to ensure this electricity can be handled at acceptable economic conditions, both in times of low feed-in and when there is excess supply. As a consequence, both the

114 Gausemeier et al. 1996.
115 Gausemeier et al. 2009.
116 UNITY 2011.
117 BUND 2011.
118 CEC 2009.

distribution and transmission grids have been expanded for the requirements of the new energy system (1D) Industrial customers in particular are making concerted use of the options for load shifting (3B), which are enabled by the system-wide uniform ICT infrastructure (2B). All areas of the smart grid exhibit a high degree of interoperability (7C/D), some of which is due to industrial standards and some to internationally agreed standards, as well as, in a few cases, political requirements. This does lead to energy costs accounting for a relatively high proportion of household income, as well as to high price volatility (6D). However, at the same time, interoperability enables a broad range of new and innovative services in the smart grid (5C). For this reason, the new energy system enjoys broad public support.

– **Scenario "Complexity trap":**
This scenario describes a "Complexity trap" which has arisen in part due to inconsistent political frameworks (8B). Competing individual interests at national and European levels, combined with other obstacles, prevent a single framework from being established. The necessary restructuring of the transmission grids or even a pan-European overlay grid have only been partially successful (1B), even though the expansion of the distribution grid is now appropriate to the requirements of the new energy system. The rise in wind power and solar power is sluggish. However, Germany has, in part at least, moved into bulk generation using renewable energy sources, such as solar power from Southern Europe and Northern Africa in particular. The electricity supply is complemented by

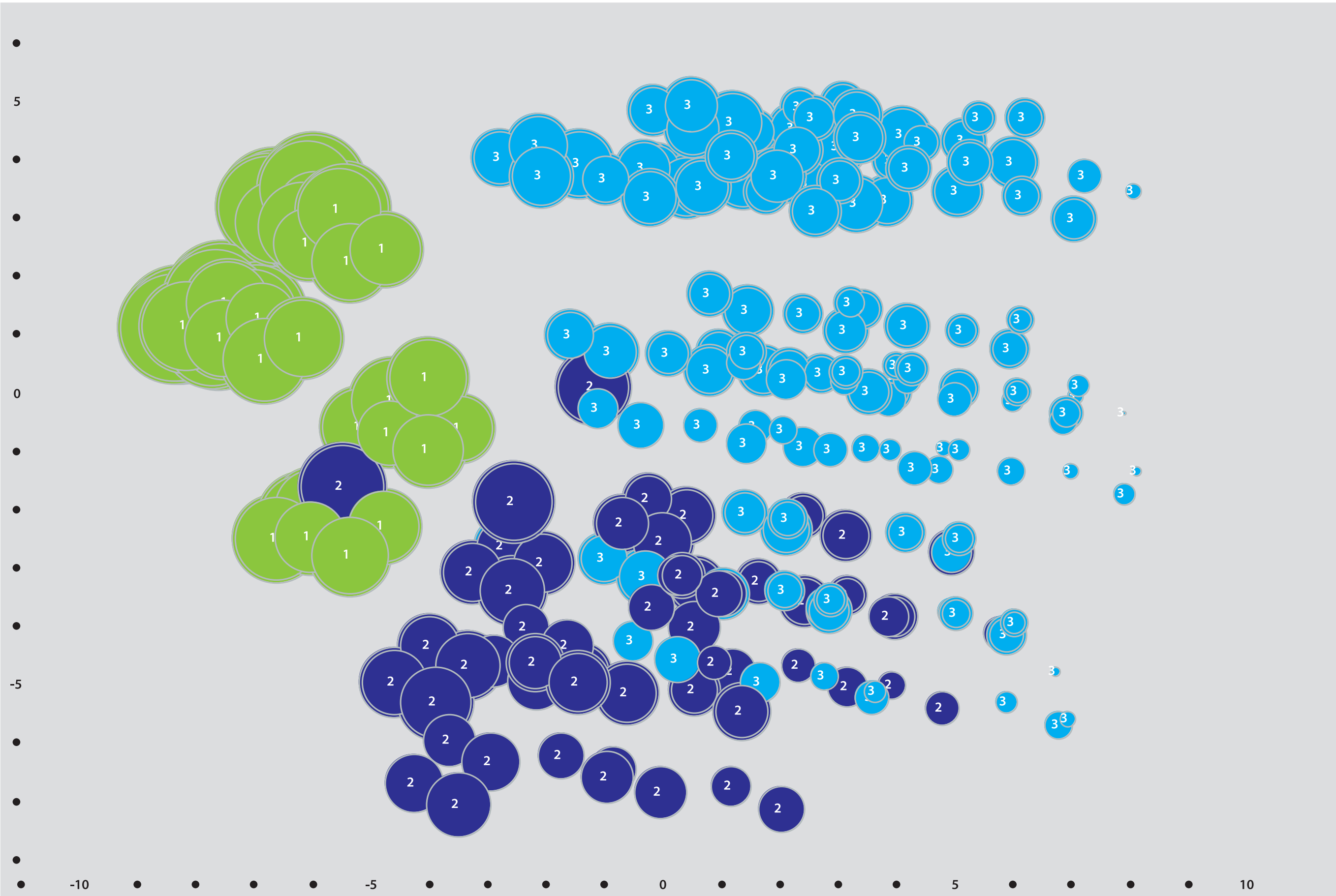


Figure 7: Clustering of the projection bundles.[116]

additional low-carbon, bulk, non-fluctuating power generation (4B). While the volatility of prices has not increased in comparison with today, costs are relatively high (6A). The use of load shifting in domestic households is negligible, with exceptions such as the widespread use of electric mobility, for example. In contrast, industrial customers have implemented comprehensive measures to allow them to benefit from load shifting. Grid charges have been lowered or energy costs are being saved by the application of variable tariff structures (3B). Depending on regional factors, either a proprietary ICT infrastructure is in place, or there is only basic support for energy services (patchwork coverage – 2A). In the system overall there is a high degree of interoperability, comprising partial compliance with market standards and a great number of proprietary solutions (7B/C/D). Only a few other services are offered in addition to the aforementioned load-shifting services for larger consumers (5B/C). However, some services providers are able to position attractive offers and as a result become quasi monopolies.

– **Scenario "20th century":**
In the third scenario the energy system retains a similar look to that of today in many respects. The transmission grid has been expanded considerably (1C) in order to promote trading at European level. The energy mix strategy has been subject to review, supported consistently by politicians, which has resulted

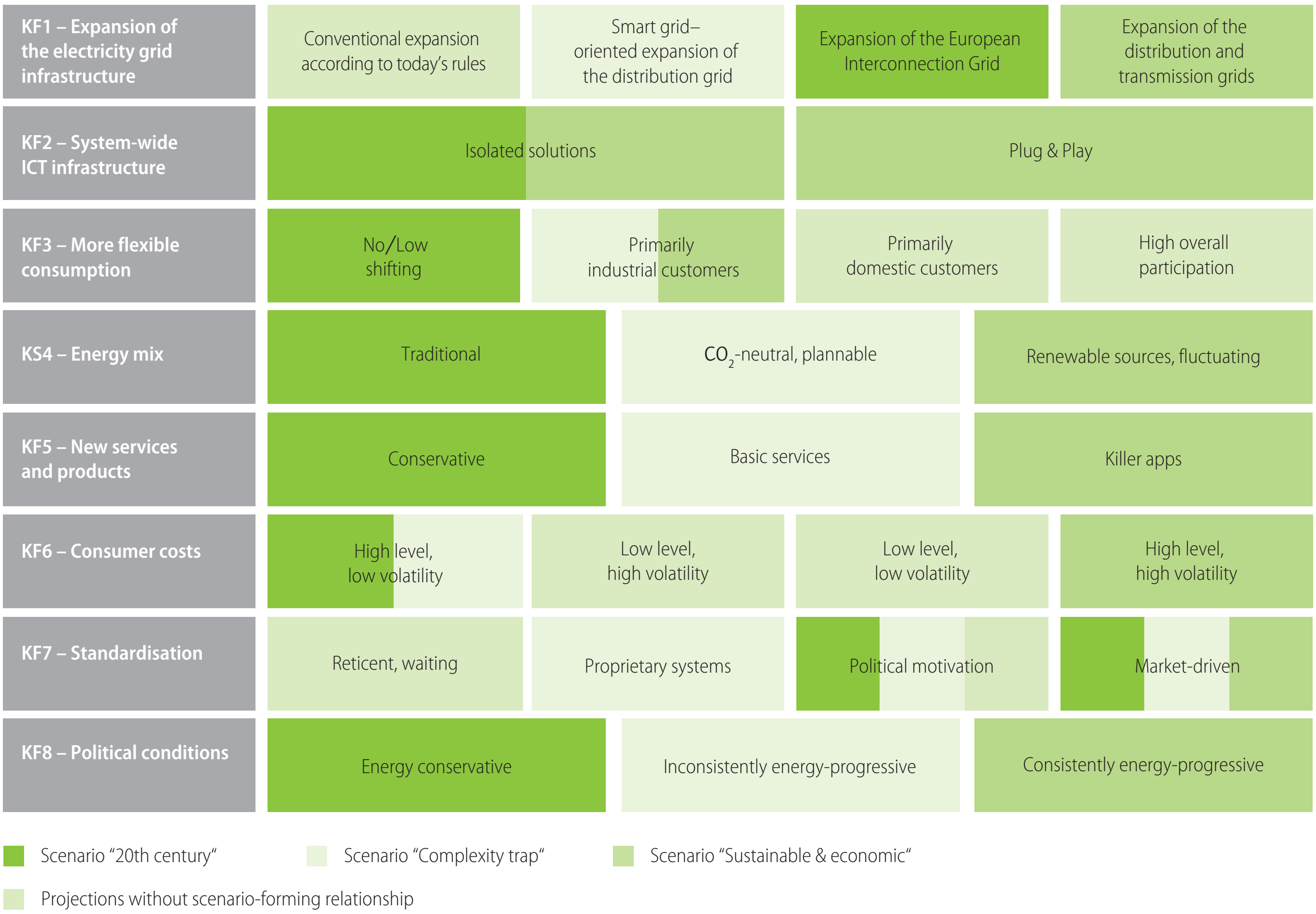


Figure 8: Selection of the properties for the key factors used to create the scenarios

in the expansion of renewable energy slowing down and even grinding to a halt in some areas (8C). The resulting energy mix focuses on fossil fuels and nuclear power (4A). No load shifting is operated throughout the system (3A) and no new services and products have achieved market penetration. Only a few basic services are offered (5A/B). Despite the lack of a uniform ICT infrastructure (2A), interoperability has been supported by both the market and political will (7C/D). Household electricity costs are relatively high, but exhibit low volatility (6A). This scenario has a strong similarity to the future vision for Japan in the "New Policies Scenario" of the IEA[119] and to the "Scénario énergétique de référence DGEMP-OE" of the French General Directorate for Energy.[120]

2.4 SCENARIO "20TH CENTURY"

2.4.1 OVERVIEW

This scenario[121] describes a situation in which the main initiatives for the smart grid and integration of distributed generation from renewable sources into the electricity supply have not been implemented. In order to ensure a significant contribution is made by the electricity supply to the climate protection goals and at the same time not jeopardise the reliability of supply, this scenario must take account of significant cuts in economic feasibility as a third dimension of the triumvirate of energy policy objectives.

The electricity supply takes the form of a bulk system with a high percentage of imported low-carbon electricity. Bulk fossil-fuel generation dominates, from which CO_2 emissions have been increasingly reduced (for example brown-coal fired power plants with CCS technology).[122] The transmission grids have been well expanded for this purpose, with sufficient national and transnational overlay grids. The distribution grid has been expanded and designed for a load flow directed toward the end consumer. The existing infrastructure enables neither integration of any noteworthy renewable power generation and distributed power plants (onshore wind and solar power) nor the use of load shifting or any other form of controlling electricity consumers. Continued use is made of the offshore wind farms installed up to 2014 and the distributed power plants that can still be operated at a profit without EEG subsidy and with the restrictions of the distribution grid. Any shortages are avoided by expanding capacity through installation of additional primary systems (cables, transformers) and the costs are spread over all electricity customers via an EEG subsidy. The cost of electricity remains stable but high and a very high degree of efficiency is achieved in the generation, transmission and consumption of electricity.

2.4.2 SIGNIFICANT DEVELOPMENTS

The energy policy of the Federal Government has largely been followed. However, from a certain point it has become evident that it is too costly or too technically complex to carry on with expanding and further integrating renewable energy sources into the electricity supply with the existing incentive-based models. There is a lack of alternative investment incentives aimed at achieving greater integration of renewable energy sources at various levels of the grid. These could include:

- Options to reallocate costs of the smart grid that are not specific to operating equipment but would enable optimised restructuring of the distribution grid as grid charges. This could mean that a given grid was utilised to a higher degree of capacity and then be expanded for capacity reasons.
- Pragmatic and rapid approval of new high and medium voltage power lines, in order to integrate additional distributed plants and exploit the potential of onshore repowering.
- Investment-friendly subsidy for the installation and exploitation of energy storage facilities.

119 IEA 2010a.

120 DGEMPOE 2008.

121 It should be noted once again that the scenarios do not necessarily represent the most probable or even most desirable future developments with relevance to the smart grid, but that as consistent scenarios they cover the range of possible futures.

122 Following the accident at the Fukushima Daiichi nuclear power plant accident, an intensive review of nuclear power is at least being considered in every country with nuclear power plants. For the latest on the international discussions see ISTT 2011.

This results in a mass shift in investment towards low-carbon production technologies based on fossil fuels.

> Integration of renewable energy sources does not occur for economic reasons. CO_2 emissions are reduced by importing electricity and using modern large power plants with CCS technology, for example.

In order to cut CO_2 emissions caused by electricity generation, low-carbon electricity is imported from countries with a high proportion of constant generation from renewables such as hydro and solar power. In addition, low-CO_2 methods for generating electricity from fossil fuels are also used. The rise in electricity use is limited by efficiency measures. For example, nuclear power can be imported from France, wind power from Denmark, hydroelectric and nuclear power from elsewhere in Scandinavia and hydroelectric power from Switzerland.

The efficiency measures that were taken due to high cost pressures have caused electricity consumption in 2030 to fall by 20 percent compared with 2008.[123] Little use was made of the national energy sources that are only economically feasible for distributed generation of power. Dependency on imports for electricity was high. Altogether, this resulted in a high increase in efficiency in the use of electricity. The measures that have led to this ranged from avoiding wasting power by not keeping appliances on stand-by to the use of modern heating pumps on the part of consumers and the use of highly efficient electric motors in industry.

For reasons of cost efficiency, a significant proportion of electricity is imported. The remaining share is covered, depending on the load band, by bulk brown-coal fired power plants using CCS technology and offshore wind farms with storage and potentially also by gas-fired power plants, operated in part using biogas, as well as the existing nuclear power capability, small hydroelectric power plants and existing CHP and wind power plants that can still operate profitably given the lack of a smart distribution grid. The progress that has been made in improving the efficiency of brown-coal fired power plants, which was 43 percent at the end of the twentieth century, is largely lost due to the implementation of CCS technology.

The transportation of electricity imports from the high-sunshine areas of the world[124] and from the hydroelectric installations in northern Europe and of the electricity generated by offshore wind farms is resolved by an expanded transmission grid based on a European association and a HVDC overlay grid. In contrast to 2010, when the peak load of the ENTSO-E grid was 530 GW, this grid has now been expanded for significantly higher peak loads. Bottlenecks at the interconnection points that are relevant for German power generation have been overcome. At national level, the transmission grid has been expanded by the addition of a 750 kV HVDC mesh grid that enables redundant transportation of high levels of power. This grid also incorporates a fixed-location mass storage facility based on gas generated by methanisation[125], in order to balance out fluctuations in the feed-in from wind power generated by offshore wind farms. To guarantee the stability of the distribution grid, the integration of further solar power plants, additional CHP and wind power plants is generally made more difficult by the imposition of a ceiling on EEG subsidies in Germany, which are in any case running out. New systems may only be connected as a replacement for an existing plant or if evidence is provided that no problems will be created in the specific distribution grid. In individual cases, where the expansion of the distribution grid and the higher-level grid has to be driven forward due to additional load, new, distributed feed-in may be taken into account and approval for additional feed-in may be given. Feed-in from the existing distributed renewable sources into the grid is partially limited according to the load status of the distribution grid, which can temporarily prevent trade in this electricity on pan-regional or European energy markets. Profitable operation of such plants is therefore generally not possible, due to the expiry of the EEG subsidy and the lack of access to pan-regional markets. Profitable operation is thus only possible in exceptional situations, if the distribution grid has corresponding reserve capacity or the individual plant is at full capacity in covering the usage requirements of its operator.

123 BUND 2011.
124 DESERTEC 2011b.
125 Nitsch et al. 2010.

As the incentive regulation only takes account of energy technology operating resources but not ICT components that could make the use of the distribution grid more efficient, the level of equipment in the distribution grids in terms of intelligent sensors and actuators and automated functions is minimal. Monitoring and control functions are only installed where it is economically feasible or operationally necessary, just like the situation in the transmission grid in the twentieth century. This means that overload situations, as could occur given the greater use of new electrical consumer devices such as electric vehicles or heat pumps, can be detected at an early stage and avoided.

Thanks to successful standardisation by industry and the government, IP-based communication between the automation systems and their sensors and actuators in the field is perfectly possible. As a result, the costs of automation will be lower than was the case in the twentieth century. The options for cheap monitoring and control are thus increased, especially in the area of grid protection at critical points of the distribution grid, maintaining a stable reliability of supply despite ever rising requirements for flexibility such as dynamic requirements in the area of electric mobility. In view of the lack of intelligence to control electric consumers at the distribution grid level, electric mobility is not seen as a means of integrating storage capacity in this scenario, however, but serves solely to reduce the CO_2 emissions from vehicles. Provision of additional distribution grid capacity, necessary for electric mobility, is primarily undertaken by means of costly grid expansion that leads to increased grid costs for industrial, commercial and domestic consumers.

End customers and industrial customers can access technical feedback systems with the objective of saving energy costs by adjusting their electricity consumption according to time-variable tariffs, for example. These mirror the power production costs on the wholesale market, but not the demands of the grid. Adjustments to consumption are partially automated, using DSM systems.

Connections to feedback systems and DSM systems are made via the Internet, although different protocols and technical methods are used and no standardised, system-wide solution exists. The customers of a given energy utility must use that company's specific or supported solution. The market penetration of the available solutions is therefore restricted, and the solutions are technically at different levels of development since low numbers of production units mean innovation is not of interest to the industry. The restricted use of DSM in domestic households and industrial systems does not represent a problem, however, since load-led operation can be maintained, given that:

- The share of fluctuating feed-in remains at current levels (as at the time of writing this study) due to the preferred use of bulk, timetabled power plants.
- The feed-in from households is stagnating.
- Rising capacity requirements are being met by grid expansion.

There is therefore no need for adjustment capacity as required by the smart grid. For domestic customers, the high dependency on imports, the expensive, bulk low-carbon generation of power and the high costs of grid expansion combine to mean high costs of electricity. Many customers attempt to offset this high level by frequently switching supplier. This tends to give an advantage to the energy utilities that offer pricing policies that better match typical individual consumption patterns. Customers can, if desired, read their smart meters installed in their house/apartment to discover current usage patterns, and make their purchasing decisions via the Internet, with just a few clicks of the mouse. There is barely any load shifting at domestic customer level, since the effects are too small and there are easier ways of reducing electricity costs. However, this behaviour does nothing to change the fact that costs are high.

With the loss of this central, binding component, as well as distributed feed-in and shapeable consumption, all remaining options to achieve environmental compatibility – such as the use of CCS – and reliability of supply in the triumvirate of energy policy objectives must be completely exhausted.

2.5 SCENARIO "COMPLEXITY TRAP"

2.5.1 OVERVIEW

The "Complexity trap" scenario sees the restructuring of the energy system, the "energy revolution", lag far behind the objectives set for 2030, despite political will. The main reasons for this were the differing interests of those involved, which could not be reconciled in a single political framework, as well as technical obstacles and also the lack of awareness of a possible path. The feed-in of wind power and solar power therefore hit limits as smart control of the feed-in is not permitted by the applicable laws or does not make business sense. Therefore, a bulk, controllable supply of electricity continues to dominate. A variety of measures have helped make this a low-carbon supply. The options that have been used comprise CCS technologies, the increased replacement of coal power plants by gas-fired power plants, the use of biomass and in particular the use of CSP in the form of imports. Demand response (DR) plays a minor role for small consumers and domestic customers. The ICT infrastructure has gaps and is very heterogeneous in its development. The policy prerequisites for easy entry into the IoE have not been implemented or are only partially in place. The Federal Government's climate policy objectives, as formulated in the 2011 Energy Concept[126] have therefore not been achieved.

Liberalisation of the electricity market has progressed. Many providers offer interesting products and services. There is intense competition for customers and market share, and a slightly higher switch rate compared with 2010 (5 to 6 percent).

2.5.2 SIGNIFICANT DEVELOPMENTS

The developments in this scenario are primarily due to the scope of accompanying political and regulatory measures and to the difficulties in agreeing measures among all parties. Activities and developments are not agreed between the relevant stakeholders in the framework legislation and the different initiatives for standardisation, i.e. the energy utilities, grid operators, industrial and domestic customers, and providers of new services.

> Failure to agree on the framework legislation in this way creates obstacles to the formation of new markets and services.

In this scenario, the stakeholders (generators, energy suppliers, grid operators, politicians, end consumers) are unable to reach consensus on a single, common path into the smart grid, and as a result, the prerequisites for restructuring the energy system are missing. The individual activities to restructure the grid, connect fluctuating generation sources and integrate new patterns of consumption do not follow any particular agreed model, but are individual projects that reflect short to medium-term market developments.
This is even the case for the tricky task of agreeing measures in response to EU Directives. EU framework legislation is unable to react adequately and rapidly enough to the new requirements and developments. The difficulties in matching European and German legislation also create uncertainty for consumers. Progress has been achieved in energy trading. Trading activities have gradually increased across national borders within Europe.

In view of the low volatility of electricity prices, very few consumers participate in DR measures and react to the services on offer. There is little provision of additional services, with the services that are available being provided by subsidiaries of the major energy utilities. The rate of domestic electricity customers switching provider in 2030 has risen slightly compared with 2010 at 5 to 6 percent, while the figure for commercial and industrial customers is around 15 percent[127]. No additional political or regulatory measures have been undertaken to further stimulate the switch trend in the market.

> New business models based on ICT create quasi-monopolies that then in turn establish new value creation networks.

One or two suppliers have been able to exploit the advancing liberalisation to their advantage. With innovative new business models

126 BUND 2011 p. 2.
127 Switch rate, BNetzA 2010a.

based on ICT, they have been able to provide greater value for their customers. As a result, quasi monopolies have been established, as frequently occur in the IT sector. These new energy services do not necessarily focus on cost savings for customers, but promise additional value. At the same time, these service providers occupy the space between the end customer and the energy supplier, from whom they take a large amount of value. By establishing industry standards and platforms, the quasi monopolies allow the creation of new value creation networks.

Average costs for consumers have risen. The reasons for this include the adjustment of wind power plant output and the associated required reserve capacity, the modification of the 2012 power plant mix to include more gas-fired power plants and also the use of CCS with the associated loss of efficiency. The high price of electricity is also caused by the loss of potential efficiency that has been "given away" by the lack of uniform ICT standards and by the high costs of primary energy (coal, natural gas, crude oil). The lower CO_2 emissions of gas-fired power plants and the CCS systems act as a brake on the electricity price thanks to the lower volumes of emissions certificates. Nevertheless, these revenues are far exceeded by the higher consumption of specific raw materials and the rising prices for primary energy. The lack of response by the market to reform has resulted in little or no increased volatility at all.

> Despite moderate expansion of the European grid infrastructure, intra-European trading activities have grown in strength and the reliability of the German electricity supply remains at a high level, although prices are also higher than in 2010.

Electricity generation is based mainly on fossil fuels. To reduce the CO_2 emissions, expensive but more flexible gas-fired power plants are used, along with CCS technology in the process of converting coal into electricity. Distributed cogeneration plants can be used with controls, and wind power has been expanded in comparison with 2012, albeit at a slower rate than planned by the Energy Concept.[128] Solar power plays a minor role in the energy mix, but causes regular shortages on the grid. The slower expansion of renewable energy plants is due to the lack of business incentives. Following the expiry of the EEG subsidy, wind power remains generally competitive in respect of establishment costs[129], but the costs of grid expansion, which have now risen too far, and the associated lower level of economic feasibility have prevented further growth. Commercial solar power is only economically viable in a few locations in Germany, and following the end of the subsidy programme the installation of private rooftop installations now indicates only marginal growth. In total, in 2030 renewable energy sources provide barely more than the 35 percent of gross electricity consumption set as the target for 2020. As a result, the objective of the Federal Government's Energy Concept (50 percent) has not been achieved despite a constant increase in renewable energy sources.

Large-scale plants that exploit renewable energy sources and large electricity storage facilities (mainly pumped-storage power plants) have been and continue to be built in locations with the best geological or meteorological conditions, such as the large solar arrays in southern Spain and north Africa, pumped-storage power plants in Norway and Austria and large wind farms in Denmark, Great Britain and northern Germany. The European interconnection grid has been expanded in a targeted manner in order to achieve these major projects.

In line with the continuing attempts to integrate renewable energy into the market, in 2030 the costs of connecting new plants and the costs of any work needed to strengthen the grid in order to handle the operation of these plants are charged to the plant operators (a "deep cost" approach or a hybrid approach[130]). The expansion of renewable energy sources therefore takes greater account of location-specific economic perspectives. However, as this rule does not sufficiently take account of the flexibility in the operation of distributed plants, these plants, which would make a contribution to the economy as a whole if they could be controlled, are no longer being built. Direct marketing of electricity generated from renewables

128 In relation to the importance of nuclear power, a rapid exit from the power plant capacity as determined in the latest cross-party decision has been assumed. Since it cannot be assumed, in light of current discussions, that this trend will extend to neighbouring countries, there may be specific times of day when additional imports of electricity (including nuclear power) are received from neighbouring countries.

129 Kost/Schlegl 2010.

130 Hiroux 2005.

is now standard. With lower marginal costs, electricity from wind power, solar energy and hydroelectric power continues to be prioritised, but the plant operators must now ensure that the volumes that they have previously traded can now be delivered. This is possible thanks to improved forecasting, shorter term intra-day markets and the retention of flexible generation and consumption facilities, mostly from the use of virtual power plants. Only those new technologies that are far from economic operation (for example in the case of geothermal energy, tidal and wave power) are supported with a fixed subsidy for priority grid feed-in.

The national transmission grid has not been expanded sufficiently quickly due to popular protest and a lengthy planning approval process. In particular, the domestic North/South German lines have not been implemented to a sufficient extent to allow for the planned offshore usage. The automation of the transmission grid has steadily continued. Operation of the ENTSO-E grid has improved in the European association. However, it has not been expanded to the extent required in order to realise the Federal Government's energy policy. The trading in transmission capacity along the bottleneck stretches of the grid is fully automated and integrated across Europe. However, expansion of the transmission grid and the transnational interconnects has lagged behind the expansion and restructuring of the generation capacity and there continue to be bottlenecks on certain sections of the transmission grids. Nevertheless, some stretches of the European Super Grid have been constructed. While regular transmission shortages occur, causing higher electricity costs due to the necessary balancing measures, the reliability of supply is never in danger as there are sufficient power plants available. Where possible, CSP facilities in southern Europe help to cover some of Germany's requirement and additional low-carbon power plants contribute along with the national power generation pool to balancing out fluctuations from renewable feed-in.

A lack of capacity in the transmission grid makes it more difficult to balance generation capacity over a large area. The well developed distribution grid ensures reliability of supply but leaves potential economic benefit that could be derived from the use of innovative technologies untapped.

The distribution grid has benefited from significant regional expansion in places, according to demand, to allow additional consumers such as heat pumps or electric vehicles and distributed generation to be supported. However, with a lack of incentives and the restricted options for action as a result of regulation, the DSOs are able to make only insufficient use of innovative technologies.

The continuing strong bulk generation characteristic of the energy system, which suffers only occasional fluctuation, combined with regulation that permits less market freedom on the part of the generators, mean that the implementation of measurement and adjustment technology and of ICT is not particularly more widespread than in 2012. As most power feed-in comes at the high and extra-high voltage levels, additional monitoring or automation of the distribution is only needed to a small extent in a few regions, where there is, for example, a concentration of solar power feed-in.

Households that have their own PV installations use these primarily to substitute their electricity supply. Some may operate a form of local power management in order to optimise their own consumption. This results in additional uncertainty for those managing the operation of the distribution grid. However, compared with the total share of supply, own usage can be ignored and has barely changed since 2015. Neither distribution grid data exchange nor active integration of consumers or local generation facilities has been achieved, due to a lack of business models and help from regulation.

A conservative programme of grid expansion and gradual expansion of the ICT infrastructure have allowed only partially lucrative niche opportunities for new services and business models to emerge.

The various participants in the market for end user devices have not reached agreement on uniform standards. The framework legislation has also failed to create clarity in the market through matched specifications. This situation also ensures that consumers are reticent to invest in household appliances with energy management functionality that supports the smart grid, due to the rising number of different technical solutions available in the market. Industry is also slow to invest for the medium and long term because of the uncertain market development. Moreover, the rapid technical development of new appliances means that any efforts to standardise new developments are quickly outdated. As user acceptance and application of new technologies is faltering, taking just one step at a time, growth in new business models is sluggish. An exception to this can be found in the aforementioned quasi monopolies, which, however, only contribute a small proportion of the potential value added and cannot make a sufficient contribution to the energy revolution due to the limits imposed by regulation. This results in the integration of ICT in the power system being limited to just a few applications, and being concentrated on isolated solutions.

> The reliability of supply is mainly affected by the controllable and/or bulk feed-in, so the necessity for ICT use here is reduced. At the same time, the lack of ICT systems and infrastructure prevents flexibility for distributed fluctuating generation. This results in a rising electricity price and also increases the cost of achieving lower CO_2 emissions.

In 2030, the majority of households now have digital meters. However, very few of these are "smart" or linked to other applications in the household or the distribution grid. The meters are able to provide meter readings in several tariff levels and are read remotely once a month by the metering operator. As in 2012, the main role of the majority of electricity meters is to record meter readings for billing purposes. The EUCs use this data to optimise processes and, according to their role in the market, optimise their energy procurement or grid operations on the basis of the knowledge they obtain about customer consumption. There is no opportunity to optimise the general economic benefit across market roles.

In the domestic customer segment, therefore, DR is limited to a few selected customer groups that have high consumption and a high degree of load flexibility. These include customers with electric vehicles and/or electric heating and refrigeration systems such as heat pumps or air conditioning units. As is the case today with off-peak storage heaters, customers wishing to connect electric vehicles require a special connection that is integrated into a bottleneck management system of the distribution grid so that vehicles cannot in some cases be charged in periods of local peak load. An incentive comprising lower tariffs means that flexible consumption is shifted largely into low-price times (in the night or at times of high wind or solar output).

Active load management and the use of load shifting potential are only done at a high level. Larger industrial consumers with processes that can be time-shifted, such as refrigeration and energy-intensive process steps, are motivated by greater financial incentives to optimise the planning of their energy consumption over time so that they benefit from lower electricity prices and minimise load peaks by avoiding synchronicity. This therefore creates win-win situations for the energy suppliers and commercial consumers, with support from automated power management. The development is strengthened thanks to the ability of energy suppliers to integrate customers more tightly into their energy logistics systems. They achieve this using products that buy all or some of their energy from the energy market, (for example indexed or tranche-based procurement).

> Load shifting is primarily done at a high level to support the market integration of large wind farms.

Virtual power plants are used in some instances, but are restricted to a few application areas. The support for market integration of renewable energy has meant that the operators of intermittent generation plants such as wind farms have had to buy flexible balancing generation or load facilities. Cooperation occurs between the operators of the plants that exploit renewable energy sources and the operators of flexible gas, biomass and coal-fired power plants. In individual cases, the flexibility of controllable loads such as fleets of electric vehicles or cold stores are used in conjunction with fluctuating generation facilities. Based on the proprietary interfaces used to coordinate generation and consumption, by 2030 sufficient standards have become established in this area that are also compatible across Europe.

2.5.3 EXPLANATIONS AND ASSUMPTIONS

- On growth in costs, promotion and acceptance of solar power: Without further support, the use of solar power in Germany will not be competitive in respect of the large power plants in 2020, and probably not even in 2030. The Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU; Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) assumes[131] that the development in the cost of solar power will be such that the costs of production will be €13.7 per MWh in 2020 and €10.6 per MWh in 2030. According to Kost and Schlegl[132] the forecast average cost of production for fossil fuel power plants will be around €10 per MWh in 2030. Nevertheless, solar power will be worthwhile as soon as it has achieved "grid parity" for consumers who can thus reduce their electricity costs if their own consumption is sufficiently high. The BMU believes this could occur in around 2015.
- Changes in the cost of wind power: When considering the development of the costs of wind generation, it is assumed that wind farms can continue to operate economically until 2030 without additional subsidy. This is confirmed by Kost and Schlegl. According to the BMU, the costs of production in 2020 will be €7.1 per MWh, falling to €6.1 per MWh by 2030.

2.6 SCENARIO "SUSTAINABLE & ECONOMIC"

2.6.1 OVERVIEW

In the "Sustainable & economic" scenario, the restructuring of the energy system has been completed successfully by 2030. The objectives of the Federal Government's Energy Concept[133] published in 2011 have even been exceeded. CO_2 emissions have been reduced by 65 percent in comparison with the reference year (1990).

- The proportion of renewable energy sources in national gross electricity consumption is 60 percent. According to a study by the Umweltbundesamt (UBA; Federal Environment Agency), the contribution from major offshore wind farms in the North Sea and Baltic Sea and onshore wind (the latter as a rule after repowering), additional expansion of solar power, biomass and also imported electricity generated from renewable energy sources is 132 TWh, 13 TWh, 46 TWh and 25 TWh respectively[134]. Contributing 25 percent of the electricity supply, distributed feed-in takes electricity generation close to the consumer.
- The energy market has been liberalised. Following the end of the EEG subsidy, wind power (offshore and onshore) and biomass are competitive due to the rising prices for fossil fuels. Solar power generation just exceeds the economic feasibility threshold and continues to enjoy a subsidy. There is concerted competition between the various electricity producers and providers. Customers play an active role in the market. This is confirmed by the switch rate of over 20 percent (2009: 4 percent or 1.7 million).[135] Household customers watch their electricity consumption much more closely than in 2012, both for ecological and economic reasons.
- In particular, the massive deployment of ICT at all levels of the power supply system ensures that this system not only operates smoothly, but that the exemplary reference installations in the German market provide German vendors with a competitive advantage in the global smart grid market. Exports ensure the future of existing jobs and help create new jobs as well.

2.6.2 SIGNIFICANT DEVELOPMENTS

Many prerequisites have had to be fulfilled in order to achieve this scenario. The significant factor in its success has been the consistent and coordinated energy policy, developed in close cooperation and with open and public debate with the energy utilities, vendors, the population and industrial companies as the largest consumers. Through regulation and deregulation, the government has influenced the markets, the expansion of the grid, planning for the expansion of renewable energies and the new IT infrastructure.

131 BMU 2009.
132 Kost/Schlegl 2010.
133 BUND 2011.
134 UBA 2008.
135 BNetzA 2010b.

The new rules on the payment for feed-in from renewables and the use of innovative ICT solutions are paving a more efficient way to avoiding CO_2 emissions.

The renewable energy subsidy has been revised. Time-independent feed-in tariffs have been abolished. Instead, the amount paid for electricity feed-in from all power generators is based on the market prices for electricity and operating reserve – i.e. including the payment for renewables feed-in. This has been achieved by less expensive plants, significantly better forecasting, the connection to the ICT infrastructure and integration into virtual power plants. For some time, virtual power plants have been far more than simply a logic bundle of several small generators. A virtual power plant integrates both generators and consumers, supporting grid system operators with system services such as maintaining voltage. It also supports autonomous and automated functions, such as trading on regional markets.

In the construction of bulk renewable energy "power plants" (offshore and first steps to import electricity from CSP), a European strategy was taken into consideration to determine which European locations were most economically viable for deployment. Equally, in drawing up energy legislation, local factors such as the costs of the required grid expansion were taken into account when supporting and legislating on distributed feed-in.

The pressure from negative prices on the electricity exchange resulting from the priority status assigned to renewable energy means that the pool of fossil fuel power plants has been overhauled, and this power now supports the volatile distributed feed-in and the supply of electricity from renewables.

The process of overhauling and dismantling fossil fuel power plants has progresses well. While bulk power plants were still the only major contributors to the power supply in 2012, their primary role is now to balance out fluctuating feed-in. The latest generation of fossil fuel power plants are flexible and can quickly change their power output. The power plants have been developed to be as low cost as possible during standby operation and to ensure low CO_2 emissions. Although these power plants have significantly lower full-load hours per year than the power plants in 2012, they remain economically viable, due, among other factors, to the peak prices caused by intermittent feed-in.[136]

European energy policy agrees new Directives that are interpreted and transposed at national level. Grid expansion that enjoys Europe-wide support and that has been implemented rapidly at national and European levels helps to combat inefficiency. Regulation allows grid system operators to charge fair grid charges according to usage in return for requiring them to broadcast pricing signals.

Within the ENTSO-E association, new transmission lines (many of which are already HVDC lines) are built in addition to the improved interconnect points that were planned in 2012. These new lines are now connected to a European overlay grid. This grid allows electricity to be traded across Europe, helping to even out prices on the electricity exchanges. Looking at a large area, the fluctuations from renewable feed-in barely correlate. In combination with the aforementioned grid expansion, this means that the feed-in from renewables is more reliable. Investment in the grid has been supported by funding from Europe.

The level of automation in the transmission grids has progressed much further than compared with 2012. The European interconnection grid is managed as a single grid and is supported by Wide Area Measurement Systems (WAMS) and real-time calculations and simulations of the whole grid status. Planning to expand the transmission grids is based on European demand and the long-term plans to expand generation. The expansion of the transmission grid is progressing without delay, thanks to improved legislation and high levels of popular acceptance. Management of the distribution grid makes significant use of distributed and fluctuating generators in order to ensure the quality of power. Negative prices are rare, since fluctuations can be better balanced out over the large geographical areas, and there are fewer base load power plants that would be very costly to shut down. In addition, storage facilities and DSM help to soak up a high supply of electricity.

136 Amelin/Soder 2010.

While the distribution grid in 2012 still operated according to the principle that every generator and consumer system should be connected, the expansion of distributed feed-in in 2030 also takes account of the grid costs that are incurred. The expansion of renewable energy sources in the distribution grid now takes much greater account of economic factors. Expansion plans for both the distribution grid and for feed-in from renewables are matched to each other at regional level. In order to avoid DSM or 6 million electric vehicles increasing the synchronicity factor too much, and therefore causing high costs due to the required grid expansion, grid operators use DR management to influence the patterns of consumers and distributed generators. Operational management of the distribution grid is based on real-time data and takes account of an awareness of the grid status. The distribution grid actively monitors and regulates power flows, phase and voltage control. The grid uses generators, consumers and also innovative power electronics elements as active components to help ensure the reliability of supply. While there is no mandatory requirement for smaller generators to allow the grid system operators to control their output, almost all newly installed plants offer this option, since support for grid operational management or the participation in virtual power plants provides the plant operators with significant cost advantages: For example, the virtual power plant improves the reliability of forecasts of the actual feed-in curve for a set of fluctuating generators. The operational management of the distribution grid and transmission grid are closely matched in real time.

At the same time, new concepts in power supply are tested in research and pilot projects. These may include the use of DC in the home or different tolerances for the grid frequency. Much use is already being made of the links between the electricity system and other energy infrastructures, as addressed several times.

The availability of a system-wide ICT infrastructure that is promoted by the regulator, combined with standardisation and higher electricity prices, has allowed a range of DSM products to emerge that lead to the conversion to generation-led operation.

An important factor in establishing the smart grid is the availability of standards that have been developed by industry with the support of research. The IEC 61970/61968 Common Information Model (CIM) and IEC 61850 standards, which were authoritative at an early stage, have been refined and new standards, especially those for electronic meters and DR, have been drawn up and are subject to constant revision. A uniform application of the standards has been ensured. As the standardisation process has also enjoyed mass state support, Germany has succeeded in becoming a European role model that other countries have followed. The standards developed in Europe and used in a large number of major reference implementations have been incorporated into the products of national vendors. This has allowed them to achieve a large, growing market share, not only in Europe but also around the world.

Regulation supports and encourages this development. It also prescribes the use of standards at key points, in order to ensure the openness of the system while taking care not to stifle innovation.

The second development is the availability of a system-wide ICT infrastructure in the distribution grid. This infrastructure is used for bidirectional communication for all systems, generation systems, including electronic meters, consumers and grid systems. The infrastructure is open to all participants. Standards-based interoperability (and interchangeability where necessary) and non-discriminating access managed by the regulator maintain this openness. The users of the ICT infrastructure comprise the grid system operators and all participants who wish to use the energy market. Development of the infrastructure will continue so that it retains forwards and backwards compatibility, is open to innovation and guarantees investment security.

The base costs of this infrastructure are borne from the public purse in the regulated area of operational grid management while the areas exposed to the market, such as new services, must be funded by the companies' product sales. The regulator provides sufficient incentive for investment in the necessary further developments. As large amounts of customer data are transferred through this infrastructure, great emphasis is placed on information security.

This infrastructure – a cyber-physical system (CPS) – is a non-divisible entity comprising the ICT and electricity infrastructure. Just as the electricity supply of the 20th century, this CPS is subject to the triumvirate of energy policy objectives, comprising reliability of supply, economic feasibility and environmental compatibility. The most important objective is reliability of supply, which thus requires a highly available overall ICT system. The costs of the CPS are kept within measure since the costs of ICT integration of system elements depend on their importance for the reliability of supply. In this respect, the ICT connection takes the previous n-1 principle and replaces it with an n-k principle. This means that even if some of the generators fail or can no longer be controlled, the overall system must be reliable. The system remains stable in the face of cyber attacks. The necessary technical and organisational measures are in place to ensure this.

Further liberalisation and the availability of this ICT infrastructure combined with higher electricity prices (in real terms) have created a market for services around the smart grid.

The open market with ICT-based energy services and operational grid management that takes account of the new energy mix are built on top of these important developments in ICT. Many new smart grid applications have been created. Some of these offer customers such a degree of value-added that they can be described as "killer applications" – i.e. applications that give rise to a significant new market. Companies reinvest the high profits in the smart grid to create a self-amplifying feedback loop.

DSM offers are used on a large scale, including some by domestic customers as well as commercial customers, taking account of both intermittent supplies of electricity and of grid capacity. Domestic customers contribute to DSM in particular by permitting automatic control of thermal equipment (electric heating, heat pumps, freezers, air conditioning) and electric vehicles, although their overall participation in the total potential remains low. All market activity is based on new rules that take account of the new generator structure and the opportunities provided by automated flexible DSM. This also requires the rules for energy markets and operating reserve markets to be harmonised across Europe where possible.

The costs for end consumers as a proportion of household income have risen considerably. While enormous improvements in efficiency in the generation of electricity from renewables have helped keep generation prices largely competitive, taking into account the CO_2 emission prices, the completed grid expansion and reserve power plants operating with few full-load hours push the price upwards. Nevertheless, the population was in favour of the expansion of renewable energy sources and was aware of the consequences. It not only accepts the restructuring of the electricity supply but has concertedly supported it. Rules have been made to take account of industries that use large amounts of electricity. Customers are energy aware, and only remain loyal to suppliers if the electricity supply is embedded within an attractive offering. The frequency of customers switching provider has grown considerably. This trend has been supported by regulation that makes it easier to switch supplier.

2.6.3 EXPLANATIONS AND ASSUMPTIONS

"Exports ensure the future of existing jobs and help create new positions as well." As yet, no relevant studies into this have been conducted in Germany. A detailed analysis by the Electric Power Research Institute (EPRI)[137] was able to establish the relationship for the USA. Given the good starting position of German vendors, it can be assumed that the same will apply in Germany.

"The new rules on the payment for feed-in from renewables and the use of innovative ICT solutions pave a more efficient way to avoiding CO_2 emissions." The IEA has produced estimates of this.[138] A more accurate analysis for Germany will be available following analysis of the findings from the E-Energy Model Regions.

"European energy policy agrees new Directives that are interpreted and transposed at national level. Grid expansion that enjoys Europe-wide support and that has been implemented rapidly at national and European levels helps to combat inefficiency." See also the explanations and sources for key factor 8.

"Regulation allows grid system operators to charge fair grid charges according to usage in return for requiring them to broadcast pricing signals."[139]

137 EPRI 2011a.
138 IEA 2011c.
139 Considerations on this point can be found, for example, in Angenendt/Boesche/Franz 2011.

"There are capable business models for DSM." So far it seems dubious whether DSM can offer an advantage for all customers. However, it is probable that at least a certain percentage can benefit from DSM.[140]

"The base costs of this infrastructure are borne from the public purse in the regulated area of operational grid management while the areas exposed to the market, such as new services, must be funded by the companies' product sales." See also chapter 6.

In this scenario, no assumption is made about the number of domestic customers that have systems that integrate the bidirectional electronic meters with a household energy management system with comprehensive functionality. Penetration in this scenario depends exclusively on the extent to which common economic benefit is derived. In this scenario it is assumed that the framework legislation will ensure that this advantage can be translated into individual benefit.

"The population accepts and understands the development (for example, increased prices)." See chapter 7.

2.7 SUMMARY

This chapter took a structured look at the situation of the energy supply in 2030. In line with the scenario methodology, eight key factors were identified that the authors believed to be particularly meaningful for the long-term development of the German energy supply system:

1. Expansion of the electricity infrastructure
2. Availability of a system-wide ICT infrastructure
3. Flexibility of consumption
4. Energy mix
5. New services and products
6. Costs for end consumers
7. Standardisation
8. Political conditions

These key factors integrate the dimensions of (both electric and IT) technology infrastructure, sustainability, markets and products, consumers and the energy policy. In the scope of scenario creation, the aforementioned key factors are understood to be representative of their basic orientation. Therefore, electric mobility or storage technologies have been considered as key applications within the future energy system in the context of the method, but do not actually represent key factors themselves.

The selected key factors were then projected into the future so that the analysed developments would indicate the largest possible differences. This allows a space to be created for each key factor, covering the long-term developments in this area as comprehensively as possible.

The projections that were developed were subjected to a bundling process in order to form the scenarios. The projections were compared two at a time and awarded a consistency rating. The resulting bundles were then clustered so that the clusters indicated internal homogeneity and external heterogeneity. This process produced three scenarios for 2030:

1. "20th century" The energy supply system remains consistently based on fossil fuels and renewable energy sources, permitting the load-led approach within the grid infrastructure of the twentieth century. Fossil fuel generation plants are expanded by technologies such as CCS. The generation of electricity from fluctuating sources such as wind power falls. Very few new services emerge to complement the supply of electricity. Costs for end consumers have risen considerably and variable tariffs have generally not been applied. In addition, due to the low degree of flexibility built into structures, the options for optimisation beyond 2030 are limited.

2. "Complexity trap": The development of smart grids has not been satisfactory, due to competing interests and a lack of uniform framework conditions. The infrastructure, especially in ICT, has been developed in a heterogeneous manner. The consistent use of fluctuating renewable energy sources and load shifting are restricted due to a lack of coordination.

140 Bothe et al. 2011.

Controllable generation plants are preferred. The offering of new services is also limited so that mostly only one or two market participants provide services, and these are often restricted to basic functions. The lack of uniformity in development is reflected in high costs for the energy supply system, which trickle down to the end consumer.

3. "Sustainable & economic": Smart grids have developed successfully. Thanks to a lasting, close coordination of energy policy, society, energy utilities and technology providers, a cost-efficient and sustainable energy supply system has been created. The supply of electricity is based mainly on renewable sources with most power generated by the wind. The system-wide ICT infrastructure and the requirements-based expansion of the transmission grid and distribution grid form the backbone for the efficient operation of the power supply and the platform for a range of new services that act increasingly as drivers for new business models. The higher costs for end consumers have been accepted by the population as they have been viewed as the inevitable price of the energy revolution. In addition, there is increased competition due to the improved opportunities for switching providers, and due to the flexible tariff structures.

The next chapter considers the development of the power supply system from a technology perspective. In this context the developed energy scenarios are considered again and described in relation to the anticipated technological developments.

3 THE ROLE OF ICT IN THE FUTURE ENERGY GRID

Now that the three scenarios that set out the framework for the migration paths have been defined, this chapter will analyse the technology areas and their development. Initially, this chapter only deals with the starting point – a consideration of the current state of affairs in relation to ICT use in the electricity supply system. In addition, at the end of the chapter there is a description of the technologies and properties necessary in order to realise the three scenarios. This is done by describing the technology areas and then outlining the further development of each technology area in several steps. The inter-dependencies of these steps are not considered in this chapter, but will be analysed in detail in the next chapter.

3.1 METHODOLOGICAL PROCEDURE

In this chapter, in addition to the scenario-based consideration, the development of the future energy supply system is considered from a technological perspective. The focus in this instance is on the key information and communication technologies (ICT) for the management of electricity feed-in, load and distribution, optimising commercial processes and the extendability of the energy supply system in terms of new business models and services.

The analysis commences by considering the current use of ICT in the energy supply system. This creates an understanding of how the supply of electricity is currently delivered through the various grid levels and of the importance of ICT and associated communications standards in this context. The challenges that will have to be faced in relation to the transmission and distribution of electricity are also revealed.

To create a structure onto which the ICT application fields can be mapped, a model of the system is first defined. As the first dimension, this differentiates the system levels of the energy supply system, which differ in relation to accessibility and the role of communication structures. The second dimension is formed from the domains of the energy sector, which distinguish technological and regulatory roles. The selected system levels and domains take into account, among other factors, the findings of the National Institute of Standards and Technology (NIST)[141], the Electric Power Research Institute (EPRI) Intelligrid Architecture[142] and the European Technology Platform (ETP) for Smart Grids[143].

Within this model of the system, this chapter then goes on to define the technology areas. Each of these describes a technological function or component with reference to ICT. Each technology area is assigned to a system layer and relevant domain in the model mentioned above. The technology areas have been identified using the domains and system levels, but primarily the IEC Seamless Integration Architecture (SIA), which was considered in studies including the standardisation process for the BMWi Funding Project E-Energy[144] and subsequently the German Standardisation Roadmap E-Energy/Smart Grid[145]. As shown in Figure 9, the architecture brings together the established standards of the International Electrotechnical Commission Technical Committee (IEC/TC) 57 and IEC/TC 13, and indicates how they inter-relate. The aspect of integration of technology and participants through ICT and the corresponding communication standards are seen as a significant property of a future energy system in the context of the analyses conducted for this study, with the result that the architecture is suitable as a framework for the technological assessment of such a system. When defining the technology areas during the export workshops, the distinction made in the architecture between applications and business partners (area A, for example energy management systems – EMS), energy systems and field devices (area B, for example Intelligent Electronic Devices – IED) and the cross-cutting technologies (area C, security and data management) was crucial. Papers and presentations given at major Smart Grid conferences, published on web pages and in journals were investigated for potential technology areas as a form of quality control, and the findings assigned to the areas and system levels.

The individual technology areas were each described in respect of their functionality and role within the overall system. In order to provide a structured view of the development of the technology areas

141 NIST 2010.
142 EPRI 2011 b.
143 Østergaard 2006.
144 OFFIS/SCC Consulting/MPC management coaching 2009.
145 DKE 2010.

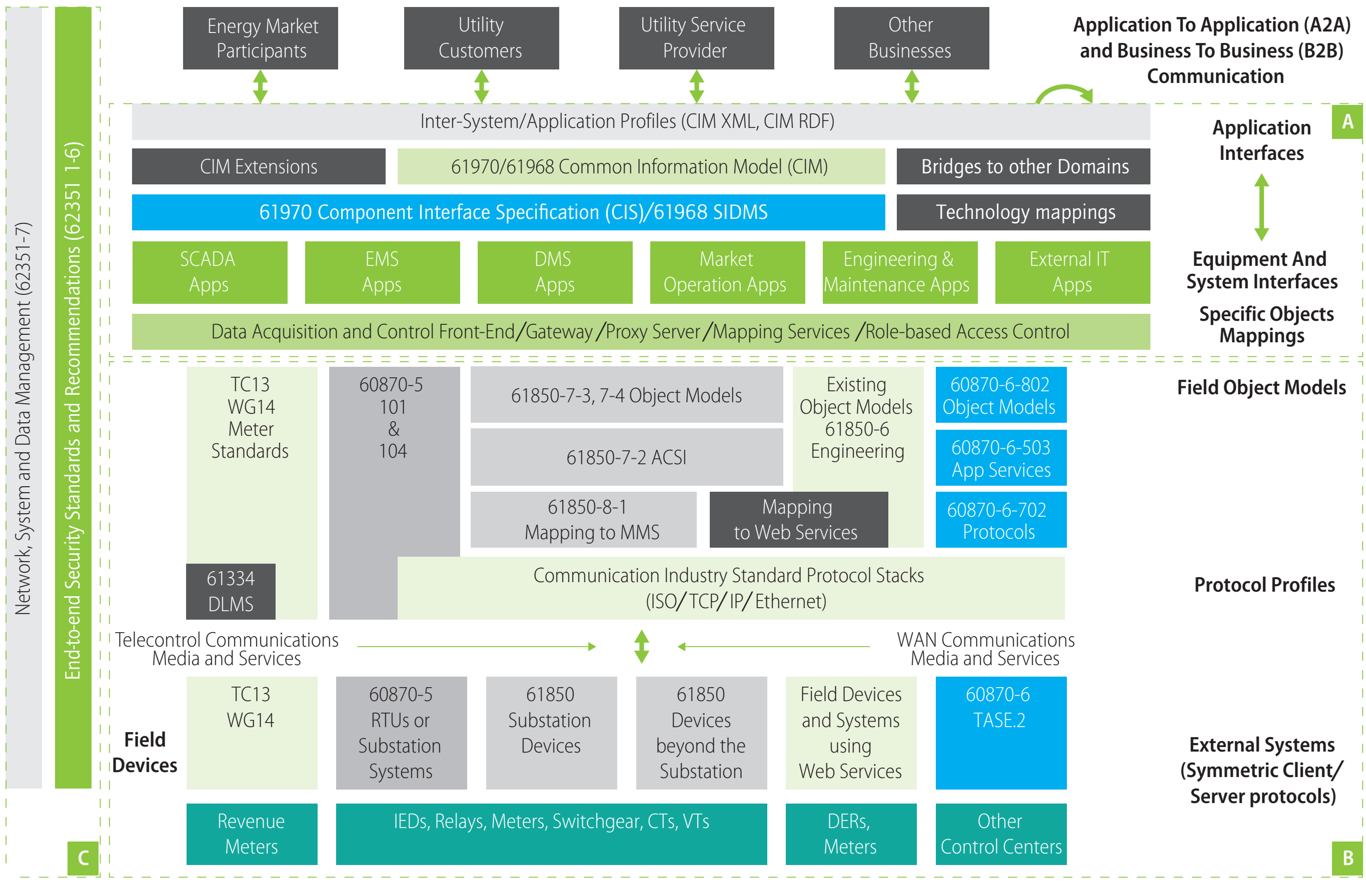


Figure 9: IEC 62357 ed. 1.0 Seamless Integration Architecture (graphic based on IEC 2009, p. 41).

between 2012 and 2030, where possible five development stages have been identified and described for each technology area, starting with the current state of the art. The development stages should not be interpreted as forecasts of exact functionality at a given point in time, but rather represent a specific level of maturity in the technology area in question. The methodological basis for this procedure is taken from the Smart Grid Maturity Model[146]. This distinguishes, as shown in table 1, five different levels of maturity (starting from level 0) for an organisation in respect of the progress of its business strategy in the smart grid environment. The model is therefore strongly geared towards corporate strategies, but the approaches are already available to make it adaptable for a wider range of uses.[147]

5 – PIONEERING	Organization is breaking new ground and advancing the state of the practice within a domain.
4 – OPTIMISING	Organization's smart grid implementation within a given domain is being funded and used to further increase organizational performance.
3 – INTEGRATING	Organization's smart grid deployment within a given domain is being integrated across the organization.
2 – ENABLING	Organization is implementing features within a domain that will enable it to achieve and sustain grid modernization.
1 – INITIATING	Organization is taking the first implementation steps within a domain.
0 – DEFAULT	Default level for the model

Table 1: Levels of maturity from the Smart Grid Maturity Model (based on SGMM 2010, p. 7).

146 SGMM 2010.
147 Rohjans et al. 2011.

Based on this concept of maturity level, corresponding development stages have been identified for each of the technology areas in expert workshops. In the initial levels, the development stages mostly describe technological developments that are already available in prototype or have already been investigated in detail by research and development (R&D). The higher development stages are more abstract, in line with the time horizon reaching to 2030, and represent visions of the potential developments within the area under consideration. When achieving a development stage, the corresponding functionality should be available in a form that would permit actual use within the power supply system. The aspect of practical implementation of the technological development stages is particularly important for the migration paths developed and described in chapter 4.

Once the development stages have been defined, the final section of this chapter deals with the assignment of the technology areas to the Future Energy Grid scenarios. One development stage from each technology area is assigned to each scenario, so as to describe the scenario's technological properties (with a focus on ICT). In the context of the SGMM, this assignment of the technological development stages and the scenarios can be viewed as defining the system properties with a varying degree of maturity. The process of determining the technological level of maturity for the scenarios forms the basis for developing the migration paths in chapter 4.

3.2 STATE OF ICT IN THE ENERGY SUPPLY SYSTEM IN 2012

Table 2 summarises in a greatly compressed format the degree of penetration by ICT into the German electricity grids. As a result of the principle of directed load flow (generation in major power plants, transportation through transmission grids, distribution through medium-voltage grids down to the end-customer's low-voltage mains sockets), imposed for historical reasons, a strict distinction is drawn between the different voltage levels.

3.2.1 THE STRUCTURE OF ICT IN THE EXTRA HIGH VOLTAGE AND HIGH VOLTAGE LEVEL (380 KV; 220 KV)

The extra high and high voltage level (380 kV and 220 kV[148]) has two main tasks. It is used to

1. receive large-scale generation from power plants (> 100 MW) into its grid,
2. transport the electricity it receives nationally through a suitably dimensioned grid to the centres of consumption, and in the case of fault to ensure an uninterrupted flow of reserves both nationally and internationally (from Portugal to Denmark, for example). More recently, there has also been an increasing amount of trading-related energy transportation.

Within this "motorway network" that comprises the electricity supply grid, significant conditions (active power, reactive power, apparent power, voltage range, utilisation of grid components such as cables and transformers) must be upheld. A further key reference variable is the grid frequency of 50 Hz. This 50 Hz target must be met within a very narrow tolerance (±0.2 Hz) in order to guarantee the high quality and stability of the overall system. As electricity is transported via electrons in an electrical field that propagates at the speed of light, generation, storage and consumption must occur absolutely simultaneously within these physical limits. The change in the frequency over time is used as a measure of the equilibrium of the grid. As such, the first controlled variable, the primary control, is available locally at each large generation unit without any communication requirements. All subsequent measures (secondary control, minute reserve) are dependent on the communications infrastructure. At the same time, both the static and dynamic stability of the system must be upheld.

This system can be imagined as a strictly controlled system of storage reservoirs, in which the water is maintained at an absolutely constant level. If the system were to be over-filled (too much generation), the result would be flooding. In contrast, under-filling (too much load) would cause the associated distribution grid layer to dry out.

148 When it comes to pending reinvestment measures, with the aim of achieving the commercially optimum voltage level (0.4 kV/MV/110 kV/380 kV), 220 kV grid components are being upgraded to 380 kV, replaced by 110 kV or removed completely.

<table>
<tr><th>VOLTAGE LEVEL</th><th>ICT IN USE</th><th>CHARACTER</th><th>REQUIREMENT</th><th>CONTROL FUNCTIONS</th><th>CHALLENGES</th><th></th></tr>
<tr><td>Extra-high voltage/
High voltage
380 kV / 220 kV</td><td>– Control systems
– Further development</td><td>Quasi-real time</td><td>Data security
Availability (24/365)
Active
data management</td><td>f (Hz)</td><td>– Wind
– Trade</td><td rowspan="4">The grids are increasingly being operated at the limits of their capacity.</td></tr>
<tr><td>High voltage
110 kV</td><td>Control systems/telecontrol systems</td><td>Quasi-real time</td><td>Data security
Availability (24/365)
Active
data management</td><td>Voltage</td><td>– Wind, PV-large plants
– Bidirectional load flow
– Demand response</td></tr>
<tr><td>Medium voltage
10 kV/20 kV</td><td>Telecontrol systems
Consumption metering</td><td>not
time-critical</td><td>Data collection and processing</td><td>In part
voltage</td><td>– Wind, PV
– Rural areas
– Over 800 system operators
– Bidirectional load flow
– Demand response
– Reactive power provision</td></tr>
<tr><td>Low voltage
0.4 kV</td><td>–</td><td>–</td><td>–</td><td>–</td><td>– Distributed feed-in especially PV
– Rural areas
– Active customers (prosumers)
– Virtual power plant
– Consumption tracks generation
– Electric mobility</td></tr>
</table>

Table 2: ICT usage and challenges across the voltage levels

In line with this principle, great importance has always been attached to a simple and secure information and communication structure. Within the management and control rooms of the transmission system operators, this structure enables the staff to know the switching state and load of the grid elements, to maintain voltage tolerances and to influence load flows (for example by increasing or reducing feed-in, controlling load, importing or exporting energy). Maintaining frequency stability is accomplished by means of the primary control of the power plants' rotating mass. Fast adjustment of the feed-in power (active power P and reactive power Q) is based in this instance on the grid frequency.

A high availability (24 hours day, 7 days a week) IT network has been created for the purposes of grid monitoring and control. The network guarantees that active data management can occur in real time. There is a range of network control systems that comprise the IT network, each of which is assigned to part of the voltage level hierarchy and is able to communicate with the others. A grid control system (see technology area 2) comprises the grid control desk, the station control technology and the remote control systems. The grid control desk controls and monitors the substations from a remote location. Located in proximity to the substations, the station control system controls and monitors the switchgear inside the substations and communicates with the grid control desk. The telecontrol systems control and monitor individual switchboard sections and communicate with the station control systems. The starting point for any switching action is the grid control desk. The main task of the grid control desk is to monitor and forecast the active power, reactive power, apparent power, voltage range, switching state and resource load, and to ensure supply is upheld in the case of faults. To realise this, the grid control desk has available to it a range of functions that can be classified as SCADA (Supervisory Control and Data Acquisition) functions and higher-level decision-making and optimisation functions. The SCADA functions are concerned with monitoring and reporting process states, and also for controlling and regulating a range of different processes. The higher-level decision-making and optimisation functions are used for the purposes of commercial optimisation and to support switching actions (interlock checking), availability and the safety of operational staff. The grid control desk sends the corresponding signal to the station control system which in return transmits information to the grid control desk and forwards the commands of the grid control desk to the remote control systems. The remote control systems actually carry out the commands on the corresponding switchboard.

A variety of communication standards is used to ensure communications within and between the grid control systems. These include:

- IEC 60870: Open communications standard for switchgear, remote control and grid control technology.
- IEC 60870-5: Remote control facilities and systems – part 5: Transmission protocols
- IEC 60870-5-101: Application-related standard for basic telecontrol tasks: Serial transmission protocol between grid control systems and substations
- IEC 60870-5-102: Application-related standard for meter reading transmission in the electricity supply sector
- IEC 60870-5-103: Application-related standard for information interoperability between protective systems
- IEC 60870-5-104: Access for IEC 60870-5-101 to networks with standardised transport profiles (using the Internet protocol TCP/IP)
- IEC 60870-6 (also known as TASE.2): Coupling of various grid control systems via the TCP/IP Internet protocol/ networking of control systems (has established itself as a worldwide vendor-neutral interface)
- IEC 61850: Communications networks and systems for power supply automation
- IEC 61850-6: Language to describe the configuration of communications in stations consisting of intelligent electronic devices
- IEC 61850-7-4: Basic communications structure – compatible logic node classes and data classes
- IEC 61400-25: Communications concerning the control and monitoring of wind turbine generators
- IEC 61850-7-410: Hydroelectric power plants – Communication for monitoring and control
- IEC 61850-7-420: Communications standard for distributed energy resources

The IEC 61850 series of standards represents the state of the art in communications standards. It includes the use of Internet protocols, real-time Ethernet communications for transmission of digital sampling data, and plant engineering with a standardised machine and system descriptive language.

In relation to data exchange between applications at grid control level, increasingly the standards series IEC 61968, IEC 61970 and IEC 62325 are being used (for example within the European Network of Transmission System Operators for Electricity (ENTSO-E) in order to exchange topological grid data). These standards series define object-oriented (OO) data models and interfaces for the transmission and distribution grids, market communications and services to access these data models.

- IEC 61968: Integration of applications in electricity supply systems – system interfaces for grid management
- IEC 61970: Application program interfaces for energy grid management systems (EMS-API) (in particular Part 301: Common Information Model (CIM): General information model)
- IEC 62325: Communications in the energy market

Figure 10 provides an overview of the use of the standards mentioned above. In addition, Rohjans[149] and Uslar[150] et al. 2010 collected and evaluated international standardisation recommendations, giving a good overview of the ICT standards in the smart grid.

A future challenge in this respect will be to integrate large bundled loads from offshore wind farms into the system. The problem here is less the technical integration and more the forecasting of the expected feed-in that will be needed in order to manage the associated pool of wind turbine generators appropriately.

149 Rohjans et al. 2010.
150 Uslar et al. 2010.

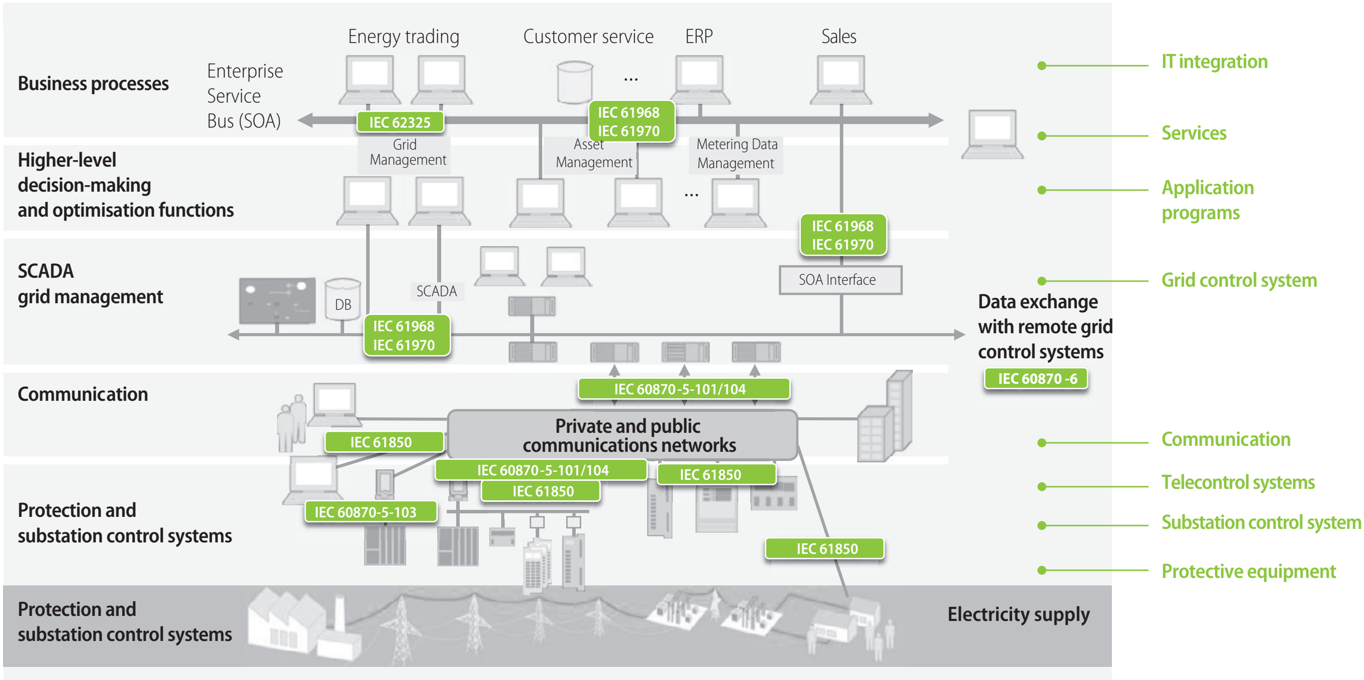


Figure 10: The use of communication standards within the electricity supply (source: Siemens).

3.2.2 ICT STRUCTURE IN THE HIGH VOLTAGE (110 KV) LEVEL

In our reservoir analogy, the downstream 110 kV distribution grid can be seen as a system of canals that direct the electricity towards where it is consumed. The electricity from the 380 kV or 220 kV system is received at substations via 380 kV/110 kV and 220 kV/110 kV transformers. It is then fed to the distribution system through a range of feeders (outputs) via a 110 kV/20 kV transformer from which it then flows into a much more branched distribution grid. At these points (distribution grid and local substations), the distribution grid operator's control centre has load-flow information available at its fingertips in near real time. The task here is to observe the voltage, and therefore the load (power) within the system as the control variable and to maintain this within a technically viable band. If the voltage is too high, the system must balance this out by means of power factor correction. If the load is too high, feed-in operators must be removed from the grid in critical situations (overheating of the line conductors and cable systems). Therefore, the task at this level also is to maintain high availability of the distribution grid system, around the clock.

A particular challenge for this system comes in the form of the current 27 GW installed power of onshore wind farms. These volatile generators will generate increasing load peaks in some (mostly rural) areas of the grid that have a comparably less powerful grid structure. If they are unable to shift the feed-in power to suitable grid nodes in the upstream 380 kV grid, the grid system operators will only be able to react by switching off the feed-in. This results in a further challenge that today's distribution grid must face – bidirectional load flow.

3.2.3 ICT STRUCTURE IN THE MEDIUM VOLTAGE (20 KV) LEVEL

The role of the distribution grid in the electrify supply system is particularly important. It supplies both domestic customers and energy-intensive commercial customers, as well as a large proportion of industrial users. The requirements in terms of the quality of supply represent a major technical challenge at this level, due to the high process-based dependency on an uninterrupted supply of electricity. Some voltage quality requirements (e.g. for data centres) are frequently managed by the customer, through the use of corresponding technologies, such as UPS (uninterruptible power supplies) and even emergency power systems. The degree of ICT penetration in this area is limited to the statutory consumption metering of commercial and industrial customers with annual consumption in excess of 100,000 kWh. According to this statutory requirement, the distribution system operator or metering operator is required to inform the customer of its previous day's consumption profile by 10am the next day where possible. Within the past few years this has led to the development of a number of proprietary solutions to the problems of data collection and processing. The meter readings have mainly been submitted using analogue telephone lines (electronically, via modem) or using GSM mobile communications. In recent years, IP (Internet-protocol) based packet communications media have come to dominate.

There is no other ICT structure at this level of the grid. Similar to the challenge at the 110 kV level, load situations in which the electricity has to be directed to the upstream grid level (bidirectional load flow) also occur in the medium voltage level – primarily due to smaller wind farms and biogas power generation systems.

The German Association of Energy and Water Industries (BDEW; Bundesverband der Energie- und Wasserwirtschaft) has responded to this. In June 2008 it published its Guideline "Erzeugungsanlagen am Mittelspannungsnetz" (Generation Systems in the Medium Voltage Grid)[151]. This stipulates that grid system operators may require that such generation systems be incorporated into their remote control systems.

3.2.4 ICT STRUCTURE IN THE LOW VOLTAGE (0.4 KV) LEVEL

Based on the telecommunications industry terminology, this finely meshed grid can be referred to as the last mile, or local loop. Each 20 kV/0.4 kV local substation is connected to around 250 domestic consumer units in a string-like formation. The local substation transformer steps down the feed-in voltage into one of the narrow bands defined by EN 50160. This voltage is no longer measured from this point, however. There is no ICT structure in this distribution grid.

An extreme challenge at this level of the grid stems from the installation of PV (photovoltaic or solar power) systems, which have soared in number in recent years. This results in stress situations in the form of voltage level breaches and overloaded equipment. At the moment, system operators are only able to respond by expanding their grids (additional cables and local substations), which adds significantly to the overall costs of the system.

Smart meter infrastructure that is already being constructed could be used in the future to allow this grid level to be monitored where this was previously not possible. Controlling this grid level, however, remains one of the major challenges facing the industry, in view of the massive number of customer systems. In the low voltage level in particular there is a lack of binding standards. An overview can be found in "die deutsche Normungsroadmap E-Energy/Smart Grid" (The German E-Energy Standardisation Roadmap" published by the DKE and VDE (DKE/VDE).[152]

3.3 SYSTEM LEVELS MODEL

A model of a system is used to allocate and structure the actors, applications and technologies within it. The system is thus divided into further subsystems and their relationships are defined. A variety of potential subdivisions are possible, depending on the division of roles. In the scope of studies and roadmaps that analyse and describe the future development of power grids, there is a range of different models that can be used to schematically visualise these findings. These models define the domains of the energy sector and establish the relationships between these domains. A domain represents a specialist area or application area that encompasses a specific, identifiable role within the overall system. The solution used to realise a domain itself makes specific requirements in terms of the construction of the overall system.

151 BDEW 2008.
152 DKE 2010.

For example, in the Intelligrid Architecture[153] the EPRI distinguishes at the top level between the domains "Central Power Generation", "Transmission Operations", "Market Operations", "Distribution Operations", "Distributed Energy Resources", "Consumer Communications" and "Federated and System Management Services".

Building on this, in its Smart Grid Concept Model, NIST identifies the top-level domains "Bulk Generation", "Transmission", "Distribution", "Customer", "Markets", "Operations" and "Service Provider". These domains are related to each other via electricity grids and communications links.[154] The approach is particularly good at structuring the interoperability standards required to ensure communications can be exchanged between the different actors. However, it should also be noted that some actors and system functions may straddle a number of the aforementioned domains, and are there relevant to multiple domains.

Another model with an additional structure for domains is used in the scope of the "European Electricity Grid Initiative Roadmap and Implementation Plan"[155]. As shown in Figure 11, the model distinguishes between the grids (transmission grids, distribution grids and heating grids), ICT and applications supported by ICT, such as virtual power plants, electric mobility, smart homes and/or marketplaces, and structures these over the three layers of the model.

The model used in this document approaches the structure through a combination of model layers and domains. The model layers are identified as layers of the system, and shed light on the electricity supply system from an ICT perspective. The abstract base model in Figure 12 is an initial, domain-free version. The domains are described in the context of the individual scenarios, and allocated to the levels of the system model. By comparing the model properties, the

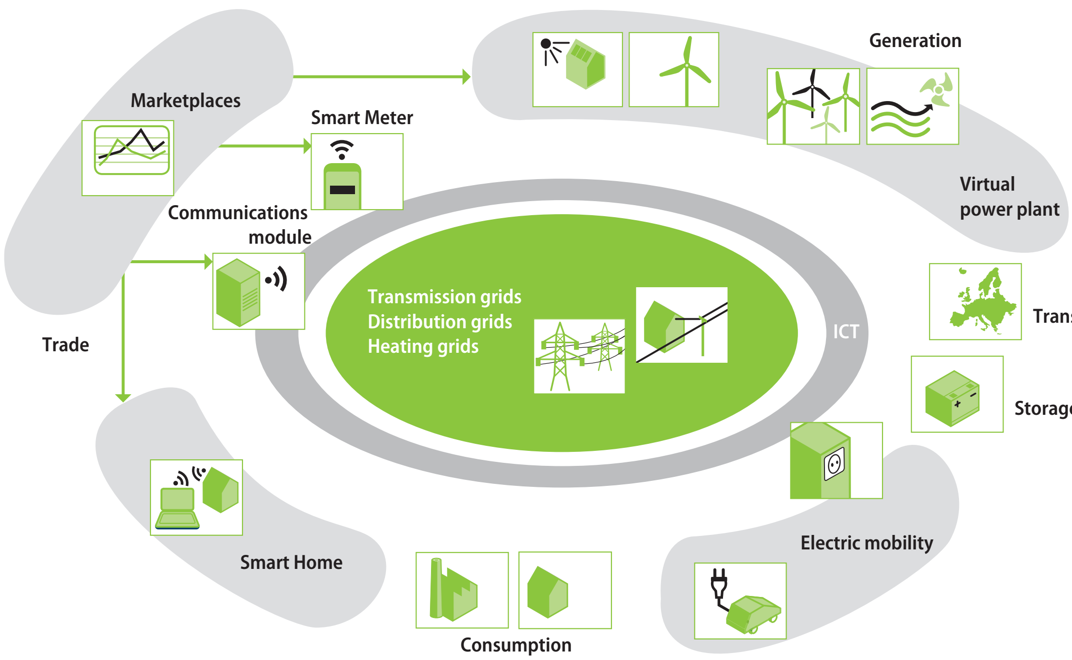


Figure 11: System model of the "European Electricity Grid Initiative and Implementation plan" (based on graphic produced by WG2 of the IT Summit).

153 EPRI 2011b.
154 NIST 2010.
155 EEGI 2010. The model was created by Working Group 2 at the National IT Summit.

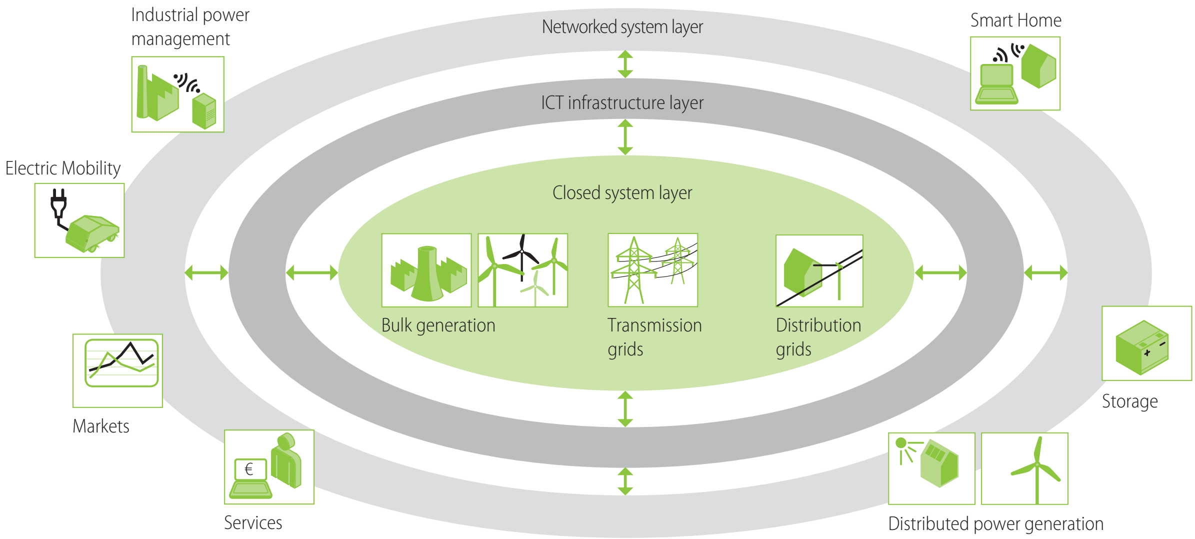


Figure 12: Abstract model of ICT-based visualisation of the future energy system, with three system layers and sample functionality and application areas within the layers.

differences in orientation of the energy system between the scenarios can clearly be seen.

For the task at hand, to define technology areas that have a close link to ICT and to assign these as unambiguously as possible, the structuring process is undertaken largely at the top level.

The layers contained within the model are the product of the assumption that in the expansion of the future energy supply system, the exchange of information will be as important as the flow of electricity. Accordingly, three layers have been established within the energy supply system, which differ according to their architecture, their functions that are replicated through ICT applications, their accessibility, their intensity of information exchange and other non-functional properties.

- **Closed system layer:**
  The closed system layer comprises system-critical systems that will probably remain permanently in the control of the grid operators (or of future actors with an equivalent role). Many of the parts of the system, in particular the aggregation layer and the remote layer, are subject to high quality of service (QoS) requirements. Access and external control are not possible for these parts of the system, or at least are only possible with a high degree of restriction. During operation, however, additional information lying outside the borders of this system may be accessed, such as the feed-in from distributed energy resources. A typical example of the closed system layer is the control of switchgear.

- **Networked system layer:**
  The main characteristic of this layer is the high degree of networking among a broad range of heterogeneous participants. Therefore, in the case of incoming information, no assumptions can be made about its "trustworthiness". Nevertheless, with further expansion in distributed energy resources, this layer will certainly be system-critical. The heterogeneous nature of the systems relates, among other factors, to the size (for example, PV IED vs an exchange-based trading system), real-time requirements (the use of wind power in power factor correction vs. smart meters), communications frequency or security requirements. Typical examples include modules to control CHP (combined heat and power) plants or virtual power plant systems.

- **ICT infrastructure layer:**
  To realise communications between the components in the open and closed system layers, additional components are required to

provide explicit interface functionality. These are located within the ICT infrastructure layer. An example of these components would be communications networks.

The selected three-layer structure also provides the required level of flexibility to replicate the different technological properties of the electricity supply system. Depending on the character of the scenario in question, the system layers may be more or less detailed. The level of detail will depend on the technologies used to fulfil a given system function. The location (central/distributed), medium (electricity/information) and accessibility (public/private) of the technologies used may differ between two scenarios. This means that the basic characteristics of the overall system may be central and closed in nature. In such a context, the networked system layer would play a less important role than in a distributed, open system architecture.

3.4 TECHNOLOGY AREAS

Building on the system layer model described above, this chapter now deals with the technology areas of the Future Energy Grid (FEG). This corresponds to the vision of ICT connections to new, distributed energy resources as can be found in the roadmaps published by NIST[156] and the IEC[157], for example. Alongside the existing, secure communications channels in the current supply systems, both of these roadmaps also include Internet-based communications channels that are used to open up the closed ICT infrastructure. As described in the context of the methodological procedure in 3.1, during the expert workshops held to determine the technology areas, use was made of IEC 62357 SIA. The aforementioned system layer model is appropriate here and differentiates between open and closed system layers that are linked together via interfaces located in the ICT infrastructure layer. The three system layers are complemented by the cross-cutting technologies. These comprise technological aspects that apply across all domains and system layers.

Figure 13 illustrates how each of the individual technology areas can be assigned to the domains of the energy sector[158]. These include generation (bulk and distributed), electricity infrastructure (transmission and distribution), customers in industry and domestic households, the energy markets and service providers. In addition, figure 13 also uses colour to indicate the assignment of the technology areas to the corresponding system layers.

For each technology area, the key information for categorisation within the FEG system context is first summarised within a table. The content of the corresponding area is then discussed and linked to associated technology areas.

In respect of the migration paths subsequently developed in chapter 4, the development stages that represent the development of the technology area to various levels of maturity are then discussed. The development stages are therefore based on the maturity levels of the SGMM[159] and have no fixed time reference. The initial development stages normally correspond to technological developments and concepts for which a prototype implementation already exists or which have, conceptually at least, become more advanced in the scope of R&D work. The higher development stages and in particular the final stage analysed in each case represent a vision for development of the corresponding technology area.

156 NIST 2010.
157 IEC 2009.
158 Based on NIST 2010.
159 SGMM 2010.

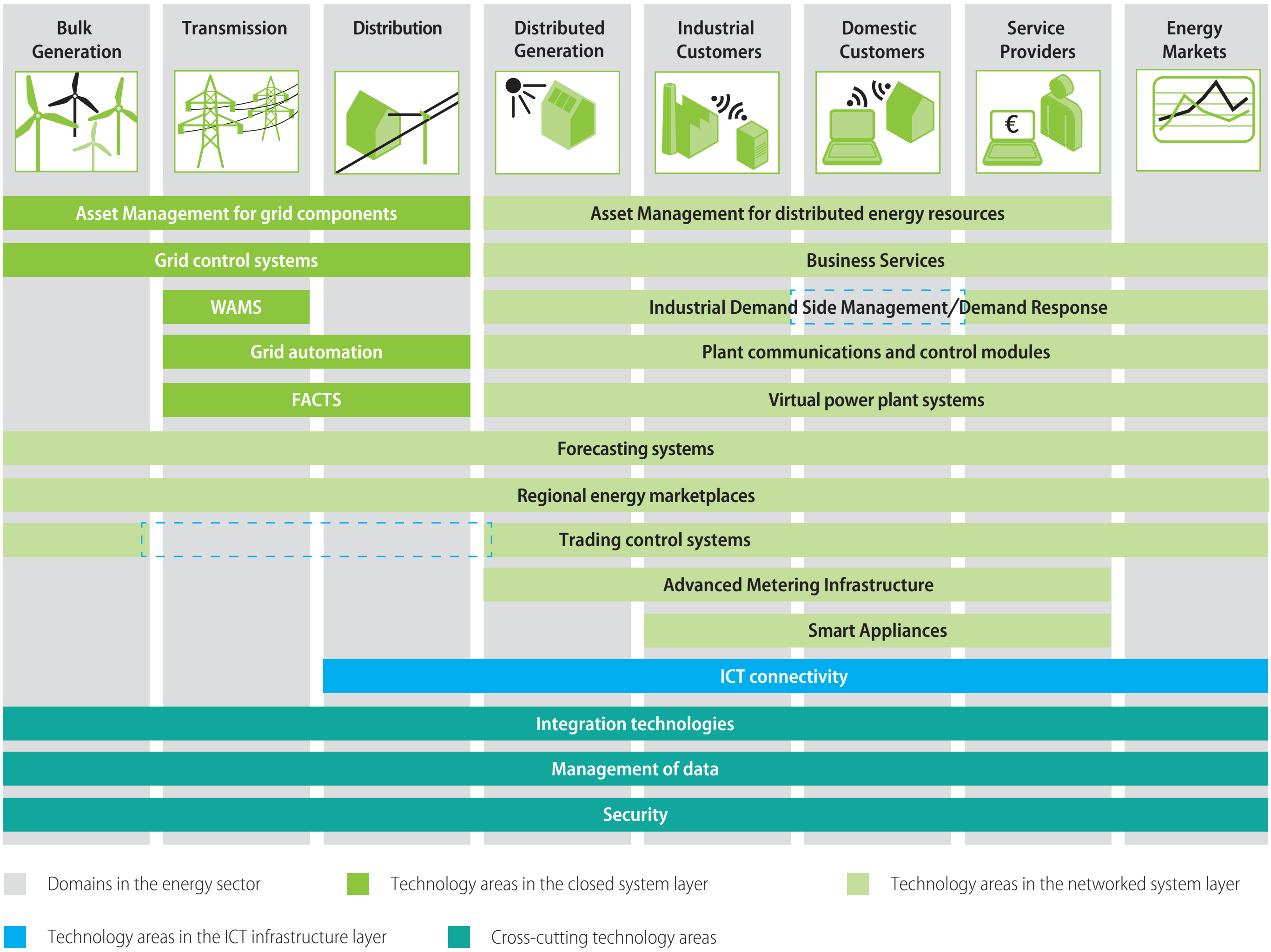


Figure 13: Technology areas in the Future Energy Grid. Visualisation of the categorisations at system layer and domains of the energy sector (source: own graphic based on IEC 2011c, p. 17).

3.4.1 TECHNOLOGY AREA 1 – ASSET MANAGEMENT FOR GRID COMPONENTS

DEFINITION	Assets of all types are managed in asset management systems, with the objective of optimising the way in which the assets are planned and deployed, both technically and commercially.
SYSTEM LAYER	Closed system layer
DOMAIN	Bulk generation, transmission, distribution
ACTORS	Transmission system operators, distribution system operators
VENDORS/SECTORS	SAP, Siemens, ABB, Oracle
SPEED OF DEVELOPMENT	Slow
MATURITY LEVEL	Mature for the current state of requirements in the market, in development for new specific solutions such as energy services or metering operations.

Description/explanation

Assets of all types are managed in asset management systems, with the objective of optimising the way in which the assets are planned and deployed, both technically and commercially, over the entire lifecycle.[160] The energy sector is subject to particular requirements in this respect, since the assets must be managed and deployed so as to guarantee a sustainable, economically viable and secure energy supply. Potential assets must be differentiated according to their role in the energy market, whereby all assets must be deployed in a manner that is sustainable, economically viable and secure[161]. The technology area is both operational and strategic in nature, since while the assets that are used must be planned with their resource usage, they must also be planned across much longer phases. The manager of an asset must therefore make optimum investment decisions that take account of the requirements of current and future demand. These decisions are based on the lifecycles of the individual components or entire systems, which must be taken into account for operational management and in future investments.

160 Schwab 2009.
161 Balzer/Schorn 2011.
162 Balzer/Schorn 2011.

As part of the market liberalisation process, the energy sector has already been challenged by a number of requirements to differentiate individual assets according to role. As a result of further regulatory requirements and more complex assets, asset management systems must meet these challenges.

By extension, asset management is a process for optimising the management of assets, taking account of the following areas[162]:

- Commercial control functions, including:
  - Budget planning and monitoring throughout the entire lifecycle
  - Feasibility comparisons with other assets
  - Risk analyses
- Technical control functions, including:
  - Fault statistics, damage logging, grid asset value analysis
  - Condition monitoring
  - Risk analyses
- Integration of automation technologies for the managed assets
- Planning and implementation of maintenance, servicing and upgrades
- Integration of automation technologies for the managed assets
- Planning and implementation of maintenance, servicing and upgrades
- Integration of the asset management system with other systems (e.g. GIS (Geographical Information System), finance, HR, etc.) for each market role, or integration across several market roles if assets are shared, for example.

Further development of the asset management for grid components can be expected in the evaluation of equipment condition (condition monitoring).

Development stages

Today: asset management is only used for central production plant and mainly manages static asset data. The asset management of core components is automated, everything else is done manually.

Stage 1: In a first development stage, data from central assets are increasingly being recorded as part of an automated process. This is a broad development from static to dynamic data, with more frequent updates enabling the asset management process to obtain more up-to-date information on the condition of assets.

Stage 2: With greater standardisation and thus simpler integration options for new assets, asset management is now not only available for core components but also for smaller assets.

Stage 3: Current condition reports are integrated into the asset management system and are taken into account for the purposes of planning. This allows asset management systems to be connected to control systems, for example, supplying parameter values directly to control the operation of the assets.

Stage 4: The integration of external costs into the asset management system allows the calculation of optimised dynamic grid usage charges. Generators and suppliers can be sent pricing signals that reflect the strain on the grid according to the planned usage and therefore offer incentives for feed-in and exit at levels that are optimised to ensure efficient operation of the system. In addition, this gives grid system operators more precise cost monitoring options, enabling them to carry out more detailed commercial planning of their asset deployment.

Stage 5: All operating resource data that are related to a given asset and collected over time are logged, evaluated and scheduled in a form of "resource" health-check. The old and new condition of the assets are taken into account to ensure their optimum operation.

3.4.2 TECHNOLOGY AREA 2 – GRID CONTROL SYSTEMS

DEFINITION	Grid control systems are used to monitor and control existing supply grids and to communicate with upstream grid levels.
SYSTEM LAYER	Closed system layer
DOMAIN	Bulk generation, transmission, distribution
ACTORS	Transmission system operators, distribution system operators
VENDORS/SECTORS	Siemens, GE, PSI, BTC, ABB, KISTERS, etc.
SPEED OF DEVELOPMENT	Slow
MATURITY LEVEL	Mature technology; EHV, HV and selected MV grid sections are controlled electronically; Wide areas of the MV and LV grid are not remote controlled or remotely monitored.

Description/explanation

The transmission and distribution substations (with the exception of local substations) are managed using grid control systems. This relates to the process control systems associated hierarchically to the individual voltage levels. These systems monitor the grid condition online and can automatically implement grid stabilisation measures such as feed-in management load shedding or switching actions. The grid control desk (control room) communicates via telecontrol systems with the associated substations (telecontrol stations and substations such as transformer substations), in which the switch panels and switchgear are controlled and their condition is reported back to the grid control system. The station control system assumes the local control and monitoring tasks in the transformer substations, while the telecontrol systems look after on-site control and monitoring[163]. Alongside these tasks, the grid control desk also coordinates the load situation in collaboration with the major generators (such as power plants) and consumers (such as industrial operations), to the extent that this is necessary to ensure the availability of the electricity supply. Moreover, the grid control desk carries out higher-level decision making and optimisation functions, including those of an economic nature.

163 Schwab 2006.

Today's grid control systems cover the supply situation in the extra-high, high and medium voltage levels (EHV, HV and MV). These individual levels can also be linked together horizontally, to other grids operating at the same hierarchical level, to ensure a highly reliable supply. Currently, the medium and low voltage (MV and LV) distribution grids are generally operated without any knowledge of the current grid condition. Due to the top-down design of the supply system, however, it has been possible to ensure high quality supply in the scope of the anticipated grid load. In order to maintain the high quality of supply in the future, despite the increasing amount of distributed energy resources with fluctuating feed-in as a result of the Erneuerbare-Energien-Gesetz (EEG; Renewable Energy Act), the expanded installation of sensors that register the grid conditions over a wide area and of actuators to help control the load in the LV lines will become vital, as well, of course, as the ability to process this information in the grid control system.

Smart meters and additional sensors within the grid already provide a range of current measurements at the end-points of the LV grid. By equipping the LV grid with autonomous agents, it will be possible to evaluate the data they gather, using adapted algorithms to determine switching commands for controllable consumer devices and storage facilities. The objective in this case is to ensure the most efficient usage of the LV grid downstream of the transformer, maintaining the permissible voltage range. Generally, this section of the grid would feed around one hundred households. Such systems are, to a certain extent, grid control systems that are deployed at remote level. Potentially critical grid conditions can then be resolved or alleviated automatically by the locally controlled system with no need for intervention from an upstream instance. The management of the individual agents is restricted to simply assigning parameters and rules, and dealing with a selection of potential problems. The basis can be a model of the physical grid, with the grid topology and the installed cables, replicating the corresponding energy feed-in and exit positions. This technology provides grid operators with a view and outlook over their grid condition, taps into consumer flexibility in conjunction with the loads that occur in the grid, and creates a dataset that can be used to plan future grid construction. Moreover, armed with the corresponding knowledge of the generation and consumption profiles, grid operators can provide secure data that allow connected customers to participate in the balancing power markets (the aggregator model) or manage feed-in and exit to provide this capacity securely.

When it comes to organising a grid control system for the distribution grids, self-organising models are as attractive as hierarchical ones. Moreover, the next generation of grid control systems will need to provide greater support for workflow and decision-making, as well as automation in places, in order to ensure that the increasing complexity is manageable for human operators. For this reason, the software architecture of control systems is moving away from monolithic structures and becoming more modular.

Development stages

Alongside the developments in the distribution grid that have been listed here, there will also be a need for innovation in the transmission and transportation grids. For example, wide-area grid connections, the integration of the HVDC (High Voltage Direct Current) grid and a European Super Grid must be taken into account by the grid control. These developments are described in detail in EEGI 2010.

Today: The grid control systems are reliably fulfilling their role. In 2009 in particular, Germany once again registered a new record value in the average interruption to supply to grid customers (SAIDI; System Average Interruption Duration Index) of 14.63 minutes. However, currently the grid control systems do not support any business processes between generators and consumers. The software systems take the form of monolithic structures, each of which has been created to support a specific single function. The deployment of grid control technology in the distribution grids is very low, since historically there have not been unexpected power flows and the distributed transactions are generally still easy to manage.

Stage 1: Grid control systems are moving into the MV level in increasing numbers. Components in the MV grid are increasingly equipped with intelligent electronic devices (IEDs) that enable communication with the equipment and allow them to be integrated into the grid control systems. In this way, the load flows in the MV grid can be recorded and forecast, and the deployment of power-flow regulating systems including Flexible AC Transmission Systems (FACTS) can be planned.

Stage 2: The grid control systems are now able to switch components in the MV grid as and when required. Power-flow regulating systems are used in a targeted way by grid control systems in order to optimise the power flows and prevent voltage level breaches. This means that the available resources are used more efficiently and voltage maintenance problems are avoided. The effect of faults, switch actions and other actions can be simulated by the grid control system in real time.

Stage 3: By integrating forecasts for resources, process-based systems can be introduced into the grid control system. These allow processes to be triggered according to resource forecasts, so that anticipated problems can be countered effectively with corresponding measures before they occur. The grid control systems are modularised, with open interfaces that allow integration with other systems.

Stage 4: Open interfaces are added to the grid control technology, through which access can be granted to plant located in the connected system layer. The grid control systems thus have access to forecasting systems, asset management and demand-side management (DSM). Moreover, autonomous LV agents are integrated into the grid control system.

Stage 5: Alongside self-organising systems that reach into the LV grids, increasing use is also made of microgrids. The grid control systems are largely automated. The grid control system is able to detect and react appropriately and autonomously to faults and impending problems (self-healing properties).

3.4.3 TECHNOLOGY AREA 3 – WIDE AREA MEASUREMENT SYSTEMS

DEFINITION	The WAMS technology area consists of field-based technologies used to measure, transmit, archive and visualise high-resolution, time-synchronous phasor measurements These measurements are used to determine system stabilisation measures.
SYSTEM LAYER	Closed system layer
DOMAIN	Transmission In the future, potentially: distribution, bulk generation, distributed energy resources
ACTORS	Transmission system operators In the future, potentially: 110 kV distribution system operators
VENDORS/SECTORS	Power automation (Siemens, ABB, GE, SEL, Psymetrix)
SPEED OF DEVELOPMENT	Rapid
MATURITY LEVEL	Mature technology, deployed in the field; In the near future, applications will be developed and deployed to evaluate and in some circumstances regulate the grid.

Description/explanation

Wide Area Monitoring[164] supports the grid operations manager at the grid control desk, and power transmission companies' protection engineers or grid planning engineers, in detecting, analysing and rectifying medium-term changes such as power fluctuations, voltage instability and frequency deviations in the power transmission grid. The underlying electrical measurements are recorded by Phasor Measurement Units (PMUs) that are located within the substations. The recorded measurements are time-coded and sampled at a rate of up to 60 measurements per second thanks to the use of precise time synchronisation (accurate to less than 5 µs) and transmitted to a central server via an IP communications network. There, the data is sorted chronologically, monitored in respect of tolerances and entered into a ring buffer. Additional simple and complex calculations, such as power calculations, angle difference calculations and the detection of power fluctuations are carried out on the basis of these data streams, and the

164 Chakrabarti et al. 2009.

results made available in a clear format to the operator at the grid control desk or the staff in the grid calculation department and protection department. Important events and selected measurements can be forwarded via a specific interface to the grid control system. Troubleshooting analyses are carried out on the basis of the archived data, during which the archived data can be processed either in the WAMS or in another system.

With a continued increase in distributed feed-in to the 110 kV grid and at lower voltage levels, the tasks mentioned above – which are currently exclusively the mandate of the transmission system operators – will also have to be fulfilled, possibly in a slightly modified format, by the distribution system operators, (e.g. type of measurement, time interval). In the long term, monitoring will increasingly become a management activity (see technology area 2).

Development stages

Today: WAMS implementation in transmission grids occurs around the world to a lesser or greater extent. A data processing concept for archiving measurements is already available. Pilot projects in the distribution grids are currently investigating the extent to which the basic concepts of WAMS technologies can be implemented In the distribution grid (at MV level), from both technical and commercial points of view.

Stage 1: Use cases relating to the recording of the grid condition in the distribution grid are available for the sensors (using PMUs or Remote Terminal Units; RTUs). Thus, there are also concepts for using WAMS in MV segments. The first pilot systems have been deployed and are implementing these use cases.

Stage 2: Implementation in the MV level is increasing. Different technological approaches (for example, both local and central optimisation) are being pursued. Visualisation tools and analysis tools have been adapted to meet the requirements of the MV grid. WAMS/PMUs are available in the form of products for use in the distribution grid.

Stage 3: Application systems that evaluate and analyse data from the MV grid are available. Different options for coordination (local vs. central optimisation) are being developed further in parallel. The technical and economic benefits for each grid configuration are known and deployments are spreading accordingly.

Stage 4: The basic concept of WAMS is being used in individual LV pilot projects (at the 400 V level). In particular, these aim to answer the question of whether system reliability can be maintained in the 400 V level even if the communications connections from the aforementioned sensors are not present.

Stage 5: Data regarding voltage, current and phase shifting are all available with synchronised timestamps at the required points of the MV grid. The system is evolving from being a measurement system to becoming a bidirectional management system, and is capable of handling mass data movements. The components are cheap and reliable. They are being deployed in the LV grid segments.

3.4.4 TECHNOLOGY AREA 4 – GRID AUTOMATION

DEFINITION	The Grid Automation technology area comprises ICT components located at substation or field level that control or process data gathered from grid components and measuring transducers.
SYSTEM LAYER	Closed system layer
ACTORS	Producers, transmission system operators, distribution system operator, power suppliers, metering operators, metering service providers
VENDORS/SECTORS	Siemens, ABB, AREVA, GE, Schneider, Schweizer, NARI, Sprecher
SPEED OF DEVELOPMENT	Slow
MATURITY LEVEL	Mature technology, deployed in the field;

Description/explanation

Despite the automation of the distribution grids being a core aspect of the smart grid, due to the broad scope of the topic and the diversity of the technology area it is only possible to provide a brief and incomplete overview at this stage.

Local substations will become key points in the distribution grid. This will include LV segment management, with the handling of meter data, power quality (PQ) optimisation, reactive power factor correction and harmonic wave compensation, control of distribution grid transformers and coordination of feed-in and load. In the MV segment, the local substation management is concerned with monitoring and control, automatic supply restoration, data sources for monitoring the MV distribution and to coordinate feed-in and load.

When deploying new products, the primary focuses are usability, simplicity of the engineering, multi-faceted interoperability with a range of communications systems and extensibility. A substation automation system is equally suited to deployment in energy utility company switchgear and in industrial plant.

The areas of deployment and functionality supported by a substation automation system include:

- Operation of switchgear with a single system
- Scalable system to cover range of uses and support distributed plant configurations
- Communication with downstream field devices via communications protocols (e.g. Ethernet, serial, profibus), to allow substation equipment to be controlled and process data to be recorded
- Communication with upstream control centres (gateways) via communications protocols such as Ethernet, serial
- Fully graphical process visualisation system located directly in the substation
- Integrated testing and troubleshooting functions
- System-specific automation tasks can be created using suitable tools (for example, Continuous Function Chart – CFC, Sequential Function Chart – SFC)
- Calculation and evaluation of PQ measurement data to determine the grid quality
- User management to ensure that only authorised staff have access to each task area, such as configuration and operation or management
- Allocation of individual switch permissions down to information level to increase operational security
- Messaging functions using email and /or SMS text messaging to warn of impending faults
- Increased resilience thanks to redundant systems, interfaces and equipment. In the case of interruptions to communications, the redundant component recreates the process connection
- Secure data transfer using certificates
- Monitoring of operational status of communication components such as switches

Field automation

In local substations and transformer substations, most of the secondary systems such as switch panels, protective equipment, measuring transducers deployed at field level today do not have their own IEDs. Protective equipment cannot be coordinated. It is already possible to connect measuring transducers in local substations via a range of communications channels to the grid control system. The services of the measuring transducer outside the local substations can also be used by means of special end-customer meters, for example to measure the voltage curve along a cable segment.

Development stages:

Today: The high voltage segment is already automated. Substation and field computers are used in switchgear. In the distribution grid, connections to the grid control systems are generally only realised in the MV segments. Substations at the 20 kV level are in some cases equipped with intelligent protection systems.

Stage 1: The MV grid has been widely equipped with measuring transducers that incorporate field computers (retrofitted). Remote-control sensors for use in the distribution grid are common on the market and are in occasional use.

Stage 2: Switchgear in MV segments have IEDs and can be controlled. Increasingly, measuring devices with IEDs and connections to the grid control system are being installed in the LV segments. Where technically useful, digital meters can also assume this role.

Stage 3: Also in the LV segments, ICT-supported actuators (switches and protection) are used if the local grid situation demands this due to, for example, distributed generation or special load profiles due to electric mobility usage.

Stage 4: The IEDs in the LV segments possess functions that allow them to act autonomously.[165] Autonomous grid agents are deployed in local substations to monitor local generation and consumption, make adjustments where necessary and activate the actuators on the local grid. They therefore take on the role of a grid control system (see technology area 2). In doing this they also process information from the entire networked system.

Stage 5: IEDs have been developed for all grid components in the LV levels, and these can be autonomous or remote controlled. At critical points, the LV grid can be operated almost entirely automatically. These IEDs already provide support for frequency stabilisation and voltage control at LV level in conjunction with neighbouring and upstream grid segments, and coordinate their activity among each other. The system is intelligent and the IEDs are able to learn, improving the stability improvement responses according to the situation at hand.

3.4.5 TECHNOLOGY AREA 5 – FACTS

DEFINITION	FACTS are power electronics control systems that affect power flows in electricity supply systems. This technology area considers the embedded ICT components in this field.
SYSTEM LAYER	Closed system layer
DOMAIN	Transmission, distribution
ACTORS	Transmission system operators, distribution system operators, communications network operators
VENDORS/SECTORS	Siemens, ABB, Areva, GE, Toshiba, Hitachi
SPEED OF DEVELOPMENT	Medium
MATURITY LEVEL	Mature technology, deployed in the field; No deployment worthy of note in distribution grids as yet

Description/explanation

FACTS are power electronics control systems that can be used in power grids for the targeted instantaneous adjustment of power flows. Thus they enable the grid to be operated at the limits of its technical load capacity and stability, thereby increasing its transmission capacity[166]. In contrast to traditional regulating transformers, FACTS have the advantage of allowing a jump to a given communicated target tap position so that an adjustment measure can be implemented significantly more quickly (within a period of less than 10 ms) than a regulating transformer. FACTS come under the grid control technology umbrella, and are controlled using grid control systems (see technology area 2). So far, FACTS have been installed selectively, close to critical grid segments such as transmission corridors or potential bottlenecks, requiring wide-area distribution and connection via telecontrol systems. The full functionality of FACTS can only be exploited if they are linked by ICT to the protective and control systems. The RTU of the FACTS component therefore requires various interfaces, including a connection to a GPS (Global Positioning System) device for the purpose of time synchronisation.[167]

When using FACTS to optimise grid operations, an additional online monitoring system is required to determine the grid condition. Today, PMUs are used for wide area calculation of grid condition. They take system-wide measurements at a resolution that is a multiple of the grid frequency, so that transient and dynamic oscillation phenomena can be observed (see technology area 3). The high time resolution means that large amounts of data are generated, which must first be processed using suitable algorithms (data stream management, complex event processing, etc.) before they are then provided as measurement data streams in the telecontrol and measurement system. Bottlenecks in the transmission grid will increase due to the growing offset between consumption falls and feed-in – in this case primarily from (offshore) wind power – so that grid operation will have to become more efficient during periods of greater capacity utilisation of individual lines closer to the capacity limits. This requires further expansion of FACTS (increasingly also into the distribution grid level). At the same time, the basis of measured data must increase so that the system condition can be assessed more precisely and a timely response made to

165 See, for example, Rehtanz 2003.
166 Schwab 2006.
167 Crastan 2009.

topology changes (due to other resources adjusting voltage) and to optimise power flow configurations and enable precise forecasts to be made in respect of grid-stabilising adjustments. To obtain the required level of quality of measurements for these applications, around 50 percent of the transformer substations would have to be upgraded with PMUs[168]. In order to manage the volume of measurement data which must rise in direct proportion, the use of autonomous distributed or self-organising regulating systems will play a key role in the future. The first approaches in this respect are undergoing testing now.[169]

Development stages:

Today: FACTS are used sporadically today for the purpose of targeted shifting of power flows to meshed transmission grids and for ad hoc alleviation of neighbouring grid segments.

Stage 1: FACTS can be integrated into WAMS. The WAMS are able to detect global grid problems at an early stage and implement countermeasures. Moreover, power flow optimisations and voltage stabilisation measures can be implemented in response to topology changes resulting from the highly dynamic supply situation.

Stage 2: The extremely dynamic grid information that can be gathered by a WAMS can be used to coordinate the regulating and stabilising capabilities of several FACTS across a segment of the grid. This allows the detected transient and dynamic oscillation phenomena in the EHV and HV grid to be countered by a FACTS network.

Stage 3: In the next stage of development, active grid components in the MV and LV grid levels are taken into account in coordination activities that span grid segments, so that the grid capacity utilisation can be increased and stability of the supply grids improved overall.

Stage 4: In this development stage, the active grid components are able to communicate with each other and to coordinate their activity without restriction, as has long been possible in the transmission grids, according to the rules imposed by a control system. The impact of the different grid levels on each other can therefore be controlled, allowing them to provide mutual support.

Stage 5: The regulating measures implemented to stabilise the grid are taken autonomously. Multi-agent control systems allow the FACTS to coordinate their activities and adapt accordingly. The IEDs used in the FACTS must therefore have the corresponding algorithms and communication modules on board. These can be implemented to carry out real time actions in very short time periods. The wide area options provided by metering, controlling and regulating functions mean the sensors and actuators in the primary and secondary systems allow the grid management to take advantage of all of the new possibilities. The active grid components coordinate their actions across grid levels.

3.4.6 TECHNOLOGY AREA 6 – ICT CONNECTIVITY

DEFINITION	The technology area ICT connectivity refers to the communication technologies and information technology prerequisites that must be in place in order to address and connect to power components in smart grid applications with guaranteed QoS.
SYSTEM LAYER	ICT infrastructure layer
DOMAIN	Bulk generation, distributed generation, transmission, distribution, industrial customers, domestic customers, service providers, energy markets
ACTORS	All smart grid actors
VENDORS/SECTORS	Telecommunications, IT industry, home networking
SPEED OF DEVELOPMENT	Rapid
MATURITY LEVEL	The relevant communication solutions have been standardised and have already been brought to the market; work on the enhancements for application-specific protocols to support new intelligent power grid functions has begun.

Description/explanation

ICT connectivity encompasses the IT communication links between all ICT-relevant system components in smart power supply systems. These communications links range from connections to sensors and actuators from the electricity grids through to monitoring and control systems and on to market communications. Communications links

168 Zhang/Rehtanz/Pal 2005.
169 Häger/Lehnhoff/Rehtanz 2011.

ensure the exchange of information and control functions between the various applications relating to power generation, distribution, storage and transmission, through to consumption. Sample applications include Wide Area Situational Awareness (WASA) and SCADA systems used to monitor and control transmission and distribution grids, and to address and control industrial plant, smart meter communications used to access smart meters and household networks to control energy consumption by household appliances. At the business-process level, there are business communications between the business support systems of a range of actors and market participants. In the scope of future evolution of the technology area, it is important to differentiate between the various grid/voltage levels since these make differing demands of the communication interfaces. Many of the required communication technologies are largely already available. However, there is a need for corresponding investment and experience to adapt them for use in the electricity supply system and to establish them in this sector.

In view of the need for interoperability, the standardisation of the ICT connectivity solutions plays a key role. In general there is already a range of standardised communication solutions that have been introduced to the market. These will also be used within the electricity supply system. There should be no recourse to proprietary communication solutions below application level. In general, the energy supply system will benefit from this approach of dynamic development in the communications sector. The existing application-specific standards (for example IEC 61850, IEC CIM, Device Language Message Specification/Companion Specification for Energy Metering; DLMS/COSEM) have been developed to enhance the new functionality offered by the smart power grid. This has been taken into account and encouraged in a number of studies and standardisation roadmaps.[170]

Various communication solutions come into play to provide ICT connectivity, using different technologies depending on the area of use in the different communication layers (these correspond to the Open Systems Interconnection (OSI) layers). In the network layer, IPv6 has emerged as the suitable standard. At the lower communication layers, down to the physical transmission layer, both radio-based (for example GSM/General Packet Radio Service – GPRS, Universal Mobile Telecommunications System – UMTS, and in the future Long Term Evolution – LTE) and wired solutions (such as Digital Subscriber Line – DSL, fibre networks, Power Line Communication – PLC) can be used.

With the real-time requirements of the energy supply systems, the selected communication technology must be able to fulfil or even guarantee end-to-end QoS requirements. In the application layer, the trend is for service-oriented approaches (for example web services and Service-Oriented Architectures, SOA). When selecting and defining the specific communication solutions, specific requirements for the given application must be taken into account. These include aspects such as availability, reachability, data volumes, latency and security, as well as real time capabilities and session awareness/statefulness.

Alongside the definition of interfaces and the communication connection, technologies are required that allow information about the entire system to be stored and archived. These include services that control authorisation, authentication, and the locating and provision of access to resources. Such a uniform basis, in the form of a kind of "middleware", is a prerequisite for the construction and operation of a smart grid. Therefore, the provision of a simple and open platform would represent a significant development in this technology area, since it would allow third parties to develop and introduce their own services. The past and continuing development in the telecommunications sector is analogous to this situation.

Development stages

Today: The transmission grid is equipped with ICT and can interact with transmission grids operated by other operators. Communication is largely accomplished via point-to-point connections and proprietary interfaces. The distribution grid has no ICT connections with the exception of a few spots. Renewable energy and CHP plants that produce over 100 KW are able to connect via ICT and can normally be regulated by the grid system operators.

170 DKE 2010; NIST 2010.

Stage 1: The first plants have been integrated into a rudimentary directory service. The core directory service contains details of the connected systems and some technical data and information about how the system can be controlled externally by ICT. The directory service can also be used by market players outside the grid. With the introduction of corresponding sensors and actuators, and their integration into the grid, it is possible to control and maintain grid stability. Sensors and actuators are also incorporated into the system. QoS is implemented through a range of ad hoc solutions. In various pilot studies, the initial attempts at a unified platform are already in use. These allow dynamic management of QoS.

Stage 2: Further expansion is being carried out by means of specific regional solutions from individual grid operators.[171] Heterogeneous ICT solutions are being related and combined according to area of use and efficiency. Data from distributed energy resources, consumers or storage that are required for technical control functions can be recorded in a uniform system within the local region. This results in a functionally comprehensive ICT network within individual regions. However, these regional "islands" are not interconnected and such links are difficult to implement due to a lack of standards.

Stage 3: The realisation of communication interfaces and services that guarantee data integrity and security means that information of technical relevance for recording and control can also be used across regions. These information structures can be summarised as data hubs[172] in which data is distributed and can simultaneously be accessed as and when required in a controlled manner through the well-defined interfaces. This development enables automated interaction between the market participants and ensures improved efficiency.

Stage 4: The provision of platforms as standardised solutions enables a future-proof, simplified means of connection. Plug & play solutions support faster and more comprehensive expansion of regional smart grids and the associated functionality in the overall system. Assuming sufficient authorisations have been granted, in principle all actors can access all information in the system. Absolute restrictions on access are only planned for the closed system layer.

Stage 5: The system is completely networked. All power supply components[173] can be incorporated into the plug & play infrastructure. The availability of tried-and-tested solutions leads to a fully networked system. The guarantee of high standards of quality and security leads to a high degree of automation and further improvements in efficiency due to the exploitation of synergies and interaction between the market players. This is also the basis for increased expansion of the application layer.

3.4.7 TECHNOLOGY AREA 7 – ASSET MANAGEMENT FOR DISTRIBUTED ENERGY RESOURCES

DEFINITION	An asset-management system is an information system in which the operational and commercial data for the assets can be processed.
SYSTEM LAYER	Networked system layer
DOMAIN	Distributed generation, industrial customers, domestic customers, service providers
ACTORS	Power service companies, aggregators, distribution system operator, operators of DER systems
VENDORS/SECTORS	SAP, Oracle, Microsoft (ERP software developers)
SPEED OF DEVELOPMENT	Slow
MATURITY LEVEL	In development

Description/explanation

Traditional asset management systems (for electricity, gas and water grids) manage assets so that their use can be optimised from a commercial and technical perspective. If an asset-management

171 This form of operation is also referred to as a microgrid.

172 Based on BDI 2011.

173 It is anticipated that the energy sector will also see a convergence of fuels/energy sources (electricity/gas/heating/fuel). For example, discussions at the moment are focusing on "power to gas". For this reason, the future smart grid will also integrate components that do not belong to the electricity sector. The first ideas in this area were presented towards the end of the 1990s by Siemens (Bitsch 2000).

system is extended to manage distributed power generation systems, then the range of individual plant systems means that additional factors must be taken into account and implemented in this type of system.

Asset management is little used in distributed power plants at the moment. The pioneering systems will be asset management for wind turbines, since these offer synergies with the asset management of large offshore wind farms.

In large wind power plants and combined heat and power (CHP) plants, as well as micro cogeneration plants there is already an existing type-specific condition detection system and historical data management. Type-specific maintenance programmes have already been implemented successfully today.

However, there are currently no mature asset management systems for these plants that evaluate their condition and propose corresponding replacement investment measures or maintenance plans. The reasons for this include the lack of knowledge concerning a correlation between historical operating data and the actual condition of the distributed energy resource (DER), as well as the relatively weak financial leverage of such systems due to their lack of size. The complexity of development for these systems is due to the fact that each individual generation plant has its own life expectancy (illustrated by the bathtub curve). There is a need for R&D measures to investigate the reasons for the latter, with validation from operational data. For this reason, it can be assumed that the speed of development in this technology area is relatively slow.

Ideally, this type of system could be used to coordinate plant-dependent maintenance measures at a targeted, regional level. For example, such a system could be used as a usage/generation forecasting tool, supplying other actors (distribution system operators, power plant schedulers, aggregators, maintenance companies, etc.) with data. This functionality is not supported by traditional asset management tools. The task is to develop a technology-specific asset management system with extended functionality (including condition monitoring, fault report coordination, etc.). It can be assumed that this sort of system will only be developed in the large DER segment (wind power, large CHP plants producing > 1 MW of electricity) and will then be slowly adapted for use in smaller generation systems. Whether or not a complete asset management solution is of any use for the smallest systems will be decided by the commercial viability of the measures. Here it can be anticipated that simply replacing components when they reach the end of their life expectancy will be the most economically feasible solution, and that asset management systems will be difficult to introduce to this segment.

Development stages

Today: Plant diagnosis and systems (remote diagnostics, maintenance forecasting) for large, conventional generation plants, in particular for the major components such as turbines, generators and boilers, already exist and are being further developed. However, there are not yet any end-to-end asset management systems for medium-sized and small distributed energy resources. Asset management systems for large non-conventional generation plants are being developed and prototypes are being implemented. The focus is on optimising the economic management of the assets. Modules that detect the condition of distributed plants by comparing the actual and expected power output also exist.[174]

Stage 1: With the increased importance of distributed energy resources, asset management systems are being used in large distributed power plants. These measures allow the plants to be operated at a greater level of efficiency.

Stage 2: Experience gained in using the asset management systems for large-scale plants has been used to build similar systems for medium-output plants and to optimise their operation from an economic perspective.

Stage 3: While asset management has so far been used to operate individual plants more efficiently, the data gathered within individual regions are now useful for other parts of the power supply system. The planned deployment of individual plants and their integration into virtual power plant systems have thus been optimised. In addition, increasing levels of integration within the power sector

174 See, for example, SMA 2011.

process workflows have ensured that, for example, service providers are more effectively integrated and some process steps can be automated.

Stage 4: The interfaces to systems that can benefit from the information supplied by asset management systems are further expanded. Asset management for distributed energy resources becomes built into an ICT infrastructure that enables information to be exchanged in both directions. In this way, the information from the asset management systems is provided to a large range of associated systems. At the same time, the asset management system is able to utilise information from other system parts, such as weather forecasts, in order to support its own business processes.

Stage 5: This stage of development is characterised by the wide dissemination of asset management systems and comprehensive connections to associated systems through well-defined interfaces. As a result, individual plants can be ranked according to commercial viability within the overall context of the power supply system. This allows the importance of a given plant to be assessed at any time, both at regional and national levels. Business processes that relate to the asset can be carried out more efficiently, taking account of comprehensive information, a tailor-made approach, and massive potential for automation. The deployment of the corresponding systems is therefore economically advantageous for a range of assets.

3.4.8 TECHNOLOGY AREA 8 – REGIONAL ENERGY MARKETS

DEFINITION	Regional marketplaces for energy are used to allow industrial, commercial and domestic customers to participate actively in the market and to integrate load flexibilities and distributed energy resources actively into the market through new pricing regimes.
SYSTEM LAYER	Networked system layer
DOMAIN	Bulk generation, transmission, distribution, distributed generation, industrial customers, domestic customers, service providers, energy markets
ACTORS	Domestic and commercial customers, distribution system operators, energy suppliers, aggregators, energy service providers, metering service providers
VENDORS/SECTORS	Potential vendors: IBM, SAP, Siemens, BTC, small and medium-sized companies/ IT sector
SPEED OF DEVELOPMENT	Medium
MATURITY LEVEL	In development/being tested in pilot projects

Description/explanation

The objective of regional energy markets[175] is to change the currently passive industrial, commercial and domestic customers into active market participants, one of whom is the distribution system operator. A key driver is the increasing level of distribution of power generation that requires new pricing systems and market models. The energy marketplace offers an opportunity to successfully transform the energy market in this segment. The basic concept is to exploit potential flexibilities in power consumption and generation to match generation and consumption taking account of the limitations imposed by the distribution grid. This includes optimisation of the increasingly variable load patterns caused by fluctuating feed-in. Such optimisation can be achieved by shifting peak loads and integrating micro generators while taking account of grid bottlenecks.

Flexible loads and micro generation can either be traded directly on the regional energy marketplace or can be aggregated to form portfolios. The regional energy markets can allow new, possibly

175 Serious changes are also needed on the European markets in order to make full use of the smart grid, to integrate renewables and distributed energy, and to realise the European market itself. The principle challenges in this regard can be found in EEGI 2010.

regionally-specific products to emerge, and may also be linked to other markets. The trade on wholesale markets in flexibilities aggregated from the regional market can be organised by a trading control room (see technology area 9), which permits the creation of tradable positions on the basis of the data supplied from the regional energy marketplace. The concept of "regionality" relates only to grid aspects. Among the products, the advantages in terms of meeting the needs of the distribution grid will be assessed and rewarded.

The energy marketplace is primarily purely a platform for automated trading between power suppliers and consumers. It may also become a communications platform, with the assistance of which the participating actors may interact at a business-relationship level, processes may be supported and data may be exchanged. The marketplace can also provide information such as consumption and generation data. The actors include domestic and commercial customers, electricity suppliers, metering service operators, distribution system operators, energy service providers and aggregators. Automated market processes and suitable support for processes offered by the market operator guarantee rapid, coordinated cooperation between the participants in the marketplace, with the automated interaction ensuring more efficient handling of processes. For example, switching supplier can be accomplished within a very brief period of time. A distribution system operator can benefit from the measurement of load and generation profiles, obtaining more detailed knowledge of the way in which the capacity provided by its grid is used. Since the high number of participants also entails a high number of transactions and large volumes of data, a scalable market architecture is key. The unique assignment between the distribution system operator and the domestic and commercial customers allows contracts to be agreed at purely local level. The scope of functions offered can then be matched to the local conditions.

Development stages

Today: Active power is traded over the counter (OTC) on the European Energy Exchange (EEX) (and other exchanges)[176]. With just a few exceptions, end customers purchase their power from energy suppliers. The sale of balancing power is highly regulated and limited to transmission system operators as buyers. System services are accessed through the grid. In the USA there is a system of "nodal markets" in which costs for the transportation of electricity are taken into account implicitly. The aim is for these markets also to take account of the lower voltage levels, so that thousands of regional marketplaces could be created. In Germany, regional energy markets are being set up in the context of the E-Energy marketplaces, but the applicable framework legislation prevents them being operated at a profit.

Stage 1: Industrial companies and other major customers use tools with appropriate interfaces (see technology area 9) to participate in the energy market. These are being used in pilot marketplaces to gather experience[177]. Products are being defined for trading. There is no automatic connection into the EEX, but marketplace operators can ensure that the prices are balanced.

Stage 2: The marketplaces offer products that can also be used by domestic customers (as micro generators and consumers). In particular, DSM or load shifting potentials are offered.

Stage 3: New system services are offered for distribution system operators, such as voltage control. This service may be particularly attractive in areas with a high amount of feed-in from PV installations, since in such situations problems can typically be experienced in relation to voltage control.

Stage 4: The regional can be integrated automatically and on a real-time basis with the wholesale marketplaces (EEX, etc.) and with pan-regional markets. As a result, new bundled products, comprising smaller volumes (such as micro flexibilities) are created on the wholesale and pan-regional markets.

Stage 5: The regional marketplace offers all stakeholders and power plants interfaces and products that they can use to become integrated with the market. Such integration thus enables economically generation, consumption, storage and electricity transportation to be allocated in an ecologically efficient way. Regional marketplaces form an integral component of the energy supply.

176 https://www.eex.com, http://www.apxendex.com/

177 This requires, of course, that the energy legislation can support these processes

3.4.9 TECHNOLOGY AREA 9 – TRADE CONTROL SYSTEMS

DEFINITION	A trade control system or trade control desk is a tool for energy traders to analyses and participate in energy trading. New functionalities are coming to the fore, in particular from the operation and marketing of distributed energy resources, and from consumers via demand-side management (DSM).
SYSTEM LAYER	Networked system layer
DOMAIN	Bulk generation, distributed generation, industrial customers, domestic customers, service providers, energy markets
ACTORS	Energy suppliers, balancing group managers, energy traders, portfolio managers, aggregators
VENDORS/SECTORS	IT
SPEED OF DEVELOPMENT	Medium
MATURITY LEVEL	Low

Description/explanation

With a rising number of distributed energy resources (DERs) and also increased exploitation of the potential of DSM, there is now more flexibility in electricity generation and consumption, which needs to be utilised as economically as possible. However, there are as yet no widely available tools to provide information and support the decision-making of energy traders in relation to the potential usage of these flexibilities. Approaches can be found in the functionality offered by virtual power plant control desks and in energy data management (EDM) systems and software for portfolio management and power plant scheduling. In a trading control desk, which has yet to be developed in the form of a consistent software component, all required data is compiled, aggregated and displayed in a way that is suited to supporting the energy trader's decision making. The energy trader must be able to compare information at balancing group level on the traded position, forecast generation and load with horizons of one hour and one day for the current generation and load. This will allow information about the tradable volumes and available generation capacities to be obtained. At the same time, information must be provided on the costs of trading and tradable volumes at different times on different markets. This makes it possible to actively commercialise previously untapped flexibilities at balancing group level, with the support of optimisation algorithms, information offers and automated processes.

While currently there is a system of top-down forecasting and recording of load data and generation data from distributed wind power installations for the day-ahead market and the spot market, the migration to the exploitation of smaller flexibilities on the market would require bottom-up recording of positions, since top-down forecasting in these circumstances would be very inaccurate.

A vital prerequisite for the realisation of trading control desks for handling flexibilities is the availability of high-performance, economically feasible information and communication connections that use recognised international standards. Moreover the usable transmission capacity in the electricity grid is of importance for the successful implementation of trading in aggregate flexibilities, in a similar way to the capacity of interconnects in the case of cross-border wholesale trading. A key property of trading control desks is the ability to handle mass data, with wide-ranging automation of data aggregation and data analysis and preparation of relevant information to support and notify decision-making options.

The aggregation of flexibilities that arise from the load shifting potential among consumers and from distributed feed-in can be done at regional marketplaces, for example.

Development stages

Today: Tools are available to support trading on the spot market and the day-ahead market. Balancing group positions are recorded on a top-down basis. Functions have been created for portfolio management and the integration of EDM systems. Demo versions include trading functions in virtual power plant control desks.

Stage 1: The trading system can record positions and forecasts on distributed generation and distributed consumption on a bottom-up basis, and provide suitable aggregation. Visualisation functions can be used to show data at balancing group level.

Stage 2: In addition to new functions, other variables that are relevant for trading are visualised and linked to the other functions.

Stage 3: The trading control system is able to estimate costs for flexibilities – this means that it also knows the price elasticity for electricity consumption according to customer profile – and trade corresponding in the products. This process takes account of balancing energy prices. The effects of price signals on end consumers can be simulated and forecast.

Stage 4: Advanced analysis functions that take account of all existing data, forecasts, consumption patterns, exchange price forecasts and the trader's objectives provide active support for decision making.

Stage 5: The systems allow fully automated trading.

3.4.10 TECHNOLOGY AREA 10 – FORECASTING SYSTEMS

DEFINITION	A forecasting system calculates an estimate of the future condition of a variable. In the energy sector, these variables normally relate to consumption or generation.
SYSTEM LAYER	Networked system layer
DOMAIN	Bulk generation, distributed generation, transmission, distribution, industrial customers, domestic customers, service providers, energy markets
ACTORS	Vendors, producers, energy users, energy traders, energy exchanges
VENDORS/SECTORS	Siemens, SAP, ABB, Procon, Eurowind, energy meteo systems
SPEED OF DEVELOPMENT	Medium
MATURITY LEVEL	Available, further areas under development

Description/explanation

Forecast systems are used to predict future developments and events. In the energy sector, these systems are required in various areas including the planning of investments, optimisation of market participation and scheduling of timely maintenance measures. With the increasing proportion of irregular generation from wind power and photovoltaic installations, weather forecasts and the subsequent generation forecasts (specifically produced according to the characteristics of wind and solar power generation) are playing an ever more important role. In these areas, therefore, significant further developments are expected in line with the increasing penetration of fluctuating feed-in.

Forecasting systems are required for energy logistics, in order to mitigate the pricing and volume risks. This is of relevance both for generation and for consumption. In the medium term storage may also be integrated into the forecast systems. Storage may comprise bulk or distributed plants or even mobile storage facilities. The mobile storage provided by electric vehicles requires the forecasting systems to also take account in the change in location and therefore different grid connection point.

Today, vendors are required to buy energy volumes for domestic customers on the basis of their given standard load profiles. With the introduction of smart meters, customers' usage will be able to be forecast more accurately, individually and in total. Forecasts of consumption both for domestic households and industrial customers help improve power plant scheduling and planning of energy procurement on the exchanges. New consumers mean it is necessary to include forecasts from outside the domain, for example mobility forecasts to predict the standing and charging patterns of electric vehicles.

At grid level, forecasting systems are required to detect the extent of capacity utilisation of specific grid segments in the future. This is relevant for grid expansion and maintenance, but also for short-term demand response applications. DR is gaining in importance, since the higher levels of uncontrolled feed-in to the distribution grid are already causing voltage control problems and these will further increase. They can be dealt with by rejecting the feed-in, but a more economical method is supported by DR applications that can take out energy locally at higher levels for a short period of time.

In the gas sector, forecasting systems are equally important since the physical and chemical properties of the gas must be taken into account.

Development stages

Today: Forecasting systems are currently used in some parts of the energy sector, supporting energy procurement in the short term and investment planning in the long term. Transmission system operators use forecasts of feed-in from wind power, so that they can sell energy from renewables on the exchange. Solar forecasts are primarily used for investment decisions. Higher resolution PV forecasts are being developed.

Stage 1: With the increasing relevance of direct marketing of renewable energy volumes, improved wind forecasting tools are being used that provide, in particular, more granular, regional forecasts.

Stage 2: The more wide-spread use of digital electricity meters and time-variable tariffs allows more detailed consumption forecasts for individual consumer groups or (grid) regions. These can be used as important decision-making tools for trading and grid control.
Stage 3: Correlations between different forecasts are taken into account appropriately, so as to produce more accurate forecasts overall. Applications that forecast the generation of electricity from PV installations are being brought to the market. The effect of variable tariffs and other feedback and information systems on the consumption of electricity (price elasticity) can be estimated.

Stage 4: The generation forecasts for renewable energy plants can take account of plant-specific details, such as age (àloss of effective output) and thus provide even more accurate forecasts.

3.4.11 TECHNOLOGY AREA 11 – BUSINESS SERVICES

DEFINITION	Business services support and optimise the significant processes of a company. They are used in all of the value chains in the electricity sector.
SYSTEM LAYER	Networked system layer
DOMAIN	Distributed generation, industrial customers, domestic customers, service providers, energy markets
ACTORS	Producers, energy users (commercial), transmission system operators, distribution system operators, energy suppliers, balancing group managers, balancing group coordinators, energy traders, energy exchange, metering operators, metering service providers, energy marketplace operators, energy service providers, communication network operators
VENDORS/SECTORS	SAP, Oracle, Schleupen
SPEED OF DEVELOPMENT	Medium
MATURITY LEVEL	Mature, well used technology; Further developments of the technology allow/support new (information) services and corporate processes

Description/explanation
Business services are used to handle a number of corporate processes with the objective of optimising control of the business processes, making efficient use of resources, reducing costs and simultaneously guaranteeing high availability and reliability. A key characteristic of these services is also that they require information systems that support mass data storage and processing, given the typically high number of transactions in this area (for example when dealing with end customers). Examples of the most important business services in the electricity sector include Customer Relationship Management (CRM), Billing, Service Management, Advanced Metering Management (AMM), Energy Data Management (EDM), Analytics and Enterprise Resource Planning (ERP) modules, which are used in a similar manner to other sectors. In the future, business services in the electricity sector will also include services that support processes for electric mobility, such as special billing and roaming services.

Business services differ according to whether they relate to the trading and sales areas on one side or to grid operations on the other. In the grid, business services are used primarily to ensure proper implementation of the continuing changing regulatory and statutory requirements for grid operations and customer mobility in terms of switching supplier. In the trading and sales areas, business services can be used for the objective of, for example, increasing customer satisfaction, scheduling the use of power plants, discovering new revenue opportunities and implementing new tariffs and business models, as well as simply optimising general business processes.

Current developments in business services are moving in the direction of increased process integration and speed (real time, mass data processing) and mobile, distributed applications. In the trade/sales areas, faster analysis opportunities using more detailed (real-time) measurements from the smart grid will allow support for DSM and the integration of electric mobility. Overall, further development of business services will encourage greater flexibility in business processes involving customers and business partners.

Development stages

Today: The statutory processes, especially those governing the regulated grid operations, are completely supported by business services today. In relation to the sale of electricity, there are simple business services for CRM and for billing/statements of payments on account and energy consumption.

Stage 1: In the first stage, business services that are common in other services (e.g. e-commerce) are also deployed by energy utilities. Examples include customer self-service systems that allow customers to start processes like registering a move of house themselves.

Stage 2: The availability of in-memory technologies and the widespread use of sensors in the grids, as well as digital meters, allow real-time analysis of the grid and consumption data on the basis of which processes can be optimised.

Stage 3: Cloud computing[178] is also increasingly being used by energy utilities and grid operators, as processes have become more consistent and interfaces standardised so that software providers are able to offer a growing range of applications to support standard services for the energy sector.

Stage 4: The energy management systems used by major customers are linked to business services provided by energy utilities to allow DSM potential to be exploited profitably for both parties.

Stage 5: Integrated plug & play DSM is extended to small end customers, since standardised interfaces allow the processes of the energy utility or grid operator to be linked to the consumption side. The power supplier's ERP systems and those of industrial companies can be integrated to allow energy-specific cross-company processes to be automated, such as intervention in production processes via DR.

3.4.12 TECHNOLOGY AREA 12 – VIRTUAL POWER PLANT SYSTEMS

DEFINITION	A virtual power plant system (VPP) is an application that bundles several systems that generate power or consume power together via ICT and thus improves the deployment of these systems to deliver active power, system services and balancing power.[179]
SYSTEM LAYER	Networked system layer
DOMAIN	Distributed generation, industrial customers, domestic customers, service providers, energy markets
ACTORS	Producers, energy users, distribution system operators, energy suppliers, balancing group managers, energy traders, energy exchange
VENDORS/SECTORS	Siemens, ABB, KISTERS, (suppliers of smart grid technology and energy automation)
SPEED OF DEVELOPMENT	Medium
MATURITY LEVEL	Mature, technology used in the field (for balancing power and large distributed power plants)

178 BITKOM 2010.
179 The entire system of distributed energy resources and ICT systems is also frequently referred to as a VPP. However, in this instance, only the ICT application system is referred to.

Description/explanation

The characteristic element of the future energy supply is the metering, forecasting and controlling integration of distributed or fluctuating consumption and generation.

The concept of the virtual power plant (VPP) was developed against this backdrop. This refers to the grouping together of a number of smaller systems, under the management of an EMS. The VPP represents a central concept for controlling the smart grid, and was investigated in conceptional and experimental terms at an early stage.[180]

In a VPP, distributed power management and communication with the generating entities play a key role. The distributed energy management system, acting as the "brain" of a distributed generator pool, links together the generator entities in a network through which it exercises central control, helping to schedule deployment according to both economic and ecological rules so that the potential of the VPP is fully exploited. It provides functions to forecast the loads and renewables generation, and uses this data to calculate the optimum timetables for deployment of the distributed generation and possibly consumption systems. All relevant technical and commercial conditions are taken into account. On the basis of the deployment schedule, any plan deviations that occur during operations can be redistributed in the most cost-efficient way to generators, storage and affectable loads on a cyclical basis, ensuring that the planned targets can be met. To the outside world, therefore, all requirements relating to procurement, supply and for corresponding contracts are met. A VPP can be used both to provide active power, for example through participating on the market, and to provide system services, such as voltage control and reactive power factor correction, or can be used on the balancing power market if the associated systems and ICT QoS level permit. There are various methods for establishing a hierarchy within a virtual power plant or operating them in self-organised associations.

In the case of greater penetration by distributed energy resources in the low-voltage levels, VPPs can help balance out the fluctuating feed-in and loads in microgrids at local level. Such microgrids are much more autonomous and can thus help to ensure a reliable power supply. In developing countries, they allow the growing demand for electricity to be covered more at a local level, thus reducing the cost intensive expansion of the transmission grid.

Development stages

Today: VPP are used commercially to provide balancing power. Many different installations have been implemented on a trial basis.

Stage 1: VPP systems are commercially available and are able to accept and control timetables. Interfaces for telecontrol systems already exist along with the corresponding standards.

Stage 2: Components for the use of lots of small heterogeneous plants form part of the VPP and allow it to calculate timetables for a large number of plants, distribute these and respond to deviations in real time.

Stage 3: Grid calculations can be integrated into the timetables. The VPP is able to optimise grid segments autonomously. "Autonomous grid agents" can be deployed in the low-voltage level. These embedded systems with VPP functions can process data from various meters, measuring transducers and forecasts, in order to influence generator systems directly. VPPs are capable of calculating control signals for an entire grid segment, so that the plants can be activated according to a defined timetable agreed with the neighbouring grid (as long as the connected plants permit this).

Stage 4: VPP systems are capable of linking up horizontally with other VPP systems. A VPP system is therefore no longer a "central" solution, rather the control intelligence can be distributed across several systems.

Stage 5: Activity in the distribution grid can be operated largely along self-organised lines. The convergence of ICT and the electricity system is complete. Intelligence has been fully distributed, as generator and consumer systems have their own IEDs (see technology area 13) that are linked to each other, the grid control system and the market.

180 Bitsch 2000.

3.4.13 TECHNOLOGY AREA 13 – PLANT COMMUNICATION AND CONTROL MODULES

DEFINITION	This technology area describes systems embedded in distributed consumers, generators and storage that provide control and communication links.
SYSTEM LAYER	Networked system layer
DOMAIN	Distributed generation, industrial customers, domestic customers, service providers, (regional) energy markets
ACTORS	Distribution system operators, in the future potentially aggregators of switch rights, electric mobility, end customers
VENDORS/SECTORS	Bosch, Siemens, ABB, SMA and others
SPEED OF DEVELOPMENT	Rapid
MATURITY LEVEL	Mature technology, but hardly any commercial usage in this context

Description/explanation

The basic premise of the smart grid is to connect all generator and consumer systems through ICT.[181] The actuators and sensors in the systems must be equipped with embedded logic to support communications and certain other functions. In the energy environment, these systems are frequently known as IEDs[182]. These modules may also contain local intelligence, or applications that trigger control signals for the actuators on the basis of analysis of the local environment. The modules can be wired or use wireless technology for communications, according to the area in which they are deployed. Depending on the system type and the intended use, a wide range of functions and non-functional requirements may be implemented. As a result, a module in a PV system producing less than a kilowatt might be realised with just simple measurement functions for monitoring and a communications connection with no other specific requirements. On the other hand, a module in a wind turbine may need more complex control options and highly synchronised secure communications, so that it can react to future grid control system signals. Electric vehicles also need special components that link up mobility aspects with the smart grid. Development is moving from simple measurement to more complex control, and from simple reactions such as autonomous deactivation when the grid frequency is too high to more complex agents that sell system power on the local markets.

Development stages

Today: Power plants are frequently controlled using proprietary connections. Even smaller cogeneration plants are equipped with IT. Large consumer systems have programmable logic controllers (PLC). Renewable energy and cogeneration plants with installed output of >100 KW always make a communications interface available in order to allow the grid operator the opportunity to switch them off (Sections 6 & 11 EEG). In R&D projects, plants have already been controlled using local intelligence. Small plants react autonomously to potential grid problems.[183]

Stage 1: Generator plants with output between 30 KW and 100 KW are able to use a standardised communications interface. Simple functions have been realised for thermal large consumers > 100 KW. Technically this enables the grid or the operators of virtual power plants to integrate these plants into a control concept. Small plants continue to react autonomously to potential grid problems, but are able to differentiate their reactions.

Stage 2: The IEDs have variable control concepts to allow them to react to requests. They are available for all generator plants and medium-sized consumers of > 30 KW.

Stage 3: IEDs have the first attempts at "smartness", as the systems react autonomously to their environment. For example, they are able to interpret timetables. Unidirectional plug & play[184] has been implemented to allow systems to be detected and controlled. The IEDs can be updated remotely.

Stage 4: There are IEDs on the market that allow autonomous control and have a standardised communication interface for all systems. This

181 The idea that smart objects can be integrated into a communication network is also found in other places, (also known as the Internet of Things, or Cyber Physical Systems – CPS)
182 Narrowly defined, an IED is a control module for protection and transmission systems in automated substations.
183 Several mechanisms are in discussion or have already been implemented, such as response to excess/insufficient frequency and contributions to voltage control, etc.
184 Unidirectional means that the system to which the IED is attached recognises and can use this IED with interfaces and services.

connection can be realised with bidirectional plug & play[185]. Where required, plants can be integrated into other EMS (multi-utility).

Stage 5: The IEDs are capable of autonomous system intelligence. As with the development of smart appliances, the systems can be seamlessly integrated with aggregation systems such as VPP systems, regional energy markets, control systems and similar.

3.4.14 TECHNOLOGY AREA 14 – ADVANCED METERING INFRASTRUCTURE

DEFINITION	An Advanced Metering Infrastructure serves to measure consumption, implement smart metering processes and transmit and process smart meter mass data.
SYSTEM LAYER	Networked system layer
DOMAIN	Distributed generation, industrial customers, domestic customers
ACTORS	Metering operators, metering service providers, energy service providers, communication network operators
VENDORS/SECTORS	IT
SPEED OF DEVELOPMENT	Medium
MATURITY LEVEL	Developed, so far used only in isolated installations in Germany; first products already available on the market; standards are in the process of being established

Description/explanation

An Advanced Metering Infrastructure is an automated infrastructure for implementing smart metering processes and for high-performance transmission and processing of mass data from smart meters installed at end-customers' premises. Alongside smart meters themselves, which may be identified as electronic household meters or Sym² (synchronous modular meter), or EDL 21 meters in reference to the corresponding sections of the EnWG (Energy Economy Act), a communications gateway to the field level is also required. This may be incorporated into the smart meter, as a plug-in communications module or as a separate device. For example, with the addition of a corresponding module, an EDL 21 meter can be converted into an EDL 40 system. Alternatively, the data from digital meters for various media in the household are encapsulated and passed through a single gateway for outside distribution. Such a multi-utility communication (MUC) controller standardises the functionality and interfaces of the electricity, gas, water and heating meters for the end customer, the meter operators and the metering service providers. Within each household, it is possible for there to be one interface with the end user, taking the form of a feedback system to provide transparency for energy usage. This could be a simple display as on the EDL 21 meter, or a fully functional home display that receives data wirelessly, or even a PC or other user interface. A range of WAN transmission media are available to transmit the data from communications-enabled smart meters to the meter operator's/metering service provider's back-end systems. In the case of an indirect WAN connection, the communication unit is connected via a PLC to the data aggregators built into the local substations, from which a WAN connection provides access to the back-end systems. As a result of the variety of concepts up for discussion, as well as pending questions relating to standardisation[186], statutory requirements[187] and security[188], it is not currently possible to describe a single direction of development in Germany. The rules on security requirements are particularly important, since acceptance will depend significantly on security, but rigid security rules could act as a massive obstacle to the roll-out.

In terms of the ICT infrastructure and data processing, there are various approaches:

In the context of an automated meter reading (AMR) infrastructure, the energy consumption data is recorded via a one-way remote reading process. It is not possible for switch commands, tariff information, firmware updates, etc., to be transmitted.

185 Bidirectional means that the system into which the IED is inserted is recognised by the IED and that the IED behaves accordingly.
186 The need for standardisation is currently being established in the scope of EU mandate M/441.
187 Determined by EnWG and the rules of BNetzA. The regulations are developing rapidly.
188 In particular, the BSI has published a Protection Profile that was the subject of much debate as this text was being written.

An AMI expands the capabilities of the AMR by adding the option of bidirectional communications between the grid/metering operators/ metering service providers and the field level.

Development stages

In contrast to most other technology areas, only three development stages are described. This is due mainly to the fact that, in comparison with the other technology areas, metering is less complex and is less technologically diverse.

Today: The range of functionality supported by individual digital meters varies widely. The connection format for the meters is proprietary. Equally, reading the meters and processing the data is subject to proprietary processes. Major installations such as ENEL in Italy usually centre around dependency on one vendor. There are no large installations in Germany.

Stage 1: The AMI has been standardised. The functions and standards that must be supported by the meters have been defined.

Stage 2: Advanced meter management (AMM) comprises additional data and energy services that are based on the collected data. The focus is increasingly on the consumer, offering the opportunity of transmitting data to the consumer and supporting additional services and applications within the household. The next generation meters are capable of providing the data with high resolution data, that supports calculation of the grid condition in the low-voltage segment[189] (see technology areas 2 and 4).

Stage 3: It Is assumed that every meter location also has the possibility for a secure, available communications interface. Apart from the meter and the communications interface, no other special higher functions are required in the smart meter area. All objects that maintain an interest in smart metering have a reliable IP connection to the Internet and other information channels. As a result, there are no additional servicing and maintenance costs for smart meters caused by the ICT connection. The AMI can, therefore, move seamlessly into the general infrastructure to connect the house (smart home) and systems (smart appliances).

3.4.15 TECHNOLOGY AREA 15 – SMART APPLIANCES

DEFINITION	Smart appliances are devices in the household, buildings and small commercial installations that have the capacity for intelligent control and a communications interface.[190]
SYSTEM LAYER	Networked system layer
DOMAIN	Distributed generation, domestic customer, customer service
ACTORS	Energy users, feed-in, distribution system operators, energy suppliers, metering operators, metering service providers, energy service providers, communication network operators, energy marketplace operators
VENDORS/SECTORS	Vendors of household appliances and electronic consumer goods, vendors of mobile end-user devices, ICT industry (systems integrators)
SPEED OF DEVELOPMENT	Slow to medium
MATURITY LEVEL	Developed technologies, but mostly still only used in pilot projects; The existing separation of household technology (including supply and metering); relevant technologies converge in the long run

Description/explanation

Despite available technologies, domestic households and commercial enterprises are primarily reliant on manual data gathering and analysis to identify and control consumption and load shifting when it comes to personal energy management (room heating, hot water, lighting, device power consumption, etc.) From the consumer's point of view a key obstacle is that the automated basic solutions offer little benefit in return for the cost outlay. Despite the trend of convergent technologies, and national and EU-wide harmonisation, there are still too many different incompatible lines of technology (heating, white goods, consumer electronics, in-home communications, actuators/sensors for smart home management, smart meters, etc.) with different, sometimes competing, standards (KNX, ZigBee, Z-Wave, M-Bus, OMEGA, PLC, SITRED, SML, DLMS/COSEM, EEBus and many more). Research projects (for example OPENmeter, SmartHouse/SmartGrid) and strategic initiatives (such as OMS) with the aim of ensuring the necessary interoperability

189 The extent to which this functionality is used or its use may be permitted is still a matter of discussion. For example, questions of data protection are relevant here.
190 As described in AHAM 2009, for example.

of hardware and software components in the different system layers (protocol, services, applications and user layers) are primarily concerned with technological feasibility and less with the customers' requirements (which to some extent have yet to be awakened), such as autonomy, personalisation, modularity, security, economy and ecology. In order for mass-market (sub) metering devices to obtain a critical mass rapidly, the focus has to return to the previous efforts undertaken for the MUC concept and the research findings that are available for that (for example E-Energy) and to the further development of these. Embedded system and IP-compatible networking technologies and highly standardised components (such as connectors, adaptors and cables) in the device network are key technical drivers for innovation. Costly certification processes and statutory calibration requirements are potential obstacles to innovation that must be discussed in respect of the possible solutions. At the same time, in the end-customer sector there are many developments for adding intelligence to devices and networking them to join the Internet of Services and the Internet of Things.[191]

A problem for the deployment of energy management by industrial users is the mutual dependency on smart appliances, in-home communications and offers from energy utilities. Each of these three sectors is waiting for the others to take the lead. Nevertheless, the market for smart appliances is predicted to be large.[192]

Development stages:

Today: In some applications autonomous energy management state (photo-sensitive/thermal controls, automatic stand-by) can be used without needing to be connected to the smart grid. Smartphones are increasingly being used as a means of accessing the Internet. The first energy applications for joining up with consumption measurements have been offered in pilot projects.

Stage 1: Larger thermal consumers, such as heat pumps and air conditioning, have both local intelligence and the capability for integration into a communications network.

Stage 2: Larger white goods, such as refrigerators, freezers, tumble dryers, etc., are mostly equipped with ICT components and external interfaces, at least at the top end of the product range. The ICT components in the devices hold information on their internal condition and can evaluate this. The information can be incorporated in to an energy management system, and is therefore capable of being used in DR programmes. There are comprehensive groups of functions available for energy control on end-user devices with user interfaces (UI) such as smartphones.

Stage 3: Devices can be integrated independently into existing home communications systems.

Stage 4: The Internet of Things trend and the smart home (intelligent building) concept are gaining pace. The devices possess autonomous intelligence. They can be integrated independently into an energy management system. Device functions can be controlled from the outside.

Stage 5: Autonomous intelligence and a connection to the Internet are finding their way into small devices too. Devices are able to perceive their environment using sensors. The boundaries between the physical and virtual worlds are becoming blurred.

191 Mattern/Flörkemeier 2010.
192 ZPRY 2010.

3.4.16 TECHNOLOGY AREA 16 – INDUSTRIAL DEMAND-SIDE MANAGEMENT/DEMAND RESPONSE

DEFINITION	Demand Response (DR) describes the effect exercised on the current power requirement by tariffs via an energy supplier (e.g. grid operator) or via electricity prices on an exchange or via an independent procurement management system. Industrial Demand-Side Management (DSM) describes the opportunities for directly influencing consumer systems.
SYSTEM LAYER	Networked system layer
DOMAIN	Industrial customers, service providers, energy markets
ACTORS	Energy users, energy suppliers, balancing group managers, energy exchanges, energy service providers, grid operators
VENDORS/SECTORS	Entelios, Joule Assets, European Demand Response Center
SPEED OF DEVELOPMENT	Slow
MATURITY LEVEL	Load shedding is agreed as a form of DSM today, but is seldom used. Demand Response is implemented via two-tariff solutions; Purchases of electricity on exchanges in the context of procurement management have a stronger influence.

Description/explanation

The activation of electrical load shifting and load reduction potentials, and of flexible production processes in the industrial context, form the objective of industrial DSM activities in the scope of the paradigm shift from load-led to generation-led operations. In 2009, 40 percent of Germany's demand for electricity was generated in the industrial sector.[193] That clearly shows the contribution that this technology area could make in the context of smart grids in the future. A distinction is drawn between the active controlling of electric loads and DR, which can be understood as the pattern of responses of electric loads to price or other signals.

Two basic options for electricity DSM can be identified. First there can be a direct influence from outside on the industrial requirement for electricity. Already today, transmission system operators have the option of disconnecting industrial consumers from the grid using telecontrol systems. This option was created in the context of the five-stage plan[194] for blackout-avoidance, but is not integrated in any way into industrial processes, which could have high costs for the industrial operations in the event of disconnection. Moreover direct intervention is possible via virtual power plants (VPP). The flexibilities of generation and consumption systems operated by industry are used to obtain optimum market returns. The power capacities are made available on the energy trading markets and the balancing power markets. However, the more complex a manufacturing process, the more complex and costly it is to integrate into industrial DSM.

In the case of industrial DR, there is no direct control and the primacy of control over the generation and consumer systems lies with the system operators. In the context of DR, these systems are motivated by means of incentives such as time-differentiated tariffs to shift their electricity requirements to periods in which the electricity is cheaper to buy. Time-based tariffs can be agreed and applied both on the energy procurement side and on the grid usage side.

Two different options are available for energy procurement. First, the energy suppliers may offer time-variable tariffs. This normally takes the form of a peak/off-peak tariff model and relates to commercial and smaller industrial companies. Depending on the savings potential, the company may consider load shifting and orient its industrial processes accordingly. On the other hand, a larger industrial operation may have its own energy procurement management through which it can itself buy and sell volumes of energy on European energy exchanges. Depending on the savings potential, the company may consider load shifting and design its industrial processes accordingly. Since it is possible for hourly products to be traded on the electricity exchanges, this form of procurement is similar to the highly dynamic tariffs of an energy supplier.

Alongside energy procurement, tariff-based incentives for grid usage are also relevant to industrial energy management. These allow grid operators and industrial customers to agree allowances in accordance

193 BMWi 2011c.
194 VDN 2007.

with Section 19 para. 2 StromNEV (Ordinance on Electricity Grid Access)[195], if the actions of the industrial customer are beneficial for the grid load. To leverage the savings potential for industrial companies, it is necessary to integrate energy management into the manufacturing organisations' ERP programs.

Hardly any individual development stages can be determined for DSM for industry, due to the diversity of the applications. Therefore, a rough analysis has been split over two stages.

Development stages

Today: Industrial DSM now generally takes the form of a tariff-based incentive (DR). This is done via the tariff models of energy utilities, via procurement management (based on market prices) or via tariff models that relate to grid usage (atypical grid usage). Automatic load shedding by industrial operations is partially technically possible, and planned for emergency situations to avoid blackouts. A tariff-based realisation can be found in the case of thermal energy consumers (>150 kW) that participate in load shifting in the context of peak/off-peak tariffs or atypical grid usage[196]. In the case of procurement management, industrial companies attempt to purchase the energy volumes they require from the energy markets themselves. Normally this requires an adjustment of the industrial processes to deal with the peculiarities of the market, so that any load shift is dependent on market prices. In the context of direct effects, industrial customers have negotiated agreements to reduce the load they take from the grid, at the request of the grid operator, in return for lower grid charges, as a form of manual load shedding. In the USA, direct effects take the form of virtual power plants that permit direct control of loads not dependent on the industrial process (for example lighting power).

Stage 1: Increased usage of time-variable tariffs by energy utilities leads to differentiated load shifting on the part of industrial customers. Growing numbers of industrial customers are either taking a direct path via their own procurement management, or are following an indirect approach using service providers to access the energy markets. Market prices serve as the main motivator for the actions of industrial operations. As a result, load shifting is carried out on the basis of economic principles.

Stage 2: In the scope of DR, both the system services (load/generation adjustment for the overall frequency stabilisation and local voltage control) and energy procurement management are fully integrated into the manufacturing process ERP systems. The principle challenge is to understand the industrial processes in respect of these new requirements, since process reliability must not be called into question. Companies are now able to participate even in the short-term supply-dependent price changes in intraday energy trading, controlling their energy procurement. In this way, industry has been able to exploit its potential for adjustment in terms of its electricity supply.

3.4.17 TECHNOLOGY AREA 17 – INTEGRATION TECHNOLOGIES

DEFINITION	A variety of integration technologies are used in the smart grid in order to enable interoperability – the capability of several systems to work together at semantic and syntactic levels to exchange data.
SYSTEM LAYER	Cross-cutting
DOMAIN	Cross-cutting
ACTORS	Relevant for all actors
VENDORS/SECTORS	SAP, IBM, Oracle, Tibco, Siemens, OPC Foundation, OSGi, Seeburger
SPEED OF DEVELOPMENT	Rapid to medium
MATURITY LEVEL	Partially mature technology, deployed in the field; Development of an Enterprise Application Integration (EAI); Following the direction of Service-Oriented Architecture (SOA), Cloud possible and encouraged

Description/explanation

With the dismantling of the traditional monolithic solutions within an electricity utility company (EUC) and the appearance of new market

195 BMJ 2010.
196 Loske 2010.

participants, there is an increasing need for joining together previously separate, heterogeneous systems and environments. This recombines data sources from a range of actors and establishes new system interfaces within the application landscape. To enable this, there needs to be syntactic and semantic interoperability. In contrast to data integration and functional integration, however, the realisation of the existing systems does not change; the interface realisation is done on an integration platform, normally the middleware. By shifting intelligence into the interfaces, coupled with intelligent routing provided by publish/subscribe eventing mechanisms, powerful architectures can be built for actor-independent cooperation.

The SOA approach to integration goes a step further. Enterprise Application Integration (EAI) can be seen as the predecessor to SOA, since they share significant technological concepts. However, SOA requires certain properties according to the service paradigms of the applications to be connected, in order to enable process integration. Services are contained within a directory and can be accessed by third parties or process engines; this involves the transfer of data. In addition to the possibility of direct connection, here also the use of a platform with suitable functionality to act as middleware is possible or perhaps even necessary. This may comprise specialist logic, data transformation, connections to data sources, automation technology, logging and reporting or filtering and transformation. This complex middleware is often described as the Enterprise Service Bus (ESB). Nevertheless, as a central data hub such a platform can become a bottleneck for distributed services. For that reason it is beneficial to build redundancy into the middleware design. If part of the IT infrastructure is no longer operated by the electricity utility company (EUC) itself, but has been transferred to a third-party operator, the infrastructure provided to the EUC becomes abstract and opaque, as though surrounded by a cloud.

With the switch from a central IT system to distributed systems that integrate generators, storage, consumers and other data sources in the smart grid through ICT, the aforementioned integration paradigms can also be applied in the smart grid in communications, automation and in secondary and primary IT. To simplify this, there are internationally standardised solutions such as IEC 62357 SIA, which can also be realised through a SOA, or IEC 62541 OPC Unified Architecture as a SOA-based approach for data exchange. Nevertheless, there can also be gaps with this concept, in which the semantic and syntactic interfaces require further harmonisation. In addition to the standards agreed by the national and international standardisation committees, quasi monopolies or vendor agreements frequently lead to the emergence of industry standards, especially in the ICT sector.

Development stages

Today: Many of the base technologies described in the following stages have already existed for some time and have become well distributed in specific sectors such as banking and e-commerce. However, the currently dominant paradigm is that of integration of heterogeneous systems using modern IT integration technologies within landscapes characterised by monolithic systems. This results in highly integrated systems with point-to-point connections and data exchange processes that may use initial EAI technologies and solutions, but still have additional potential for optimisation. For some market processes such as the German GPKE (Business Processes for Electricity Suppliers), standards have been laid down. There are standards for many areas of use of the smart grid, and plans for their further development.

Stage 1: The first stage in the development of this technology area focuses on the broad deployment of SOA. SOA does not describe a specific out-of-the-box solution, but is rather a paradigm for the development of systems that meet individual requirements. Developers are provided with a structure that allows them to combine various distributed systems. As an architecture paradigm, SOA is concerned with the manipulation of business processes that are distributed across a range of existing and new, heterogeneous systems. These systems are also frequently at the control of different actors.[197] Accordingly, SOA meets requirements of the IT infrastructure of smart grid actors that equally have a high degree of distribution. Common cloud solutions are still restricted to infrastructure products (Infrastructure as a Service – IaaS) or higher functions that are not, however, particularly easy to incorporate into the energy utilities' applications. Standards are increasingly being applied.

197 Josuttis 2007.

Stage 2: In this stage, standards-based syntactic interoperability is achieved. See also figure 14. This means that two or more systems are able to communicate with each other and exchange information. The specification of data formats, data serialisation and communications protocols is essential for this. Standards such as eXtensible Markup Language (XML) and Structured Query Language (SQL) and their dialects allow syntactic interoperability. Syntactic interoperability is a prerequisite for further forms of interoperability.[198] The standards mentioned have been tried and tested in practice already. In this stage, the relevant applications are designed so that the standards mentioned are supported. Cloud-based energy services are being tested in pilot projects. Domain-specific standards such as IEC TC 57 are being used increasingly, in particular in grid automation. Work is ongoing to develop use cases for the application of the standards. New standards are being developed.

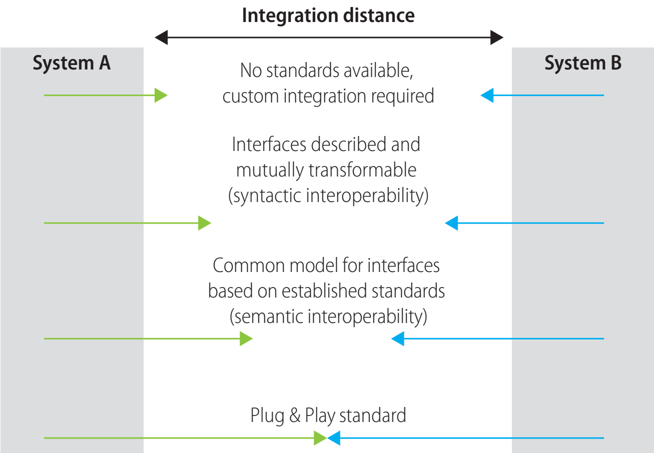


Figure 14: Potential integration distances between two systems.[199]

Stage 3: Following the achievement of syntactic interoperability, corresponding reference architectures can be defined for the development of new systems. Reference architectures describe a special type of domain-specific architecture and describe a large class of systems in abstract terms. They allow developers to obtain information on the design of specific system classes. Typically, they are derived in the context of their development from domain-specific studies. Overall they represent the ideal architecture including all possible functionalities that can be realised by systems.[200]

Stage 4: Semantic interoperability reduced the distance of integration in comparison with the third stage (see figure 14). Therefore, it is defined as the capability of evaluating the exchanged information sensibly and correctly so that meaningful results can be obtained for all participating systems. To achieve semantic interoperability, the participating systems must agree on a shared, content-oriented reference model for exchanging information. The content of the exchanged information is clear – what is sent is semantically the same as the content interpreted by the recipient.[201] In a smart grid with a range of heterogeneous components connected via ICT, this is enabled by suitable standards and the associated use cases and tools. Profiles are defined for the key application cases. Test beds exist for many use cases and standards. Standards have been harmonised.

Stage 5: The final stage of development describes integration into the energy domain via cloud solutions. Just as is the case with the smart grid, there are various definitions of cloud computing. A broadly accepted definition is provided by NIST, and is subject to continual revision.[202] NIST defines cloud computing as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction." The definition lists five essential characteristics (on-demand self-service, broad network access, resource pooling, rapid elasticity or expansion, and measured service). It also lists three "service models" ("Software as a Service", "Platform as a Service" and "Infrastructure as a Service"), and four "deployment models" ("private", "community", "public" and "hybrid").[203] This definition establishes the prerequisites for business

198 Uslar 2010.
199 Uslar 2010.
200 Sommerville 2010.
201 Uslar 2010.
202 NIST 2011.
203 NIST 2011.

models – based on the service and deployment models – for different actors as participants in the smart grid.

3.4.18 TECHNOLOGY AREA 18 – MANAGEMENT OF DATA

DEFINITION	Management of data comprises IT technologies used to describe data semantically, and to aggregate, analyse, structure and store it.[204]
SYSTEM LAYER	Cross-cutting
DOMAIN	Cross-cutting
ACTORS	Relevant for all actors
VENDORS/SECTORS	Siemens, Oracle, Microsoft, SAP, IBM, Google, Accenture, BTC and others
SPEED OF DEVELOPMENT	Rapid
MATURITY LEVEL	Mature technology that must be transferred in part from other application domains to the energy domain

Description/explanation

Management of data is concerned with all components of the FEG since it forms the basis for data entry and evaluation and for decision-making and control support. The particular challenges here are the large number and variety of data records, the widely distributed creation and storage of the data, the number of data owners and the increasingly important integration of unstructured data.

The more ICT becomes established in the FEG, the more data are created and must be processed. Five data classes can be identified, essentially: operating (operational readiness and behaviour in the grid) and non-operating (condition of the grid and grid components) grid data, consumption data (real time meter data and statistics such as maximum and average), event indicators (notification of faults or for preventive purposes) and meta data (descriptive data required for the purposes of organising and evaluating data).[205] A sharp rise in data volumes can be anticipated in all areas, required new techniques for data entry and processing as well as new options for analysis and control. This is particularly visible in the case of smart meters. While data from end customers are normally recorded just once a year at present, in the future this will be done every 15 minutes (a multiple of 36,000) or even more frequently. Such frequency will allow customers to obtain consumption information in real time and modify their behaviour in response to price changes.

Technologies to manage large volumes of data have already been tried and tested by other industries. For example, networks such as mobile telephony and the Internet operate with massive volumes of data and are logged so that user patterns can be analysed and controlled by means of incentives, with simultaneous monitoring and operation of the infrastructure. Concepts relating to the management of data streams are relevant here. However, the challenge is not only rising volumes of data. An even bigger problem is presented by the heterogeneous nature of the data, high number of transactions and changes in requirements. This combination of circumstances demands, in particular, technologies to manage meta data and methods from the semantic web.

It should not be a surprise, therefore, if many companies that were previously not in the energy sector now wish to offer data management services. For example, Google and Microsoft are already offering services to monitor and control domestic customers' energy consumption, while IBM and Accenture provide comprehensive consulting services around the future energy grid. It is important, therefore, for all participants in the FEG to come to terms with the topic of data management, in order to adjust the existing technical infrastructure to the new roles and integrate these at an early stage instead of redeveloping them in parallel.

Development stages

Today: Data management is currently used intensively in IT-supported system functions in control technology systems. As with the source applications, the management of data is often not yet integrated into

204 What is meant here are "generic" technologies and their application in the energy domain. Specific data models, as created in CIM for example, do not form part of the technology area in this definition. Equally excluded are architectures designed to retain, store and process data. Both of these are handled in technology area 17.

205 Hoss 2010. The source is limited to the data produced by smart meters. These statements can also be applied to other data sources, however.

business processes. Data storage is characterised by data sources and sinks that are syntactically and semantically diverse. Currently, more "traditional" technologies such as relational database management systems (RDBMS) are used.

Stage 1: With the expansion and ICT integration of distributed energy resources (DER) and consumers in the networked system layer, plus the necessary expansion of actuators and sensors in the closed system layer, the future requirement for data-producing participants will grow strongly. As a consequence, the basic availability of data will increase with the growing integration of software systems. This relates both to the area of data stream management and to data warehousing.

Stage 2: Context is growing in importance alongside the actual data. Corresponding meta information is used more and more when recording and analysing data. This improves the quality of processing for unstructured data too. Meta information relate in particular to the data lineage/provenance and to the quality of data.

Stage 3: In the next stage, the data are semantically enriched by the addition of meta information. These semantically enriched data can be better analysed using data mining techniques and other associative analysis, for the purposes of obtaining better information. Semantically enriched data support automation. Increasingly, the data are considered away from the system in which they are generated, but their lineage remains intact.

Stage 4: Management of data is an integral component of the entire process chain. Relevant data is identified for input and output in real time. The data can be integrated semantically and analysed in context, creating additional value for the companies and their customers. Data stream management techniques have been adapted for this task. A glance at the data is frequently more important than a glance at the application.

Stage 5: Management of data takes place in the cloud. The origin of the data is no longer technically relevant. Analysis tools offer dedicated support for the evaluation of data.

3.4.19 TECHNOLOGY AREA 19 – SECURITY

DEFINITION	Security relates here to information security. This is defined as the security of information in relation to its requirements for availability, confidentiality and integrity. It is distinguished from functional security (safety), which describes the correct functioning of a system in all operating conditions. Information security is concerned with protecting a functionally secure system from external attack.
SYSTEM LAYER	Cross-cutting
DOMAIN	Cross-cutting
ACTORS	Relevant for all actors
VENDORS/SECTORS	ICT sector, et. al.
SPEED OF DEVELOPMENT	Slow
MATURITY LEVEL	In development, partially used in the field

Description/explanation

Critical infrastructures such as the energy sector are categorised as particularly worthy of protection, since any failure can lead to long-term supply shortages. The topic of security and especially the associated reliability of supply, is a consistently important theme for all areas of the energy supply system. Alongside safety, information security is increasingly key due to the growing number of attacks on the energy infrastructure. In particular, the Stuxnet[206] computer worm discovered in 2010 highlights the vulnerability of the infrastructure to IT attack. A successful attack by hackers on the certificates trading system at the beginning of 2011 forced the EU to suspend CO_2 certificate trading for some time.[207] New challenges have emerged for security, especially following a range of changes in the energy sector. Firstly there is the transformation from closed, proprietary and process-specific technologies (security by obscurity) to more open, networked standard IT systems. While previously systems such as those using SCADA were previously sealed off in partially in-house developed operating systems, nowadays these can often be controlled via the Internet, and the associated

206 Ginter 2010.
207 Europa 2011.

databases are linked to commercial systems. The linking of energy infrastructures to other systems is a security challenge that has already caused damage in the past. A further challenge is the increased number of participants due to the liberalisation of the sector in compliance with Section 9 EnWG, plus the associated increased number of interfaces and data transmissions. The developments that have resulted in ubiquitous computing also increase the number of attack vectors for the energy domain. Alongside the traditional objectives of securing confidentiality, integrity and availability, other differentiated objectives have emerged, such as commitment, authenticity and anonymity. Naturally, all security objectives are generally important, but their relative importance in relation to each other differs according to domain and participants. In general, in process control systems, availability is seen as having the highest priority. In this area, after all, security is mostly about protecting life and health, rather than purely protecting data. Data must be provided in a timely manner since otherwise the power plants could be given incorrect control information. At the same time, the power plant control information and response must be coordinated in time, since otherwise accidents may occur. While in commercial systems, even the important servers can be switched off overnight, control systems must generally run around the clock. In the past, with the greater compartmentalisation of the systems, confidentiality had a lower priority. With the use of open systems and also the increased volumes of data, required to achieve energy efficiency, this has changed. To achieve energy efficiency, ad hoc messages concerning the current situation of generation (e.g. in wind power) and the demand for energy (e.g. using smart meters) are required. Especially in the case of domestic customers, the use of digital meters to record consumption gives raise to data protection concerns and increased need for confidentiality. When considering and realising these security objectives, security measures from other sectors cannot always be transferred one-to-one to the energy sector. For example, it is necessary to ensure that the availability and the ongoing process are not hindered, for example by a virus-scanning routine.[208]

Development stages

Today: The current security requirements in the domains are known. The NISTIR 7628 series of guidelines provides a great deal of information and also outlines future developments. General security standards are available, while domain-specific security standards and binding protection profiles are still being developed. For example, the Bundesamt für Sicherheit in der Informationstechnik (BSI; Federal Office for Information Security) has developed a Common Criteria Protection Profile for the smart metering domain.[209] IT attacks are conducted in the domain. There has been a variety of documented cases in the past. In smart grid pilot projects, the primary focus is on testing new functionality, with less emphasis on security.

Stage 1: The systems in the energy domain are expected to become increasingly networked and therefore increasingly complex. This increases the susceptibility to failure and also the potential attack vectors for the overall system. The consistent implementation of the security requirements is developed in this stage. IT attacks or damage tend to increase with greater IT networking. Accordingly, there is a need to develop tools that can analyse the dependency and interaction of the hardware and software components, and monitor these.

Stage 2: Side effects such as losses in performance, overly complex access rules and therefore a corresponding loss of usability in the ICT systems can be anticipated as a result of standard security measures. It is likely that some side effects will not be known until testing commences. (Domain-specific) security solutions without side effects are developed and adjusted in this stage. These include in particular domain-specific intrusion detection systems that apply standards such as IEC 62351-7. Subsequent changes or additions to security concepts for running systems may be made, but this is not the best way of going about it. IT attacks are less common on systems that have integrated new security solutions. However, when they do occur the consequences are much more far-reaching due to the growing level of networking. The functional security of the overall ICT system is also guaranteed in the event of power outages.

208 Lukszo/Deconinck/Weijnen 2010.
209 BSI 2011.

Stage 3: Security solutions for the smart grid are ubiquitously available. Experience is incorporated into domain-specific security patterns[210] and standards.

Stage 4: According to the experience of stages 0 to 3, future smart grid projects will be implemented in compliance with the "security by design" and "privacy by design" principles[211] in system architectures and products such as IEDs and smart meter infrastructures. Comprehensive best-practice assessments are available, some of which have been implemented in libraries and frameworks.

Stage 5: The smart grid is a self-healing system that can react in a semi-automated fashion in response to IT attacks and partial failure of components. Security measures can be automated at short notice in exceptional situations. New technologies allow information from attacks or attempted attacks to be evaluated and to thus provide evidence pointing to the originator (via cyber forensics) and, in particular, to differentiate between technical failures, terrorism or other forms of attack.

3.5 TECHNOLOGICAL VIEW OF THE FUTURE ENERGY GRID SCENARIOS

Below, the technology areas that were presented in the previous sections are considered in the context of the FEG scenarios. Depending on the scenario being considered, different technological developments may be expected. In combining the scenarios with the technology areas, different types of development in the context of the smart grid may emerge, which differ significantly in their maturity level. The resulting system states for 2030 form the basis for the migration paths subsequently developed in chapter 4.

While there is some discussion of the cross-cutting technology areas, a more detailed analysis in relation to technology areas 1 to 16 is done in the context of the migration paths in chapter 4. As the cross-cutting technology areas must be considered in their corresponding application context, no general allocation of development stages to a scenario is carried out.

3.5.1 SCENARIO "SUSTAINABLE & ECONOMIC"

Overview

The "Sustainable & economic" scenario is characterised by a wide-ranging spread of distributed and frequently small generators, making significant contributions to the supply of electricity and the reliability of supply and thus replacing a corresponding number of large power plants. Consumers are present on new markets and may occasionally act as generators. The distribution grid is strengthened so that it can handle the comprehensive, mostly fluctuating feed-in. The basis for these developments is the establishment of innovative cross-cutting technologies.

Figure 15 shows the characteristics of technology areas 1 to 16 in the "Sustainable & economic" scenario. The maximum development stages are indicated in light grey. Starting from the current technological state of affairs, the graphic shows the developments required in each technology area through to 2030. The numbering indicated is used in the following descriptions for each technology area.

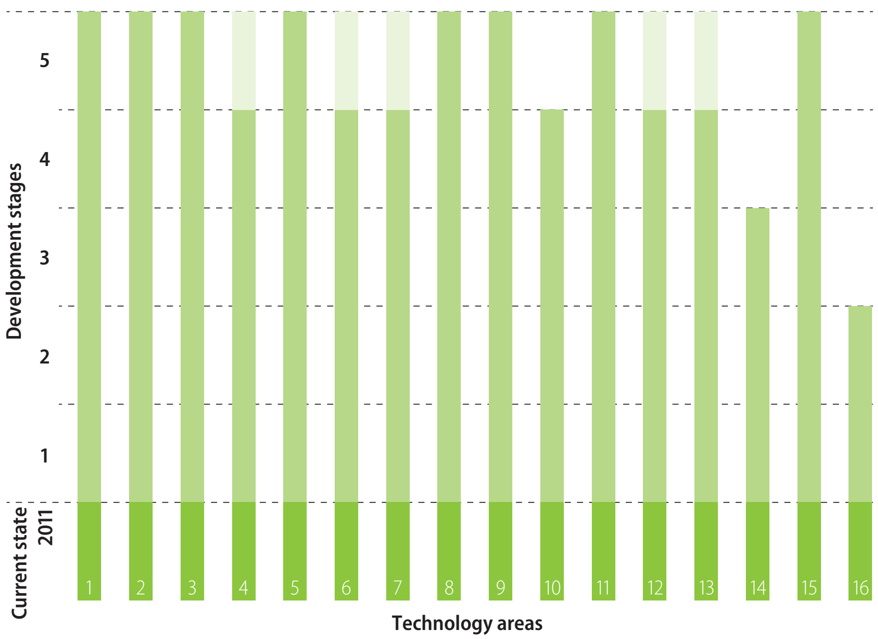
Technological characteristics of the scenario

From an ICT perspective, this scenario is characterised by the many new operational/technological and business processes that must be implemented, some of which must run semi-automatically. New information flows are created that must satisfy a range of new functional and non-functional requirements. The required technologies and components are primarily as yet undeveloped, or are at a level of maturity that does not sufficiently support this wide-ranging scenario.

While today the topics of smart meters and AMM are two of the most discussed aspects of the smart grid, by 2030 the **Advanced Metering Infrastructure** (technology area 14) has largely lost relevance since it has been replaced by other technologies or subsumed into them. As the competition and market-driven development behind the Internet of Things and Internet of Services is moving considerably more rapidly than the regulated energy sector, product innovations in the smart home and smart appliance fields are brought to market with significantly shorter development cycles than is the case in the current introduction of AMM

210 Beenken et al. 2010

211 Security by design means that security aspects have played a key role from the early system planning phases through to later testing.



1. Asset management for grid components
2. Grid control systems
3. Wide Area Measurement Systems
4. Grid automation
5. FACTS
6. ICT Connectivity
7. Asset management systems for DER
8. Regional energy marketplaces
9. Trading control systems
10. Forecasting systems
11. Business services
12. Virtual power plant systems
13. Plant communications and control modules
14. Advanced Metering Infrastructure
15. Smart Appliances
16. Industrial Demand Side Management/ Demand Response

Development space of the technology area
Development in the scope of the scenario
Current characteristics of the technology area

Figure 15: Characteristics of the technology development stages for the "Sustainable & economic" scenario.

technology to the market. The "Sustainable & economic" scenario does not require today's generation of smart meter. However, a bidirectional digital meter with corresponding statutory calibration requirements must be provided for billing purposes. Equally, communications are required for data transmission and in some cases a real-time connection for grid operators to evaluate information via the LV grid.

The trend towards increasingly intelligent devices, **smart appliances** (technology area 15) has continued without interruption for years and will continue further in the future. Examples of these products that are already available or for which prototypes have been developed include the RFID (radio frequency identification) chips, Internet-connected washing machines, smartphone-controlled heating systems, applications in the field of networked vehicle transportation/traffic and applications referred to as Ambient Assisted Living (AAL). In this scenario, numerous other devices use local intelligence to make a contribution to energy efficiency. In addition to brown and white goods there are many other smaller devices with such functionality and the required autonomous intelligence. As sufficient market incentives and suitable standards are developed too, then devices will be introduced to the market that can link into energy management systems. The latter can use the functions integrated into smart appliances in order to improve energy efficiency, for example with automated advice on how to save energy or, in the case of larger appliances, how to contribute to the reliability of supply. This provides access to a range of new, market-driven services that allow end customers to benefit from tariffs that vary according to load, without suffering a loss of usability.

The comprehensive expansion of fluctuating feed-in is accompanied by numerous changes in the area of consumption. The potential of small domestic consumer devices in relation to load management and measures associated with generator-led operation is quite low in comparison with the commercial and industrial major consumers. Control systems in the industrial processes have interfaces to their own EMS, which is itself connected to the systems of the energy supplier or of the market and grid operator. As a result, **industrial**

Demand Side Management/Demand Response (technology area 16) becomes an integral part of the process landscape. The process control now "understands" what shifting and saving potential the corresponding process permits and can therefore decide or help decide whether any intervention in the processes is desired on both a technical and economic basis – i.e. electricity costs vs. cost of altering the process.

This function, which is normally integrated into the ERP system, is highly dependent on the individual production process concerned, and must therefore be individually designed for a range of different industries. The shifting potential and the consequences of intervention in the production process are so well known that the intervention can be largely automated.

Examples of potentials already detected and realisable today include (according to information from the BMWi[212]) the production of chlorine, the paper industry, the aluminium industry, and iron and steel production.[213] This allows the companies to adjust their energy supply in a targeted fashion to the variable prices in the market for active power or to generate revenues by offering the grid operators services to stabilise the system so as to help with local voltage control and/or frequency stabilisation.[214]

While energy trading is conducted at a European level and is needed in order to even out the Europe-wide fluctuating peaks from renewables feed-in at market level, **regional energy markets** (technology area 8) must ensure that generation and consumption are balanced at a local level and therefore, above all, meet the grid's demands. Products that are designed for small amounts of electricity in particular and the associated profiles are developed and implemented for these market platforms This allows all stakeholders and systems to be integrated and ensures an efficient allocation of generation, consumption and the grid. The regional marketplaces are linked with the pan-regional exchanges.[215]

However, there are many changes on the wholesale side too. The increased volatility and negative prices, combined with regional marketplaces and many other changes, mean that major electricity suppliers, large buyers in industry and wholesalers require new **trading control systems** (technology area 9) that will let them participate successfully in electricity trading. These control desks support traders with a range of new functions for optimising and visualising trading on the various markets, such as the spot market, the day-ahead market and the intraday market. They lack for nothing in comparison to the complex trading systems of the financial markets, and integrate many other functions such as forecasting the grid status, which allow them to react quickly to overload situations and adjust their dealing activities accordingly. In contrast with the products traded today, this system is able to integrate new products (such as load shifting potential) into its optimisation. Automated proposals are provided for buying and selling electricity. Automated trading in electricity products is possible. The trading control desk is able to integrate many other systems such as forecasting systems, systems that generate time-of-use tariffs and virtual power plants (VPP).

The ERP systems used by companies in the energy sector support new **business services** (technology area 11). Energy suppliers also benefit from the developments in other domains. For example, customer self-service functionality allows end customers to use or access the energy utility's services irrespective of time and (to some extent) location. Analysis is possible even with large data sets and complex algorithms, where necessary also in real time. The business services developments also benefit from developments in the technology areas Management of Data and Integration Technologies.

In its equipment, the distribution grid is very similar to the transmission grid in respect of measurement systems, actuators and role – and therefore also in the area of operations management; however, it also has more autonomous functions. This is seen in particular in the **grid control systems** (technology area 2). The connection to a large

212 BMWi 2011d.

213 While aluminium-manufacturing operations already participate in the balancing power market, this will be difficult for the steel industry, even in the future. In this case, adjustments are made to electricity price fluctuations, for example by delaying the start of a smelt after loading the furnace.

214 The potential for shifting in industry is not yet sufficiently well understood.

215 A prototype has been developed by the eTelligence (www.etelligence.de) project, for example. A related concept is used in the USA to remove load from low-power grids. In the USA, the grid load is taken into account implicitly in the price calculations at the local marketplaces ("nodal" markets). See also chapter 6.

number of measurement points in the MV and LV levels means that the grid conditions can be assessed in real time. The local conditions are known at each relevant grid node (e.g. the local grid voltage). The grid control system uses functions from other systems: For example, predictions from the forecasting system (technology area 10) are used to calculate the future grid conditions and initiate measures to secure the power quality at an early stage. The connection to the asset management system ensures that the capacity utilisation of resources is more strictly based on monetary factors, without endangering the reliability of supply. The enormous quantity of data arising from the comprehensive grid monitoring is no longer manageable for human operators, and so a variety of analysis functions is available to evaluate these data and prepare them for human consumption. As in the transmission grid, the control system has numerous functions that allow it to control active grid components, generators, storage and consumers (potentially via a VPP system) in order to secure the power quality by means of supply-side management and DR. In addition, autonomous agents are usually used in local substations, to obtain information on the condition of the LV grid and also provide an opportunity to control the distributed components connected to it, independently in the case of any impending threat to the quality of supply.[216] These components are also regularly supplied with information that enables them to coordinate their actions in real time, for example to contribute to frequency stabilisation. In this respect the grid has a self-healing property. The grid control systems in the various grid levels and areas exchange aggregated information using standardised semantic exchange formats (see technology area 17).

At the higher voltage levels, the coordination is automated and the information flow improved. The grid control system in the highest voltage level also communicates with the grid control systems at the downstream voltage levels from which it requests services such as load minimisation and DSM (technology area 16).
The prerequisite for realisation of the functionality described above is the availability of suitable field components for **grid automation**, the IEDs (technology area 4). In the field, corresponding IEDs for recording measurements are installed at all necessary locations and secondary technology components. This applies especially to transformer substations. The conductor lines in the LV level are equipped with measurement systems. Grid protection equipment responds to situations having first coordinated its action with other components. As in the transmission grid in which FACTS are already used at some points today, the meshed distribution grid utilises FACTS (technology area 5) to control cable flows. Due to the high number of units and simpler construction, these FACTS cost significantly less than their typical counterparts used in today's transmission grid. Grid management is largely automated, but continues to be monitored by human operators. Just as with the actions of many other active grid components, the actions of the FACTS are coordinated across grid and voltage levels.

Both the transmission and distribution grids are monitored using **Wide Area Measurement Systems** (technology area 3), as increasing levels of reactive power factor correction are required and these measures must be coordinated. PMUs are also manufactured and used in the LV area.

Asset management systems for grid components (technology area 1) record the entire operating and load history of each component. The maintenance processes are organised in line with the actual aging determined from the historical data, and no longer according to predefined service intervals. The automation components for the operating resources also store some of these data remotely. External costs are internalised within the asset management system: for example, maintenance is done when the drop-out of the corresponding operating resource is least costly according to forecasts on market prices, distributed feed-in and grid utilisation.

On the generation side, **virtual power plants (VPP)** (technology area 12) are much needed in this scenario. Most of the distributed energy resources (DER) and many consumption systems are linked into the control functions of one or more VPP. Also incorporated into the VPP system is a reliable prediction of consumption and generation of the integrated systems. The VPP system is able to meet predefined timetables, to the extent permitted by the connected systems, and to react appropriately to variations from plan, by adjusting the schedules of individual systems or adding new systems to the

216 These systems are a hybrid form of grid automation component and grid control system.

VPP system. This ensures that volatile feed-in is balanced out and that also the quantity of energy or power output that can be offered on the active power market or as balancing power can be increased. Depending on the intended purpose of deployment, the VPP can also be integrated into either the grid control system or into the trading control desk.

A VPP is aware of the location of the systems in the distribution grid and can therefore contribute a variety of responses in terms of grid stabilisation. The system services to be provided by the DSO, which in 2012 are the preserve of the transmission grid operators, are frequently initiated by VPP systems. The VPP systems can be operated in isolated mode, and in such cases ensure that a predefined timetable for exchange with neighbouring grids is maintained. They coordinate autonomously (for example through a regional marketplace) with the neighbouring grids. A special form of VPP could be an autonomous grid agent, an autonomous active component in the local substation that provides grid control system functions.

In order for distributed plants to be integrated into virtual power plants or grid control systems, they must be equipped with **system communication and control modules** (technology area 13). With a generally available infrastructure (technology area 6) and plug & play standards (technology area 17), these modules can easily be connected to and accessed via VPP systems and grid control systems. The modules are capable of establishing the condition of the system, while they also have functions to ensure compliance with individual timetables and for power factor correction as well as gathering other information that is important for operations. The individual timetables are met. A proactive message is sent to the VPP if variations occur. The system communications and control modules are able to respond to requests to alter the timetable. They communicate with the grid control system, partially in real time, providing it with information on their own timetable and receiving control patterns that indicate how the system can act autonomously to provide grid services in the event of certain thresholds being exceeded. In this way the DER make direct contributions that have an effect even beyond the German supply system.

In order to improve the commercial viability and reliability of the systems, distributed plants are also included in the **asset management systems** (technology area 7). In a similar way to the grid operating resources, these systems use local plant data concerning the operating history of the plant and link this with data from other plants and prediction systems, as well as the market prices, in order to determine the service intervals and other operating options.

As will already be clear from the examples above, improved **forecasting systems** (technology area 10) play a key role in grid control systems, for VPP and in the connection of renewable energy. This is especially applicable to the "Sustainable & economic" scenario, which is highly reliant on fluctuating and distributed feed-in. The forecast for distributed generation and consumption is specific to certain cables and uses both weather and operating data from the plant and historical consumption data. Possibly, sociodemographic data can also be used, assuming this is desired or even simply accepted by consumers and is possible given the data protection prerequisites. The forecasting systems can be integrated easily via corresponding standards. Forecasts can be correlated to each other, as well as simply providing an output value for a given point in time. Moreover, in addition to output data they provide information relating to the anticipated load shifting potential, volatility in a given time period, etc., in order to ensure the best possible operations management for the desired purpose. Forecasting systems are used in all voltage levels and in many aggregation levels.

The most important prerequisite, as described in the key factor "standardisation", is the opportunity to allow the large number of distributed ICT systems at field level and ICT systems in the distribution grid, plus the aforementioned grid control systems and systems to control virtual power plants, to exchange information simply among each other. **Integration technologies** (technology area 17) therefore also play a key role. For the targeted application cases, uniform, semantically interoperable data models must be defined so that information can be exchanged without altering the system software. As smart grids do not represent an end state but a dynamic process of modernisation, the ICT systems must be capable of responding flexibly to alterations. For this reason, modern, flexible architectures that have been developed from current paradigms such as SOA are updated to take account of the requirements of smart grids. Smart grid reference architectures are available to provide assistance in systems development. Many of the required services can be uncoupled from the central systems. As a large number of actors are active in this ICT-intensive scenario, these services are often not hosted locally but operated in the form of cloud services. This also allows small companies to subscribe to and use these necessary yet complex services at an acceptable cost, or to offer their own specific services. All companies are relieved of this since they obtain resources from the cloud and therefore benefit from economies of scale.

The IT backbone of the energy system in the "Sustainable & economic" scenario is the ICT infrastructure (key factor 2). The technological basis is **ICT connectivity** (technology area 6) which ensures a communications infrastructure to which all of the systems can connect and via which all control systems and field systems can communicate. The communications network of this infrastructure offers a range of QoS levels, which are adjustable according to application context. It is protected against attack and is robust in the face of technical outages, and in the face of power outages at the appropriate points. A system of authorisations allows authorised parties to query targeted system information, such as current condition and technical capabilities. In conjunction with the establishment of suitable standards and additional **integration technologies** (technology area 17), a plug & play connection to the communications infrastructure is enabled. Above the communication layer, a semantic layer allows a number of semantic queries to be performed, for example to establish which plants would be able to offer negative balancing power at a given time.

The automation and the overhaul of a critical infrastructure thanks to mass ICT utilisation, thus creating a CPS, also pose many risks in addition to the many opportunities. Successful attacks or the failure of the ICT system can, in the worst case, cause widespread power outages. Insufficient security concepts permit unauthorised parties to read or manipulate data. In order for this not to become a reality, all ICT systems are protected by adequate organisational and technical measures that serve to fend off any attacks (**security**, technology area 19). As early as the design phase, when the systems are being conceived, and then subsequently during development, projects are implemented according to the principles of security by design and privacy by design. The topic of data security for digital meters, which currently and in years to come will play a role the importance of which is impossible to overestimate, along with end-customer acceptance, must be considered in a wider context since a very much greater number of devices in the home will be transferring private information. In view of the increased volume of data, its diversity and the dependencies of almost all system functions on the quality of data, advanced **data management technologies** (technology area 18) will also be used. Management of data forms an essential component of the energy supply system in all process stages and relies in many cases on semantically annotated data models that support the high degree of system automation.

3.5.2 SCENARIO "COMPLEXITY TRAP"

Overview

This section describes the effects of the "Complexity trap" scenario on the developments of the technology areas. At its core, the lack of uniformity among the relevant market players in the redesign of the energy supply system has created an environment with little security for investment. This acts as a barrier to investment both by the government and by private enterprise, in particular in the technology areas that are relevant for infrastructure. Increases in operating costs can be offset by improvements in the efficiency of business processes and trading, however. Overall, the lack of consistent conditions means a lack of uniformity in the development stage of technology.

Figure 16 shows the characteristics of the technology areas in the "Complexity trap" scenario. The ultimate development stages of the technology areas, which indicate the development space independent of the scenario, are shown in light grey. Starting from the current technological state of affairs, the graphic shows the developments required in each technology area (1 to 16) through to 2030. The numbering indicated is used in the following descriptions for each technology area.

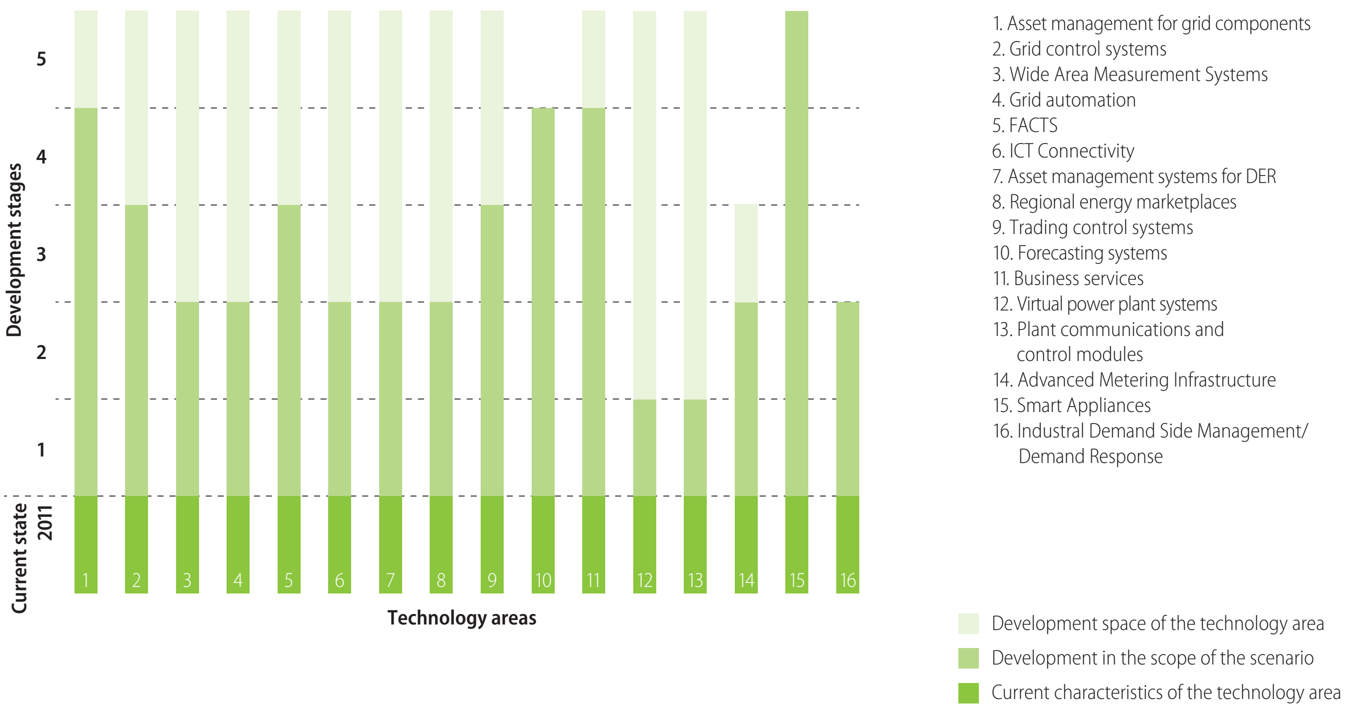


Figure 16: Characteristics of the technology development stages for the "Complexity trap" scenario.

Technological characteristics of the scenario

The overhaul of the energy supply system is progressing sluggishly in general. As the integration of small, distributed plants is technically not possible in part, the system as a whole returns to bulk power plants for a large amount of its needs. An opening up of the **grid control systems** (technology area 2) towards open system concepts is not pursued, as the transmission grids (EHV and HV) and MV segments of the distribution grid can still be reliably operated using the existing control technology based on closed concepts. Actuators connected via telecontrol systems can intervene to control these grid segments more and more. Operating resources may predict their own load and thus inform the grid control system to take action to optimise the load flow and switch the flow of power at an early stage.

The necessary **forecasting systems** (technology area 10) are capable of both forecasting generation and consumption down to the level of domestic and commercial customers, and predicting distributed feed-in, if necessary aggregated to local grid level. These advanced systems are characterised by the fact that in comparison with the systems of today their much higher resolution predictions are not only more accurate but can also be correlated to each other. The findings obtained from these predictions create value added for the operation of the entire system. The predictions of the generation of electricity from wind power and photovoltaic installations are more reliable due to the greater resolution in the forecasting processes, and this improves the options for direct marketing of electricity yields. The maintenance of the plants can also be better scheduled with information from the forecasting system. Access to generation and consumption forecasts allows maintenance work to be conducted at the best time in terms of cost: For example, if forecasts indicate high feed-in from wind sources and a good price on the direct market, then no maintenance should be conducted on either the critical grid resources or the wind power facilities during this time, in order to maximise the renewable power generation. Complete integration of the systems is not achieved in this scenario, however.

Optimisation of the lifecycle of existing grid resources and bulk generation power plants is key, since the lack of security for investment prevents widespread use of new components. Asset management systems support the maintenance planning for bulk and distributed plants. Significant progress is made in the area of **asset management for bulk generation power plants and grid components** (technology area 1). The previously manual process of condition monitoring is automated. Relevant data about the condition of resources can be automatically recorded throughout the system. These are processed by the asset management so that the physical aging of the components is taken into account when planning the deployment of resources. External costs that are incurred from interrupting the direct marketing of distributed energy resources, for example, can also be accounted for in the asset management system, ensuring that maintenance is done at the most appropriate time in terms of cost. An interface with the grid control systems ensures that maintenance tasks do not put the reliability of supply at risk. Information is exchanged between the asset management system and neighbouring systems via a standardised object model.

In comparison with the above, **asset management for distributed energy resources** (technology area 7) has been considerably less well promoted. As the distributed feed-in does not play a supporting role for system stability and direct marketing does not achieve sufficient returns, investors in this area face limitations. However, periodic maintenance scheduling is possible for the existing plants. Historical information for the individual plants can be accessed online.

In many cases, problems arising from the integration of fluctuating generation are resolved by expanding the affected grid sections. The use of **grid automation** (technology area 4) with a combination of sensors and actuators is limited to the HV and MV grids. In many cases, new components are only installed as and when necessary, as existing systems are simply modernised by retrofitting. Measurement devices are installed in just a few parts of the LV grids, to improve the level of monitoring.

Wide Area Measurement Systems (WAMS, technology area 3) are only used to a limited extent, given the corresponding low level of automation in the overall distribution grid system. The technology continues to enjoy widespread use in transmission grids and at HV levels, however. Use cases have been developed from the pilot projects investigating the deployment of these technologies in the distribution grid. These use cases describe the options for grid condition monitoring in this area. **Wide Area Measurement Systems** (WAMS, technology area 3) are only used to a limited extent, given the corresponding low level of automation in the overall distribution grid system.
FACTS (technology area 5) are integrated with the WAMS in order to optimise the use of the existing grid capacities and to react appropriately to the highly dynamic supply situation. FACTS, the power electronics system deployed in several grid areas, can be used to regulated and stabilise the system on the basis of grid information. Where required, active grid components are taken into account in the MV to LV grids to shift load flows.

wIn contrast to FACTS, cross-the-board use of ICT is not possible. Technically viable solutions to detect economic potentials cannot be used within the legislation applicable to this scenario. Comprehensive **ICT connectivity** (technology area 6) is therefore not put in place. In selected regions, there are solutions that allow ICT to be used in the distribution grid, though these are the results of pilot projects. The structures installed in these are mostly proprietary and vertical in nature. Accordingly, while individual functions can be supported or fully realised using the ICT, there is no comprehensive support for business processes. The flexibility and potential value-added in such an infrastructure therefore remain very limited overall.

For trading in electricity, industry, commercial and domestic customers can all access tools to allow them to participate in **regional energy markets** (technology area 8). As a result, participation in regional energy trading is possible for anyone who is interested. Trading in derived products, such as grid services and DSM, is supported technically by appropriate tools, and is available to all market participants. The importance of these products in the marketplace, however, is limited in view of the comparably low proportion of distributed energy resources. Particularly in the domestic customer segment, DSM plays only a minor role. There is no integration of the regional marketplaces with upstream markets.

While regional trade via marketplaces is only established to a limited extent, the **trading control systems** (technology area 9) used in the upstream markets continue to be developed significantly. To deal with the conditions, increased pressure of costs and the associated complexity of market activity, the participants in energy trading are interested in refined trading systems. Such systems can register trading positions and forecasts consistently and aggregate data as and when required. For example, it is possible to visualise all relevant information at balancing group level. The functions provided by a trading control system are appropriately grouped and trading data is displayed all together, improving the effectiveness and efficiency of the systems. The system is also able to evaluate and forecast the market value of flexibilities. Moreover, it is able to estimate the extent of any effect of real-time price signals for large customers in industry and commercial sectors, and if appropriate send the corresponding signals via an interface to the tariff systems to create indirect incentives to load shifting. While the control system aggregates and visualises the key trading data, there is no need for any active decision-making support or (partial) automation in this area, since the scope of the information required to support trading is adequately visualised and aggregated for the trader.

Inter-company and customer-related business processes in the energy sector are supported by corresponding **business services** (technology area 11) Business services are capable of analysing the data they use in real time. Technically, the services are hosted in a cloud-based architecture, to improve availability and flexibility. The energy management of major commercial and industrial customers is integrated into that of the service providers, in order to leverage potential in this area and to increase competitions.

The **virtual power plants** (technology area 12) are used solely for large, bulk controllable distributed consumption systems, such as cool buildings and generation plants (normally CHP), since trading in energy from smaller distributed systems in this scenario is not sufficiently well motivated. VPP systems have become established to aggregate the output of systems and are able to offset random fluctuation from generation within a grid segment. Furthermore, they adhere to timetables in order to profit from price changes on the exchange. To do this, the VPP systems calculate the supply potential from the connected plants on the basis of the plant data and forecasts, and then use that information to calculate the most profitable timetable. The manufacturers of larger CHPs and even some other large feed-in plants have added **plant communication and control modules for generation plants and consumers** (technology area 13), so that they can be connected to and controlled by a VPP system at no real additional expense. Corresponding communication and control modules are used for thermal large consumers (> 100 kW power), for example, although only simple functions are supported. In the area of generation, plants with output of between 30 and 100 KW are also equipped with corresponding modules. However these are generally only used for plant monitoring and have proprietary interfaces and applications. In some cases vendors develop larger turnkey VPP by selling the ICT for the distributed energy resources and the VPP system as a proprietary single solution in combination with the appropriate services.

The **Advanced Metering Infrastructure** (technology area 14) provides a technical infrastructure that allows meter data to be read remotely, supporting bidirectional communication and the use of data by higher level applications in the scope of the AMM. DSM has had only limited success in transfer to domestic customers and does not play any role in the energy market. Nevertheless, the energy utilities have made intensive use of the possibilities of AMI in order to improve their customer processes (Business services, technology area 11). Some customers allow service providers to process their data and in return benefit from new services.

Energy management is of major importance for industrial and commercial customers. The objective is to reduce energy costs by increasing their internal energy efficiency, responding to variable pricing and offering support services to the grid (DR). **Industrial Demand Side Management/Demand Response** (technology area 16) therefore achieves a fair amount of penetration. Via EMS, this aspect is incorporated automatically into operational planning processes. Production planning and control systems (PPC) contain a function to assess the load-shifting and savings potential of the industrial process. This allows the system to decide on a commercial basis (electricity costs vs. costs of changing the process) and a technical basis whether any intervention in the industrial workflow is desirable. Alongside this more advanced form of adjustment in respect of energy prices, in many processes the change in energy consumption is based on simple tariff changes (peak/off-peak). Energy management of this kind is developed along highly individual lines for the corresponding domain and processes.

Irrespective of the smart grid and the AMI, significant developments have been made in the field of **smart appliances** (technology area 15). All of the device types found in the home, from white goods to small electronic devices, are able to register with a home monitoring and control system and offer their functionality through it. The connections are simply plug & play. The home monitoring and control system supports the consumer in monitoring their energy consumption, and therefore providing a basis for using the autonomous intelligence of the individual appliances. The functions on offer address the home directly, and refer only rarely to the overall system outside the home. The driving forces in the area of smart appliances are the appliance manufacturers who wish to address new markets with these products.

Interoperability at information systems level in the energy supply system is achieved at many points in the **integration technologies** field (technology area 17) using standardised interfaces. These guarantee the syntactic interoperability of the various systems by allowing access to specified data formats, data serialisations and communications protocols. In addition, the individual process steps are offered in the form of services, along the lines of the SOA concepts. Due to a lack of uniformity among vendors and unequal conditions, not all standardisation projects succeed, and in many situations vendors have recourse to proprietary solutions. In relation to reference architectures or semantic interoperability, the actors in the energy supply system therefore fail to reach consensus. As a result, while basic interoperability is ensured, any potential above and beyond this in increasing efficiency and flexibility of the overall system is lost. In the cases in which quasi monopolies have been formed, their formats have become industry standards.

The increased use of ICT within the energy supply system makes higher demands in terms of the **Management of data** (technology area 18). Despite the restrictions imposed by conditions, ICT achieves greater importance in the realisation of system functions within the energy supply system. At the same time, the business processes of the energy sector are increasingly supported by information systems. With this development, both the volume of data and the requirements for its availability grow. In order to support data analysis and also enable unstructured data to be evaluated in the process stages, meta information is used to explain the context of the data, such as its origin and its quality. Here, too, however, value-added that might arise from the semantic enrichment and integration of data throughout the process chain remains untapped at many points.

The **Security** (technology area 19) of the data and applications is ensured overall. The security requirements at application level are mostly recognised early on and add to the complexity of the system and therefore enlarge the potential attack vectors. The very different framework conditions and technical development also have an effect on this area, however. Although security concepts exist for the technologies that are used, and are being integrated into running systems, end-to-end security solutions are being impeded across the system.

3.5.3 SCENARIO "20TH CENTURY"

Overview

This scenario describes a situation in which smart grids and the integration of renewable or distributed energy resources into the electricity supply have developed very little compared with the present day.

- The offer is based on bulk generation from fossil fuels, producing less and less CO_2 (for example thanks to the use of CCS (Carbon Capture and Storage) technology) and on low-carbon imports of electricity.
- The transmission grids have been well expanded for this purpose, with sufficient national and transnational overlay grids. The distribution grid has been designed for a load flow in the direction of the end consumer, and has been expanded in line with this.
- Noteworthy amounts of fluctuating and distributed energy (onshore wind and PV) are not integrated, and load shifting and other controllable consumers play no significant role.
- The costs of electricity remain constantly high, and in the area of generation, transmission and usage of electricity, very high levels of energy efficiency have been achieved.

Figure 17 shows the characteristics of technology areas 1 to 16 in the "Sustainable & economic" scenario. The maximum development stages are indicated in light grey. Starting from the current technological state of affairs, the graphic shows the developments required in each technology area through to 2030. The numbering indicated is used in the following descriptions in conjunction with each technology area.

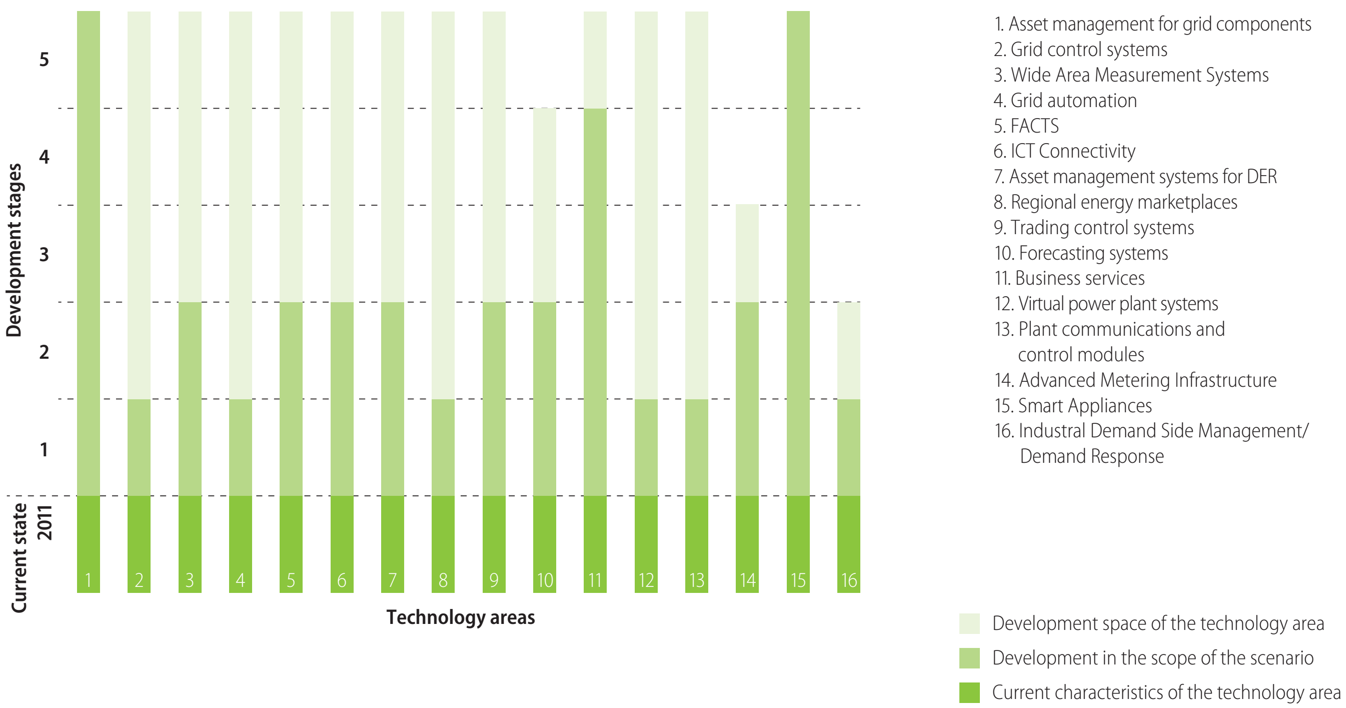


Figure 17: Characteristics of the technology development stages for the "20th century" scenario.

Technological characteristics of the scenario

Asset management systems are split into those used for **grid components** (technology area 1) and those used for **distributed energy resources** (technology area 7). The former have come a very long way by 2030. Across the system, it is possible to automatically register the data from all plants. This is enabled by factors such as standardised object models. Interfaces to the control system allow plants to be operated securely from a technical point of view as well as in full control of costs. For example, an events-based overloading of a plant, which will cause the plant life to shorten, is frequently tolerated as long as the costs incurred by the faster aging are lower than the profit available on the market from the overload.

These asset management systems are referred to as resource healthchecks, which record the entire history of the grid components. Equally, maintenance and operation are adjusted according to physical aging of the system and the costs that are incurred. The reason for the mature development of these systems is the decision to encourage grid expansion rather than to optimise the entire system by integrating intelligent technologies into the grid. As a result, the amount of capital tied up in the grid also increases. For similar reasons, asset management systems for distributed energy resources are not so well developed.

The energy mix is composed primarily of bulk fossil-fuelled generation, with a stagnant proportion of renewable energy. Very few new PV and wind power facilities are installed. Only some historical plant data are available online, and the maintenance of distributed energy resources is carried out at predefined intervals according to predefined schemes of work. Further development of corresponding asset management systems does not appear to be profitable.

In terms of electricity supply from sources other than the aforementioned energy mix, the remaining requirement is imported in the form of low-carbon energy from neighbouring countries (including nuclear power from France, hydroelectric power from Scandinavia and electricity from solar power projects such as DESERTEC). As the supply system is therefore mostly concerned with bulk generation plants and only major consumers are integrated into the overall system in a controllable fashion, development is focused on modules for **plant control and communication** (technology area 13) in these areas. Consequently, in the area of standardised connections, only thermal large consumers (>100 KW) and generation plants > 50 KW are taken into account. These connections should not be seen as intelligent, however. They fulfil only simple functions, usually simply responding to control signals. The prioritisation of fossil fuel-based generation and the politically motivated regressive dismantling of renewable energy resources also contributed to the rather weak development of **forecasting systems** (technology area 10. Improved predictions, especially in the form of aggregated data on the consumption of domestic and commercial customers, help to support grid control decisions This is necessary in order to deal with the constantly rising loads.

To be able to import electricity and connect major generation plants, the focus is on expanding the transmission grid. The expansion of the distribution grids takes less precedence since distributed generation plays a minor role in this scenario. This also affects the development of various technologies: For example, the functionality provided by **grid control systems** (technology area 2) has not penetrated to the lower voltage levels. While it is still possible to conduct a condition evaluation of the MV grid, and work has also already started on integrating planning and forecasting there, the monolithic systems supporting individual functions continue to dominate this area. Another affected technology area is that of **Wide Area Measurement Systems** (technology area 3), for which application cases for the use of sensors in the distribution grid have been identified so as to implement visualisation and analysis tools on this basis. These are now used in the MV level (20 kV), but not in the LV level. **FACTS** (technology area 5) are integrated at critical points in the meshed distribution grid, with ICT connections to WAMS components that allow the system to respond to and offset highly dynamic supply situations by changing the load flow. In addition, it is possible to implement coordination across several grid segments and adjust or stabilise several FACTS on the basis of highly dynamic grid information. Also as a result of the focus on grid expansion, the deployment of actuators in **grid automation** (technology area 4) is ad hoc, with sensors limited to monitoring in the HV and MV levels. These comprise new, modern measuring components and the retrofitting of equipment already installed in the field.

As a result of the structure of generation and the grid, the energy costs are characterised by high prices with low price volatility. In addition there is very little potential for load shifting, and as a result the **regional marketplaces** (technology area 8) are barely built up. Tools to support trading are available, but are only suitable for companies in industry and the economy that have a high energy requirement. In respect of smaller customers, they are too expensive and their functionality is overly complex. Cross-regional markets, in particular the European exchanges, have become more important as a result, so that corresponding **trading control systems and desks** (technology area 9) have been subject to consistent redevelopment. These tools have supported the bringing together of a range of functionality. In addition, trading data can be visualised together and no longer have to be displayed in isolation, requiring manual combination or aggregation. Options for bottom-up entry of positions and forecasts and suitable aggregation functions have also been implemented. **Virtual Power Plants** (VPP) (technology area 12) also form part of the energy system and are supported by suitable systems. Due to the low spread of renewable energy and the neglected development of forecasting systems and the lack of regional trading, however, VPPs are only technically able to operate to predefined timetables or participate as a pool in balancing energy markets, in order to offset fluctuations in generation or demand. The systems to be controlled comprise larger controllable consumers and distributed generators such as CHPs.

In the area of **ICT connectivity** (technology area 6) in this scenario, only demand-driven isolated solutions can be found. Within these isolated solutions, consumers and distribution grids are found along with generators. This results in just partial interfaces between the networked and closed system layers. In general, the development of new services is rather conservative, with basic services being developed only when specific demand exists. These services are simply following the general trend for **Business services** (technology area 11), adapting the corresponding concepts for the energy sector. As a result, there are flexible, inter-company processes that can be used for the purposes of real time analysis, among other options. These continue to be operated primarily in private clouds, and are mainly offered through "Software as a Service" models. The energy management systems of the major customers of energy utilities integrated these services.

Smart meters are incorporated into **Advanced Meter Management** (technology area 14). This means that energy consumption data is recorded using bidirectional communications between the grid operator or metering operator/metering service provider and the field level. Furthermore, the system comprises additional data and services, which build on the gathered measurement data. This places the focus more squarely on the energy consumer, allowing data to be sent to the customer and more complex services and applications in the home to be supported. Independently of the developments in smart meters, the appliances in the home have been developed to become **smart appliances** (technology area 15). This is mainly due to advances in the IT sector and in telecommunications. A massive range of applications is available for mobile devices, supplying information on the energy consumption of individual appliances. In addition, small appliances are increasingly equipped with autonomous intelligence, so that all functions can be integrated into an overall control system. New devices are recognised automatically and integrated straight into the system. The functionality is restricted entirely to the household itself, however, so while the population as a whole is more aware of energy and electricity consumption, there are no functions available such as load shifting or complex external controls that would significantly affect the supply system itself. In general, any option for load shifting in the overall system is barely used. Domestic and commercial customers have hardly any incentive for load shifting due to the low levels of price fluctuation. Even in industry, **Demand Side Management/Demand Response** (technology area 16) is used only in isolated cases since neither suppliers nor DSOs have created any attractive offers to incentivise the implementation of DR, for example. The idea of energy management has spread throughout industrial operations, however. Gradually, early adopters are starting to make their consumption more flexible. Initially this simply means adjusting to basic tariffs such as peak/off-peak.

The development of cross-cutting technologies, both **integration technologies** (technology area 17) and management of data and IT security in the supply system, has been patchy. Initiatives at European level have led to the development of standardised interfaces for some systems.

This is supported by the market to the extent that companies are also increasingly implementing SOA. Semantic interoperability between all systems is only achieved for smart appliances, however. Among the other technologies, semantic interoperability is limited to the information exchange required by liberalisation of the market.

Requirements for **Management of data** (technology area 18) arise mainly from the increased volume of data to be processed in the early development stages of the technology areas. Exceptions to this include the forecasting systems, which require semantically enriched information for their predictions, and smart appliances, which need meta data for their communications.

The comparably low level of ICT penetration into the energy supply system means that demand for newly developed IT **security systems** (technology area 19) is also low.

In a range of cases, security measures are subsequently integrated into existing systems. The systems for ICT connections to FACTS, business services and smart appliances are practically redeveloped from scratch due to the extensive new functionality requirements. As a result, security requirements form an integral part of the development process (security by design).

3.6 SUMMARY

This chapter looked at the importance of ICT for the energy supply system. In the context of the current state of affairs in 2012, it was initially clear that, at all voltage levels, the corresponding grids are being operated at their performance limits. Nevertheless, these loads are not permanent. They occur in the form of peaks due to fluctuating feed-in from wind power (various sizes of onshore and offshore installation, depending on the feed-in to the extra-high, high or medium voltage levels) and from solar power (mostly into the low voltage grid). Particular challenges exist in controlling pools of power plants on the basis of forecast data (for example for large offshore wind farms), handling the bidirectional load flows (reversing the flow of electricity back up to the higher grid level) and not least in ensuring that the low voltage grids can be monitored and observed. ICT and the corresponding communication standards can contribute to overcoming these challenges.

As a framework for the technological analysis, a system model was defined that comprises three system layers. The closed system layer is (currently) characterised by largely autonomous or manually controlled components that strictly regulate communications with other components. This may be sensible for security reasons, for example in the control of power plants. The networked system layer contains components that are required to communicate or exchange data with other components or actors in order to fulfil their functions. Examples here include regional energy markets. A flexible platform for the (future) networking of components is provided in the form of the ICT infrastructure layer. This occurs both within the system layers and as a connecting component between the closed and the network system layer. The second dimension comprises the domains, which are formed after considering the energy supply system from technological and regulatory perspectives. These include all electricity generation (bulk and distributed), grids (transmission and distribution), customers (industrial and domestic customers) and the service providers and energy markets.

Within the model comprising the system layers and domains, 19 technology areas were previously defined in the preceding chapter. Five of the technology areas, such as grid control systems, form part of the closed system layer and are allocated to the domains bulk generation, transmission and distribution grids. Ten technology areas have been placed within the networked system layer. These, such as the forecasting system, stretch across all domains of the model. Further examples within the network system layer include asset management systems for distributed energy resources, plant communication and control modules, regional energy markets and the Advanced Metering Infrastructure. The ICT connectivity technology area considered the potential developments within the ICT infrastructure layer. In addition, the three cross-cutting technology areas were identified in integration technologies, management of data and security. These must each be considered in the context of the 16 other technology areas. As a result, they are allocated neither to a single domain nor to a single system layer.

Potential developments have been described starting with the current state of technology for each technology area. Depending on the development stage being considered and the technology area, each stage represents either R&D activity to be completed or an across-the-board introduction of a technology that already exists today. Based on the SGMM[217] up to five development stages were identified, revealing the potential developments for the technology area under consideration. In view of the large time horizon, the highest development stage should be interpreted as a vision of the development of the technology area.

On the basis of assessments given by experts in the corresponding domains, the following section assigned the technological development stages to the extreme scenarios described in chapter 2. A variety of different technological properties are produced based on the environment within the scenarios outlined by the key factor projections. The technology areas of asset management for grid components, business services and smart appliances experience comprehensive development in all three scenarios. In the cases of asset management and business services, it is assumed that optimisation of the commercial viability in these areas is driven forward irrespective of the structural development of the energy supply system. The development of smart appliances in the context of the scenarios will be done mainly by the providers on the market. Depending on the composition of a corresponding ICT infrastructure, the connection to the energy supply system will differ. The functions of the smart appliances will either be limited to the home, or incorporated into the energy management of the entire system, depending on the characteristics of the infrastructure. The development of the other technology areas is heavily dependent on the characteristics of the scenario under consideration in each case, in terms of the infrastructure (energy and information) and energy policy conditions.

The development of the technology areas and their properties within the scenarios “20th century”, “Complexity trap” and “Sustainable & economic” are described in further detail in the next chapter. First, the dependencies between the development strands of the technology areas are established. These are subsequently used for development of the migration paths, which outline the development of the energy supply system in respect of ICT.

217 SGMM 2010.

4 MIGRATION PATHS TOWARDS THE FUTURE ENERGY GRID

So far, both the current state of affairs and the target state of affairs in respect of the use of information and communications technologies (ICT) have been described in detail for all relevant technology areas in each of the three scenarios that cover the selected future space. In order to visualise a migration path, it is now necessary to describe the development over time. This can be determined by considering the inter-dependencies of the development stages for the technology areas in terms of content, and then mapping this dependency matrix onto a time axis. An analysis of this overall picture can then identify the critical points. It will become apparent that three phases of development can be distinguished for the "Sustainable & economic" scenario.

4.1 METHODOLOGICAL PROCEDURE

In chapter 2, a scenario technique[218, 219] was used to develop the scenarios "20th century", "Complexity trap" and "Sustainable & economic". These revealed, in several dimensions, the key factors, and initially the development space for the future ICT-based energy supply system. In chapter 3,the ICT-related potential developments were then sorted into the technology areas and described. The assignment of their development stages to the scenarios revealed parallels, but also divergent development paths within the three layers of the system model.

In this chapter, the first section analyses the development stages of the technology areas in respect of any inter-dependencies. For each of the technology areas from 1 to 16, the prerequisites for the individual development stages are revealed. The reference to the development stages achieved in the individual scenarios clearly indicates the development requirement for each technology area. In respect of the cross-cutting technology areas – integration technologies, management of data, and security – separate sections describe their importance for the development of the remaining technology areas.

The contextual visualisation of the technology area inter-dependencies is then used to determine and establish the complete migration paths for the scenarios. The importance of the technology areas and their development stages is determined by means of a quantitative analysis. This method reveals hot spots or critical paths within the technological migration process. As the "Sustainable & economic" scenario is currently the closest to the target vision described in the "energy revolution", and also is the one that pursues the most ambitious set of objectives, the development of the technology areas for this scenario is structured in more detail by splitting it up into specific development phases. The findings of the analysis are used to derive core statements that summarise the main developments and connections for migration towards an ICT-based energy supply system.

4.2 RELATIONSHIPS BETWEEN THE TECHNOLOGY AREAS

The development stages identified in chapter 3 for the 19 different technology areas are investigated further in this chapter, with the aim of discovering their mutual dependencies in relation to the continuing development of the Internet of Energy (IoE). For each of the technology areas that can be assigned to a system layer, the dependencies of other technology areas are described on the basis of the corresponding sequence of development stages from 1 to 5.

For the cross-cutting technology areas integration technologies, management of data and security, however, this chapter reveals the development stages for which these technology areas are prerequisites: While the cross-cutting technologies are not actually cornerstones of the system in themselves, they do represent key prerequisites for its functionality.

The visualisation is limited to first-order dependencies. For example, if development stage 9.3 (third development stage of technology area 9) is dependent on development stage 10.3, which in turn is dependent on development stage 14.1, the dependency between 9.3 and 14.1 is not shown. These transitive dependencies can be seen in the overall visualisation of the migration paths scenario in section 4.3.

218 Gausemeier et al. 1996.
219 Gausemeier et al. 2009.

4.2.1 CLOSED SYSTEM LAYER

Technology area 1 – Asset Management for Grid Components

Asset management for grid components develops relatively independently, as shown in figure 18. There are simply preconditions for early development stages, which are the result of ICT Connectivity and Management of data. The final development stage is achieved in the scenarios "20th century" and "Sustainable & economic", while the "Complexity trap" achieves the penultimate stage.

In order to automate the registration of all main components in the asset management system, these must first be networked for ICT (development stage 6.1). To expand this process system-wide in the next development stage, the ICT Connectivity must improve. First, microgrids are fully networked. Among these isolated solutions, therefore, an option is created for registering grid components automatically (6.2). A standardised object model improves inter-operability. This also results in a rising volume of data, however, which itself requires appropriate data management (18.1).

After that, neither the interface to the control system (1.3), nor the integration of external costs into the asset management system (1.4) nor the maintenance and operation based on the physical aging and costs of a plant (1.5) are dependent on advances made in any other technology areas. These development stages can be launched on top of the foundations that have already been laid.

Technology area 2 – Grid control systems

As shown in figure 19, grid control systems are dependent on progress in other technology areas in nearly every development stage. At the same time, they are the key components of the closed system layer.

Development progress within the scenarios differs greatly, so while in the "20th century" scenario only the first stage is reached, the "Complexity trap" scenario reaches the third stage, and the "Sustainable & economic" scenario reaches the fifth and final development stage. This technology area therefore represents a key differentiating factor for the development of the IoE in the context of the three different scenarios.

Condition monitoring in the medium voltage (MV) grid (2.1) requires the provision of corresponding monitoring data from grid automation (4.2). Selected individual plants in the distribution grid must be reachable via ICT interfaces so that their data can be accessed as a basis for calculating the condition (6.1). Progress is also required in the development of forecasting systems so that more detailed predictions can be made on load and feed-in, for example (10.1). Moreover, the increased volume of data requires a concept for data management (18.1).
In order for the grid control systems in the next stage to be able to use their grid control options in the medium voltage (MV) grid (2.2),

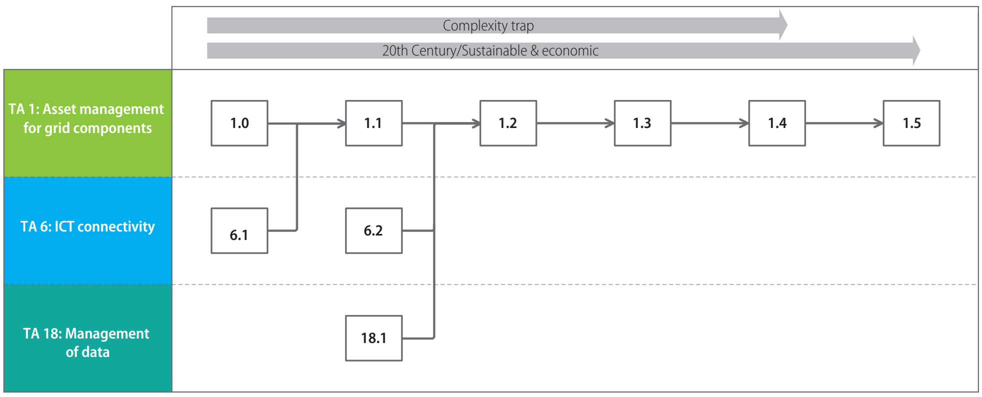


Figure 18: Dependencies of technology area 1 "Asset Management for Grid Components"[220]

220 The visualisation of the paths was subsequently done using the software program EA-Viz (www.EA-Demonstrator.de), developed by OFFIS-ST.

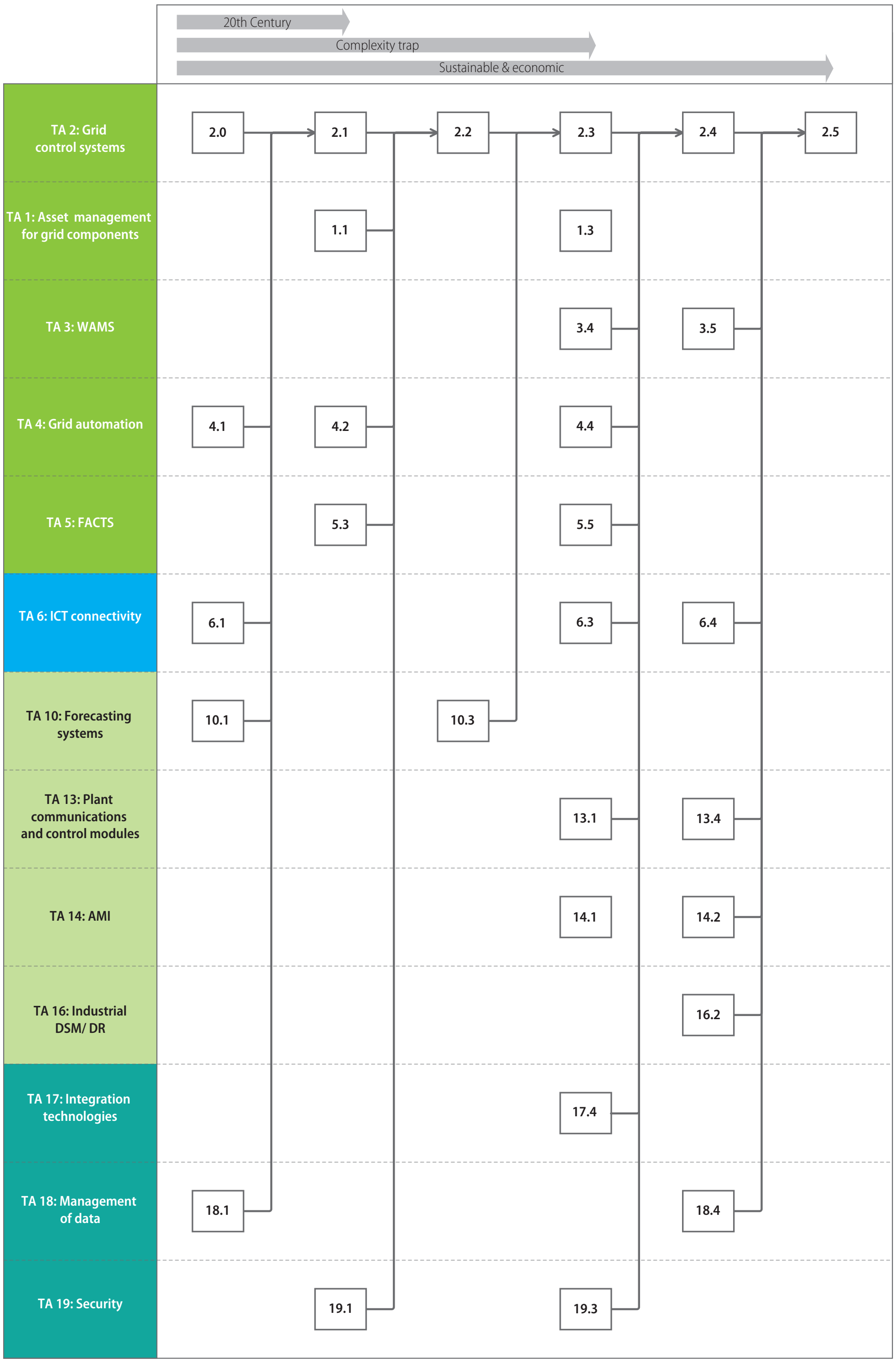


Figure 19: Dependencies of technology area 2 "Grid Control Systems"

grid automation must also develop further. Actuators for controlling MV segments must be available (4.2). Equally, automatically registered information from the asset management systems will also be important (1.1). For example, information on the overload capacity or voltage range of the grid or distribution transformers must be known in order to optimise the grid automation configuration. Flexible AC Transmission System (FACTS) are other components that are used to control load flow, which must be taken into account in controlling the MV grid (5.3). FACTS are currently primarily used in the extra high voltage (EHV) and high voltage (HV) grid. The increasing level of interconnection that the control options provide demands a higher level of security measures, which must also be taken into account when developing the control systems (19.1).

Once the MV grid can be assessed and controlled, the grid control systems will develop further to become process-oriented systems that incorporate forecasting (2.3). The forecasting systems must be able to take into account correlations between different generation and consumption forecasts in order to match planning and control to the most accurate possible forecasts of residual load (10.3).

In the next stage (2.4), the control systems are enhanced with the creation of open interfaces, through which forecasting systems, asset management systems and Demand Side Management (DSM) are incorporated. In addition, autonomous grid agents (AGA) are integrated into the control systems. For the asset management of grid components, this means that an interface to the grid control system is required (1.3). In the field of Wide Area Measurement Systems (WAMS), these must also be used at least sporadically in the LV grids (400 V) in order to supply the data required for integration of the AGAs (3.4). These must first be deployed in grid automation (4.4) in order for them to be integrated into the grid control systems. Ensuring that the AGAs measure, control and regulate components in the most economic way possible requires FACTS to allow both autonomous, grid-stabilising regulatory measures to be taken and the actuators to be coordinated adaptively (5.5). The use of a large number of interfaces by the grid control systems also means that these will need to access a large volume of data, which again will result in greater ICT requirements. Accordingly, data hubs will be required in order to ensure the required amount of connectivity is available (6.3). To introduce regulation concepts usefully at this stage, a standardised connection is required for large consumers and generation plants through corresponding plant communications and control modules (13.1). At the level of domestic customers, connectivity is ensured via a standardised Advanced Metering Infrastructure (AMI) (14.1). The number of interfaces requires a high degree of integration. As a result, standardised interfaces are a key prerequisite for connecting a large number of plants. The implementation of intelligent regulation concepts will also require semantically interoperable data models (17.4). These measures are needed to allow the data from various sources and contexts to be interpreted by automated processes in this comprehensive concept, while at the same time guaranteeing cost efficiency. This is also linked to the level of security that must be guaranteed. Experience gained in previous developments must be used to define and standardise corresponding security patterns (19.3).

In order to realise an automated, self-organising grid control system (2.5) there is a need for knowledge of synchronously time-stamped voltage, current and phase shift data at all necessary points in the grid. The WAMS needed to implement this must be designed in the form of mass-data capable management systems with the capacity for bidirectional communications (3.5). Consistent deployment in the LV grid will require a large number of components, which therefore must be available at low cost. The connection of components to the ICT infrastructure must be plug & play at this stage, so that the necessary control options can be guaranteed for all smart grid components (6.4). Among these components are generation plants, consumers and storage facilities that are to be connected via corresponding communication and control modules, even if they are small in size. At the domestic customer level, an Advanced Meter Management (AMM) system must be realised in order to make good use of the technical information produced at this level (14.2). The incorporation of automated energy management into the value chain (16.2) also creates a key prerequisite for the automation of grid control systems in industrial and commercial settings. In order to realise the necessary integration of all stakeholders, the management of data must form an integral component of all process changes relevant to the energy supply system (18.4).

Technology area 3 – Wide Area Measurement Systems

Initially, WAMS can be further developed without any dependency on other development stages. However, the issue of how WAMS can be used beneficially in the distribution grid (3.1) needs to be resolved.
Wide Area Monitoring Systems that are able to analyse the conditions

at distribution grid level (potentially of multiple grids) are then largely dependent on cross-cutting technologies and ICT connectivity (see figure 20). New tools that analyse the distribution grid data require data management technologies that are able to cope with the variety and volume of data concerned. (18.1). The "gathering" of data from many data sources requires at least basic inter-connectivity with the information technology infrastructure (6.1). All data on the sensors are stored in a database for this purpose. These prerequisites allow vendors to develop and market visualisation and analysis tools.

In order to integrate WAMS into further IT systems in the next development stage (3.3), corresponding syntactic standards must be used (17.2). Integrating WAMS data from many data sources usefully into the applications will require these data to be semantically enriched by the addition of the necessary meta data (18.3). This will allow the data to be evaluated more accurately, and more complex analyses to be conducted, such as investigation of whether the planned deployment should favour local optimisation over central or vice-versa, and what form the optimisation should take. In particular, meta data regarding data quality, sensor type, etc., must be passed to the analysis along with the corresponding information. As WAMS are already deployed at critical points in the distribution grid and are therefore key to maintaining system stability, security aspects have a key role, in terms of protection against anticipated attacks and natural disasters. The specific threat scenarios are understood and corresponding measures have been put in place. These include, in particular, the realisation of security patterns, which are publicly available and common practice in the realisation of security-critical systems (19.3).

If the WAMS should also be used in the LV grid (3.4), then an infrastructure for the energy data must be put in place for in the region of deployment. This allows compliance with the required QoS level so that the data needed to calculate the system condition are always available on time (6.3).

The additional complexity and cost of WAMS are only worthwhile if the systems in the distribution grid are comprehensively linked by ICT. This requires an energy data infrastructure that permits simple connections. If, in the highest development stage, WAMS are deployed throughout the distribution grid (3.5), and the grid automation relies significantly on these measurements, the highest level of requirements are made of the underlying ICT infrastructure (6.4). Both phasor measurement units

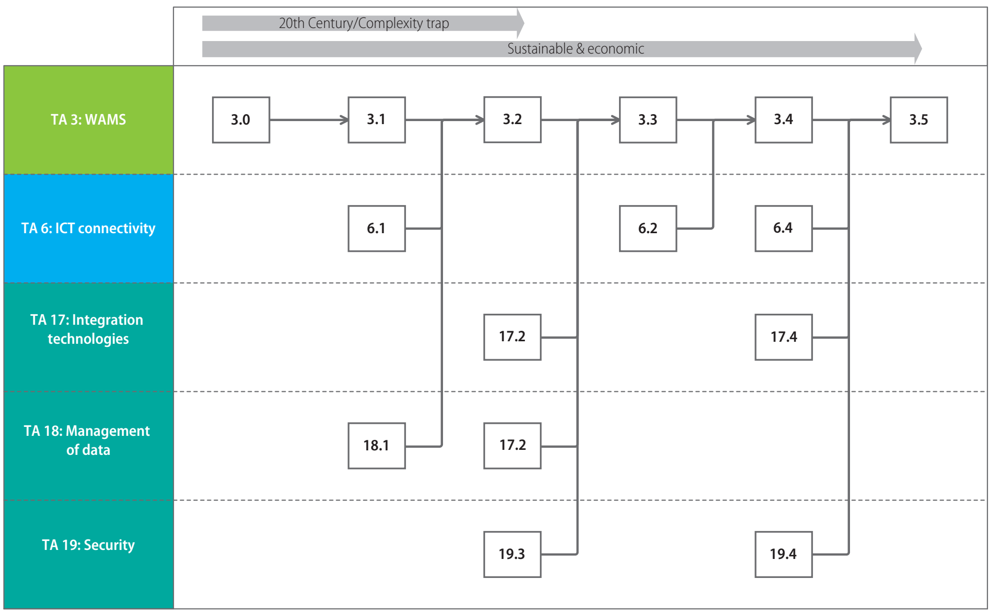


Figure 20: Dependencies of technology area 3 "Wide Area Measurement Systems"

(PMU) and other sensors are connected to the energy data infrastructure along with a large proportion of the generation and consumption systems. This platform secures the integrity and security of the data, ensures compliance with requirements for communications (QoS) and prevents usage by unauthorised persons. The integration of complex and heterogeneous intelligent electronic devices (IED) into this platform is accomplished by means of plug & play standards, which ensure semantic interoperability in particular (17.4). Since this system is based on IT at a high level, any attack on ICT components or even the failure of individual ICT components must not lead to restrictions in the energy supply system. Therefore, security requirements relating to the development of the system and the individual components are taken into account from the planning stage through the design and development stages to testing (19.4).

Technology area 4 – Grid Automation

Dependencies in grid automation result from the inter-connection of the necessary sensors and actuators (see figure 21). The realisation of consistent monitoring throughout the MV grid (4.1) as anticipated in the scope of the "20th century" scenario, first requires regional implementations of the ICT connectivity development stage (6.2) to ensure that the monitoring data can be accessed remotely. Management of data (18.1) must be assured in view of the rising data volumes. The grid automation system must be equipped with domain-specific security solutions (19.2). This stage involves not only the integration of new components, but also retrofitting to existing components to meet new requirements.

The deployment of actuators in the MV grid segments (4.2), which is anticipated in the scope of the "Complexity trap" scenario, is supported by the implementation of WAMS in the MV level (3.2) among other factors. In addition, in the context of FACTS active grid components in the MV grid and partially even in the LV grid must be taken into account (5.3). Standardised interfaces are used to connect the components to each other (17.2). Experiences from stage 4.1 are used to standardise tried-and-tested security measures and to take account of the resulting security patterns in implementing this stage (19.3).

The realisation of actuators in the LV grid (4.3) is supported by Area Management Systems (AMS) which offer similar functionality to WAMS (3.4). Together with the deployment options for FACTS in the LV grids, tested in stage 4.2, the LV level is also directly controllable.

The deployment of AGAs (4.4) to realise an autonomous, where necessary self-healing system (as anticipated in the "Sustainable & economic" scenario), makes high requirements of the WAMS or AMS, which must be further developed to become mass-data compatible bidirectional management systems (3.5). The FACTS must be able to coordinate active grid components across grids and voltage levels (5.4). Plug & play ICT connectivity is required for the large number of components in this development stage. Furthermore, this requires data management that can handle semantically interoperable data models (17.4) and semantically enriched data (18.3). The new physical and IT components must be developed according to security-by-design principles.

Technology area 5 – FACTS

FACTS will penetrate further into the distribution grids (5.1) and will therefore be more closely integrated into a coordination effort leading to the dependencies shown in figure 22. The components will be connected to a WAMS in order to be able to respond to grid problems within a system by altering power flows. The WAMS must be configured for a distribution grid (3.1). In order for power flows not to be diverted incorrectly by malicious attacks on the IT system and thus cause a system fault, the necessary security technologies must be available and in place. In view of the high volume of real-time requirements, side effects such as the effects of this on end-to-end performance must be managed (19.2). The integration of the FACTS requires at least standards-based syntactic interoperability. This means that application case-specific standards must be created for the domain, extending beyond the base standards if necessary, in order to satisfy non-functional requirements (17.2).

The inter-grid level coordination of FACTS in the next development stage (5.2, the highest stage for the "20th century" scenario) means that the security requirements will increase again significantly. The FACTS now affect each other and coordinate actions to fulfil their roles. This task would be put at risk even if just a few FACTS components were to fail. Therefore, the system design and development of the FACTS-IEDs must take account of design patterns and the developed security standards. The security-by-design approach

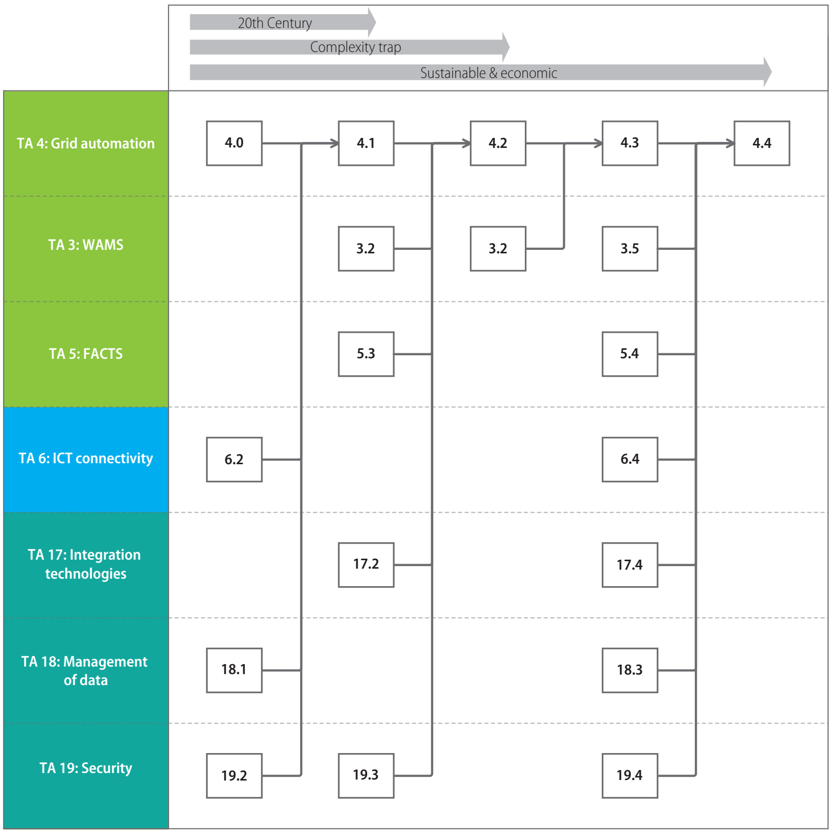


Figure 21: Dependencies of technology area 4 "Grid Automation"

is followed during the system development phase. In addition, comprehensive tools are used to improve security (19.4).

In order to take account of active LV and MV grid components in the cross grid level coordination processes (5.3, the highest stage in the "Complexity trap" scenario), at least a simple directory service must be available to take account of the potential of the systems so that this can be integrated together with the FACTS in the grid control system (6.1). WAMS components will be installed, and analysis and visualisation tools will be used for assessment purposes (3.2) in order to provide sufficient understanding of the grid condition. The evaluation of the findings of these systems will be used to direct the FACTS.

In the next stage, the FACTS communicate with each other and coordinate their actions (5.4). Therefore, the different grid levels are able to affect each other and provide each other with support. No modifications may be made to the interfaces of the FACTS-IEDs. Therefore, the ICT components must use semantic standards when communicating with each other (17.4). Use cases can then be applied to configure the IEDs. Point-to-point connections are less well suited to networking the IEDs in the distribution grid. Therefore, an ICT platform is needed that already guarantees provision of the established communications requirements and that is based on semantic standards. (6.4). To provide the FACTS with the required information, increased numbers of measurement devices, such as PMUs, will be needed in the distribution grid.

To allow the FACTS to successfully coordinate their actions with other grid components largely autonomously and without any central control and in real time (5.5, the highest stage reached in the "Sustainable & economic" scenario), the corresponding measurement sensors must be present in the grid down to LV level (3.4) in addition to the aforementioned developments.

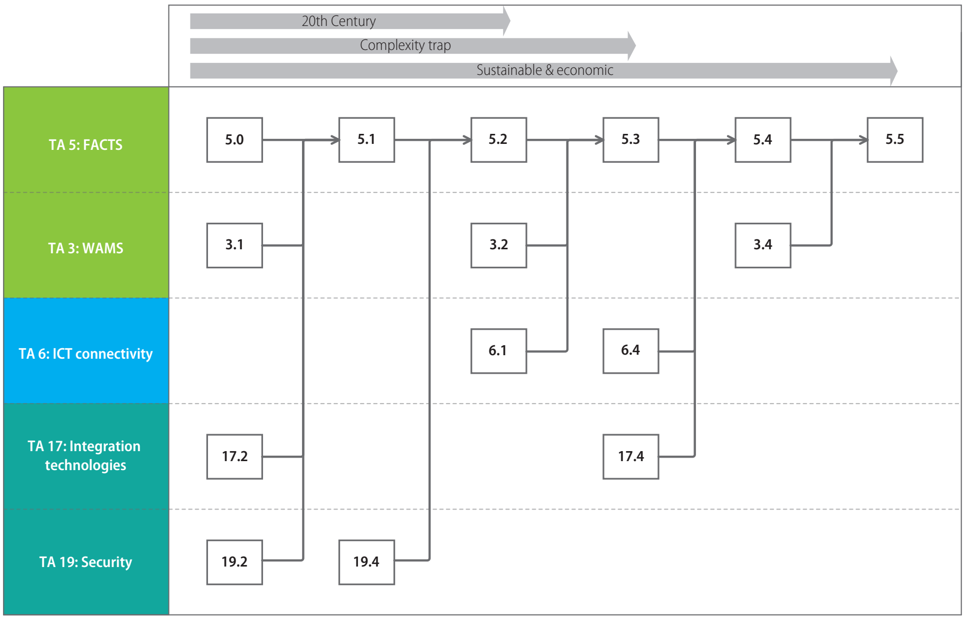


Figure 22: Dependencies of technology area 5 "Flexible AC Transmission Systems (FACTS)"

4.2.2 ICT INFRASTRUCTURE LAYER

Technology area 6 – ICT Connectivity

The technology area ICT connectivity provides the entire infrastructure that is used to realise the IT and communications connections to components in the energy supply system. It is thus a major prerequisite for realisation of an intelligent, information-based energy supply system.

Of vital importance for the successful realisation of the ICT connectivity is the development of the cross-cutting technologies (see figure 23). The integration of suitable security measures (19.2) is therefore essential for the construction of an information infrastructure, and this must be taken into account when realising the first connections within the distribution grids (6.1).

With the rapid expansion of the information infrastructure within the regional microgrids (6.2) as anticipated by the "20th century" and "Complexity trap" scenarios, the number of components to be connected rises too. As a result, effectively connecting smart grid components requires standardised interfaces and architecturally sound uncoupled information systems (17.2). As a result, the complexity of the data to be considered rises and with it also grows the number of requirements on the systems for data management in relation to availability and performance (18.1).

The further IT integration of the microgrids (6.3) increases the volume and synchronicity of information flows. Before realising this development stage, the data management systems must, consequently, be able to better structure the data by adding meta information (18.2). The expansion of the information infrastructure undertaken in this stage means that the available attack vectors also increase in number. Experience from regional deployment must therefore be prioritised to standardise tried-and-tested security measures and to allow the resulting security patterns to flow directly into the design process for the inter-regional ICT connectivity (19.4, security-by-design).

If the ICT connectivity is available across regions, and has been enhanced by the provision of plug & play connections as anticipated in the "Sustainable & economic" scenario (6.4), there will be a further major increase in requirements for integration technologies and data management. The plug & play connection of components requires

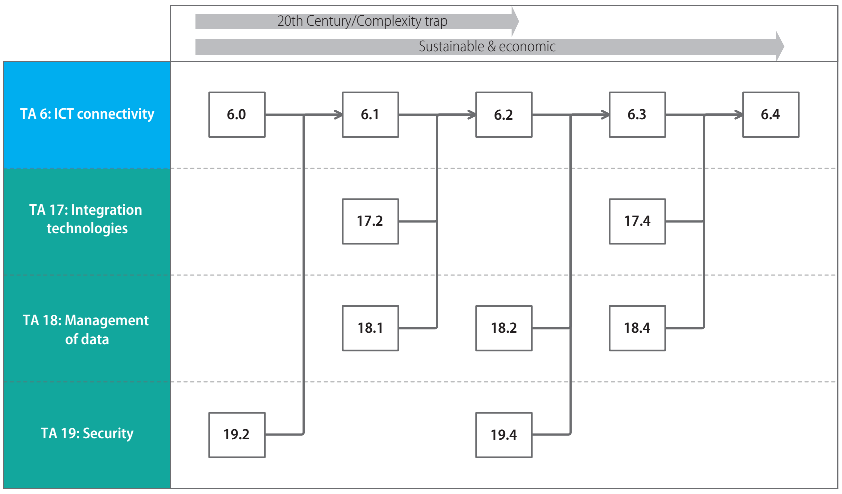


Figure 23: Dependencies of technology area 6 "ICT connectivity"

both syntactic and semantic interoperability (17.4). In conjunction with a suitably enriched data set and coverage of the energy sector process chains by the data management technology area (18.4) it will be possible to guarantee a stable IT foundation for the future energy system.

4.2.3 NETWORKED SYSTEM LAYER

Technology area 7 – Asset Management for Distributed Energy Resources

Asset management systems for distributed energy resources provide access to plant data to support the economic operation of those resources. At the current time, this area has as yet no end-to-end solutions that will be created in the process of the development shown in figure 24. When using asset management systems for larger distributed energy resources (7.1) these will first be made available for remote access functions by deploying plant communication and control modules (13.1). In relation to data management, it must be ensured that the system is able to handle the increased volume of data (18.1). In addition, the information security of the data connections must be guaranteed. Experience gained during the pilot projects may be used here to develop and integrate suitable security measures (19.1).

Following successful deployment of asset management systems for larger plants, it will be possible to transfer the selected approaches to smaller plants (7.2). Therefore there are no additional prerequisites for progressing this development stage, which is anticipated in scenarios "20th century" and "Complexity trap".

In contrast, the subsequent development stage comprises the process of making the asset management data useful in other application contexts (7.3): Energy trading and business services could benefit especially from this development. Therefore, there is a need for a flexible trading support tool into which these data can be incorporated. The support for flexible, cross-company processes also ensures the correct flow of information across organisational and company boundaries (11.1). In order for these communications channels to be realised, it will be necessary to standardise the required interfaces (6.1, 17.2). The increased level of networking also makes high demands in relation to security of communications. Experience from previous development stages can be used to take account of the security requirements as an integral component of the development process, and thereby achieve security by design (19.3).

The fourth development stage, anticipated in the "Sustainable & economic" scenario, is characterised by the further expansion of the networking of asset management systems (7.4). At least at this point, it will be necessary to integrate the asset management systems into the ICT infrastructure of the smart grid. Data exchange will now be required with the forecasting systems, to further increase the commercial viability of plant operations and enable true power output forecasting for

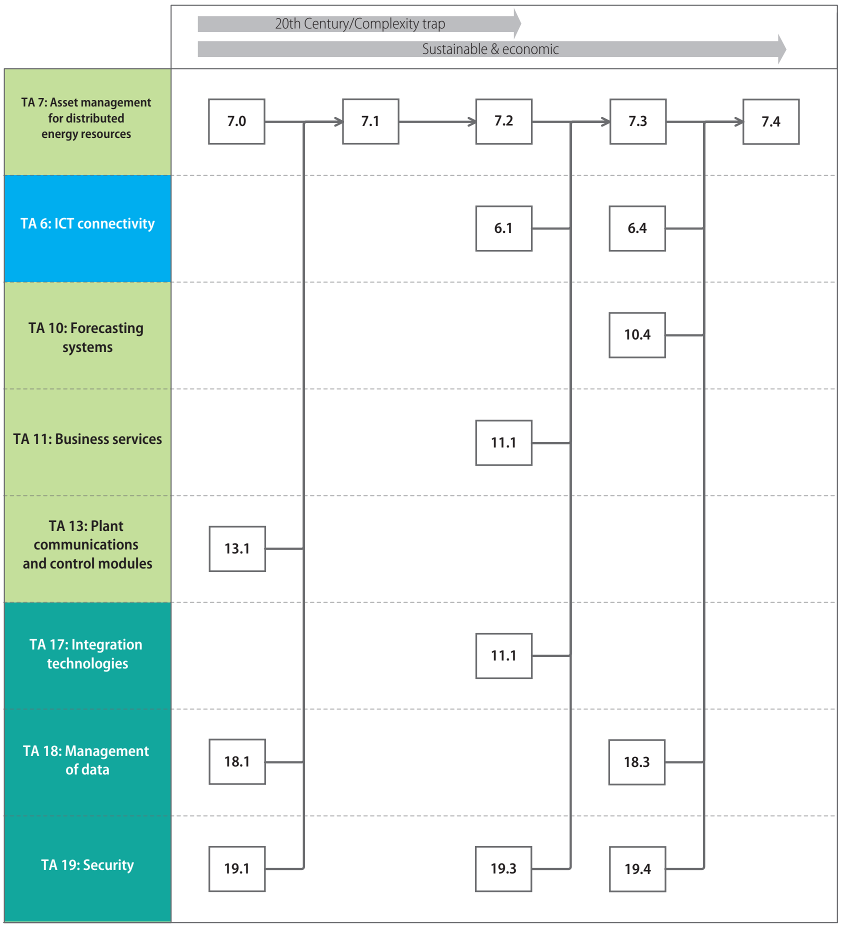


Figure 24: Dependencies of technology area 7 "Asset Management for Distributed Energy Resources"

distributed energy resources. The further increasing data volume must be dealt with in this development stage with the semantic enrichment of data. Otherwise, the lack of structure would significantly increase the complexity of data processing and analysis (18.3). Data exchange in the networked system and heterogeneous interfaces and processes require the implementation of comprehensive security measures. This will succeed if the system has been properly reinforced during the design phase and sufficient corresponding tools and experiences are available (19.4).

Technology area 8 – Regional Energy Markets

The dependencies of the regional energy markets result largely from the increased networking and subsequent data exchange (see figure 25). In order for larger plants to connect to a market platform and comply with the agreed deliverables (8.1, the highest stage achieved in the "20th century" scenario), reliable ICT connections and a directory-based plant discovery system are required (6.1). Service-Oriented Architectures (SOA) are used to ensure the necessary flexibility for process design. These use exchange formats such as eXtensible Markup Language (XML) to achieve interoperability (17.2). As the trading volume increases, the threat of fraudulent manipulation also rises. It will therefore be necessary to understand the risks and monitor operations (including by use of intrusion detection) in order to take defensive measures in good time (19.2).

In order for the integration of smaller plants in trading products and the processing of the associated transactions to be cheap and secure

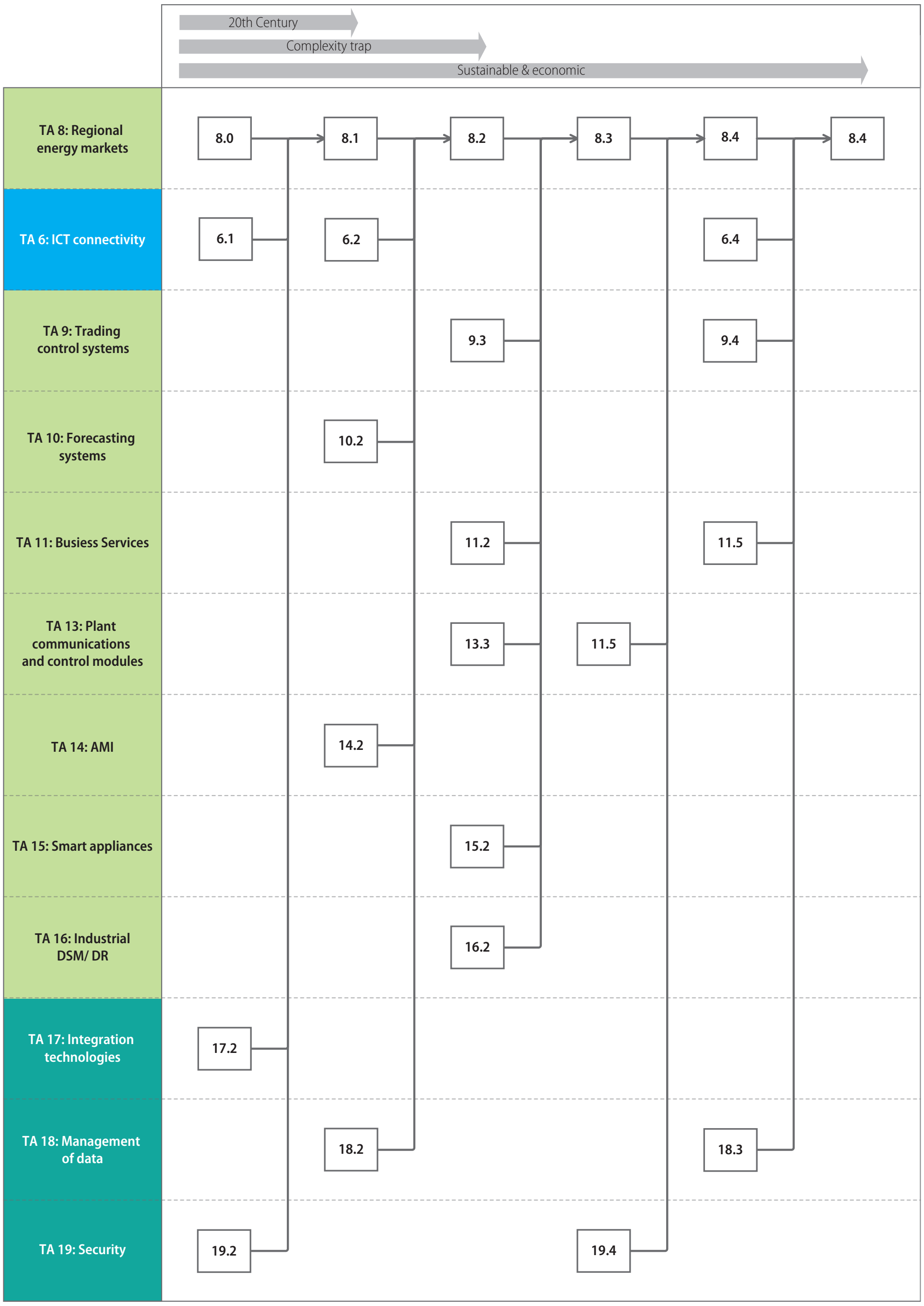


Figure 25: Dependencies of technology area 8 "Regional Energy Markets"

(8.2, anticipated in the "Complexity trap" scenario) there needs to be an infrastructure in which all of these plants are registered and connected (6.2). Improved forecasting tools (10.2) are needed for the marketing of wind power. To take advantage of flexibility on the market through corresponding designed products, consumers must be equipped with bidirectional digital meters. In part, these are able to transmit high-resolution sequences of timed measurements via the AMI to the grid operators (14.2). The consumption forecast allows the grid operator to calculate grid load per cable (10.2). The transmitted data are enriched with meta information (18.2) in order to avoid errors or faulty processing of transactions.

The requirements for transactions and the trading platform for products that are used for system services (8.3) also make more specific requirements of ICT. Participating households must fit a corresponding interface to their connected appliances, allowing customers to monitor their use at any time (15.2). The connection of a number of smaller plants requires the development and use of many new processes in Enterprise Resource Planning (ERP) systems, especially the provision of customer self-service to keep costs as low as possible (11.2). To allow energy traders to trade in the new products they need a system that is reliably able to forecast, analyse, visualise and place a financial value on the contribution of a number of small plants. Integration of end customers requires the functionality to simulate the effects of variable prices (9.3). In order to integrate smaller plants, these must be equipped with IEDs that allow low-cost integration and that support the corresponding algorithms to respond to market signals (13.3). To allow industrial processes to be integrated into the market, the controlling ERP systems or the Production Planning and Control (PPC) system must connect to the market via a trading system (16.2).

New bundled products comprising contributions from distributed consumers and generators (8.4) require a large number of plants that interact autonomously with the market (13.4). The connection to the European Energy Exchange (EEX) raises the possibility for allowing these volumes to be traded across Europe. This increases the security requirements, since security holes can both cause direct financial losses and put the reliability of supply at risk. These requirements can only be met if security is taken into account when the complex overall system is being constructed and is supported by security standards and tried-and-tested tools (19.4).

Regional markets form the cornerstone of the energy supply in the final development stage (8.5, achieved in the "Sustainable & economic" scenario). All smart grid components can be integrated into the market (6.4) without major complexity using the energy data infrastructure and standardised interfaces. For the integration of the many heterogeneous generation and consumption systems, analysis functions are needed in the trading systems to process the large volumes of data in real time, producing forecasts and joining up with the trading objectives and actively proposing decisions (9.4). The business processes associated with energy trading and services will be supported by corresponding IT services, ensuring complete end-customer integration (11.5). In order to evaluate the relevant data correctly in this context, these data must be linked and evaluated in real time (18.3).

Technology area 9 – Trade control systems

Data from many different sources must be integrated to provide information and support decision-making in the area of energy trading (see figure 26). For example, progress is required in the area of forecasting systems in order to enable bottom-up recording of trading positions and forecast data within a trading control system (9.1). These forecasting systems must be able to predict loads for commercial and domestic consumers alike, and must therefore access high resolution meter data, for example. Furthermore, greater geographical granularity is required for information on the generation of electricity from wind and solar power (PV) (10.2). When using these data for the purpose of short-notice trading, innovative data management techniques must be used to manage the heterogeneous nature of the data and the range of data sources (18.1).

The continuing convergence of trading-related functionality and visualisation of the data that are produced (9.2, ultimate development stage for the "20th century" scenario) result from the continued development of this area, however, and therefore have no additional external prerequisites.

The new calculation of costs for load shift potential represents a new level of quality, with which the effect of end-customer price signals can now also be simulated (9.3, final development stage for the "Complexity trap" scenario). To this end, it must be possible to correlate the costs of a range of forecasts with variable elements (10.3). The trading control system also uses virtual power plants (VPP) to trade in timetabled

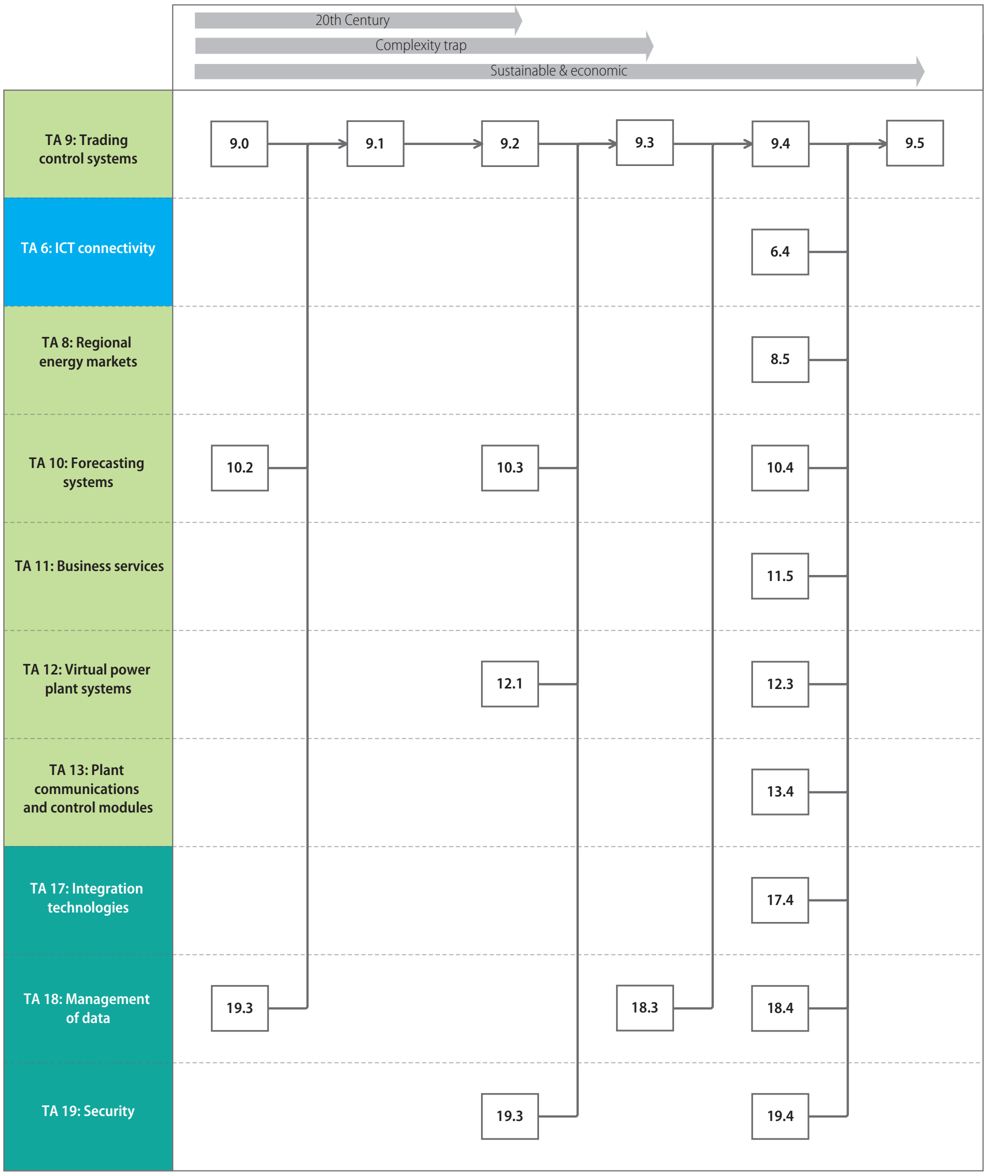


Figure 26: Dependencies of technology area 9 "Trading Control Systems"

products. Consequently, the VPP systems must understand and be able to operate timetables, and must also be remotely controllable. (12.1). These systems must ensure high standards of security in order to prevent loss and manipulation. The necessary design patterns and standards must be developed for this. These relate not only to the actual trading control desk and the communications connection to the exchange, but also to the connection to the networked system layer and detection of security problems with the connected components (19.3).

Improved data management functions are required in order to realise advanced analysis functions to support decision-making (9.4). These include the capability of evaluating meta data in order, for example, to assess the accuracy of forecasts, and the ability to find information through data mining that includes the data semantics in the evaluation (18.3).

In order for complete automation of trading through corresponding control systems (9.5, reachable in the "Sustainable & economic" scenario) to achieve the desired objectives, technological prerequisites must be met in several categories:

1. Reliable automation requires a high degree of reliability in decisions and system security (6.4, 10.4, 18.4, 19.4).
2. The cost/benefit ratio must be improved (8.5, 17.4).
3. Controlling of deployed resources must be more targeted (11.5, 12.3, 13.4).

Reliability:

An automated system must reach trading decisions that are as accurate as possible. One objective could be to maximise expected profit, taking account of a specified risk limit. First of all, the forecasts for anticipated plant output must be further improved (10.4). When it comes to market assessments, it may also be useful to query information from third-party systems (such as plants, markets and business services) in addition to the information held in the trading control system. This third-party information can be provided simply through the smart grid platform (6.4). Advanced analysis techniques are required (18.4) to be able to analyse the heterogeneous data in real time and in the context of trading decisions. Due to the many connections, the security requirements can still only be met if sufficient experience has been acquired from the implementation of secure systems and these findings have been incorporated into frameworks and tools (19.4).

Cost/benefit:

Deployment in the market will succeed if the energy market is established for smaller quantities, the technical prerequisites have been met and the transaction costs have been decreased accordingly. The greater trading volumes that will then result will reduce volatility and ensure less risk for traders. In view of the possibility of participating in energy trading through a range of products (active power products, reactive power, new flexibility products, system services) (8.5), a suitable portfolio can be selected and profit increased significantly. To keep the costs of IT integration as low as possible, standards and profiles for achieving semantic interoperability and off-the-shelf tools must support this integration (17.4).

Targeted controlling of resources:

To obtain high profits from sales, the available resources must be deployed efficiently. DSM functions integrated into the ERP systems can help control consumption and offer these services to the end customer through Customer Self Services interfaces (11.5). The latter will also help avoid costs and increase the reliability of decisions. The control of VPP systems that also use information from the distribution grid will help better tailor the plant deployment plan for grid-related products (12.3). To connect plants directly and allow them to control themselves so that the specified timetable is met as well as possible, corresponding IEDs must be developed and deployed. Advanced plants can even determine themselves which timetable promises the highest profits (13.4).

Technology area 10 – Forecasting Systems

Forecasting systems allow proactive planning and take data from a variety of sources, as shown in figure 27. In order to determine regional forecasts of fluctuating feed-in with a good degree of quality, for example, (10.1), information on anticipated or planned maintenance activities is required in addition to the weather. This can be obtained by connecting to the corresponding asset management systems (1.3). Wind power systems must currently be deactivated more frequently because of potential grid problems. However, if the grid condition can be included in the forecast, impending bottlenecks in the grid can be better predicted when forecasting the electricity supply. This requires measuring transducers, PMUs and sensors to take temperature, insulation and noise measurements (3.1, 4.1).

In order to supply improved forecasts for consumption (10.2, the ultimate development stage for the "20th century" scenario), high resolution load data must be produced by digital meters (14.1). Due to the larger quantities of data and range of different meters, advanced data analysis methods are used. These must accept various heterogeneous data sources. In addition to meters, these sources can include weather data and forecasts, and sociodemographic data, etc., to improve the accuracy of consumption predictions (18.3).

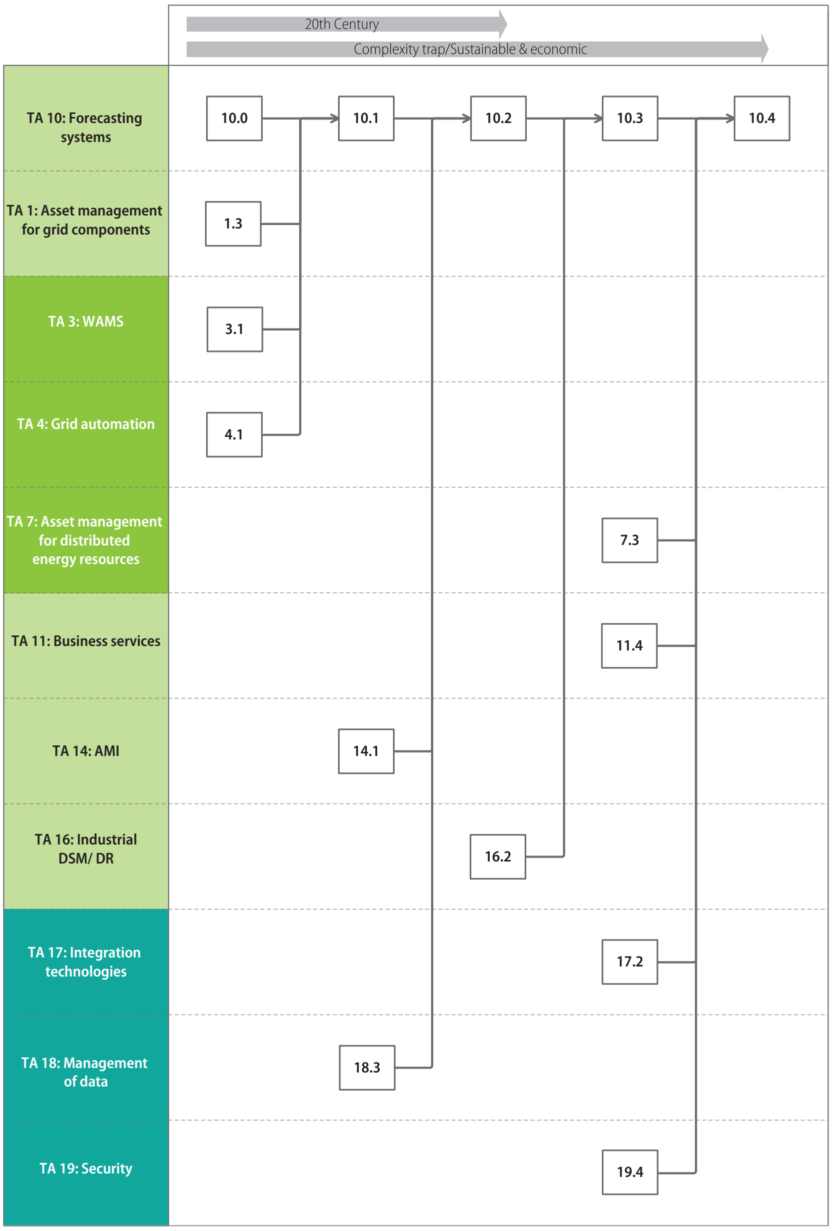


Figure 27: Dependencies of technology area 10 "Forecasting Systems"

The evaluation of correlations between different forecasts allows forecasts to be produced that are more accurate overall (10.3). Weather, consumption and generation forecasts are combined so that a detailed basis for decision-making is available to allow selection of a suitable control mechanism. As a result, the effects of variable tariffs or other feedback or information systems on electricity consumption can be assessed (price elasticity). For industrial DSM, therefore, system services (load and generation adjustment for overall frequency stabilisation and local voltage control) and energy procurement management must be integrated fully into the production process

ERP systems (EMS - energy management systems) so that the available adjustment potential can be exploited usefully (16.2).

For the creation of plant-specific forecasts (10.4, achieved in the "Sustainable & economic" scenario) the plant data and history must be taken into account. This is retrieved from the asset management systems (7.3). Customer Self Services provide access to additional information that can be incorporated into the forecasts. The integration of major customers' EMS enables improved assessment of the required electricity (11.4). As the forecasting systems evaluate data from many other systems and need to integrate additional systems flexibly and rapidly, a flexible architecture concept and standardised, open interfaces are needed (17.2). To combat threats, a mature security architecture and corresponding tools (19.4) are required for the now mission-critical use of forecasting and networking with many other systems.

Technology area 11 – Business Services

In order to support processes that relate to customers, multiple organisational units or companies with corresponding business services, access must be provided to the required data and systems (see figure 28). Today, information that is needed for a process is frequently held in a variety of different systems and is therefore very complex to evaluate. A key step is the integration of systems in which resources and other systems are managed (11.1). For this purpose, the asset management systems must be equipped with standardised interfaces or later even with data models that allow consistent data access and maintenance (1.2). SOA are used to integrate systems flexibly into the ERP system (17.1). The data required for this may also be supplied by the plants. To accomplish this, a directory service must be provided containing information on how to access plant data (16.1). The security mechanisms used should meet the specific characteristics of the energy sector, in order to broadly avoid the side effects of the standard solutions (19.2).

In order to carry out real time analyses (11.2), the necessary data must be available and accessible. The procurement of data from distributed resources requires an infrastructure to which these resources are connected, at least at regional level (6.2).

The use of cloud computing by energy utility companies and grid operators (11.3) entails standardised, cross-company data access and corresponding data processing. Security solutions and tools must be provided that are sufficient for the services offered in the cloud and also for communications with distributed plants. These must be planned as an integral component (19.4) when designing the system architecture.
Linking the EMS of the major customers to the business services of energy utilities (11.4, ultimate development stage for the "20th century" and "Complexity trap" scenarios) enables more effective usage to be made of DSM potential for both parties. This requires an AMM that forms the structure for communication between the energy utility and the customer in respect of energy management (14.2).

With complete end-customer integration (11.5, achieved in the "Sustainable & economic" scenario) it is possible to integrate processes and appliance control into energy-related business services for small and large industrial end-customers alike. This requires the option to integrate appliances and plants easily into the communications structure. The interfaces are self-describing and the system authentication transparent (6.4). In order not only for the plants to be easily connected, but also for the functionality of the corresponding IED to be used fully by business services, the latter must be able to evaluate and process timetables and other standardised information (13.3). As it is not anticipated that customers will react themselves to DR (Demand Response) signals, these must be transmitted directly to the appliances that can then optimise their energy consumption according to the demands of the user (14.3, 15.4). To integrate business services offered by the energy utility into the production processes of a customer, industrial DSM must be incorporated into the customer's ERP systems and integrated into the control systems (16.2). Such deep integration of very heterogeneous systems will only succeed if standardisation has become very advanced. The standards must allow integration without the need for modifying any software. As the services are also standardised up to a certain extent, or at least configurable according to the level of demand, these can be obtained through an energy cloud (17.5). In view of the large number of connected plants and software systems, the data management system must be capable of recognising all of the data of relevance for a given process and of semantically integrating this information, which may come from a variety of sources (18.4).

Technology area 12 – Virtual Power Plant Systems

As shown in figure 29, the first stage comprises the provision of VPP systems that can calculate and manage timetables for a group of

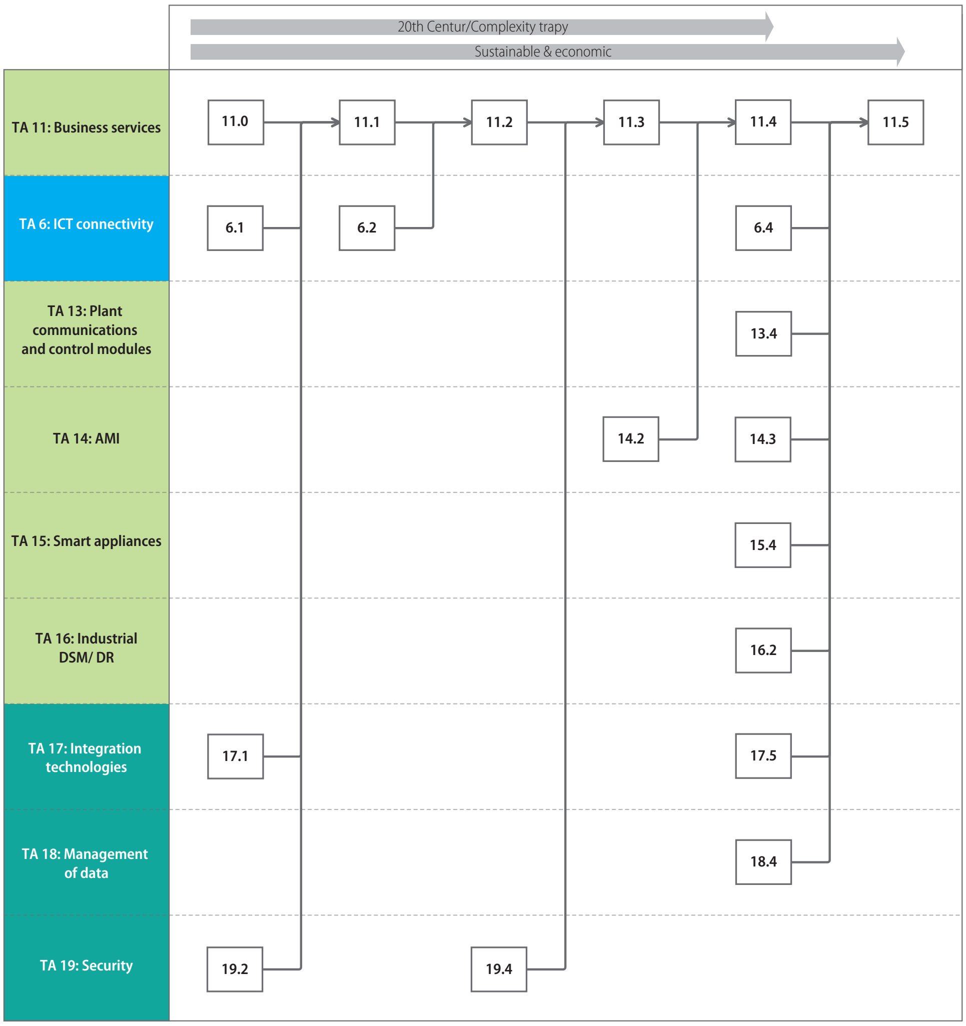


Figure 28: Dependencies of technology area 11 "Business services"

distributed energy resources (12.1, the ultimate stage for the "20th century" and "Complexity trap" scenarios). The development, marketing and operation of such systems is only economically viable, however, if the plants are easy to locate and integrate into the VPP system. For this purpose, the plants must be integrated into a simple energy information structure via ICT components (6.1). Application-case specific security standards must be developed from the available standard security measures for use by the communications connection. The potential side effects, such as performance loss or limitations due to complex access rules, are tolerated initially, as there is no real time requirement (19.2). Forecasting tools are required in order to integrate fluctuating generators in a timetable model. The forecast must be triggered locally, especially if grid requirements are also to be taken into account (10.1).

As development progresses. standards will allow increasing numbers of small plants to be integrated into VPP systems (12.2). On the side of the plants, IEDs are required that understand the timetables (13.2). Where no standards exist for integration, only very simple functionality can be used and plants from a limited range of vendors can be integrated. As syntactic standards and an energy information infrastructure provide information to query the plant interfaces, the plants can

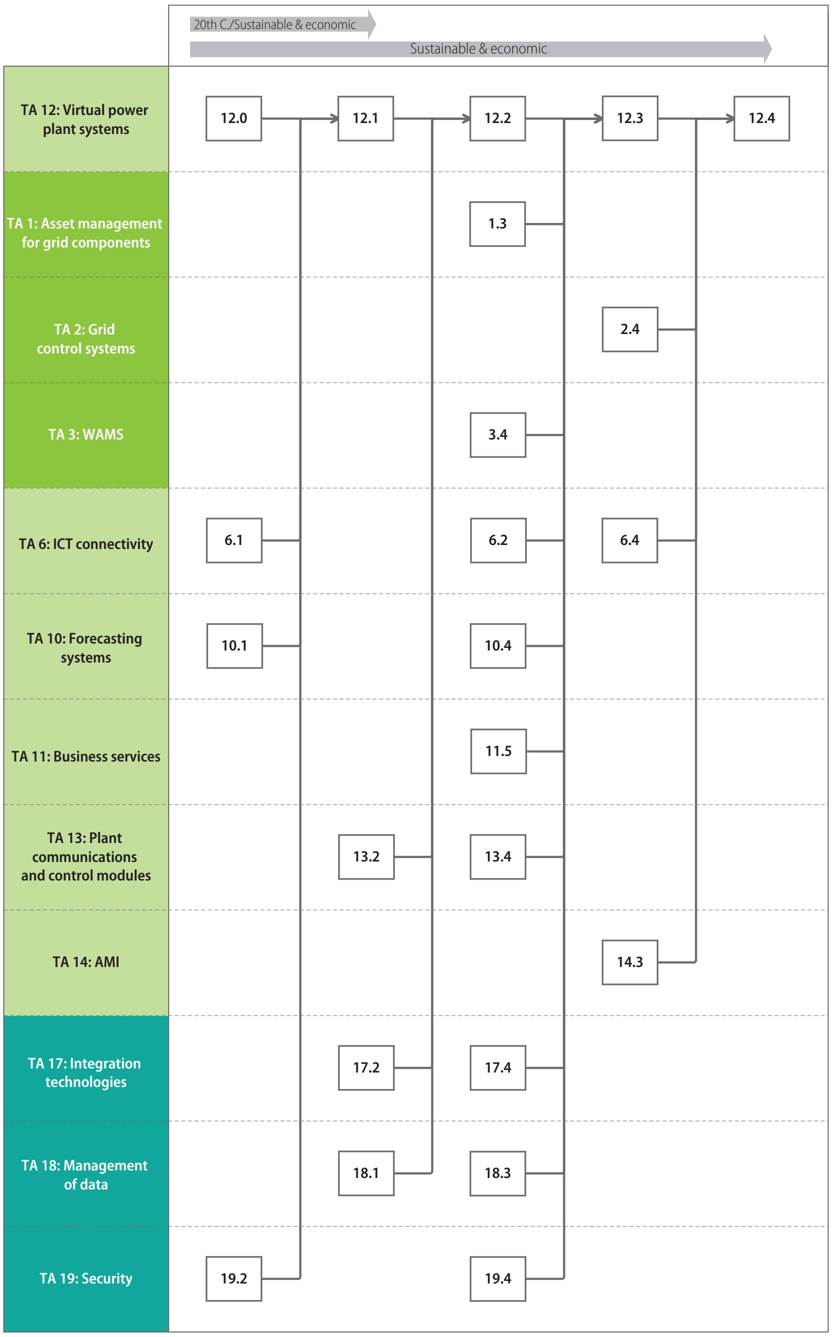


Figure 29: Dependencies of technology area 12 "Virtual Power Plant Systems"

then be integrated with at least basic functionality if no plug & play standards have been developed (17.2). To support a fast response to timetable variations, a large number of individual timetables can be distributed in real time to a large number of plants. This is made possible using technologies such as data stream management to manage data (18.1).

In this stage, the VPP system is able to make autonomous control decisions (12.3) thanks to the data supplied from the grid sensors and the attached generation and consumption systems. VPP systems are also used in local substations to have a stabilising effect on a grid segment. The procurement of information must be significantly improved for this. The asset management systems for the grid components contain information about the plant condition and history, and therefore enable the resources to operate at greater capacity utilisation levels (1.3). WAMS data are processed to enable fast reactions to the requirements of the distribution grid (3.4). Data must be comprehensively semantically enriched to allow more advanced analysis. This makes it easier to work with missing or faulty data, for example (18.3). In addition to real time processing – responding to events in the electricity grid and the market – improved forecasts must be used to optimise planning. These not only have to predict consumption, but also assess the response to variable tariffs or predict small renewable energy plants so that planning for responses to fluctuations will be possible down to the individual cable (10.4). The connection to the plants must be low-cost and offer the appropriate service levels. For this purpose, a single energy information infrastructure must be created per grid area, to which all plants are connected and which provide services to the entire system, for example allowing the VPP system to locate all plants with specific properties (6.2). Cheap and reliable connections are guaranteed by uniform architectures and semantic standards along with the matching tools (17.4). In relation to the plants, the integration prerequisites must also be met. Therefore, the plants must also be plug & play. Local intelligence is available (13.4) to help them respond to new timetables The complex system is protected against attack and faults, with the highest levels of security requirement. No side effects, such as performance impairments, are permitted. The system has been designed to be secure from the very beginning (19.4). Business services keep pace with this development. They are capable of being deployed for multiple types of participant. All participants can access or modify these support services directly (11.5).

In the final development stage, as anticipated in the "Sustainable & economic" scenario, the energy supply system primarily makes use of VPPs that are connected to each other and coordinate their activity with each other (12.5). The grid control technology works in close conjunction with the VPP systems. At LV level in the local substations, the difference between VPP systems and grid control systems (2.4) becomes fuzzy. All of the major components are integrated into the ICT infrastructure and enable interactive data exchange. Grid agents can access all plants, although grid assets remain in a closed area (6.4). Even small consumers can be integrated into the VPP systems. In buildings and domestic households alike, this includes appliances and the buildings management systems, so that consumer appliances can be addressed directly or via a gateway (14.3).

Technology area 13 – Plant Communication and Control Modules

Plant communications and control modules for generation plants, consumers and storage facilities ensure the integration of components into the ICT infrastructure of the smart grid, so that they are able to communicate measurements or provide control functions. They are therefore primarily reliant on the development of cross-cutting technologies to provide improved connectivity between the open and closed system layers (see figure 30).

Initially, corresponding modules will also be used for generation plants between 30 kW and 100 kW, and for thermal large consumers from 100 kW. A standardised connection will be used for this (13.1, maximum development stage for the "Complexity trap" and "20th century" scenarios). As a result, the number of integrated plants will rise and the connection will become simpler in comparison with the proprietary solutions in use today. The expanded area of use will require progress to be made mainly in respect of security measures and improved ICT connectivity. Firstly, the side effects of the security solutions must be detected in the systems and corresponding solutions integrated into the running systems, so that the number of communicating plants can be increased without causing security risks (19.2). Secondly, a basic directory service must be established, in which the plants that are equipped with the modules are listed (6.1). Of key importance is the ability to call up technical information according to the communications capability of the plant, so that standardised connections can be realised (17.2).

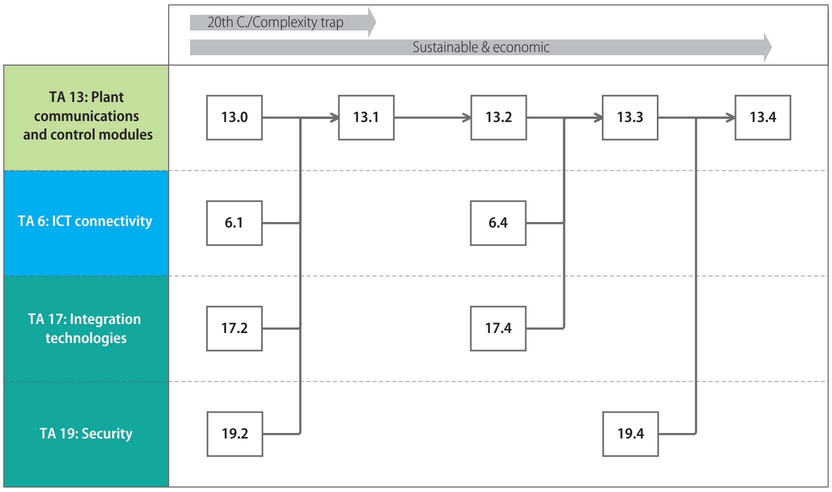


Figure 30: Dependencies of technology area 13 "Plant Communications and Control Modules"

This progress also entails prerequisites for the second development stage (13.2). The number of plants that can be contacted via ICT is further increased and the cross-cutting technologies follow this development. Variable control concepts can be developed internally and have no additional external prerequisites.

The third development stage (13.3) in contrast requires progress in the area of integration technologies and ICT connectivity. For example, it is necessary for platforms to be made available in the form of standardised solutions, so that unidirectional plug & play can be enabled. This also requires development in semantically interoperable data models, enabling the exchanged data to be interpreted without error or further cost (17.4). Moreover, depending on permissions, the plants can obtain the necessary information about the overall system so that they can respond independently to their own environment once the ICT connectivity provides this functionality (6.4).

The strongly increasing proliferation of control modules with the option for bidirectional communications (13.4, reached in the "Sustainable & economic" scenario) makes higher demands in terms of security measures. New plants that already integrate communication interfaces and control components have been developed according to the principles of security by design (19.4). The development of control functions and communication interfaces takes account of potential risk scenarios. The self-configuring integration into the communication network and increasingly intelligent control concepts (both local and distributed) can be realised on the basis of developments achieved in previous stages.

Technology area 14 – Advanced Metering Infrastructure

Development of the AMI depends mainly on ICT connectivity and cross-cutting technologies (see figure 31).

The creation of initial ICT infrastructures at distribution grid level (6.1) is therefore required for the use of a standardised AMI (14.1). The required interfaces must be provided in standardised form (17.2). Since the volume of data will rise rapidly with the construction of this infrastructure, the data management technologies must be adapted to this growth (18.1). In order to secure the connection, measures are required that take account of domain-specific factors (19.2).

When it comes to construction of an AMM (14.2) as anticipated in the context of the "20th century" and "Complexity trap" scenarios, additional options for real time data analysis are needed (11.2). In this way, processes can be optimised on the basis of the data supplied by the AMM. In the scope of the management and analysis, the meta information must be included for the data (18.2) since information such as data origin and quality is of vital importance for processing meter data.

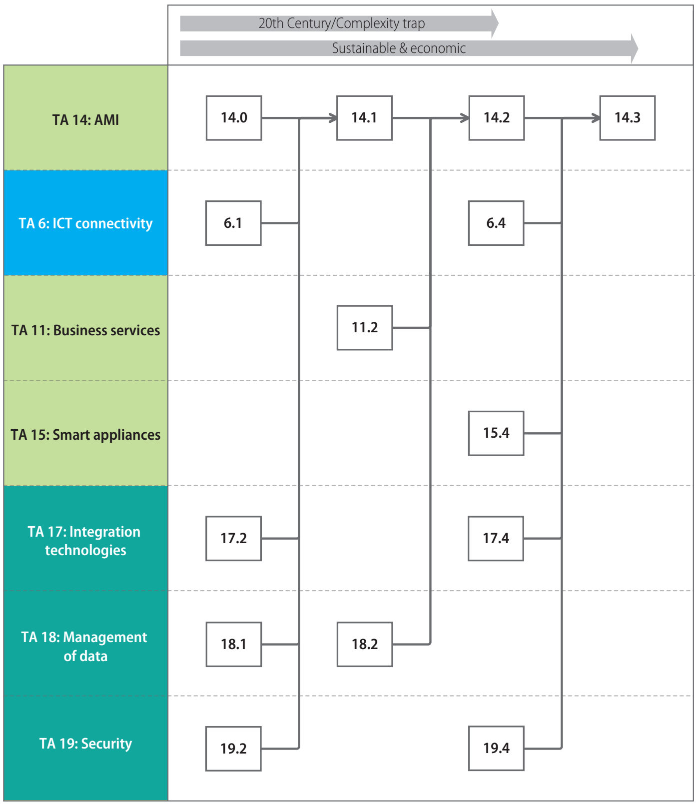


Figure 31: Dependencies of technology area 14 "Advanced Metering Infrastructure"

The final development stage in this technology area (14.3) describes the move of the coordination and control functionality from the AMM to the individual applications and appliances (smart appliances, smart homes, etc.) in order to realise an economically sustainable energy supply system. This stage uncouples the registration of measurement data from the application and appliances control and communications. To bring the stage to its conclusion, plug & play connections are required both for ICT connectivity in the form of the infrastructure (6.4) and at the layer of the smart appliances themselves (15.4). Semantically interoperable data models (17.4) permit the connection of applications and appliances, and the realisation of autonomous intelligence. Due to the further distribution of functionality, the components used must comply with the principles of security by design (19.4).

Technology area 15 – Smart Appliances

Smart appliances support services and functionality for energy management within domestic households. These services can create value added within the households themselves, or also provide energy services externally as a form of DSM. The latter is primarily anticipated in the scope of the "Sustainable & economic" scenario, while the functions offered in the scope of the "20th century" and "Complexity trap" scenarios will be largely confined to the households themselves. The prerequisites for this technology area are located in the information infrastructure and cross-cutting technologies areas (see figure 32).

Energy management using large thermal consumers (heat pumps, heating systems, air conditioning systems, 15.1) can primarily be realised using current technology. In order to guarantee the operational security of these controllable components, security solutions designed for these application contexts must be specified (19.2).
The use of large household devices for energy management (15.2) also requires new communication structures. Accordingly, the initial ICT connections must be configured within the distribution grid (6.1) in order to deal with both the increased number of appliances and the

different load patterns of the different appliance classes, and to test the potential control options. Deployment of an AMM (14.2) is expected as the primary communications interface into households for the purpose of establishing the grid condition within the LV segments. Standardised interfaces (17.2) are required in order to ensure cost efficiency and thus to promote the take-up of corresponding appliances. The appliances and their communication modules must be developed using security-by-design principles (19.4) to prevent misuse and data manipulation.

Semantically interoperable interfaces (17.4) are required in order to use smart appliances along plug & play principles (15.3). In addition to simpler configuration, these interfaces will also meet the initial prerequisites for self-organised operation of the appliances.

The increased number of smart appliances and growing autonomous functions (15.4) require semantic enrichment of data during the subsequent development stages. Together with the communication interfaces realised in the preceding stage, such a form of data management will create opportunities for higher value services.

The developments described primarily enable smaller appliances to be integrated too (15.5). It is anticipated that this development will arise naturally, based on the experiences of the preceding stages.

Technology area 16 – Industrial Demand-Side Management/ Demand Response

Only two development stages were identified for the industrial Demand Side Management/Demand Response technology area. The first stage is achieved in the "20th century" scenario, while the second stage comes in the "Complexity trap" and "Sustainable & economic" scenarios (see figure 33).

In order to enable industrial operations to respond to time-variable tariffs via service providers (directly or indirectly), thereby obtaining differentiated load shifting options (16.1), it is necessary to further develop the grid automation. Consistent monitoring in the MV grid must be in place in order to use the resulting measurements to calculated corresponding load-related tariffs (4.1).

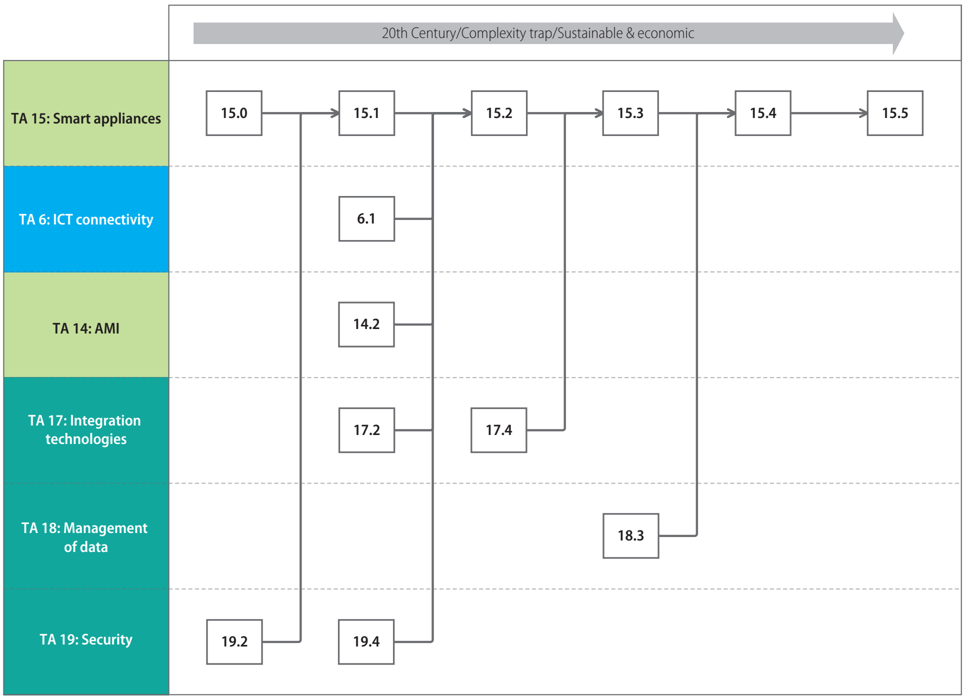


Figure 32: Dependencies of technology area 15 "Smart Appliances"

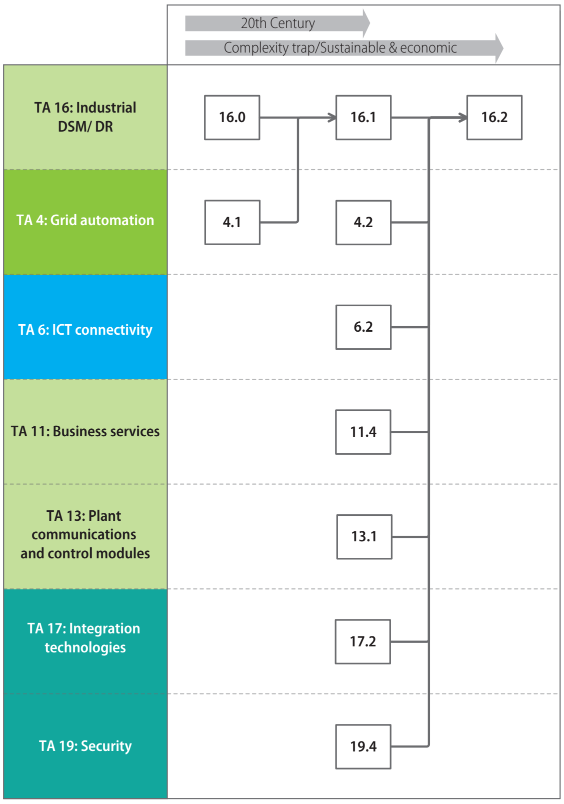


Figure 33: Dependencies of technology area 16 "Industrial Demand Side Management/Demand Response"

In order to integrate all industrial customers into DSM (16.2), monitoring using appropriate sensors must also be extended in the LV segments (4.2) to support grid automation, as with the aforementioned situation regarding the MV grid. Equally, ICT connectivity must be improved to ensure that all industrial customers can participate in DSM. At the very least, this requires the implementation of isolated solutions, although these may cover an entire energy utility company's system that offers its prices via DSM (6.2). Moreover, the EMS of the industrial customers must be integrated into the business services of the EUCs so that the potential DSM options on both sides can be exploited profitably (11.4). In order for the industrial customers to be integrated into concepts such as VPP, thus improving the flexibility of the adjustment potential, the foundations must be laid in the form of primitive functions in the scope of plant communication. (13.1). In respect of cross-cutting technologies, progress is required in both integration technologies and security. Accordingly, standardised interfaces must be offered that guarantee seamless data exchange (for example of prices or for plant control) (17.2). Since the development and integration of these systems by industrial customers represent innovative implementations, it is recommended that the security requirements be taken into account and implemented directly during the implementation phase (19.4).

4.2.4 CROSS-CUTTING TECHNOLOGIES

As the IoE and smart grids depend heavily on ICT, the relationships with and between the cross-cutting technologies are explored here. Although these represent largely independent development pathways, they are also prerequisites for many development stages of the other technology areas.

Therefore, the technology area integration technologies has no conditional development stages that must be put in place by other technology areas. However, from the opposite point of view, the concepts such as standardised interfaces and semantically interoperable data models must be implemented correctly in context for many of the technology areas.

The same is true of data management. As a cross-cutting technology it is largely independent of the other technology areas. The only prerequisites are put in place by integration technologies (see figure 34). In order to manage energy sector data throughout and beyond all process chains (18.4), corresponding semantically interoperable data models are required (17.4). Equally, before being able to realise data management via the cloud (18.5) basic prerequisites in respect of a corresponding application architecture must first be met (17.5).

As security is not a factor that can be generalised, but must be considered separately for each individual implementation, there are also no general technology areas that can be defined as prerequisites for it as a technology area. Accordingly, the various properties of security measures must be developed in context, as appropriate.

In the following sections, therefore, the perspective is reversed. Looking from the point of view of the development stages of the cross-cutting technology areas, the next sections identify the general technology areas for which they are prerequisites.

Technology area 17 – Integration technologies

As a technology area, integration technologies serve to ensure interoperability between the various subsystems of the Internet of Energy. This area therefore represents a key prerequisite for the development process of nearly every technology area (see figure 35).

SOA (17.1) provide a key impetus for strengthening customer processes and supporting workflows across organisational units or even entire companies (11.1).

Standardised interfaces (17.2) are of major relevance for all technology areas. In the closed system layer, corresponding arrangements are essential in preparation of data processing concepts for WAMS (3.3), for the wide-area connection of actuators for grid automation (4.2) and for integration of FACTS in WAMS (5.1). In the networked layer, the provision of standardised interfaces is equally important since these enable the creation of an IT infrastructure in the scope of the regional microgrids (6.2). In respect of connected applications, the use of asset management data from distributed energy resources by third-party systems (7.3), the connection of industrial customers to regional markets (8.1) and the improvement of accuracy in forecasts by the use of additional data (10.4) are dependent on the creation of corresponding interface specifications. The provision of energy timetables for VPP systems (12.2), distribution of plant communication and control modules for generation plants with output of between 30 kW and 100 kW (13.1), the construction of an AMI (14.1), smart appliances with relevance for the energy supply system (e.g. DSM via white goods, 15.2) and the comprehensive integration of energy management into industrial and commercial value creation processes (16.2) cannot be realised efficiently without such specifications either.

Building on standardised interfaces and practical experience gained during projects and/or the regional construction of new infrastructure to realise a smart energy supply system, reference architectures will be able to be formulated in the course of subsequent development (17.3). These will benefit the optimisation of new installations in the IoE without forming a mandatory prerequisite for other technological development pathways.

Semantically interoperable data models (17.4) enable semantic interoperability on the basis of syntactic interoperability (which is realised by standardised interfaces). Semantic interoperability is needed when a process integrates a number of layers (both applications and data) as is the case in the advanced development stages of the technology areas. For example, the deployment of AGAs in the scope of grid control technology (2.4) and grid automation (4.4), the widespread use and high granularity of WAMS (3.5) and the capability to coordinate active grid components (5.4), lead to a major increase in the number of internal and external interfaces from the previously closed system layer. In the networked system layer, a corresponding rise is anticipated in the communication interfaces to be specified in the context of trade automation (9.5), networking of VPP systems (12.3), smart connection of industrial plant communications and control modules (13.3) and domestic smart appliances (15.3). The communication between components, which is more direct as a result of these developments, and the consequential move of functionality away from the AMI (14.3) particularly requires the specification of semantic interfaces.

The use of cloud computing (17.5) for the purposes of integration will be necessary for the realisation of complete end-customer integration in the context of corresponding business services, but this entails no mandatory prerequisites for other development stages.

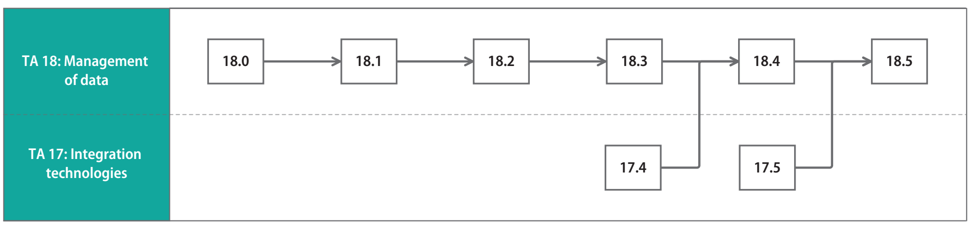


Figure 34: Dependencies of technology area 18 "Management of Data"

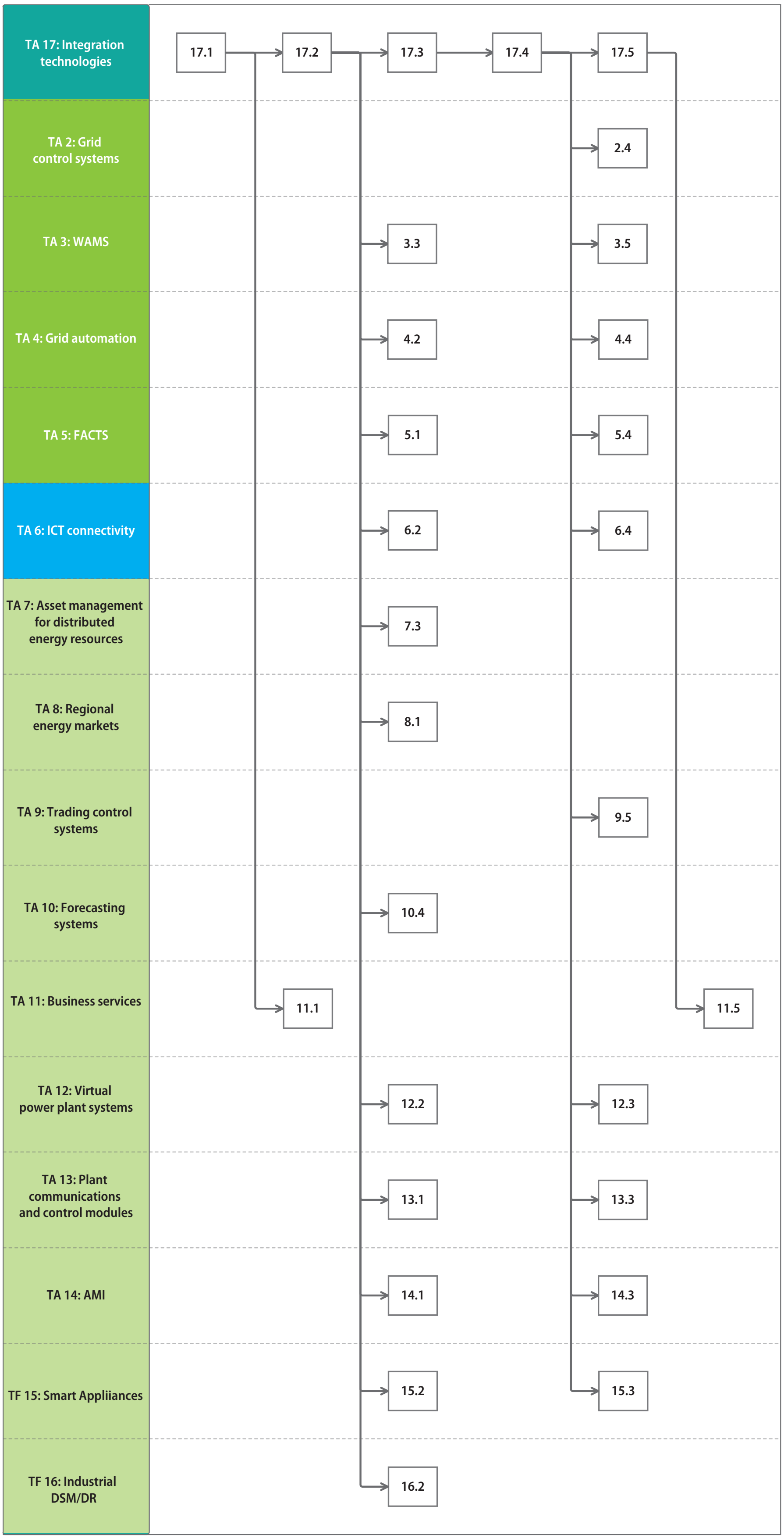


Figure 35: Prerequisites met by technology area 17 "Integration technologies"

Technology area 18 – Management of Data

The data management technology area, like the other cross-cutting technologies, is also associated with almost all of the other technology areas (see figure 36).

The first development stage, the handling of large data volumes, (18.1) is the prerequisite for developments in a number of technology areas that have development stages with increased communications requirements or increased numbers of communicating parties. In the closed system layer, an increased volume of data is anticipated from the system-wide registration of information by the asset management systems (1.2), condition monitoring in the MV grid by grid control systems (2.1), the provision of visualisation and analysis tools in conjunction with WAMS (3.2) and from the end-to-end monitoring in the MV grid for the purpose of grid automation (4.1). In the area of ICT connectivity as a networking layer, the realisation of the first isolated solutions must be able to process increased data volumes (6.2). In the open system layer, the introduction of asset management systems for larger distributed energy resources (7.1), implementation of suitable aggregation functions for trading control systems (9.1), creation of energy timetables for greater numbers of small plants in VPP systems (12.2) and a standardised AMI (14.1) all require the ability to process larger amounts of data reliably.

The inclusion of meta data when processing exchanged information (18.2) provides a basis for development of a range of technology areas. Above all, meta data concerning the origin and quality of the exchanged data are of major importance in allowing the reliability of the information of each evaluation to be assessed and corresponding control actions to be undertaken. For example, with the introduction of data hubs, ICT connectivity is reliant on a high level of data quality (6.3). In the open system layer, two technology areas are affected in the regional markets and AMI. The first of these requires the processing of meta data for the option of working with DSM (8.2), while the latter is needed in the realisation of AMM concepts (14.2).

The third development stage in data management describes semantically enriched data that are assessed after being physically disconnected from their source system and form the basis for automated processes (18.3). Within the closed system layer this development stage thus provides a prerequisite for data processing concepts in WAMS (3.3) and for the deployment of AGAs in grid automation (4.4). In the scope of the open system layer, a number of other technology areas are reliant on this development stage. For example, the data that asset management systems require for distributed energy resources must be physically independent in order for external costs to be integrated (7.4). Furthermore, a high degree of automation is necessary to integrate all systems into regional markets, thus transforming them into integral components of the energy generation process (8.5). In order for trading control systems to be able to offer active support for decision making (9.4), the data sources that are used must be analysed to ensure that they can be used to obtain information. This is ensured by semantic enrichment of the data. Semantically enriched data are also needed for forecasting systems to obtain greater geographical granularity in PV and wind forecasts (10.2). The use of AGAs for VPP systems (12.3) also relies on semantically enriched data to form the basis for automated workflows. Finally, smart appliances also need this form of data management in order to connect all appliances within a control system (15.4).

The final relevant development in data management is concerned with the management of data through the entire process chain (18.4). This forms the basis for four development stages of other technology areas. In the closed system layer these comprise the development of automation for grid control systems and their ability for self-repair or healing (2.5), in ICT connectivity they comprise the provision of plug & play connections (6.4) and in the closed system layer they comprise both the complete automation of trading by trading control systems (9.5) and the complete integration of end-customers by corresponding business services (11.5).

While cloud-based data management (18.5) is an innovative development stage, it is not seen as a prerequisite for the development of any other technology areas and is therefore not considered any further in this analysis.

Technology area 19 – Security

The security technology area is linked to all other technology areas except for the cross-cutting technologies and asset management for grid components (see figure 37), the latter since it is concerned mainly with a closed system that offers little opportunity for attack. Development

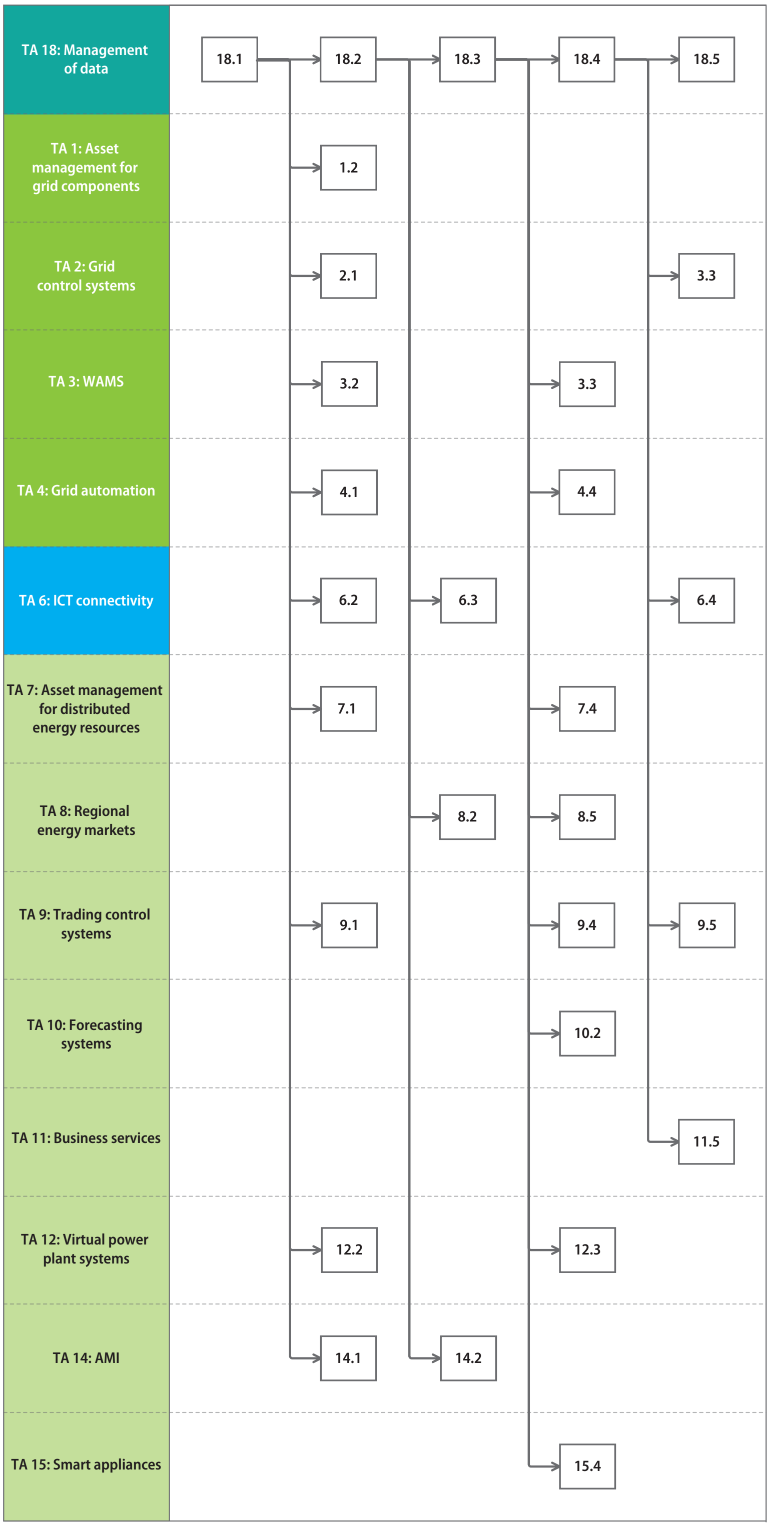


Figure 36: Prerequisites met by technology area 18 "Management of data"

stages two and four are frequently prerequisites for developments in other technology areas. This can be attributed to the fact that stage two relates to the subsequent integration (retrofitting) of security solutions, which is required when an existing technology is redeveloped, and that stage four relates to security-by-design, which is applied in the innovative development of new technologies.

The security requirements realised by stage one are required due to the increased complexity of the system (19.1). They are needed in order to realise control options in the MV grid by the grid control systems (2.2). Since this stage involves no or barely any connections with the networked system layer, the use of simple, established security solutions is sufficient. A similar situation applies to the asset management systems for large generation plants, which in the first stage are linked only to little known plants (7.1).

As the development of the technology areas progresses, a number of points are identified at which subsequent integration of security solutions is necessary (19.2). This development stage represents a major qualitative step: Measures are implemented that reinforce the now more exposed system against wide-ranging attacks. It is even possible now to deal with a power outage. The first development stages in many technology areas are concerned with the step of connecting to external systems, and therefore require security. It relates to the following stages: consistent monitoring in the MV grid (grid automation, 4.1), integration in a WAMS for regulation and response to highly dynamic supply situations (FACTS, 5.1), realisation of individual connections between the distribution grid and consumers (ICT connectivity, 6.1), tools for industrial and commercial customers to support trading on regional energy markets (8.1), flexible inter-company processes (business services, 11.1), offsetting stochastic fluctuations in generation (VPP systems, 12.1), deployment of modules for generation plants between 30 kW and 100 kW and for large thermal consumers > 100 kW (plant communications and control modules, 13.1), standardised AMI (Advanced Metering Infrastructure, 14.1) and connection of large thermal consumers, such as heat pumps, heating systems and air-conditioning systems (smart appliances, 15.1).

The third development stage is concerned with ensuring that security solutions for the smart grid are available end-to-end, and that experience is collated and flows in to design patterns and standards (19.3). These security standards are a prerequisite for the opening up of grid control systems using open interfaces (2.4) and the now necessary connection of components in the networked system layer, for which it is not possible to assume trustworthiness. As the stability of the distribution grid is now underpinned by the coordinated action of WAMS components (3.3) which also have great demands for real time communications, potential side effects from using smart-grid specific security patterns must be managed. For the same reason, after introducing actuators to the MV grid for grid automation (4.2), design patterns must exist to implement secure control.

In the networked system layer, reliable security standards are important if data from the asset management systems for distributed energy resources are to be made available externally (7.3): Data from many distributed energy resources are made available by asset management systems to other systems that then use the data for trading activities or grid stabilisation measures, for example. This complexity can only be implemented by means of suitable design patterns.

Also, when using flexibilities in the trading control systems there is an increased requirement for real time consumption and generation data from external sources, so that the corresponding security standards play a central role (9.3). Security-by-design and privacy-by-design (19.4) as well as the comprehensive tried-and-tested methods and tools enable a new level of security to be assured, which is sufficient for the subsequent development stages.

In the later development stages of the technology areas, the new functionalities largely demand new system developments. This offers the opportunity of integrating the necessary security-by-design principle into development.

In both the closed and networked system layers, standardised protocols are used to allow the systems to communicate via a common infrastructure (6.3). The consistent use of WAMS in the LV grid (3.5), the use of AGAs in local substations (4.4) and the use of FACTS (5.2.) in the closed system layer are all largely automated and reliant on real time systems. Unauthorised intervention by external parties here could result in the worst possible damage. Therefore retrofitting security to individual systems is insufficient in security terms. Only a security-by-design solution will ensure secure operation.

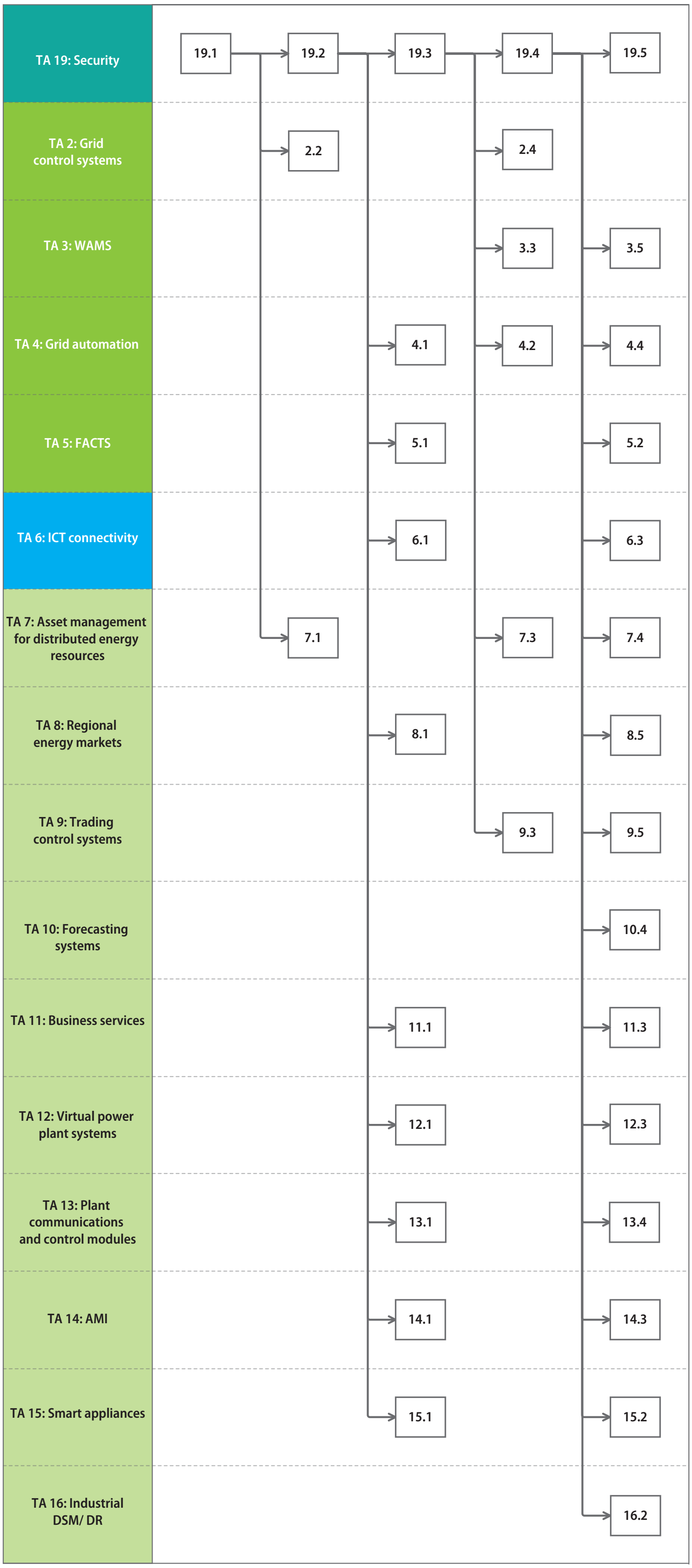


Figure 37: Prerequisites met by technology area 19 "Security"

In the networked system layer, the attack vectors would become even larger due to the intensive connections: direct financial damage from manipulation of trading and/or billing (8.5, 16.2) must be prevented.

The components in the networked system layer are now system critical when considered as a group, even if not on an individual basis. These include the forecasts that determine the deployment of plants (7.4, 10.4), the VPP systems in conjunction with the AGAs (12.3) or direct access to plants (13.4), (14.3, 15.2, 16.2). Security measures must also provide direct protection to domestic and industrial consumers against attack in their areas (14.3, 15.2, 16.2). The use of cloud-based services, which by this time will be intensive, is new but not specific to the energy sector. It should be anticipated that security solutions for the cloud are sufficiently well established.

The intelligent, semi-automated response to IT attacks (19.5) described in the final stage of this technology area is a principle that offers a number of advantages, but it is not absolutely mandatory for the development of the other technology areas.

4.2.5 CONCLUDING ANALYSIS OF THE CROSS-CUTTING TECHNOLOGIES

Section 4.2.4 explained which development stages would be required as prerequisites for the cross-cutting technologies. In summary, in terms of the integration technologies, the development of standardised interfaces in the early stages and semantically interoperable data models in later stages is of major importance for a range of technology developments. The realisation of a cloud in contrast can be viewed as non-critical. In the context of data management, it is important to be able to manage increased volumes of data in a number of areas, and to have semantically enriched data available for analysis purposes. A cloud-based data management system is not needed for any development stage. Equally, two areas of focus can be identified in the areas of security. First, it is important to integrate security solutions into existing technologies, where these are further developed, and second, security-by-design must be used when technologies have to be completely redeveloped due to the introduction of wide-ranging new functionality. Intelligent and semi-automated attack responses are not needed for any further development stages.

4.3 ANALYSIS OF THE MIGRATION PATHS

Following the investigation of technology areas 1 to 16 in order to establish the prerequisites for each of the individual development stages, it is now necessary to establish which sub paths, technology areas and development stages are critical for migration towards each of the scenarios.

A quantitative analysis is conducted at various levels of granularity to identify the importance of individual elements for the overall migration paths. The basis for the analysis can be found in figures 38, 39 and 40, from which the dependencies of the three scenarios can be identified.

Critical development stages

The objective of the first part of the analysis in each case is to identify the development stages that are critical[221] and less critical[222] for the scenario concerned. A development stage is viewed as critical if a delay to this stage would delay the development of the overall system. The importance of the development stages can be measured on the basis of the number of leaving edges[223]. A high number of leaving edges raises the possibility that this is a potentially important development stage. In contrast, a low number of leaving edges is an indicator of potentially less important development stages.

221 A critical development stage has a significantly high number of leaving edges (after rounding, double the average of all edges of the development stages for a scenario).

222 A less critical development stage has only one edge that indicates a dependency for the next stage in the same technology area. In addition, it must not be a direct or indirect prerequisite for a critical development stage. Development stages that represent a final state and therefore have no leaving edges are also classified as less critical in the context of the overall development.

223 In this context an edge indicates a prerequisite that represents a development stage for the achievement of another development stage. It is indicated in the figures as a directed arrow, leaving from the prior condition, between two development stages.

Critical technology areas

In addition, for each scenario a list of the critical[224] and less critical[225] technology areas is determined. These are the technology areas that are seen as enablers. Particular emphasis must be placed on these areas during the migration.

As with the development stages, once again the leaving edges are considered: The number of leaving edges from all development stages in a technology area is calculated. This total allows assumptions to be made regarding the criticality of the technology area. Only connections to other technology areas are taken into account; internal prerequisites are ignored. Subsequently, the results for each of the three scenarios are shown.

This investigation does not include the cross-cutting technologies (technology areas 17 to 19), since these have already undergone this type of analysis. As the most complex migration, the "Sustainable & economic" scenario is split into three phases. Section 4.3.6 summarises the findings established in relation to its investigation.

4.3.1 CRITICAL TECHNOLOGY AREAS AND DEVELOPMENT STAGES IN THE SCENARIO "20TH CENTURY"

In many respects this scenario is similar to the current situation and requires very few innovative developments in the ICT field. Therefore, the number of critical development stages is significantly lower than in the two other scenarios (see figure 38).

Analysis of the Development stages

In the closed system layer there are the development stages 3.1 (3) and 3.4 (3), in the ICT infrastructure layer there are 6.1 (10) and 6.2 (3), and in the networked system layer there is stage 10.1 (3) As in this scenario many technology areas develop without influence from their environment, many final states are reach so that in 11 of the 16 technology areas development stages represent a final state (1.5, 2.1, 3.2, 5.2, 7.2, 8.1, 9.2, 11.4, 12.1, 15.5 und 16.1). Equally, a relatively large amount of development stages were identified that did not form part of critical paths and that are only used for internal developments. Alongside stages 1.1, 1.2 and 5.1 in the closed system, stages 11.1, 11.3, 15.1, 15.3 and 15.4 are affected in the networked system layer.

Considering the overall picture, the only particularly critical stage is the individual connection of the distribution grid and the consumers in the context of ICT connectivity (6.2). Relatively speaking, with around 15%, a similar number of stages were identified as critical in this scenario as were identified for the "Sustainable & economic" scenario. The relative number of non-critical stages is extremely high, however, at around 65%. These include, as in both of the other scenarios, the development stages for smart appliances. However, three stages each in asset management for grid components and business services are viewed as non-critical.

Analysis of the technology areas

ICT connectivity (12) is the only critical technology area of the "20th century" scenario. As a result, there are many technology areas (half) that have no leaving edges. These comprise grid control systems, FACTS, asset management systems for distributed energy resources, regional energy markets, trading control systems, VPP systems, smart appliances and industrial DSM.

224 Critical technology areas have a significantly high number of leaving edges to other technology areas (more than double the upper median of the leaving edges of the technology areas in a scenario).

225 Critical technology areas have a significantly high number of leaving edges to other technology areas (less than half the upper median of the leaving edges of the technology areas in a scenario).

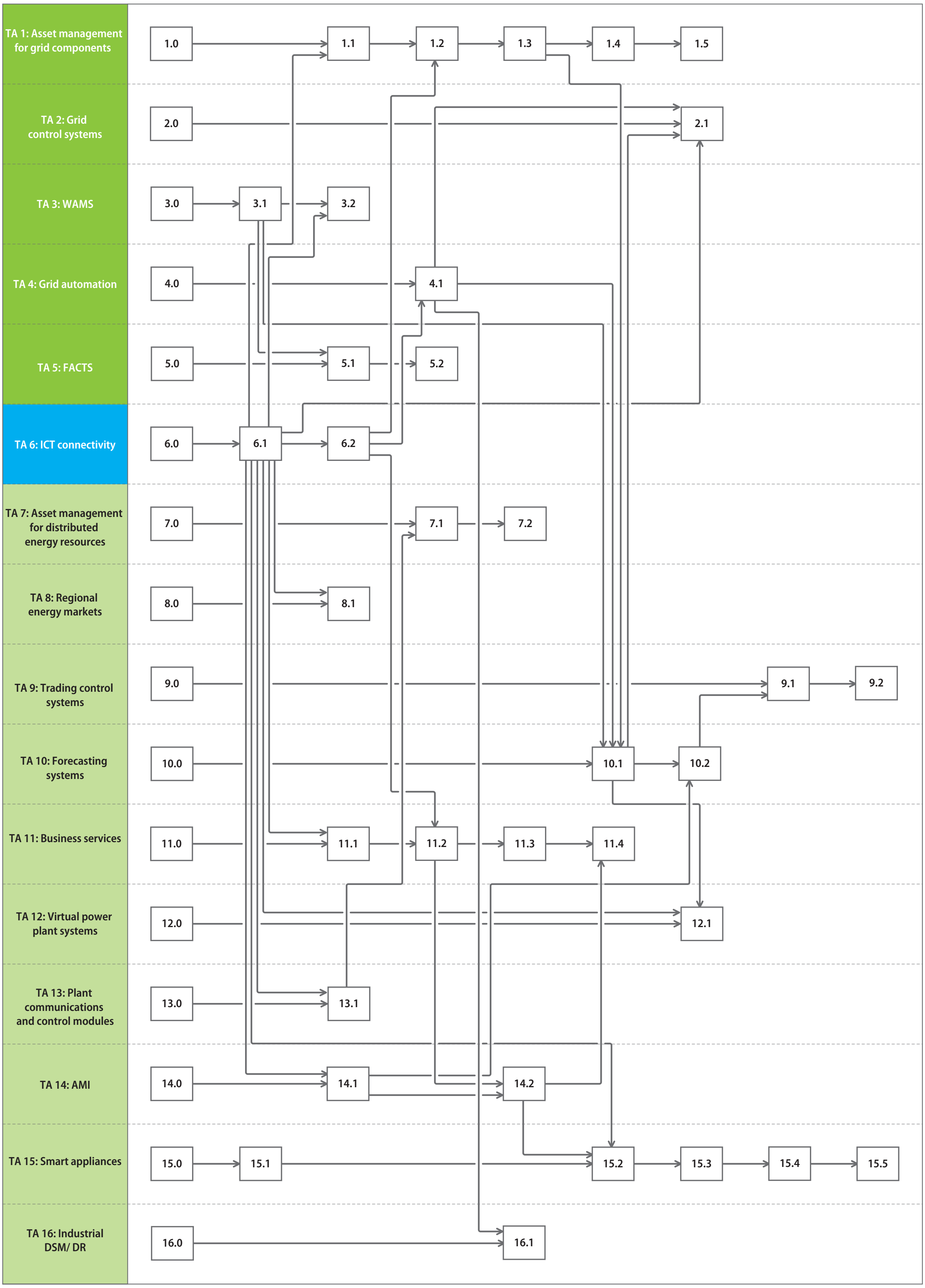


Figure 38: Overview of the migration paths for scenario "20th century"

4.3.2 CRITICAL TECHNOLOGY AREAS AND DEVELOPMENT STAGES IN THE SCENARIO "COMPLEXITY TRAP"

This scenario is considerably more complex and demands more development stages than the "20th century" scenario. This is seen in the following analysis from the increased number of critical connections (see figure 39).

Analysis of the Development Stages

In the closed system layer, above all development stages 3.1 (3), 3.2 (3) and 4.1 (4) are viewed as critical. ICT connectivity indicates a high number of connections in its development stages 6.1 (11) and 6,2 (5). Most critical stages, notably 10.1 (3), 10.2 (3), 10.3, (3) and 14.2 (3) are located in the networked system layer. Alongside the non-critical final stages (1.4, 2.3, 7.2, 8.2, 9.3, 10.4 and 15.5), as described in the preceding section, only stages 2.1 and 2.2 are required for further internal development in the closed system layer. In the networked system layer in contrast, stages 7.1, 8.1, 9.1, 9.2, 15.1, 15.2, 15.3 and 15.4 are affected.

In summary it becomes clear that in this scenario, too, the development stages for ICT connectivity are the most important for subsequent developments. Of these, the functionality for individual connection of the distribution and consumers stands out especially. Furthermore, the consistent monitoring in the MV grid is also a very important stage in this scenario. Three development stages of the forecasting systems are assessed as being critical, indicating that their early functionality in particular has a high degree of importance for the overall development. In total, approximately 21 percent of the development stages are critical, significantly more, therefore, than in the subsequent scenario "Sustainable & economic". When considering the non-critical development stages, it becomes clear that smart appliances fall completely into this category and that, furthermore, all trading desk system functionality that has been achieved is used only for internal developments. In general, around 41 percentage of stages are non-critical, which is slightly more than in the "Sustainable & economic" scenario.

Analysis of the technology areas

Once again, in the "Complexity trap" scenario, ICT connectivity is the technology area that acts as an enabler, since it has 15 leaving edges from only two development stages. Grid automation (5) in the closed system layer and forecasting systems (6) in the networked system layer are again seen as critical. These scenarios include technology areas that are not prerequisites for any other technology areas and therefore are only needed for further development of their own functionality. These comprise the grid control systems, asset management systems for distributed energy resources, regional energy markets, trading control systems and smart appliances.

4.3.3 CRITICAL TECHNOLOGY AREAS AND DEVELOPMENT STAGES IN THE SCENARIO "SUSTAINABLE & ECONOMIC"

The greatest penetration with the ICT areas yet to be developed can be found in the technologically ambitious Scenario "Sustainable & economic". For this reason, this scenario also contains the greatest number of critical technology areas and development stages (see figure 40).

Analysis of the Development Stages

In this scenario most dependencies can be seen in the form of leaving edges. In the closed system layer, primarily stages 1.3 (4 leaving edges), 3.4 (5) and 4.1 (4) have a high number of leaving edges. In the ICT infrastructure layer, three development stages of the ICT connectivity technology area are identified as equally critical. These are 6.1 (12), 6.2 (8) and 6.4 (11). The networked system layer reveals a relatively evenly distributed picture, with only development stages 13.1 (4), 13.4 (5), 14.2 (5) and 16.2 (4) of increased importance. Alongside the final stages (1.5, 2.5, 7.4, 9.5, 12.4 and 15.5), which while not representing actual prerequisites must be completed in order to meet the requirements of the scenario, a range of development stages that are only needed for internal development of a technology area are viewed as non-critical. However, it must be taken into account that these may be directly or indirectly part of a path that leads to a critical development stage and that in these cases they should not be assessed as less critical. Accordingly, in the closed system layer only stages 1.4, 2.4, 4.3, 4.4, 5.1, 5.2 and 5.5 should be viewed as rather non-critical. The ICT infrastructure layer has no non-critical development stages. Within the networked system layer, the same investigation reveals the less critical stages 7.1, 7.2, 8.1, 8.2, 8.3, 8.4, 9.1, 9.2, 12.2, 15.1, 15.3 and 15.4.

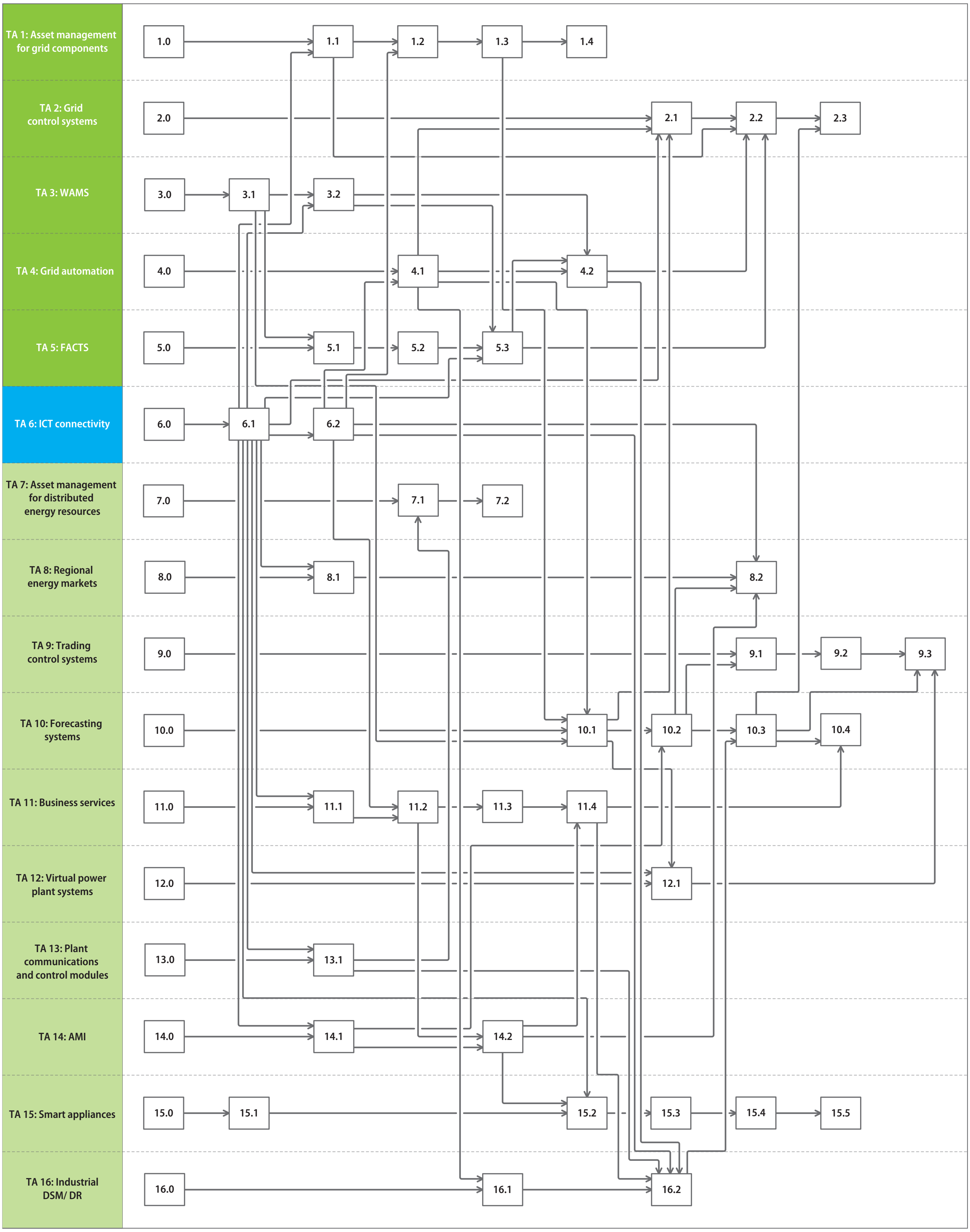


Figure 39: Overview of the migration paths for scenario "Complexity trap"

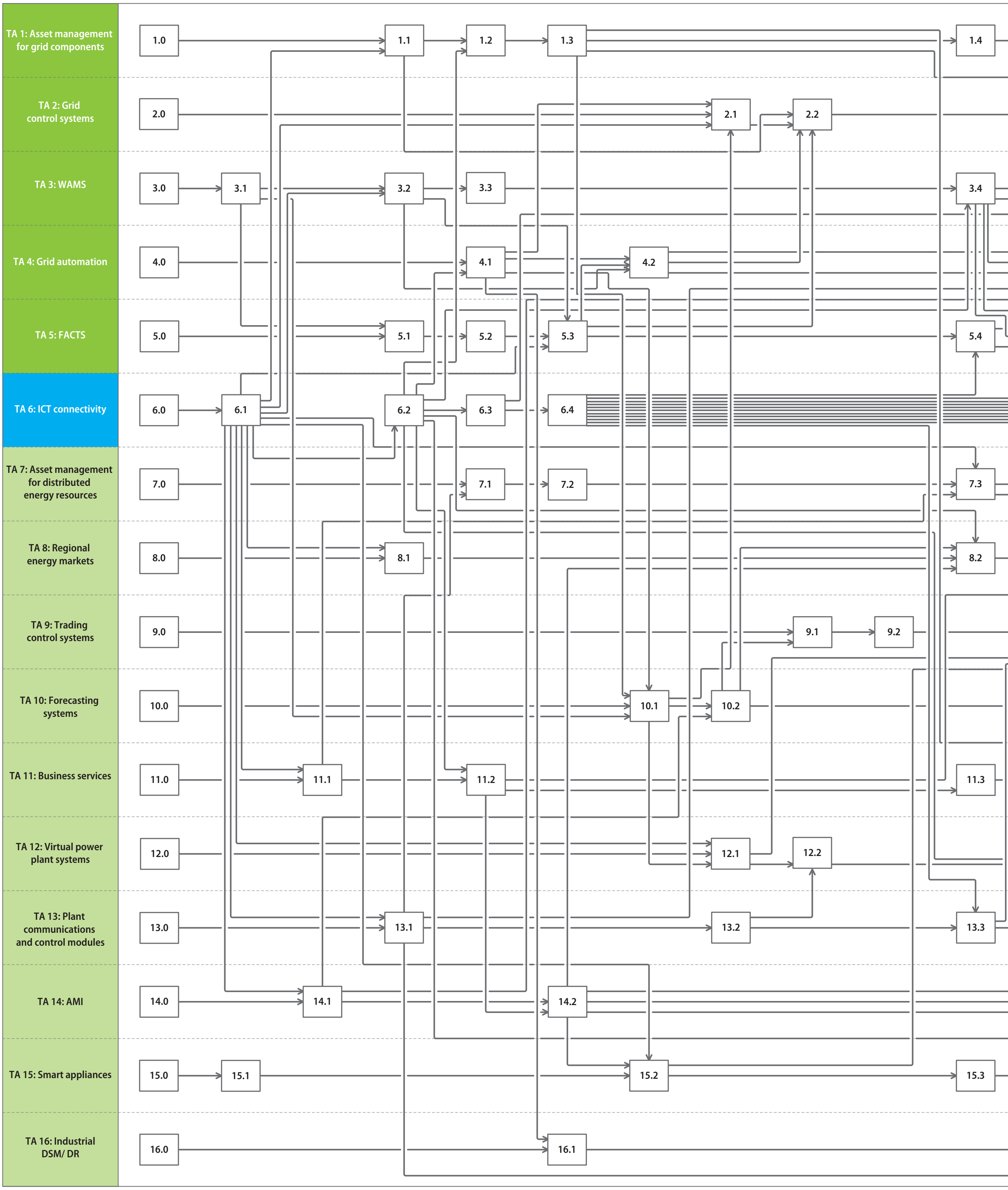
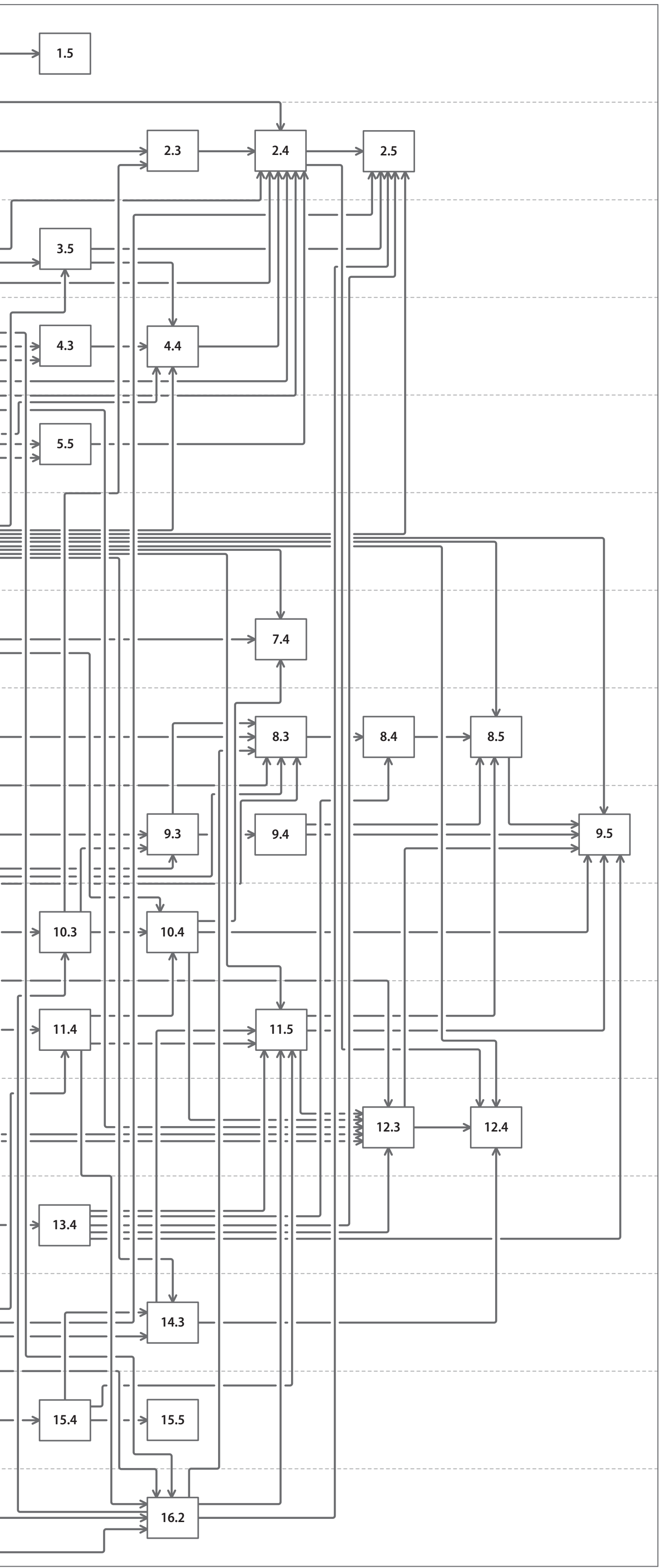


Figure 40: Overview of the migration paths for scenario "Sustainable & economic"



Considering the overall picture, it is especially clear that the individual stages in ICT connectivity are critical in nature and are necessary enablers for many technology developments. The data hubs form an exception, since with two leaving edges they do not stand out as clearly as the other development stages in the technology area. Nevertheless, they are necessary for the realisation of subsequent plug & play connections. In addition, the individual use of AMS in the LV area, the autonomous plant control with bidirectional plug & play and AMM should be viewed as significant stages. It is equally noticeable that stage four in each of the WAMS, ICT connectivity and Plant communications and control modules technology areas represents a well advanced development as a prerequisite for many further developments. Overall, around 15 percent or ten development stages are seen as critical. In contrast, the first four development stages of the regional markets technology area are only required for internal development of the technology and even the final stage only has one leaving edge resulting in the final state. A similar situation exists for smart appliances, for which only DR is an external prerequisite for the development of regional markets. Equally in each of the technology areas FACTS, Asset management for distributed energy resources and Trading control systems there are three non-critical stages, representing a clear block. Alongside the six final states there are a further 19 development stages that can be viewed as rather non-critical; this corresponds to around 36 percent of the total stages in the scenario.

Analysis of the technology areas

In the "Sustainable & economic" scenario, the technology area ICT connectivity is particularly critical (30 prerequisites). This is to be expected, in line with the individual development stages that have already been identified as critical. In addition, the technology areas WAMS (10), plant communications and control modules (10), forecasting systems (9), business services (8) and AMI (8) can be classified as critical. The scenario also contains technology areas with development stages that in total represent only a few prerequisites. For example, the technology areas grid control systems, asset management for distributed energy resources, regional energy markets and smart appliances each only represent one external prerequisite. Among the last two, the analysis of the individual stages already indicated non-critical technology areas. In addition, the technology areas trading control systems (2) and VPP systems (2) and be viewed as rather non-critical.

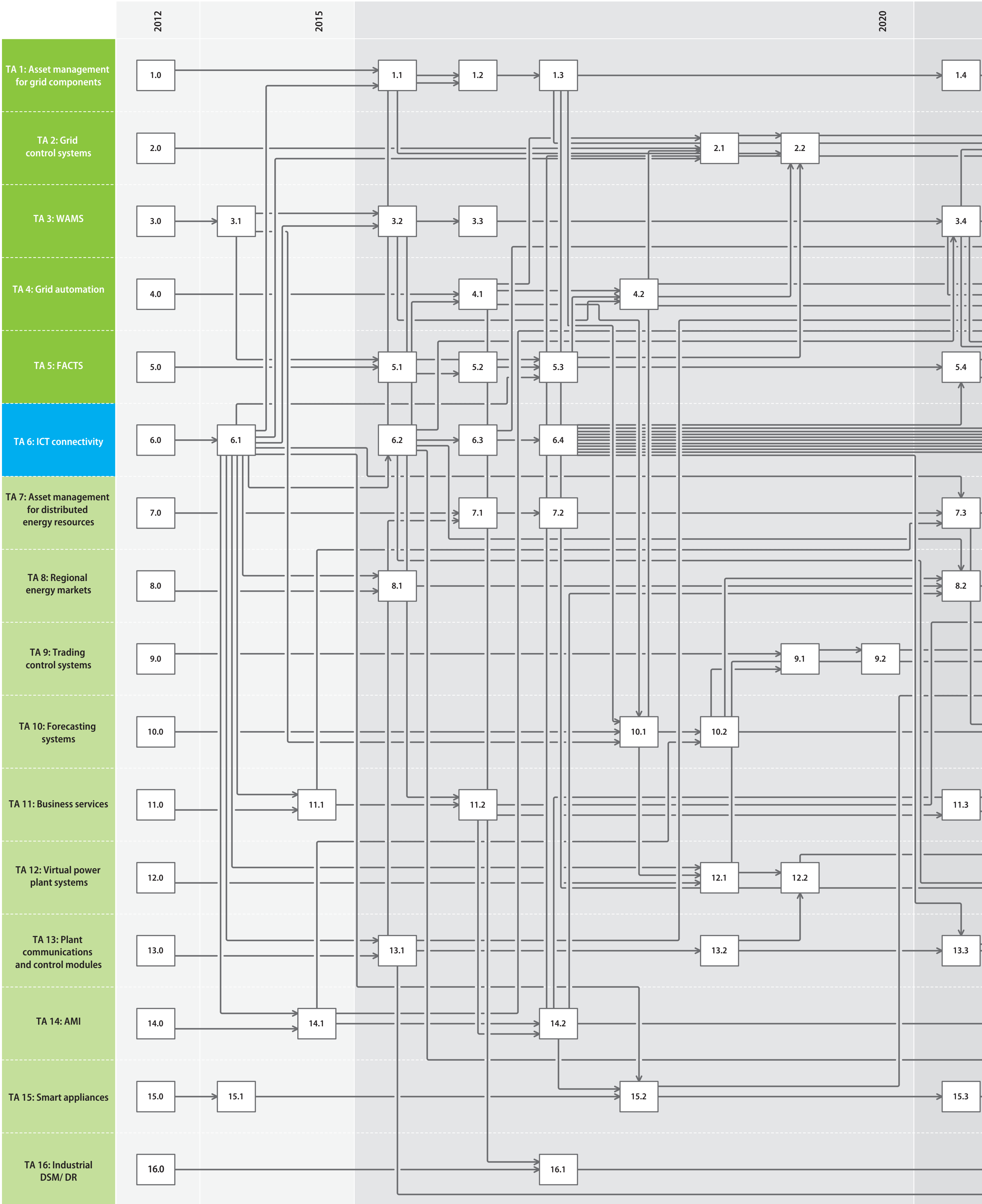
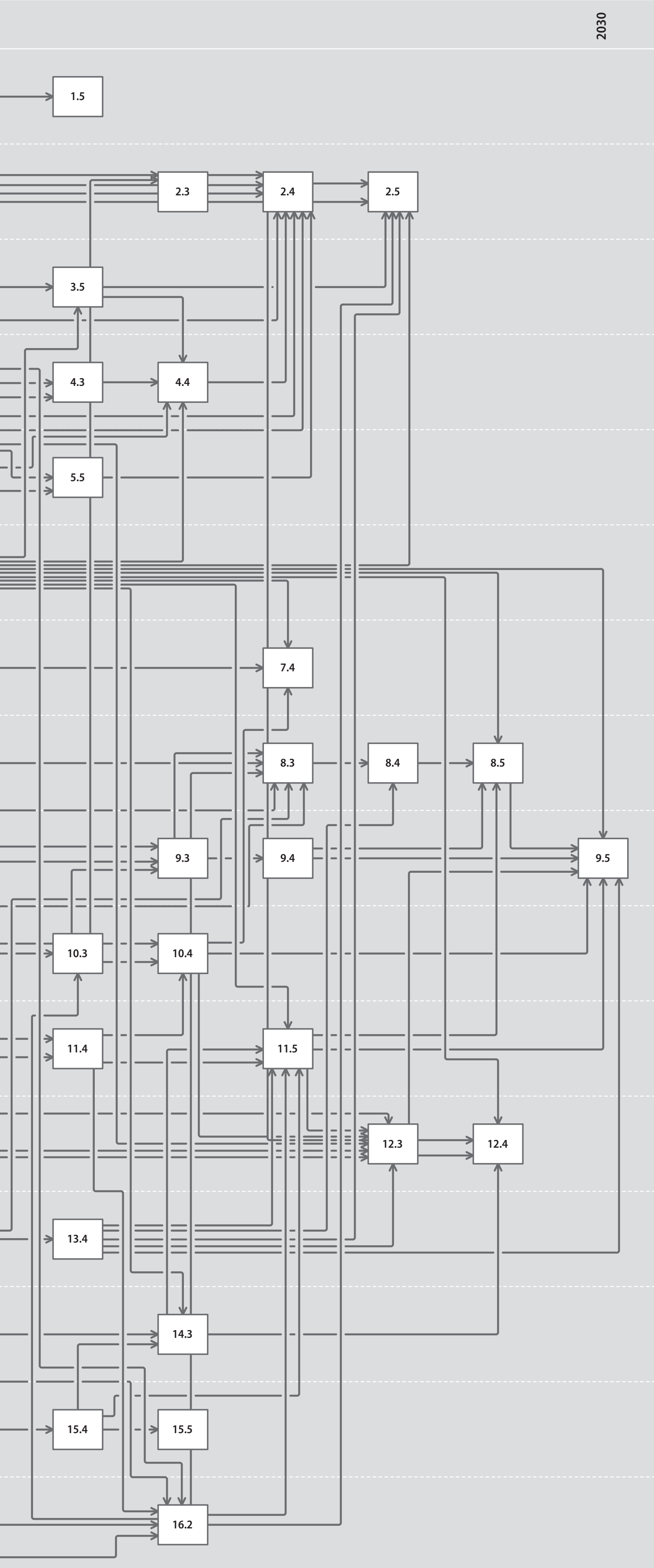


Figure 41: Technological migration paths for scenario "Sustainable & economic"



4.3.4 CROSS-SCENARIO ANALYSIS

Looking at the developments in all three scenarios, it is obvious that many technology areas are largely unaffected by the scenario in which they find themselves. The technology area Smart appliances achieves the furthest development stage in all scenarios, while Asset management for grid components and Business services are also well developed in all scenarios. Industrial DSM represents a special case, with only two development stages that it nevertheless achieves in two scenarios, "Complexity trap" and "Sustainable & economic". As a result, these technology areas have particular importance, since they must provide the described functionality of the individual development stages in all cases, irrespective of how the overall electricity supply system develops. The technology areas Grid control systems, Plant communications and control modules and VPP systems only achieve their further development stages in the "Sustainable & economic" scenario. This indicates that the future functionality in these areas will definitely be required in a very well developed electricity supply system.

4.3.5 MIGRATION PHASES FOR THE "SUSTAINABLE & ECONOMIC" SCENARIO

The "Sustainable & economic" scenario is used to represent the developments that form the objective of the energy revolution, since it describes the furthest developed overall system in technological, ecological and economic terms. For these reasons, the migration paths for the scenario have been put into a timeframe, as shown in figure 41. Starting from the current state of technology in 2012, development process milestones were set for 2015, 2020 and 2030. Three phases of development can be determined - the concept phase, the integration phase and the fusion phase.

Each development stage is thus assigned to one of the three phases, which vary in length at three, five and ten years. As the overall period extends to 18 years, the exact deployment time of a given technology is not usefully determined and as a result no attempt was made to schedule all individual development stages. The sequence of the development stages within the phases and the links between the technology development stages represent a qualitative perspective.

Alternative variants of the individual contexts are conceivable, but they do not alter the meaningfulness of the core findings. In addition, reference is made to the findings of the quantitative analysis mentioned in the preceding sections.

This classification is used to provide guidance in terms of the necessary level of market penetration for the corresponding functionality. In order to guarantee the introduction to market and market penetration of a technological development within a given phase, the necessary research and development must be conducted in advance.[226] For the introduction of the corresponding technologies within the outlined time periods, it is assumed that the deployment of the corresponding technologies will be as economical as possible for all participants, which may lead to a difference between availability and actual deployment. When considering the figure it should also be noted that the sequence of the technology development stages relates exclusively to the German market and may easily differ for other countries. The following paragraphs describe the core points of each phase.

Concept phase (2012 to 2015)

During the concept phase, the foundations are built and the main course set, indicating the direction in which the development of the FEG should then progress. These relate in particular to the closed system layer and the ICT connectivity.

For example, a concept is developed for the deployment of WAMS in the distribution grids. This is done by modelling grid condition monitoring by sensors in PMUs or Remote Terminal Units (RTU) in the form of use cases (technology area 3, stage 1). With the creation of the initial ICT connections in the distribution grid and a first, rudimentary directory service for distributed energy resources (technology area 6, stage 1), it will be possible to locate distributed energy resources and to deploy them taking into consideration the concepts of grid stability. In the networked system layer, transparency for the customers of the energy utility companies is increased by corresponding customer self-service systems (technology area 11, stage 1). The handling of processes that are integrated into several organisational units is better supported by the deployment of advanced information systems. In the area of domestic energy management, significant impetus is also given. Large thermal consumers such as heating systems and air conditioning systems are integrated more intelligently in relation to their energy management capabilities and can also be connected to a communications network, in addition to offering the local functionality (technology area 14, stage 1 and technology area 15, stage 1.).

Integration phase (2015 to 2020)

During this phase, the information from the components in the networked system layer is increasingly integrated into the systems in the closed system layer.

First, infrastructure and control concepts are introduced. WAMS are further developed on the basis of findings from the concept phase and are deployed increasingly in the MV grids. Due to the available data processing concepts, the demand-based realisation of optimisation measures (local and central) is possible (technology area 3, stages 2 and 3). AMS-WAMS are intermeshed with FACTS, which can use the data gathered to coordinate activities across grid segments and make a key contribution to stabilising the HV and MV grid levels (technology area 5 stages 1 to 3). In the networked system layer, standards are created for AMI (technology area 14), and Plant communications and control modules (technology area 13), in order to guarantee application connectivity in the FEG. Carrying these ideas forward, the construction of ICT connectivity in general is at the centre of this phase. For example, regional networks (technology area 6, stage 2) enable the first applications to support the grid and more efficient exchange of information. The further development of connectivity through inter-regional networking (technology area 6, stage 3) and especially the provision of standardised plug & play interfaces (technology area 6, stage 4) are of particular importance for the long-term development of the FEG. By constructing a corresponding infrastructure and focusing on interoperability it is possible to build an environment that promotes innovation, on which technologies introduced in the fusion phase in particular can build.

While the construction of structures for the FEG is at the core of this phase, the first applications to use these structures are introduced. In the closed system layer, grid control technology (technology area 2)

226 The associated process must, to the extent that it contributes to the national economy, add value for the participants (see chapter 6).

and grid automation (technology area 4) are able to influence the electricity infrastructure in a more targeted manner to meet adjustment requirements, thanks to improved information and the increased use of actuators in the distribution grids. The networked system layer contains the infrastructure measures including applications in VPP systems (technology area 12) that are now able to integrate small plants and create timetables on the basis of forecasts, market data and plant operating data. Asset management systems (technology areas 1 and 7) and forecasting systems (technology area 10) provide the system with further support from other information sources.

Fusion phase (2020 to 2030)
During the fusion phase, the closed and networked system layers merge, as do the electrotechnical systems and ICT system. The now high mutual dependency between closed and networked system worlds requires, in particular, a high level of development among the cross-cutting technologies and ICT connectivity. Major importance is attached to security.

The supply of electricity is reliant on this fusion system. The closed system layer requires the information and ability to control components in the networked layer in order to ensure stability. The networked layer requires a lot of information from the closed system layer in order for processes in the networked layer to take account of physical restrictions from the start. Distributed energy resources are major supports for the energy supply, including the supply quality, thanks to ICT penetration.

The focus of developments is on the introduction of applications that will increase energy efficiency, transparency of the energy supply system, the usage of energy and regulation options, resulting in major benefit for end customers and in particular in greater commercial viability within the electricity supply system. In the closed system layer, the areas of (W)AMS (technology area 3), grid automation (technology area 4), and FACTS (technology area 5) are successively further developed by the use of networking structures to exchanging information. The (W)AMS is developed into a management system and the grids are regulated by the deployment of systems of autonomous agents right down to the LV grid. The integration of grid regulation is accomplished by means of the grid control systems (technology area 2), which use both components from the closed grid layer and information from the networked system layer to automate grid operations (stage 4) and to ensure the grid segments can be restarted automatically following a fault (stage 5).

In this phase, within the networked system layer, the components derive their benefit primarily from networking effects. Regional markets (technology area 8), trading control systems (technology area 9) and VPP systems (technology area 12) have strong dependencies on other technological developments, the information from which they exploit to create value, such as defining trading products in the grid services field, integrating the different market levels, supporting decision making and partially automating the trading environment as well as creating timetables within VPPs by processing grid, market and forecast data. The plant communications and control modules (technology area 13, stage 4) and complete integration of DSM into industrial production processes (technology area 16, stage 2) are particularly important as enablers for these functionalities. The capacity of generation plants, consumer systems and storage to communicate is a significant factor in their integration within VPP systems and in the integration of micro flexibilities in products that can be traded.

Together with the information infrastructure put in place thanks to ICT connectivity and the further development of grid control systems, this technological development has completed the paradigm shift that results in the Internet of Energy.

In figure 42, the three phases are shown in simplified form along with the associated increasing degree of networking and functionality.

4.3.6 CORE STATEMENTS

On the basis of the quantitative analysis of the technology areas and their development stages, as well as the selected time schedule for the “Sustainable & economic” scenario, the following core statements can be made:

- In the short term (up to 2015), the focus is on development within the closed system layer. In the medium term (up to 2020), this will shift through the ICT infrastructure layer (using ICT connectivity as a backbone) into the long-term (looking forward to 2030) networked system layer.

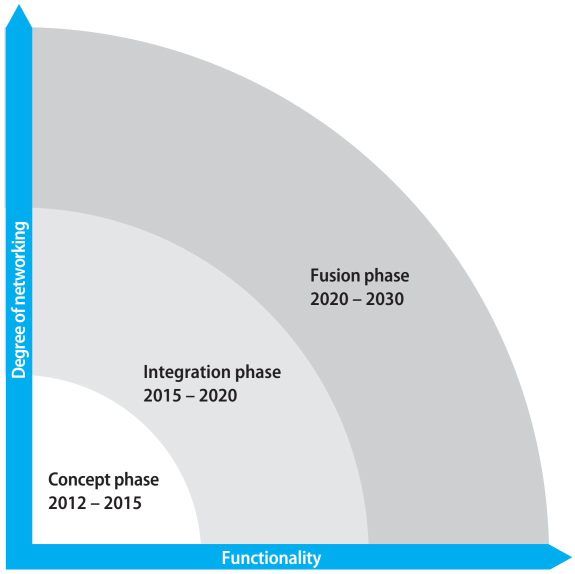


Figure 42: Development phases of the Future Energy Grid

- In each scenario, ICT connectivity forms a necessary basis for the development of other technology areas. In particular, the connection to the distribution grid and the connection of consumers, as well as the provision of plug & play connections, are of greater importance.
- The cross-cutting technologies integration technologies, data management and security each have two clearly identifiable milestones that trigger the remaining technology areas.
- Advanced functionalities for grid control systems, VPP systems and plant communications and control modules are needed primarily in a strongly distributed, ICT based electricity supply system.
- A typical enabler technology in the closed system layer can be found in (W)AMS. In the networked system layer, forecasting systems, plant communications and control modules, business services and AMI in particular drive development forward.
- In the closed system layer the grid control systems technology area especially is associated with external development. In the networked system layer this role is assumed by the technology areas regional energy markets, trading control systems and VPP systems.
- Smart appliances, business services and asset management for grid components will develop a long way in each scenario, although this initially provides no hint of their direct influence on the grid.

4.4 SUMMARY

In this chapter, migration paths have been developed that are based on the scenarios conceived in chapter 2 and on the technological characteristics described in chapter 3. The challenges in the further development of the FEG technology areas result from the many interdependencies among these developments. These have been identified and described for each development stage. The cross-cutting technologies, integration technologies, data management and security play a specific role in the ICT environment, and in many cases are vital prerequisites in the further development of other technology areas. For that reason, the applicability of the concepts described in the development stages of the cross-cutting technologies was described in a separate section.

From the results of the analysis by technology area, the migration paths were then developed for the scenarios "20th century", "Complexity trap" and "Sustainable & economic". Using visualisations that are based on the precedence diagram method of planning, the sequence of the technology development stages according to the dependencies could then be revealed. Equally, in the scope of a quantitative analysis it was possible to demonstrate the importance of the technology areas and their development stages for the different scenarios.

According to the technological development stages that were defined for the scenarios in chapter 3, the visualisation of the migration paths clearly showed the technological complexity of the scenarios. In line with its key factor projections, the "Sustainable & economic" scenario indicated a much greater level of complexity than the "20th century" and "Complexity trap" scenarios. As the vision for the successful realisation of an ICT-based electricity supply system, it was therefore described separately, and the migration process was split into three consecutive phases, named Conception, Integration and Fusion. Following an initial focus of development within the closed system layer, as the migration path progresses the focus shifts through expansion of the ICT infrastructure, with increasing implementations in technologies in the networked system layer. Moreover, the connection between the closed and networked system layers is strengthened in the long term.

5 INTERNATIONAL COMPARISON

This chapter is concerned with the international comparison that was produced at the same time as the migration paths and their interim findings were being developed. The principal aim of this comparison is to determine how Germany is positioned in comparison with other countries that display model-like characteristics. Above all, the objective is to identify potential opportunities for the German economy.

Section 5.1 is concerned with the methodology that was used to complete the international comparison. The core aspects of the methodology were expert-level workshops in which the framework conditions and evaluation criteria were initially identified. The section concludes with a detailed expert questionnaire that was conducted to assess the smart grid criteria in various countries and regions.

In order for the primary aim to be achievable, the three sub aims (see figure 43) forming the foundation must be developed, allowing Germany to be evaluated in an international context. Evaluation criteria for the comparison were established for this purpose. Section 5.2 describes how the criteria were identified to describe the current situation and then describe an approach for development. In a subsequent stage, the countries used in the comparison were selected and their characteristics highlighted in a country profile.

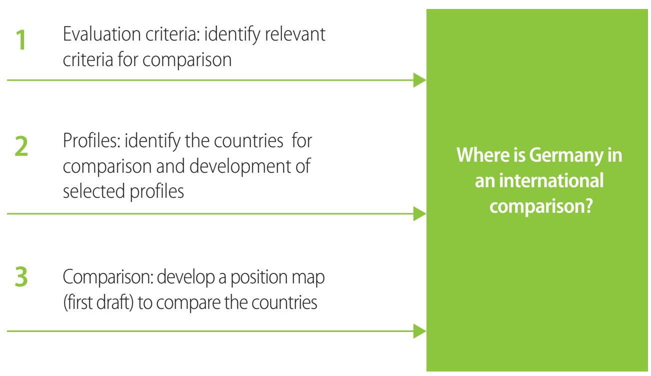


Figure 43: Subject of the international comparison.

In section 5.3 selection criteria were introduced as a means of compiling a list of countries. These characteristics of these countries are model-like and represent a specific type of country. The selected countries are described in the following section 5.4, with a profile for each country. Furthermore, section 5.5 looks at additional model projects that are located outside the countries under consideration, but which are taken into account because of their importance. In the third and final stage, the countries are compared visually using positioning maps. These were prepared on the basis of the findings obtained from a questionnaire. Both the questionnaire and the evaluation and analysis are shown in detail in section 5.6. Finally, section 5.7 reveals the core statements that have been derived from the comparison.

5.1 METHODOLOGICAL PROCEDURE

A combination of two methodological approaches was used for the international comparison. First, a group of experts undertook a qualitative study. This required them to define the criteria to be used to evaluate the countries. At the same time, the expert group also produced the descriptions of each country (section 5.4). Finally, the same group also developed the questionnaire that was used to undertake the direct comparison of countries (section 5.6). In terms of methodology, this group used a focus-group approach, which is particularly well suited to developing and assessing new and innovative concepts.[227] The focus group was composed of participants in the Future Energy Grid (FEG) project. This ensured that experts from research institutions, technology providers and Electricity Utility Companies (EUCs) were all represented.

At the same time, a quantitative survey was conducted to allow the countries to be compared directly and also to verify the previous findings. A questionnaire was developed, the results of which are evaluated in section 5.6 using descriptive methods and on the basis of a factor analysis.[228, 229] Both English and German versions of the questionnaire were sent out. It was addressed to participants in the FEG project, with a request to circulate it among their expert networks. The study was therefore open to additional specialists who also had the corresponding technical knowledge.

227 Tremblay et al. 2010.
228 Backhaus 2006.
229 Thompson 2004.

Only people who are active in the field of international energy in its broadest sense were asked to take part in the study. All therefore have pertinent experience. For the purposes of the study, 39 questionnaires were evaluated. In view of the fact that the number of suitable experts who can demonstrate comprehensive knowledge of the international energy supply field is manageable, this quantity is quite satisfactory, with the questionnaire and the analysis tailored for an anticipated return rate of 35 questionnaires.[230, 231] Consequently, the findings presented here can be said to be meaningful in respect of the number of questionnaires.

Figure 44 provides a more detailed view of the breakdown of participants. The recipients of the questionnaire work for EUCs, technology providers or in research and education. The majority of responses (over 30 percent for each) were received from people working in research/education and from those working for technology providers. Employees of EUCs and another group comprising technology and management consultants and staff of administrative organisations each contributed 15 percent of the total number of respondents. A link was identified between the activity area and the experience of the experts. The researchers who were sent questionnaires dominated the group of recipients with up to five years' experience in the energy sector. Of the remaining participants in the study, most stated that they had more than ten years' experience (see A1 and A2, figure 44).

A1 Sectors of organisations receiving questionnaire

Research/education	38 %
Technology providers	31 %
Energy suppliers	15 %
Other	19 %

A2 Experience of panel respondents in energy environment

1–5 years	41 %
6–10 years	15 %
> 10 years	36 %
n/a	8 %

Figure 44: Breakdown of respondents to the questionnaire.

5.2 CRITERIA

In order to conduct an evaluation of the countries under investigation, a project was conducted to define the evaluation criteria. When it comes to classifying countries, it is useful to distinguish between a country's archetype[232] and its development approach (see figure 45). An archetype represents the current situation in a country in multiple dimensions. The development approach summarises the plans and initiatives that mainly characterise the further development of the country. Criteria were defined for the archetype and development approach that were referred to in the comparison by country described in this study. This section is concerned with describing the composition and structure of these criteria.

5.2.1 ARCHETYPE

The countries that are to be compared have in some cases major differences in terms of their initial situations. It therefore appears useful to classify similar initial situations according to archetype. This approach allows a differentiated analysis of the countries' development approaches to be undertaken, preventing an undesirable comparison of "apples and oranges".

An archetype can be described by four significant factors. These are geography/demographics, political conditions, energy consumption and energy supply (see figure 46). The factor geography/demographics describes the particular geographical nature of the country and the basic characteristics of its economy. The political conditions relate to the history of energy policy, its importance and the degree of subsidiarity/federalism. Energy consumption characterises both the usage of energy and the users. The energy supply factor

230 Backhaus 2006.
231 de Winter et al. 2009.
232 accenture/WEF 2009.

Archetype as starting position

- Geography / demographics
- Political conditions
- Energy consumption
- Energy supply

Criteria

Development approach as strategy

- Energy suppliers
- Industry
- Politics
- Research and science

Figure 45: Comparison of archetype and development approach.

comprises the quality of the existing infrastructure and the structure of the energy market.

Geography/demographics

The basic parameters of a country in respect of its regional location and specific geographical nature have a major impact on its energy generation in general and its use of renewable energy resources in particular. The various types of renewable power generation each have different requirements. For example, wind power installations can only be operated commercially in regions with prevailing continually windy conditions of sufficient strength. In contrast, solar power installations are profitable in regions that are characterised by high levels of sunshine. In addition to the geographical conditions, the overall situation of the economy as a whole plays a major role in the definition of archetypes. For example, the future investment in smart grid technologies and other energy infrastructure will be strongly affected by economic growth. The degree of urbanisation of a country also has a large impact on its energy supply.

Political conditions

In the field of political conditions, countries can be classified into archetypes according to the history and significance of their energy policy, the degree of subsidiarity and the scope of liberalisation and regulation in the energy market. The degree of subsidiarity has a significant influence on the speed and homogeneity of the formation of a political will and of the decision-making process. The extent of regulation in the energy market determines the scope of action of the energy utility companies. Bureaucratic and lengthy administrative and approval procedures have a considerable impact on the climate for investment.

Energy consumption

In relation to energy consumption, countries can be distinguished mainly by the breakdown of the energy users. In particular here, the ratio of demand from domestic households to that from energy-intensive industrial users plays a key role. The attitudes and sensitivity of consumers in relation to their general energy consumption (efficient energy usage) and to individual types of energy (nuclear power, fossil fuels and renewables) are also important.

Energy supply

In respect of the energy supply, countries differ according to the quality and age of the existing infrastructure, the costs of infrastructure investments, the current energy mix and competition in the energy market, among other factors. The quality of the existing infrastructure and the necessary investment costs, for example to ensure reliability of supply, have a direct impact on the investment patterns of the EUCs and the State. Decisions on the future composition of the energy supply are reached on the basis of the current energy mix. Additional classifying criteria include the size and number of market participants among the EUCs in the energy market, and the market structure. This can have a major influence on the dynamic nature of competition.

5.2.2 DEVELOPMENT APPROACH

The development approach is a product largely of the activities of the actors in the energy market and the influence they exert on the future shape and situation of the energy environment. In the scope of this study the energy suppliers are significant actors that must be analysed.

Figure 46: Dimensions used to describe an archetype.

However, industry, which develops and implements the technological infrastructure must also be taken into account. Politicians establish the main framework conditions for the energy market. Research and academia bear responsibility for training and developing innovative new foundations (see figure 47).

Energy suppliers

The energy suppliers can be classified and their influence on the further development of the energy system assessed by looking at their properties and their behaviour. For example, energy suppliers influence the energy market in the context of private commercially initiated and financed pilot projects and research projects. These allow them to contribute to optimising the energy supply and improving the infrastructure. In addition to the R&D investments, the structure and composition of the energy supplier market, the dominance of individual actors and their organisation in associations can all also affect the future energy supply system. In defining, promoting and accepting industry standards, the suppliers are also able to exert a targeted influence on the implementation of new technologies.

Industry

In addition to the energy suppliers, industrial companies (as energy consumers) and technology providers may also initiate research projects and pilot projects. In this context, energy-intensive industries are particularly interested in projects that focus on finding efficient and cheap supplies of energy. Providers of energy technologies, in contrast, are interested in the development of infrastructure solutions for the domestic and foreign markets. Especially in the field of smart grids and renewable energy resources, there is currently a great deal of interest since these represent future markets with corresponding commercial potential.

Politics

In the political arena, a few core criteria have an effect on the further development of the energy system. Overarching political objectives such as protecting the environment, ceasing nuclear power production or setting a target to become a technology leader (for example in renewables) all influence the current and future energy policy to a significant extent. Incentives are created to influence the decisions of industry and domestic households, to help achieve the objectives as quickly as possible. In addition, politics can also have an impact by directly supporting given projects and initiatives.

Research and science

Alongside the potential categorising criteria applied in the field of the energy supply, industry and politics, it is also possible for the fields of research and science, especially in terms of the focus of universities and research institutes, to have an effect on the development approach of a country in respect of its energy sector. In the context of the selected areas of focus, research and pilot projects are initiated by means of which the future emphasis of the energy supply capabilities and various approaches in relation to environmental protection or resource conservation are influenced. Of key importance is also the training and education of corresponding experts. The training and availability of specialist employees have a significant influence on the whole future energy supply environment and on the technological capabilities that a country can contribute in the energy sector.

5.3 HOW THE COUNTRIES WERE SELECTED

The countries that were included in the international comparison were selected and prioritised according to the following criteria, which were identified in an expert workshop.

1. Growth
2. Geographical characteristics
3. Options for a "greenfield approach"[233]
4. Energy type and mix
5. Leading market
6. Pilot projects
7. Model region characteristics

As the subsequent step, a list of countries matching at least one of the above criteria was prepared. The countries were then grouped, allowing a single representative country to be identified for each group. In addition, the countries were prioritised whereby the allocation to a category was dependent on factors

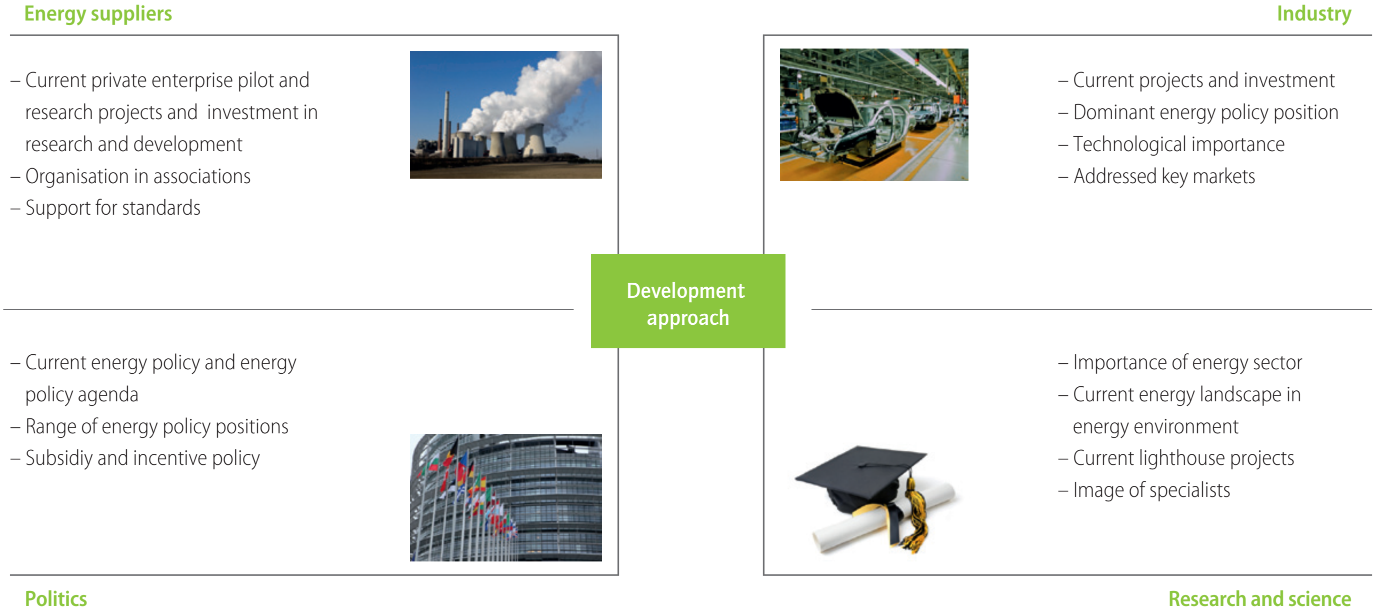


Figure 47: Dimensions used to describe the development approach.

233 This is an approach based on "greenbelt" planning.

including the number of criteria that the country met. Alongside Germany, most pertinent criteria were identified for China, the USA and Europe as a region. Primarily on the basis of their status as leading markets, the following were classified as particularly important:

- Germany (4, 5, 6, 7)
- USA (2, 5, 6)
- China (1, 2, 5, 6)
- Europe as a region (2, 5, 6)

The three countries in the next category – Denmark, France and Brazil – each met three of the criteria and also have strong model-like characteristics, since individual aspects of these countries can be viewed as prototypical. Denmark is a pioneer in the field of wind power and France is heavily committed to nuclear power and, like Brazil, the production of bio-fuels. In addition, Brazil obtains a massive proportion of its electricity from hydroelectric power.

- Denmark (2, 4, 6)
- France (4, 5, 7)
- Brazil (1, 3, 4)

India, Italy and Russia were selected as representatives of further groups of countries and also each has model-like characteristics. India is characterised by the potential for high growth. Italy stands out thanks to its high use of gas, exit from nuclear generation and advanced model regions (see below). Russia has very large potential for renewable energy resources, but at the same time has a political system that supports the expansion of nuclear generation so that it can continue to increase its exports of fossil fuels.

- India (1, 3)
- Italy (4)
- Russia (1, 2)

Alongside the countries that were selected for analysis are a number of projects that also exhibit a strong model-like characteristic.

Four projects from countries not otherwise considered are described in brief, as examples:

- Sweden
- UAE
- Netherlands
- Singapore

5.4 COUNTRY PROFILES

This section contains a brief profile describing each country, based on the criteria in section 5.3. The profiles should help to illustrate how the countries differ from Germany and what potential may exist there for the German economy.

5.4.1 GERMANY

General

Looking at Germany's profile in terms of the future electricity supply, a pioneering image emerges, primarily as a result of the country's combined characteristics of being an exporting industrialised country with a consistent plan for exiting nuclear energy by 2022.[234] There is, therefore, plenty of potential until then and through to 2030, but also a range of risks and challenges for the electricity supply.

Status quo

The exit from nuclear power, which now seems certain (around 22 percent contribution from nuclear to the electricity generation mix in 2010, around 17 percent renewables, around 43 percent coal and around 14 percent natural gas[235]) is the result of many political negotiations, which have been affected not least by the events in Fukushima. Despite the country's federal decision-making structure and the resulting occasional lack of harmonisation of legislation in energy policy, the transformation of the energy sector has been agreed. Politicians are using regulation to intervene strongly in the energy supply system, in some cases stipulating requirements down to the data

234 Liebig 2011.
235 BMU 2011a.

communications layer. Nevertheless, the prerequisites for realisation of the targeted transformation can be assessed as promising. Alongside good geographical and weather conditions, such as those listed below, its mature economy with moderate rates of growth is also an advantage on the path towards achieving the stated targets.

- Central European location
- Northern coastline, which is suitable for the construction of offshore and onshore wind farms
- Sufficient sunlight in the south, enabling commercially feasible installations of PV (photovoltaic or solar) power systems
- Enormous potential for storage of energy in natural gas or water-based storage facilities

In general, in the past few years Germany has formed a clear awareness of energy matters, which can be expressed, for example by the high regard for renewable energy This applies not only for domestic households, which in 2010[236] took around 23.3 percent of their electricity requirements from renewable energy sources, but also for commercial and craft operations (around 12.4 percent), public institutions (around 7.6 percent) and industry (around 40.2 percent), which have all included topics such as energy efficiency as key parts of their corporate strategies. All consumers in Germany can rely on a high quality supply, which also ensures that maintaining this standard is a core objective of the future energy supply system.

The German energy market has been liberalised. Local monopolies for distributors have been broken up, the grids and distribution are, in company law at least, now separate and subject to a large body of regulation (a situation known as "legal unbundling"). Parts of the transmission grids are no longer in the ownership of the major German energy suppliers. In relation to generation, there is an oligopoly comprising a few providers that also participate in trading and distribution. In the solar cell manufacturing business, the world's fourth largest (in market share terms) manufacturer in 2009 was Q-Cells, a German company. Also based in Germany, Enercon, Siemens and REpower are three of the ten largest manufacturers of wind power equipment (2009). Finally, in 2010 E.ON AG was among the companies with the highest amount of distributed energy resources in the field of renewable energy.[237]

Development

In order for Germany to continue to enjoy a dominant position in the energy environment, it is necessary to carry out corresponding research and demonstration projects. Politicians support projects, especially in the areas such as renewable generation, storage of fluctuating energy feed-in and the use of ICT to create smart grids. These are taken on and driven forward by both industry and the energy utilities. An internationally visible example is the E-Energy Initiative.[238]

The energy utilities also initiate their own projects, in relation to a wide range of technologies. Investment activity levels are low, however, due to a lack of investment security. For industry, the realisation of pilot projects is particularly important, since technology exports are core to their businesses. Like energy utilities, industry does not only focus on specific technologies, but also researches and develops in a variety of fields, in some instances on the basis of the legislative framework, such as the exit from nuclear power.

A further consequence of the transformation is the rising demand for specialists in the energy sector. This includes experts in engineering disciplines including electrical engineering, as well as, increasingly, specialists in the IT and ICT environment. While experts accord Germany a high level of technical competence in the smart-grid sector[239], in the medium to long term they anticipate a major lack of appropriately trained specialists to form the next generation.[240]

5.4.2 USA

General

As a theme, the energy supply occupies a particularly high place in the USA, the world's largest national economy. Demand for

236 AGEB 2011.
237 IEA 2010a.
238 BMWi 2011d.
239 VDE 2011.
240 VDE 2011.

deep-rooted investment in the energy sector can be attributed to a range of factors. Especially important among these are a reduction in the country's dependency on energy imports, and also the unsatisfactory state of the electricity grids, especially for an industrialised country, which entails an impact on the reliability of supply. This deficiency has been revealed in a high incidence of faults and several wide-area power outages in recent years.[241] As a result, it is unsurprising that the Obama administration has undertaken massive investment projects. The American Recovery Reinvestment Act 2009 (ARRA) earmarked 3.48 billion US dollars to modernise existing grid infrastructure, 435 million US dollars for regional smart grid demonstration projects and 185 million US dollars for energy storage demonstration projects.[242]

Status quo

The US presidency has established energy as a primary policy objective (although regulation and liberalisation have been around since 1970), and is seeking to subsidise renewables more heavily than conventional energy sources. Various mechanisms, such as the feed-in tariff and tax benefits are playing a vital role in this respect. It should be noted that the two major political parties, the Republicans and the Democrats, have different energy strategies and that the US legislative system is exceedingly complex, all of which contributes to making it significantly more difficult to forecast the future development of the energy environment.

Contributing around 19 percent of electricity generated in 2008[243], nuclear power is viewed as a having a key role to play in the energy revolution. For example, for the first time since 1970, plans to construct new nuclear power plants have been agreed.[244] In addition, new cleaner coal-fired power plants (contributing around 49 percent of the electricity mix in 2008[245]) are helping to reduce emissions while meeting the increasing demand for power. Furthermore, the exploitation of non-conventional natural gas sources (such as shale gas) has been developed strongly in the USA. This has helped to drastically reduce dependency on imports of gas. The share of generation from natural gas is anticipated to remain constant, at around 22 percent for the next 20 years.[246] In 2008, the share of renewable energy sources was relatively small, at just 8 percent of the electricity mix[247]. However, by 2010 the installed power from wind farms had more than doubled, creating the world's second largest market.[248]

From a geographical perspective, the USA offers a highly diversified range of potential locations for renewable energy (long coastlines in the east and west and the central "sun belt") and also a relatively low population density, which makes it easier to exploit these locations. Both the responsible government ministry - the Department of Energy (DoE) - and private enterprise have sponsored projects to increase the installed output of renewable energy. In some states, incentives have been offered to consumers to optimise their energy consumption. In 2008, domestic customers consumed the largest proportion of electricity, with around 36.2 percent, closely followed by the commercial and public services with around 35 percent and industrial customers with a share of around 24 percent.[249]

Development

In order for the primary objective of energy independence to be achieved, a range of additional measures extending beyond modernising the grids must be realised. Research and development measures are, therefore, not simply explicitly supported by politicians, but are also funded by private enterprise. In respect of these efforts, the main aim is not to lose the country's current leading role in ICT to India and China, as has been predicted by experts.[250]

241 Stern.de 2010.
242 U.S. Government 2011.
243 IEA 2011a.
244 DW 2011.
245 IEA 2011a.
246 DoE 2009.
247 IEA 2011a.
248 WWEA 2011.
249 IEA 2011b.
250 VDE 2011.

In the field of smart grids, the USA is viewed as a growing source of innovation.[251] The USA is home to the head offices of world market leaders such as GE Energy (12.4 percent, and 12.5 percent in 2009 together with Vestas of Denmark) in the field of wind turbine manufacturing and First Solar (8.9 percent in 2009) in respect of solar cell manufacturing. Equally, in 2010 Nextera Energy, the company with the world's second largest portfolio of renewable energy generation plants, and Archer Daniels Midland Company, Valero Energy Corporation and POET as the three largest bio-fuel producers in the world (the USA provided six of the top ten in this sector) were all global market leaders.[252]

Conclusion

In the USA, the size and diverse nature of the landscape offer a variety of options for the development of smart grids. So while the wind power industry is currently mature and saturated, the large amount of resources still offers good market entry opportunities, including for energy products.[253] It should also be noted, however, that special conditions and especially certification processes apply to those wishing to feed in to the grid. Due to the high levels of sunlight, there is also great potential for solar power. Depending on the location, the deployment of PV and CSP (concentrated solar power) technologies may be of advantage. In addition, good geological conditions permit geothermal (exploitation already possible using current technologies[254]) and hydroelectric power generation (with the majority of sources already having been tapped, at least in part). Furthermore there are also options in the area of grid components, since a comprehensive programme of modernisation is planned.

5.4.3 CHINA

General

When it comes to energy technology development, the People's Republic of China occupies a special place for two primary reasons. The first is the country's political structure as a de facto one-party state. The second is the fact that the country enjoys extremely strong economic growth, with GDP growth of 10.3 percent in 2010 and 9.6 percent in 2011.[255]

Status quo

China is the world's fourth largest country and has a relatively high population density that is concentrated in a number of massive conurbations. This distribution is down to a range of geographical conditions, that extend over 18 climate zones. Consequently, while there are good opportunities for the installation of renewable energies, there is a discrepancy in terms of location between electricity generation and demand. This is one of the reasons for the increasingly frequent energy shortages and for the planned shutdown of the electricity supply in large cities and for power outages.[256] Technologies to transport energy over long distances thus form a core focus of Chinese energy research.[257]

Chinese industry consumes a much higher proportion of the total electricity usage compared with other industrialised countries, at around 75 percent in 2008.[258] Three of the world's ten largest wind turbine manufacturers (Sinovel with 9.2 percent, Goldwind with 7.2 percent and Dongfang with 6.5 percent in 2009) are based in China, along with four of the world's ten largest solar cell manufacturers (Suntech Power with 5.7 percent, Yingli with 4.3 percent, JA Solar with 4.2 percent and Trina Solar with 3.2 percent in 2009).[259] China consumes around 20% of the world's total energy output[260] and in 2010 overtook the USA as the world's largest power consumer.

251 VDE 2011.
252 IEA 2010a.
253 dena 2009a.
254 dena 2009a.
255 GTAI 2011.
256 Du/Liu 2011.
257 SGCC 2010.
258 PDO 2008.
259 IEA 2010a.
260 NDR 2011.

Development

China is led by the authoritarian central government of the Communist Party of China. This means that decisions can be implemented without needing to accept major compromises, which frequently results in a clear policy strand evident in political decisions. These decisions can, to a certain extent, be made irrespective of the opinions and wishes of the population, or even the interests of the commercial sector. This aspect also affects the energy policy. For example, the prices of electricity, coal and oil are set by the National Development and Reform Commission (NDRC). In 2005, the Renewable Energy Law came into force, obliging grid operators to accept electricity feed-in from renewable energy sources at a higher price than that offered for energy generated conventionally.[261] Furthermore, the objective has been set to increase the proportion of renewable energy to at least 15 percent of primary energy generation by 2020.[262] In this context, the target is to increase electricity generated from wind, solar and biomass sources to output of 150 GW, 20 GW and 30 GW respectively.[263] The development in wind power especially is confirming this trend. In 2010, China installed more than half of the world's total wind farm capacity, and now leads the market with total installed power of around 44.7 GW, representing an increase of over 73 percent compared with the output previously installed in 2010.[264] Major projects are also planned in the field of solar power, such as the construction of the world's largest solar power installation in the Mongolian desert, to be completed by 2019.[265] In addition, the Three Gorges Dam is the largest hydroelectric power station in the world, with an installed capacity of 18.2 GW,[266] with further major projects planned. There are also plans to expand nuclear power, with an additional 116 reactor blocks to be constructed in addition to the ten existing blocks and five others that are currently being built.[267] The aim of this development is to reduce the share of coal (around 80 percent of the electricity mix in 2008, with 15 percent more from hydroelectric power[268]) in total electricity production. Politics will also play a major role on the future development of the energy sector.

In China, smart grids are viewed as an opportunity to reduce energy consumption, increase the efficiency of the electricity grid and also make the generation of renewable energy more manageable. To achieve these aims, in 2010 the State Grid Corporation of China (SGCC) produced a plan for a smart grid pilot programme. This extends until 2030 and comprises investment of at least 96 billion US dollars by 2020.[269]

While experts ascribe enormous innovative power in the fields of IT, ICT, electrical engineering, electric mobility and smart grids to China, their assessment of the country's technical capabilities is not as high. In general, however, specialists believe there is great potential in the area of education for industry experts.[270]

Conclusion

China will remain one of the major future markets for smart grid technologies, and due to its political situation and strategic objectives such as those in relation to electric mobility it will develop quickly, focusing on home-grown enterprise. Geographically the country has good resources for both wind power and solar power, as well as for hydroelectric power. Equally, the biogas sector offers good market opportunities for German companies, as China offers massive as yet untapped potential in this area. In contrast, the market for geothermal energy is not well developed, and has little chance of growth due to the strength of hydroelectric power. Hydroelectric power divides opinion in China, since projects have often entailed negative ecological and social consequences (such as inhabited areas in the scope of the Three Gorges Dam[271]). Furthermore, deficiencies are anticipated in service provision,

261 REW 2005.
262 CDG 2007.
263 DDWB 2011.
264 WWEA 2011.
265 FAZ 2009.
266 Spiegel 2011.
267 Nikolei 2007.
268 IEA 2011a.
269 IEA 2011b.
270 VDE 2011.
271 FTD 2011.

such as plant maintenance.[272] One technology focus is on the development and deployment of HVDC technologies, due to the large distances between the generation and consumption regions.

5.4.4 EUROPE

General

For the purposes of this description, Europe is understood to be the European Union (EU 27), the political system of which is primarily based on the Treaty on European Union and the Treaty on the Functioning of the European Union. These treaties contain intergovernmental and supranational rules. In economic terms, the EU represents the world's largest internal market, with annual GDP growth of around 2 percent (until 2008).[273] In respect of energy supply, four core aspects must be considered at European level. These are the geographical conditions, the super grid, energy policy and the subsidy programme.

Status quo

The EU is situated largely in a temperate climate zone, and has both large coastal areas and mountains, and wide-ranging lake landscapes. There are, therefore, plenty of opportunities for the installation of a range of generation facilities, although large amounts of coal and gas are currently imported from Russia and Norway respectively for the purposes of power generation.[275] The relatively diversified mix of gross electricity generation (2010) can be attributed to this situation.[275] Accordingly, 28 percent of electricity was generated by nuclear power, 27.6 percent came from coal, 23.2 percent from gas, 19 percent of power from renewables and 2.2 percent from crude oil products. The geographical distribution of renewables is such that wind power is concentrated mainly in the north of the EU, while solar power is largely in the south. Hydroelectric power is located in Scandinavia and the Alpine regions. This provides an opportunity for balancing out the fluctuations of the different generators at European level.

An initial step in increasing the reliability of supply and creating a single market is the European interconnection grid for high and extra high voltage. This has already been in place for a number of years, but is now regulated centrally by ENTSO-E[276], an association of transmission system operators. ENTSO-E was formed in 2009 from the UCTE (Union for the Coordination of Transmission of Electricity), Nordel, ATSOI (Association of the Transmission System Operators of Ireland), ETSO (European Transmission System Operators), BALTSO (Baltic Transmission System Operators) and UKTSOA (United Kingdom Transmission System Operators Association). So far the association represents 41 TSOs from 34 countries, whereby UKTSOA operates beyond EU borders. ENTSO-E thus has a key position in exploiting the potential of renewable energy in North Africa. As the corresponding projects are initially still undergoing feasibility studies, this role will only come to fruition in the long term.

Development

The energy policy of the EU was institutionalised in EU legislation by the 2007 Lisbon Treaty. The EU also agreed an action plan on energy policy in the same year. An important component of this plan are the "20-20-20" goals.[277] These goals, which take 1990 as their base year, aim to cover at least 20 percent of energy consumption with renewable energy sources by 2020. In the same period, they aim to reduce greenhouse gas emissions by 20 percent and improve energy efficiency by 20 percent. One means of achieving these aims, for example, is the EU system of emissions trading, which is also making a contribution to upholding the climate protection targets of the Kyoto Protocol. In addition, the 2011 Energy Summit held in Brussels agreed to complete the internal energy market by 2014, accelerate expansion of the electricity and gas grids, agree a common energy foreign policy and promote renewable energies.[279] An Energy

272 dena 2009b.
273 BMWi 2011f.
274 EKE 2010.
275 FAZ 2011a.
276 ENTSOE 2011.
277 EP 2008.
278 WZ 2011.
279 ECE 2011b.

Roadmap 2050 was announced for the end of 2011, a period of public comment and consultation having been completed in the first half of the same year.[279] The Directives of the EU[280] are binding on national governments.

A variety of research projects are funded at European level.[281] Alongside the many rather small programmes, the current Framework Programme 7 (FP7) is worthy of note.[282] This research programme has allocated funding for investment of around 50.5 billion euros during the period from 2007 to 2013. The funding is divided between the four Specific Programmes[283] Cooperation (the core programme comprising around 32.5 billion euros), Ideas, People and Capacities. Direct funding is available for the fields of energy (around 2.35 billion euros) and the environment (around 1.89 billion euros), as well as for energy-technology topics in cross-cutting fields such as ICT (around 9.05 billion euros). The most important projects in the overall European context are the "European Supergrid", "North Sea Power Wheel"[284] and DESERTEC[285], the aim of which is to exploit desert sunshine on a wide scale to generate electricity.

Conclusion

In respect of Europe as a region, German companies in particular have opportunities in the areas of supported projects, which thanks to their broad spectrum of applications also offer the chance to conduct research and development with a focus on ICT in the energy sector. Due to the different resources offered within the EU Member States, it is difficult to describe potential for technologies in general terms. However, is can be assumed that Europe (alongside the USA and China) will be a key sales market for smart grid technologies in the future.

5.4.5 DENMARK

General

Denmark is a monarchy with a democratic parliamentary system, whose executive power lies formally in the hands of the monarch (King/Queen). In practice, however, these powers are carried out by the cabinet, which is controlled by the Prime Minister. Geographically, Denmark is characterised by a number of islands and a long coastline. Around a third of the surface area is distributed over 443 islands, and in total there are 1,419 islands with a surface area of over 100 m^2. Greenland and the Faeroes are also equal countries within the Kingdom of Denmark. In 2011, 79.5 percent of the Danish population live in towns and cities.[286]

Status quo

The business world is characterised by a large number of medium-sized companies in the industrial and services sectors, many of which are highly specialised and also very innovative and export-oriented.[287] Many of these represent the technological cream. In 2009, the Danish company Vestas was the world market leader in the construction of wind turbines.[288]

The country's energy sector also has a very particular structure. It is highly distributed and comprises a large number of cooperatives and energy utility companies (EUCs) that are owned by local authorities.[289] As a result, the local authorities, unlike in most other European countries, have an important influence on the national energy supply. Consequently, Danish consumers are also co-owners of the EUCs, and in particular of many distributed energy resources. Responsibility for the system and the distribution grid has been in the hands of the state since 2004. The 400 kV transmission grid belongs to Energinet.dk,

279 ECE 2011b.
280 ECE 2011c.
281 JRC 2011.
282 ECC 2011.
283 BMBF 2011b.
284 ITER 2011.
285 DESERTEC 2011a.
286 SD 2011.
287 dena 2008.
288 IEA 2010a.
289 DONG 2007.

while the 150/132 kV levels belong to regional TSOs and the distribution grids to local DSOs. The entire grid forms part of the Nordel electricity grid association, along with Norway, Sweden and Finland, and thus participates in energy trading in the common NordPool electricity market. In Denmark the electricity market has been fully liberalised since 2003, with the objectives of creating transparency, enabling consumers to have a free choice of electricity supplier, ensuring the generation of electricity at fair market prices and opening up the gas market in 2004.[290] In January 2007, Denmark had Europe's highest electricity prices, partly due to the high tax component (> 50 percent).[291]

In 2010[292] 36.3 percent of the nation's electricity was generated by coal, 35 percent from renewable energy sources (21 percent from wind power alone[293]) and 27.7 percent from gas. More than half of the electricity generated came from large power plants, although these are almost entirely cogeneration plants. In 2009, electricity consumption was distributed relatively evenly over the different customer segments: Around 33.9 percent related to trading and services, around 32.7 percent to agriculture and industry and around 32 percent to domestic households.[294]

In the wind power sector, Denmark was only in tenth place in terms of installed capacity in 2010, but was by some distance the world leader in per capita consumption, as well as by size of country and GDP. In addition, Denmark has the second largest installed offshore wind power capacity after the UK.[295]

Development

Administratively the energy sector in Denmark is the responsibility of the Ministry of Climate and Energy (KEMIN), which primarily develops policy for implementation by the Danish Energy Authority (DEA) and the Danish Energy Regulatory Authority (DERA). The national Energy Plan of 2007 takes 2005 as its reference year, and pursues an overriding objective of independence from fossil fuels such as coal, gas and oil (25 percent less consumption by 2015). In order to achieve this it is planned to increase renewable energies' contribution to the total energy consumption to 30 percent. Energy efficiency is to be improved by 1.25 percent per year, using measures such as certification to reduce energy consumption to mid-1970s levels while economic growth remains constant. In the field of transportation, around 10 percent of fuels should be obtained from renewable energies. R&D investment was doubled in 2010 to around 134 million euros. The plan is to be revised in 2015 and the targets adjusted if necessary.[296] In order to achieve the desired results, the government intends to put in place a programme of subsidies to promote generation of energy from renewables, in particular with increased use of biogas. Wind power - onshore and offshore demonstration projects, plus an offshore infrastructure plan - has been identified as a strategic component and will be further expanded. Energy taxation will be reorganised. Funding programmes will support the use of efficient heat pump technologies and biofuels in CHP systems.[297] In addition, Denmark plans to reduce its CO_2 emissions by 21 percent between 2008 and 2012 (reference year 1990), in line with the EU Directive.[298] Moreover, ensuring security for investments in renewable energies is one of the government's priorities.[299]

In the area of R&D, Denmark has a pioneering role. Above all, funding is awarded to projects relating to new and more efficient technologies. This is providing valuable experience that can be accessed again when it comes to practical implementation. The emphasis is on biomass (particularly second generation biofuels), hydrogen and fuel cell technology, wind turbine engineering and energy-efficient technologies in the construction sector. This method is

290 Energinet.dk 2011.
291 Goerten/Clement 2007.
292 FAZ 2011a.
293 WWEA 2011.
294 DEA 2010.
295 WWEA 2011.
296 ICDSV 2007.
297 DEA 2007.
298 Spiegel 2007.
299 DEA 2007.

intended to create long-term financial and economic advantages for investors and consumers.[300]

Conclusion

German companies will have potential business in the field of large wind farms and also in respect of biomass plants and heat pump technology. The latter is especially due to the large Danish remote heating grid, which includes an enormous number of integrated CHP plants. A further characteristic of Denmark that will play a key role in the scope of its economic commitment is the country's predominant structure of businesses. For example, the smaller, but highly specialised companies that often form part of the international elite in their sectors make for innovative project partners. With its pioneering role in the integration of renewables, Denmark is particularly interesting for German companies in respect of the application of new technologies. In addition, thanks to its already high proportion of fluctuating electricity generation, Denmark offers an ideal platform for testing smart grid functionalities and their effects at all voltage levels.

5.4.6 FRANCE

General

France is the largest country in Western Europe, and also the most important industrialised country alongside Germany. However, France's population density is rather low in comparison with its neighbouring countries. In the semi-presidential democratic Republican system in France, the constitution gives the president a strong role. The traditional state control of the energy sector was dissolved in 2000 with the transposition of the EU Directive, and the market opened up to limited competition. Energy end users have been able to trade in energy certificates since 2006.

Status quo

In terms of end users the share of domestic households and the tertiary sector makes up around 66 percent (2009),[301] which is down largely to a significant proportion of electric heating in homes.

Within Europe, France has campaigned for a climate change levy on fossil fuels.[302] In addition, the country is pursuing the objective of becoming one of the leading nations in the renewable energies sector.[303] Until now, the share of nuclear power[304] in total electricity generation has been around 76 percent (2008) while renewable energy sources have contributed around 13 percent (2008).[305] This high dependency on nuclear power has wide-ranging consequences. For example, nuclear power plants also have to be operated in medium-load mode, and the grid has had to be expanded to form one of Europe's largest in order to enable demand fluctuations to be offset by a common effort. As a result, the electricity infrastructure is largely well developed and forms the basis for a high degree of reliability of supply. In view of the strong bias towards nuclear power in the generation mix, a research focus already exists in this area. France takes a leading role in global nuclear research, and is heavily committed to related topics such as nuclear fusion and the reprocessing of nuclear fuels.

In the transportation sector, France has a leading position in the cultivation of plants for biofuel production, with two of the world's ten largest companies (Louis Dreyfuss Group).[306] This can be attributed to the fact that France made its commitment to this sector at an early stage.

Development

In a situation similar to the German BMWi, it is the French economics ministry that takes responsibility for the energy sector. In general, the aim of French energy policy is to reduce greenhouse gases, ensuring greater reliability of supply for energy and reducing the country's dependency on imports of fossil fuels. As part of the strategy to meet this objective, the National Renewable Energy Action Plan (NREAP) was

300 DEA 2007.
301 CGDD 2010.
302 dena 2011a.
303 dena 2011a.
304 21 nuclear power plants with 59 reactors
305 IEA 2011a.
306 IEA 2010a.

prepared, which sets the target of achieving 23 percent of total energy generation from renewables.[307] This does not include the French share in the Mediterranean Solar Plan (MSP)[308], which proposes a 20 GW solar power installation in the Mediterranean by 2020. The strategy for achieving the 23 percent share outlined above was developed in 2008 and is based on both doubling the installed generation plants for renewables in comparison with 2005 and on reducing energy consumption. The focus here in particular is on the existing pool of buildings, which is to contribute around 38 percent of savings. Especially buildings that are owned by the state or by companies operated on behalf of the state are to be renovated taking account of energy efficiency measures. This is planned to start by 2012.[309]

An important project from which a number of conclusions can be drawn was launched by the distribution system operator, Électricité Réseau Distribution France (ERDF), which has installed 300,000 smart meters as part of a pilot project and has also announced that, if the project is successful, it will replace all 35 million ERDF meters with smart meters between 2012 and 2016.[310]

Conclusion

Alongside technologies for the predominant nuclear energy segment, there is also great potential in respect of technologies for the renewable energy environment. For example, after the UK, France has the second greatest potential for wind power exploitation, and higher sunshine levels than Germany.[311] The wind power market is growing strongly although the construction of wind farms is affected by specific rules such as measures against the proliferation of wind power plants. The markets for solar and CSP (concentrated solar power) are small, but are growing gradually. France is the largest agricultural nation in Europe, and therefore has good structures for the cultivation of bio energy (biogas, biomass and biofuels).[312] Equally, France is one of Europe's largest potential sources of hydroelectric power (for example in the Alps and the Pyrenees) and is also testing innovative generation technologies such as wave and tidal power.

5.4.7 BRAZIL

General

Brazil is only slightly smaller in terms of surface area than the entire European continent, and is situated in a diverse climate zone with strong differences between north and south. It is among the group of countries with the best opportunities for exploitation of renewable energy sources.[313] Alongside the hydroelectric power resources, of which significant use is already made, there is plenty of sunshine and an immense richness of biomass. The coastal areas also provide good opportunities for wind energy. The presidential, Federative Republic of Brazil is classified as a developing country, and enjoyed 5.1 percent growth in GDP in 2008 before then being set back by the global economic crisis.[314] Worthy of particular note is the low average age of the population, which at 29.3 years is well below the European average (around 39 years in a band ranging from 28.3 to 42.3 years).[315]

Status quo

The electricity generation mix[316] provides Brazil with the opportunity to assume a unique global role, since around 80 percent of its electricity is obtained from hydroelectric power (2008). A further 13 percent (2008) is can be attributed to the various fossil fuel sources. This relatively one-sided reliance on hydroelectric power can cause particular problems during arid periods, such as in 2001, when water consumption had to be reduced by 20 percent due to a period of drought.[317]

307 MEEDDM 2009.
308 ZEIT 2011.
309 MEEDDM 2009.
310 IEA 2011b.
311 dena 2011a.
312 Cassin 2011b.
313 dena 2009c.
314 BCB 2009.
315 CIA 2011.
316 IEA 2011a.
317 De Oliveira 2007.

It is now planned to counter this dependency by expanding wind power facilities in the north east, which experiences strong winds during periods of drought. In 2008, 46.7 percent of total electricity consumption was by industry, with 22.1 percent by domestic households and 22.4 percent by the public sector and commercial sector.[318]

The overall situation on the energy market is complex. The market is largely in private ownership, and electricity prices are determined via auctions with fixed upper limits.

A comprehensive transmission grid has been constructed in Brazil, and there are many local grids. However, far from all areas of the country are connected to the grid, and the country does not have a complete electricity supply.

A variety of EUCs have launched pilot projects in the smart grid field. Examples[319] include Ampla (a DSO based in Rio de Janeiro), which has installed smart meters and secure networks to reduce losses from illegal connections, and AES Electropaulo (another DSO in Rio de Janeiro), which has developed a smart grid business plan. This is based on the existing fibre optic backbone. The EUC CEMIG has launched a smart grid project based on the system architecture of the IntelliGrid Consortium (an initiative of the Electric Power Research Institute - EPRI). Furthermore, the Brazilian company Cosan Limited is among the world's ten largest owners of biofuel plants.

Development

With the Energy Plan 2030[320], the government is targeting the optimisation of the energy mix, including by shifting the consumption of bioethanol and oil over to natural gas. In addition, the objective has been set to reduce electricity consumption by 10 percent. Furthermore, the proportion of renewable energy is to remain stable despite gradually rising demand for electricity. Traditionally, hydroelectric power and alcohol from sugar cane have had a key role to play as fuels. The energy supply is largely in state hands, while administration of the energy sector is the responsibility of the Ministry for Mining and Energy at Federal level. The overriding objective is for economically sustainable growth. In the field of biofuels, Brazil is striving for global market and technological leadership, so that R&D is well funded in this area.

Conclusion

Sao Paolo is the largest base for German industry outside Germany, and in 2008 a bilateral agreement was reached between Germany and Brazil to support cooperation in the field of renewable energy.[321] Renewable energies are considered to be a growth industry in Brazil. While there is an increasing receptiveness to new technologies in the generation from renewable energies, the exploitation of this potential has been limited due to the lower levels of profitability in comparison with hydroelectric power.[322] Very good market potential exists for solar-thermal water heating, solar cooling and small hydro power plants, however.

5.4.8 INDIA

General

Alongside China, India is the largest development market in the IT/ICT sectors and offers great potentials for the energy environment, which in respect of smart grids are rather limited to essential functionalities such as reliability of supply.[323] This is due to the fact that India, despite GDP growth of 7.3 percent in 2008, is classified as a developing country. Only just over half of all inhabitants in India had mains electricity in 2008.[324]

Status quo

The electricity supply in India is organised by the state (administrative responsibility for the energy sector is divided between six ministries and authorities), while the electricity supply system is currently undergoing a phase of liberalisation, in which liberalisation is growing

318 EPE 2008.
319 IEA 2011b.
320 EPE 2007.
321 dena 2009c.
322 dena 2009c.
323 VDE 2011.
324 UNEP 2008.

gradually but slowly.[325] There is no country-wide funding system for generation using renewable energy sources, and as a result, quota and tariff-based systems are in place in just 18 of the 29 states.

India's landscape is characterised in some areas by high mountain ranges like the Himalayas. As a result, a number of storage dams have been constructed, both for irrigation and for the generation of electricity. In 2008[326] the share of hydroelectric power in total electricity generation was just 14 percent (of a total share of renewable energy of around 15.4 percent). The generation mix is dominated by coal, with around 68.5 percent. India is the world's third largest user of hard coal. Nuclear power plays only a minor role with just 1.8 percent. At the end of 2010, six nuclear power plants were in operation, with 19 reactor blocks. Five further reactors were being built. European and American companies are not involved in the construction works, and this will continue in the future as India has not yet signed the nuclear weapons non-proliferation treaty.[327] Nevertheless, Germany constitutes the key trading partner in the EU, and good relationships form the basis for entrepreneurial investment. In 2006, the German-Indian Energy Forum was formed, including provisions to strengthen relations between the two countries further.[328]

In 2008/09 end consumption of electricity was split as follows: around 37.8 percent by industry, approximately 23.8 percent by domestic households, around 19.8 percent by agriculture and around 9.8 percent by commerce.[329]

For energy trading, three electricity exchanges were established in 2008. Operations are limited, however, since electricity trading is only permitted on a day-ahead basis.[330]

The Indian extra-high voltage grid (765 kV, 400 kV, 220 kV and 132 kV) reaches 80 percent of the territory. However, the integrated grid transports only 45 percent of the generated electricity into the consumption regions.[331]

Development

In the field of solar energy generation, the Indian government launched the Jawaharlal Nehru National Solar Mission in January 2010.[332] This has the objective of installing at least 20 GW maximum performance in solar power plants by 2022. The programme includes the installation of both large and small generation plants, and also the connection of rural communities to the grid. In general, the Indian government is striving to realise a high quality, reliable energy supply, overcome energy shortages and reform the energy sector. The economic planning for this is manifested in the Five Year Plan (FYP). Currently underway is the 11th FYP (until 2012), in the scope of which the renewable energy segment is to expand to add 15 GW with wind power providing around 75 percent (the Indian company Suzlon had the eighth largest global market share of wind turbine production in 2009[333]). Moreover, the government anticipates further expansion of 30 GW between now and 2022.[334]

In 2008, India had the world's fifth largest primary energy consumption, with a generation deficit of between 10 and 15 percent.[335] Experts forecast a five-fold rise in demand for electricity by 2032.[336] In addition, electricity tariffs in India do not cover costs, and are very high in relation to the purchasing power. There are also high transmission losses and a large proportion of non-technical losses in the distribution grid. To counteract this, the government is pushing ahead with expansion of the electricity infrastructure and the pool of power plants, with a fossil-fuel led expansion strategy including

325 AA 2009.
326 IEA 2011a.
327 sueddeutsche.de 2007.
328 ZVEI 2010.
329 CSO 2010.
330 AA 2009.
331 dena 2010a.
332 IG 2010.
333 IEA 2010a.
334 dena 2010a.
335 MoP 2008.
336 GTAI 2007a.

major coal-fired power plants (up to 4 GW).[337] This requires foreign investment, however, leading to the introduction of the first regulations on open market access in 2009. There is also great interest in expanding nuclear power, thanks to rich thorium reserves, which can be exploited using fast breeder technology.[338]

Conclusion

In the wind power market, subsidiaries of almost all of the international vendors can be found alongside the domestic companies. So far the market has been limited to onshore wind farms, but it can be assumed that offshore farms will be of major importance in the future.[339] Solar power is seen as an opportunity to electrify rural areas with PV islands and solar-thermal plants.[340] There is growing interest in exploiting the immense potential of geothermal energy. However, the obstacles to almost all projects are the lack of infrastructure, both in transportation and in the electricity grid. The use of HVDC technologies such as the 800 kV HVDC system from Siemens is an option here, as it is in China.

5.4.9 ITALY

General

Extending over 7375 km, Italy's coastline is the longest of all Mediterranean countries. In addition, the Alps in the north provide access to a mountain range, while other regions are affected by strong seismic activities. The climate in Italy ranges from Mediterranean to Alpine. Natural resources are low. The government (a bicameral parliamentary democracy) was relative late (1999) in European terms in opening up the energy market, introducing full liberalisation in 2007.[341]

Status quo

In terms of electricity generation[342], Italy is heavily focused on gas (mostly from imports), which contributed around 54 percent in 2008. Other large generation sources include water (around 14.5 percent in 2008) and coal (around 15 percent in 2008). Following the Chernobyl disaster, a staged exit from nuclear power was carried out between 1987 and 1990. Four Italian nuclear power plants were switched off on a step-by-step basis. In 2008, plans were laid to build four or five new nuclear power plants, with the aim of connecting these to the supply grid in 2020. However, a referendum stopped the realisation of this project.[343] In terms of end usage of electricity[344] industry was clearly the heaviest user in 2009, accounting for 43.5 percent. It was followed by the services sector (31.6 percent), domestic households (23 percent) and with a much lower figure - agriculture (1.9 percent).

The electricity prices in Italy are high, due not least to low generation capacity. At the same time, Italy has Europe's fourth largest market for electricity. A consequence of the high prices coupled with the continually falling costs of solar technology is an attractive future market for PV and solar-thermal systems and for pellet burning stoves, which is also the result of the high cost of heating oil. Currently, due to the low investment costs, wind power remains the most attractive option, although the grid structure in the windier southern part of the country is not well suited to connection of wind power facilities.[345] Energy suppliers are currently obliged to offer a progressive electricity tariff (costs rise with consumption). This measure is intended to have a positive effect on consumption patterns. Nevertheless, there are discussions on abolishing this statutory obligation.[346]

In ENEL SpA, Italy is home to one of the world's ten largest owners of systems to obtain electricity from renewable sources.[347] ENEL is still

337 GTAI 2007b.
338 dena 2010a.
339 dena 2010a.
340 MNRE 2009.
341 dena 2011b.
342 IEA 2011a.
343 FAZ 2011b.
344 AEEG 2010.
345 dena 2011b.
346 dena 2011b.
347 IEA 2010a.

the key player on the Italian electricity market, even though the state owned company has recorded a slight fall in the share of production.

Development

Energy policy in Italy is primarily the responsibility of the Ministry for Economic Development (energy reliability of supply, infrastructure and efficiency) and the Environment Ministry (energy efficiency policy). These two ministries were both vital participants in the development of the National Renewable Energy Action Plan (NREAP)[348]. This plan has the objective of increasing the share of consumption from renewable energy to 17 percent by 2020. Another key aspect in Italy are the regional aims of autonomous regions and provinces. Examples include South Tyrol[349] with ten energy-independent provinces and where 56 percent of the energy requirement is covered by renewable energy sources (planned: 75 percent in 2015 and 100 percent in 2020), which makes it the leading location in both Italy and Europe, and the region of Apulia[350] which supplies 13 percent of Italy's energy from biomass, 19 percent of Italy's energy from solar power and in excess of 25 percent of Italy's energy from wind power.

In the field of research, the two most noteworthy are the Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA) in its capacity as the national agency for new technologies, energy and sustainable economic development, and the Istituto Nazionale di Geofisica e Vulcanologia (INGV) as Europe's largest institute for geophysical and volcanic research. Research projects in Italy are funded from international and national sources and closely integrate small and medium-sized companies.

Conclusion

In Italy, smart meters are already a widely used technology. Wind power and hydroelectric power are the dominant areas of renewable energy generation and therefore also offer good market potential. However, comprehensive grid expansion will be necessary in order to exploit the existing potential for wind power. The wind turbines market is dominated by foreign vendors. The PV market is growing gradually, and is focused on the south of the country, in areas such as Sicily. The markets for bioenergy and geothermal energy to generate heat and power play a key role in Italy, and therefore offer good potential for entry to the sector. Hydroelectric power contributes by far the greatest source of renewable power generation and is already well developed in Italy.

5.4.10 RUSSIA

General

Russia (a presidential republic with republican form of government) is the largest country in the world and is also rich in natural resources, with the globe's largest natural gas reserves and second largest coal reserves. It also has a constantly increasing demand for electricity.[351] Russia has all types of climate zone, apart from tropical. The landscape is characterised by mountains, valleys, rivers and numerous inland seas and lakes. Experts believe that for this reason, Russia could be able to cover 30 percent of its demand for electricity from renewables.[352] The government's original Energy Plan for 2020[353] proposed to expand the renewable energy resources, but also relied on nuclear power to achieve the aim of increasing exports of fossil fuels, so that the company could become the world's largest supplier of fossil fuels. A consequence of this project is Russia's great dependency on the energy sector. At the end of 2009, this plan was replaced by a new strategy targeting 2030.[354]

Status quo

The World Bank estimates that the energy sector and remaining raw materials sectors contribute around 20 percent of Russia's total economic output.[355] The proportion of energy exports in the total revenue from exports of goods is around 66 percent, while around 50

348 MED 2010.
349 Athesiadruck 2010.
350 EUROSOLAR 2010.
351 BP 2010.
352 dena 2009d.
353 Götz 2004.
354 dena 2011c.
355 WBG 2005, p. 36.

percent of the state's total income comes from the energy sector.[356] Moreover, Russia is the world's largest exporter of natural gas and the second largest of crude oil.[357] Russian economic growth is primarily down to the export of fossil fuels (following negative growth in 2009, GDP grew by 4 percent in 2010[358]). When it comes to exploiting resources in areas that are increasingly difficult to access, Russia is often reliant on technological assistance from abroad.

In 2007, industry accounted for 67 percent of electricity consumption. The proportion taken by domestic households, in contrast, was only 20 percent[359]. It is estimated that in comparison with 2000, there is potential to make energy savings of 39 to 47 percent of consumption overall.[360] Among the factors responsible is the lack of meters in many households, so that consumers pay a fixed price for the use of water, gas, heating and in some circumstances electricity, irrespective of their consumption. Consequently this promotes wasteful usage and low amounts of efficiency.[361]

In 2008[362] 68 percent of the electricity in Russia was generated from fossil fuels (approx. 19 percent from coal, some 1.5% from oil and around 47.5 percent from gas). The remaining third can be attributed almost equally to hydroelectric and nuclear power.

The vast size of the country and the poor state of its infrastructure combine to mean that 20 million Russians are not connected to the electricity grid. This is frequently handled by the use of diesel generators. In addition, some 70 percent of the country is not connected to the high-voltage grid.[363]

The electricity market in Russia is in need of modernisation in two respects: first, in view of the outdated technology and second in respect of its organisation. Since 2001 the electricity market has been restructured following a government decree, with liberalisation introduced in 2010. In the area of trading, however, only a small portion has been opened up and state-fixed tariffs still apply in the majority of the market. This should have changed by the end of 2011, so that 90 percent of the electricity can be traded on the free market.[364]

Development

The Russian Energy Ministry had already developed an Energy Strategy for 2020 back in 2003.[365] In particular, this strategy pursued the objectives of increasing the country's reliability of supply of energy, increasing energy efficiency with a focus on exploiting, processing and transporting fossil fuels, liberalising the energy market and ensuring sustainable development of the energy sector, taking account of environmental protection.

In the subsequent strategy defined in 2009, new objectives were set for 2030.[366] Their primary objective is to achieve stable economic growth from the efficient use of natural energy raw materials and the potential of the energy sector. This aim is to be achieved by means of integration in the world economy, creating a market that supports competition and the transition to innovative and energy efficient growth. It should represent a complete revolution in the economy, which would transform from being a pure exporter of raw materials to an economy based on resources and innovation (the proportion of conventional fuels in total exports should be 40 percent lower in 2030 than in 2005). As a consequence, fewer energy-intensive industries are in the focus of development. The role models in this respect are countries like Canada and regions such as Scandinavia. Furthermore, there will be support for intelligent grids for electricity transmission, the development of conductors and low-resistance composites, superconducting

356 AHK 2011.
357 IEA 2010b.
358 Merck 2011.
359 dena 2009e.
360 dena 2009e.
361 SEN 2010.
362 IEA 2011a.
363 dena 2009e.
364 dena 2010b.
365 Götz 2004.
366 dena 2011c.

electricity storage and the development of technologies for the production of hydrogen. The following developments have been forecast up to 2030: a reduction of the proportion of primary raw materials in the energy supply from 52 percent in 2005 to 46/47 percent, increase in the proportion of renewable energy sources from 11 to 13/14 percent and electricity generation from renewables amounting to between 80 and 100 billion kWh/year. An interim goal is to increase the share of renewable energy sources (excluding hydroelectric power stations with output of over 25 MW) in the total electricity generation from 0.5 to 4.5 percent by 2020. To achieve this, small hydroelectric power plants, wind power farms, tidal power installations, geothermal power stations and biomass heating plants will all need to be built.

Conclusion

Technologies to reduce fossil fuel resources must be imported by Russia. Equally, there is a need for metering technologies that should be used as an aid to reduce consumption. Due to the size of the country, Russia offers enormous potential for almost all renewable energy sources. However, the government must first create the corresponding incentives for these to be used in many cases. The construction of nuclear power plants will lead to the formation of additional technological markets. Another aspect that will offer opportunities for German companies is the urgently required overhaul of the grid infrastructure.

5.5 MODEL PROJECTS

This section describes additional model projects from countries not considered in section 5.4.

5.5.1 AMSTERDAM SMART CITY

Amsterdam Smart City[367] is an independent organisation that carries out climate and energy-related projects. It brings together companies, public authorities and Amsterdam's inhabitants to establish new technologies and make more efficient use of energy. The organisation is an initiative of Liander, a Dutch grid operator, and the Amsterdam Innovation Motor, in close cooperation with the City of Amsterdam. The primary aim pursued by the participants is to reduce CO_2 emissions in Amsterdam by 40 percent by 2025, compared with the reference year 1990. Since 2009, 16 projects have been launched by this initiative, involving more than 70 partners. The focus is on projects in four core topics that together are responsible for the majority of the CO_2 emissions: sustainable work, living, transport and public spaces. Within the past two years, valuable experience was obtained from the projects, building up knowledge of successful project cooperation, raising awareness and implementing and realising smart grid technologies. On the basis of these findings, other projects are planned, in order to achieve the primary objective. In 2011, the project won the European City Star Award 2011.[368]

5.5.2 MASDAR CITY

The Masdar City project[369] was launched in 2006 under the management of the Abu Dhabi Future Energy Company (ADFEC). It is pursuing the visionary objective of establishing a completely CO_2-neutral city in the desert, requiring pioneering work in many areas. Originally, plans were for a construction period of eight years and total costs of 22 billion US dollars. The first phase of the project, comprising a surface area of one million m^2 or one sixth of the planned six km^2, was to be completed, ready for occupation, in 2009. Due to the global financial crisis, however, the original plans have been delayed, and completion of the first phase has been postponed until 2015. The plan is now to finalise the entire project during the period from 2020 to 2025. Equally, the development costs have been reassessed and now stand at 18.7 to 19.8 billion US dollars. The city is intended to become home to 45,000 to 50,000 people. In addition, around 1,500 companies are to be located there. These should primarily come from the trading and production sectors, and should also be specialised in environmentally friendly products. Alongside the city's inhabitants, an additional 60,000 commuters are expected to arrive each day to work for these companies. Moreover, a university, the Masdar Institute of Science and Technology (MIST)

367 AIM/Liander 2011.
368 DDN 2011.
369 MC 2011.

is planned, with support from the Massachusetts Institute of Technology (MIT). It is to specialise in renewable energies. The city's electricity requirement is to be covered by a major solar array located nearby.

Cars will not be permitted in the city, with transport restricted to the public transport system and to rapid transit auto-pods. There will be connections to existing road and rail networks to provide access to towns outside the city. This means that narrow shady streets can be built that help distribute cool air within the city. The concept is supported by a city wall that protects against the warm desert wind.

5.5.3 SINGAPORE

Singapore is well suited to testing smart grid technologies in the form of a living laboratory, primarily due to its high level of grid stability (less than one minute downtime per year per customer) and a SCADA (Supervisory Control and Data Acquisition) system that is already in place and, thanks to two-channel communications, is able to detect faults in the transmission and distribution grid. For that reason, the Energy Market Authority (EMA) launched its Intelligent Energy System (IES) pilot project in 2009. The objective is to test innovative smart grid technologies, applications and solutions. The focus is on the use of ICT to establish bidirectional communications between the EUC and customers. For evaluation purposes, 4,500 smart meters were rolled out to households, as well as to commercial and industrial customers. Generally the consumers in the context of the project are of great importance, and are viewed as a core component. They are to be connected via smart meters, programmable building systems and variable pricing models. Furthermore, it is expected that outage management will play a more important role in the future, thus forming a further focus of the project. PV and CHP plants are providing test beds for plug & play solutions for use in small, flexible generation plants.

The project realisation comprises two phases. The first phase comprises the introduction of the infrastructure components such as smart meters and components allowing bidirectional communications, Outage Management and Demand Response (DR), the integration of distributed energy resources (DER) and integration of electric mobility into the grid. The second phase focuses on participation of domestic, commercial and industrial customers by means of variable tariffs and value-added services.[370]

5.5.4 STOCKHOLM

The city of Stockholm, 2010 winner of the European Green Capital Award[371], is home to the largest smart grid project, with the creation of the new Royal Seaport district.[372] Planning for the project commenced at the turn of the millennium and it is due to come to an end in 2025. Both academic and industrial partners are participating in the project, as well as the city itself and, as the core, the population as the future inhabitants. Within the new district there will be residences for 10,000 inhabitants, and around 30,000 new workplaces will be created. The first new inhabitants are intended to move in to the new district area in 2012. The project is taking on board experience gained from a similar project in Stockholm - Hammarby Sjöstad. The focus is on sustainable transport solutions, efficient construction processes, energy savings and energy efficiency. Three overarching environmental objectives have been set for the new district:

- CO_2 emissions are to fall to below 1.5 t per person per year by 2020.
- The new district is to be completely free from fossil fuels by 2030.
- Royal Seaport has been adapted for future climate changes.

Numerous charging posts have been installed for electric vehicles, and buses and trams will run on biogas. In addition, innovative recycling technologies will be used. The area was previously occupied by industrial plants, such as tank storage, container terminals and gas-fired power plants. Alongside the aforementioned accommodation, 600,000 m² is to be made available for commercial usage, and a modern port will be built. The target electricity consumption for domestic households is 55 kWh per m² per year, with 30 percent of electricity consumed generated locally from

370 Gross 2010.
371 ECE 2011d.
372 SRS 2011.

renewable sources. The planned smart grid system from Fortnum and ABB comprises a large number of different stakeholders, such as smart buildings, distributed energy systems, integrated electric mobility, energy storage for customers and grids, intelligent transformer substations and a smart grid lab forming part of an innovation centre.

5.6 COMPARISON OF COUNTRIES

On the basis of the criteria presented in section 5.2, a questionnaire was developed to allow a comparison to be made between Germany and the countries/regions Brazil, China, Denmark, EU, France, India, Italy, Russia and the USA. As explained in section 5.2, the questionnaire was sent out to experts working internationally in the energy sector. The next section presents selected findings from the collated data.

The assessments were registered on a scale of 1 to 5, with five representing the strongest value and 1 the weakest. The data was then processed to provide an arithmetic mean of the answers. When interpreting the findings it should be noted that the experts' assessments should be viewed in the context of the relative country-specific opportunities.

5.6.1 FRAMEWORK CONDITIONS

In the first part of the survey, the experts were asked for their assessments of the geographical and political conditions in each country.

The analysis of the geographical conditions (see A3 to A5, figure 48) shows that both the USA and China have perfect conditions in each of the categories of relevance for renewable energy. The assessments show that other countries have good results for individual energy types. For example, both Denmark and Germany have good geographical properties for wind power. In contrast, both of these countries are relatively badly positioned in respect of solar power and other renewable energy sources. This assessment also applies to the prerequisites needed for the creation of energy storage.

In respect of the political conditions, (see A6 to A8, figure 49) it is clear that Germany has the greatest degree of liberalisation of all investigated countries. Germany is also the leader in terms of regulatory requirements for the energy environment, however. In terms of time taken to implement energy policy decisions, Germany takes fourth spot in comparison with the other investigated countries. Particularly in a direct comparison with the USA, Canada and China, Germany comes off worst here. Therefore, the experts believe there is scope for Germany to improve in this area.

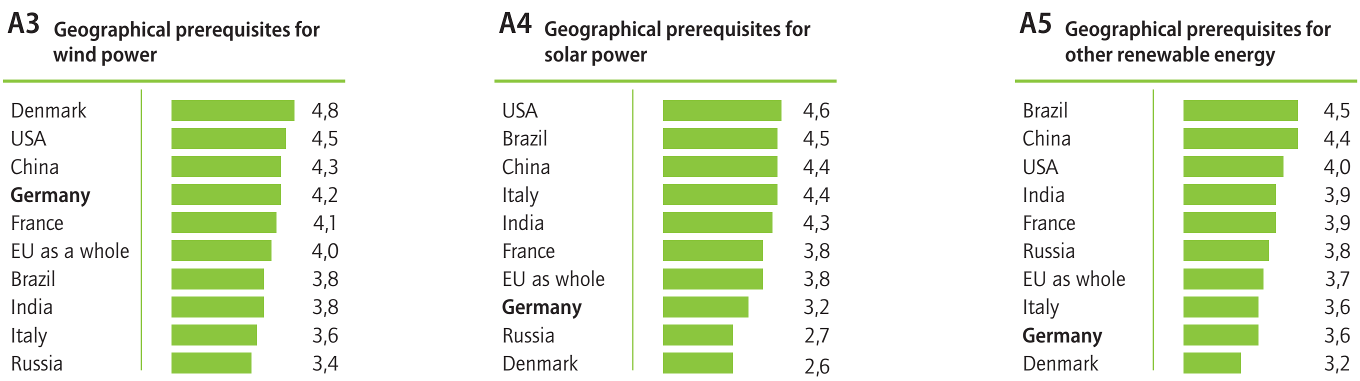


Figure 48: Analysis of the geographical conditions.

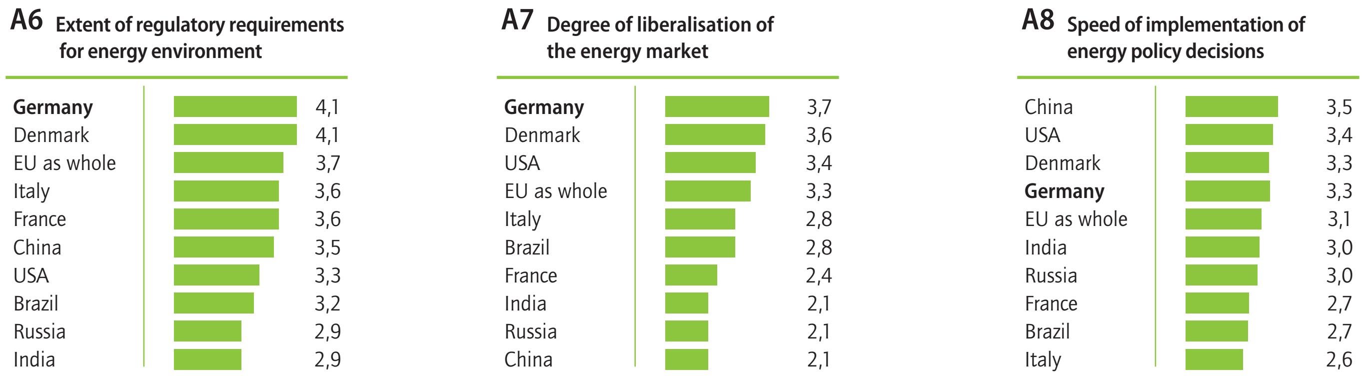


Figure 49: Analysis of the political conditions.

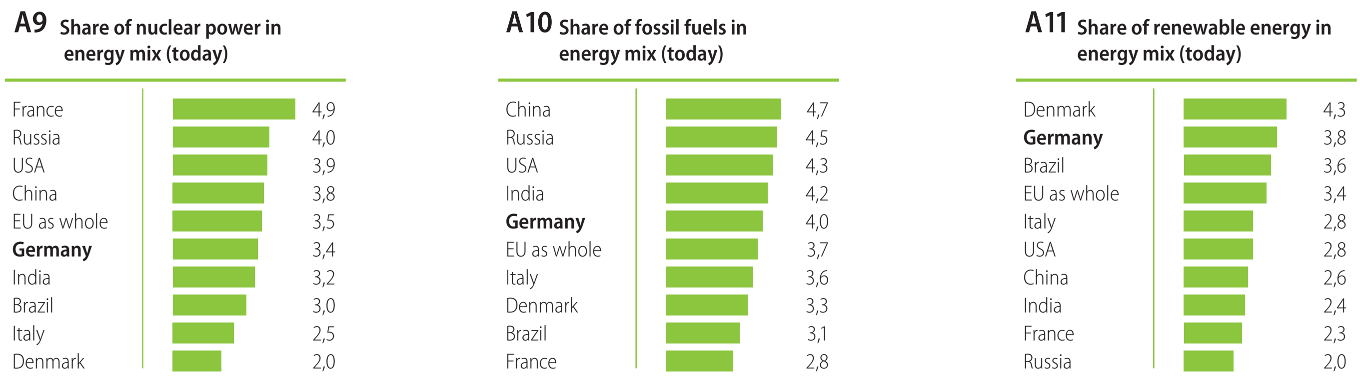


Figure 50: Analysis of the energy mix.

5.6.2 ENERGY MIX

The analysed countries have very different energy mix situations (see A9 to A11, figure 50).[373] In comparison with the other countries, Germany is already very heavily reliant on renewable energy (2nd position). Nuclear power and fossil fuels still have a substantial role to play. France is the clear leader in the use of nuclear power. The French energy mix is dominated by nuclear power generation. Fossil fuels still play a major role, especially in China, Russia, the USA and India. Regression analyses were used to analyse the development of the energy mix in the various countries.

Clear developments have emerged (see A12 to A14, figure 51):

- Countries that are currently reliant on nuclear power will have a similar share of nuclear energy in 2030, according to experts' assessments.
- Countries that are currently reliant on fossil fuels will have a slightly lower reliance on fossil fuels in 2030, according to experts' assessments.
- Countries that are currently reliant on renewable energy sources will probably be even more reliant on these energy forms in 2030.

373 Although Denmark and Italy do not produce their own nuclear-powered electricity, the data in A7 can be explained on the basis of imports from Sweden (WNA 2011a) and France, respectively (WNA 2011b).

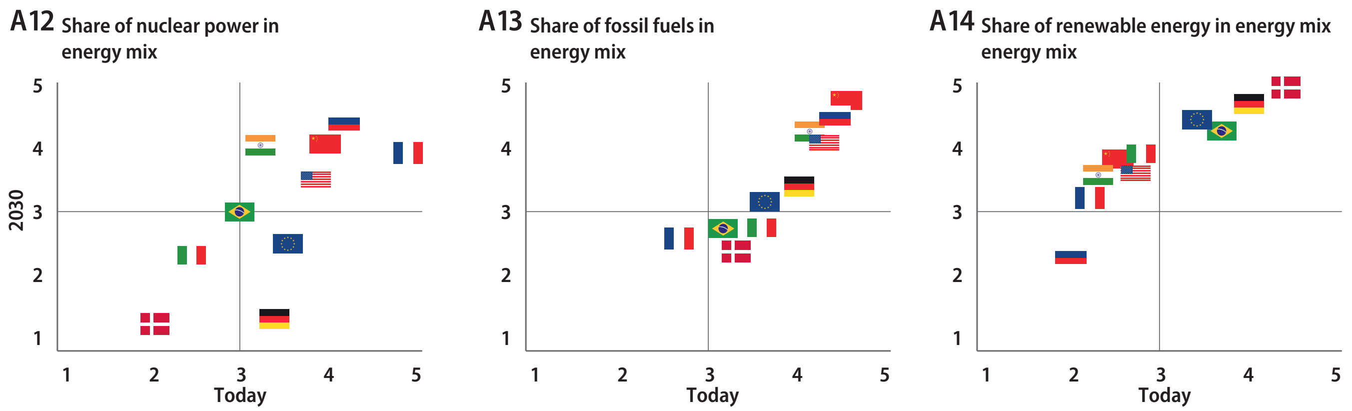


Figure 51: Development of the energy mix.

Nuclear power was the only area to register any peculiarity. A12 shows the change in importance of nuclear power. Among other contributing factors here is the fact that Germany is undergoing a radical change away from nuclear power and thus represents a special position. Experts believe that the high importance will fall quickly by 2030.

5.6.3 TECHNOLOGY LEADERSHIP

Alongside the framework conditions and the energy mix, the experts also gave their assessments of future technology capabilities in the smart grid sector. Germany occupies second place in the rankings of technology leadership for 2030, behind the USA. In respect of future availability of qualified specialists in the smart grid technology field, the experts believed Germany is in the lower middle portion of the table. Especially in comparison with other countries with high technical competence (USA, China and Denmark), Germany is assessed as being in a worse position for the availability of specialists[374] (see A15 and A16, figure 52). This could result in the loss of the country's good technological position in the future. The outlook is better for pilot and research projects into smart grids. Germany takes second place here, ahead of both the USA and China (A17).

A15 Technical competence in the smart grid environment (2030)

USA	4,1
Germany	3,9
China	3,9
Denmark	3,8
EU as whole	3,7
India	3,4
Brazil	3,1
Italy	3,0
France	2,9
Russia	2,3

A16 Supply of qualified specialists in the smart grid environment (2030)

China	3,4
USA	3,3
Denmark	3,3
France	3,2
India	3,1
Germany	3,1
EU as whole	2,9
Italy	2,9
Brazil	2,8
Russia	2,3

A17 Importance of pilot and research projects on smart grids

Denmark	4,4
Germany	4,3
USA	4,3
China	4,3
EU as whole	3,8
India	3,6
Brazil	3,3
Italy	3,3
France	3,2
Russia	2,4

Figure 52: Analysis of technical competence, specialists and research projects.

374 Germany's position behind France and India may be due in part to the current debate on the lack of specialists.

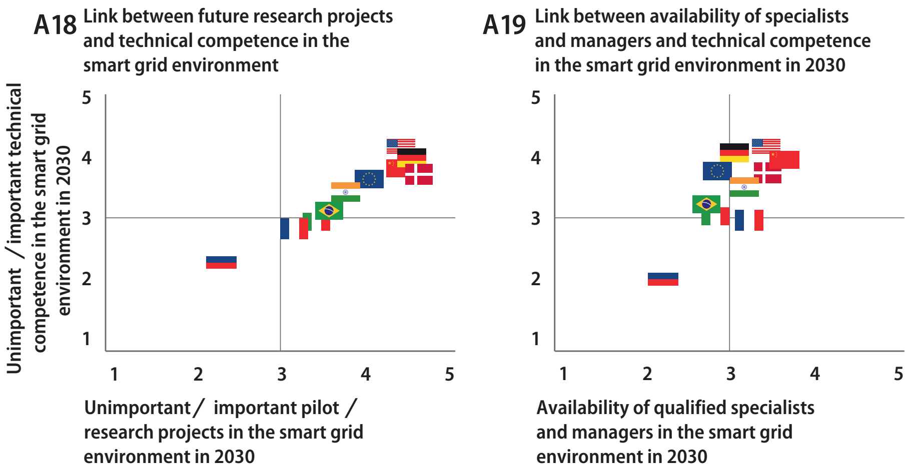


Figure 53: Analysis of technical competence in comparison with research projects and specialists.

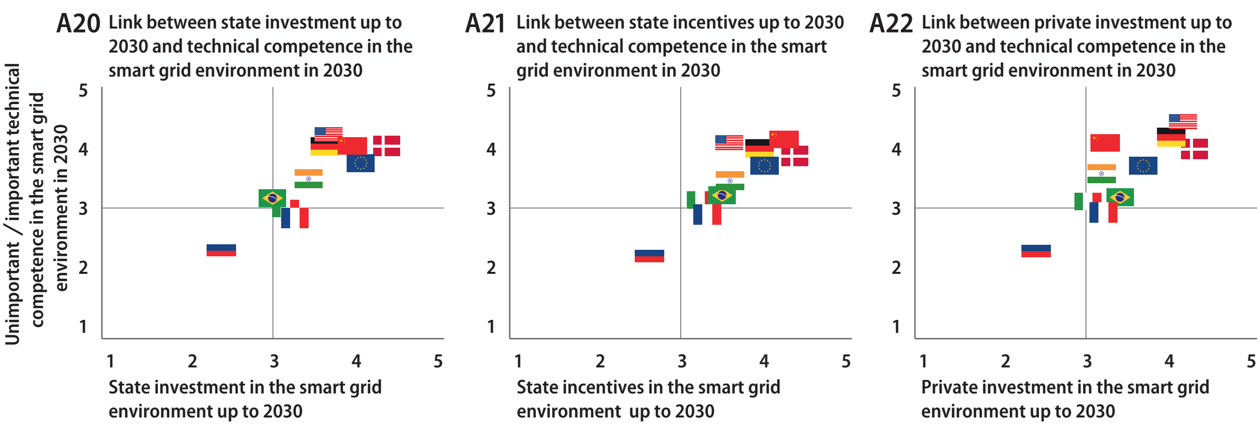


Figure 54: Analysis of technical competence in comparison with investment and incentives.

Once again, the regression analysis reveals a clear link between the specialist employees and technical competence (A18, figure 53) and between research/pilot projects and technical competence. In particular the importance of specialists is highlighted in A19.

"Investment and government incentives promote the technical competence of a country" is a viewpoint that is repeated frequently. To get behind this statement, the criteria "State investment in smart grids until 2030", "State incentives to invest in smart grids in 2030" and "Private enterprise investments in smart grids until 2030" were assessed by means of the questionnaire. Regression analysis once again points to the fact that all three criteria have a clear effect on technology leadership (see A20 to A22, figure 54). Based on this investigation, the aforementioned hypothesis can be supported. Thus it is clear that the state can also turn to effective means in order to ensure the technology leadership of its economy.

5.6.4 FUNDAMENTAL DESIGN FACTORS AND POSITIONING OF THE COUNTRIES

Design factors are formed by consolidating several similar statements and parameters. In order to identify the main design factors on the basis of the questionnaire, a factor analysis was first conducted on the basis of the future-oriented criteria. This statistical process is generally used to obtain a small number of relevant, mutually independent factors from a range output variables.[375, 376] In this case, the principal component analysis technique was used to calculate three factors that together explain more than 66 percent of the variance in the output variables. The number of factors was set on the basis of the elbow criterion.[377] According to current academic standards, the model quality can be described as "meritorious" (KMO measure of 0.805).[378, 379] The three design factors used to categorise the countries on the basis of their energy supply system in 2030 focus firstly on the importance of nuclear power in contrast to renewables (factor 1), second on the importance of fossil fuels in the energy mix (factor 2) and finally the extent of smart grid technology competence and investment (factor 3). The three factors are shown in figure 55 and briefly described below.

The first factor ("importance of nuclear power in in contrast to renewables") is based on two variables: the proportion of nuclear power and the proportion of renewables. Renewables have a negative effect on the value of the factor. This means that there is a contrasting relationship between nuclear power and renewable energy. A greater use of renewable energy therefore reduces nuclear power (and vice versa). The second factor ("importance of fossil fuels in the

F1: Importance of nuclear power in contrast to renewable energy	F2: Importance of fossil fuels in the energy mix	F3: Extent of smart grid technical competence and investment
Share of nuclear power in 2030	Share of fossil fuels in 2030 (excluding nuclear power)	Pilot and research projects on smart grids until 2030
Share of renewables in 2030 (negative effect on the factor)	Absolute energy consumption until 2030	Supply of qualifield smart grid specialists in 2030
	Importance of energy-intensive industry in 2030	Technical competence in the smart grid environment in 2030
		State investment in smart grids up to 2030
		State incentives for smart grid investment up to 2030
		Private investment in smart grids up to 2030

Figure 55: Design factors in positioning of the countries.

375 Backhaus 2006.
376 Thompson 2004.
377 Backhaus 2006.
378 Kaiser/Rice 1974.
379 Stewart 1981.

energy mix") is based in particular on the share of fossil fuels in the energy mix. The factor analysis indicates that the use of fossil fuels correlates to a rising level of energy consumption by the corresponding country. Moreover, such countries also have a high level of energy-intensive industry. The third factor ("importance of smart grid technical competence and investment") indicates first that the variables "Pilot and research projects into smart grids", "Qualified specialists in the smart grid field" and "Technical competence in the smart grid field" are closely related. In addition, these aspects go hand in hand with the investment criteria "State investment in smart grids" and "Private enterprise investment in smart grids". Thus the factor analysis confirms the relationship between smart grid investments and corresponding technical competence already outlined in the descriptive evaluation.

On the basis of a regression analysis, the corresponding factor values were calculated for each country.[380] These values are shown in figure 56. The x axis of the chart shows factor 1, and the y axis shows factor 2. The size of the circles relates to the extent of smart grid technical competence and investment, and thus factor 3. Three clusters of countries can be identified from this visualisation:

– "Renewable, low fossil fuel, anti-nuclear": Brazil, Denmark, Germany, Italy and the EU as a region are all heavily reliant on renewable energy, to the detriment of nuclear power. Moreover, the development focus of these countries is less on the use of fossil fuels. Germany and Denmark (therefore also the EU as a region) demonstrate a very high level of smart grid technical competence. Brazil and Italy fall back significantly here.
– "Fossil-fuelled nuclear powers": China, India, Russia and the USA are heavily reliant on both fossil fuels and nuclear power. This does not mean that renewable energy does not have a role to play in these countries. However, the share of nuclear power is more important in the medium to long term than the share of renewable energy. In respect of smart grid technical competence and investment, China and the USA are particularly worthy of note. India is also well positioned. Only Russia has a weak position.
– "Pure nuclear powers": Out of the analysed countries, only France has a purely nuclear-oriented energy strategy. Smart grid technical competence and investment are therefore fairly low in comparison with other countries, although specific research and development is conducted in special areas such as biofuels and innovative hydroelectric power.

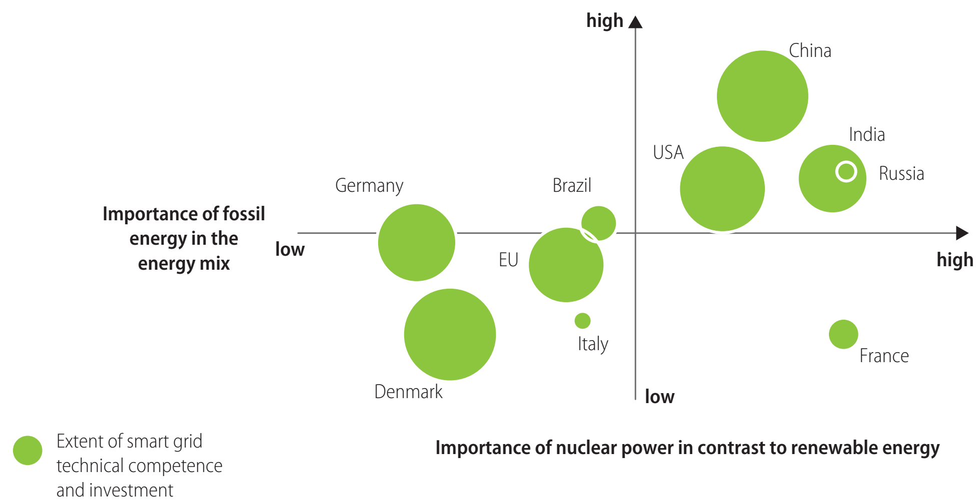


Figure 56: Positioning of the countries in the energy forms preference matrix.

380 Thompson 2004.

5.7 SUMMARY

The comparison of countries and the country profiles reveal five core summarising statements. These focus on Germany's position and on German businesses in the context of the identified countries.

- *Geographical conditions*: In the context of renewable energy, Germany has good conditions for wind power. However, in respect of other renewable sources, Germany is in the bottom third of the countries under consideration.
- *Political conditions*: In respect of the political conditions it is clear that Germany has the greatest degree of liberalisation of all of the investigated countries. However, Germany also leads in terms of the extent of regulatory requirements.
- *Energy mix*: Germany is changing its energy mix massively in comparison with other countries. Thus it is assuming a key role. Nuclear power is to be replaced entirely by renewable energy. Experience gained in other countries, such as Denmark, may contribute valuable experience to this process.
- *Technological leadership*: In respect of smart grid technology leadership, Germany is very well positioned. Nevertheless, a lack of sufficiently trained specialists may impact on this. Investment and government incentives promote the technical competence of a country. However, there are also risks here for Germany. Other countries are investing significantly more in their smart grid infrastructures.
- *Demonstration projects*: It is clear that many countries place a different emphasis on the development and use of smart grid technologies. This creates different, country-specific markets for German companies. National demonstration projects offer an opportunity for demonstrating the technical feasibility of solutions, since they can serve as "preview phases"[381] to test subsequent market delivery. They therefore form the basis for exports and participation in foreign markets.

381 ECJRCIE 2011.

6 FRAMEWORK CONDITIONS FOR A FUTURE ENERGY GRID

The development of the correct framework conditions for a Future Energy Grid (FEG) presents a wide range of challenges. This chapter identifies the existing uncertainties, places these in context and on this basis identifies the potential framework conditions for an FEG.

The underlying assumption is that an FEG is a useful and desirable objective, even though no robust cost-benefit analysis has as yet been carried out. The cost-benefit analysis planned in Germany for smart metering will provide pointers to the complexity and feasibility of carrying out such an analysis for the FEG as a whole.

In the sections below, the two components smart metering and an intelligent distribution grid will be considered separately in order to distinguish between the economic and regulatory factors. The issue of data security will not be considered.

The explanations are based on the "Sustainable & economic" scenario and on the remarks on the "Political conditions" key factor. The "Sustainable & economic" scenario describes the desired target state of affairs from an energy policy perspective. Both the decentralisation strategy and the EU centralisation strategy have been implemented in a market-based manner. The framework conditions for complex innovation processes are designed so that they do not claim to have the best answers in advance, but leave the discovery process to the market.

6.1 TRANSFORMING THE ENERGY SYSTEM AND BETWEEN THE MARKET AND STATE DIRECTION

A "Future Energy Grid" as referenced by the legislative concept of this chapter is an energy infrastructure that basically enables Demand Response (DR) and therefore the transformation from a load-led system to a generation-led system (and thus the balancing of supply and demand). Until now, all customers have been able to draw as much load from their electricity grid as they wish, in the scope of the maximum permitted load at a given grid connection point, even without having a corresponding individual grid usage agreement and completely irrespective of the condition of the grid. The responsible grid operators must provide the corresponding grid infrastructure. The energy required for this is supplied by bringing additional power plants online, which have been added in response to rising demand. This system is characterised by very high availability and reliability of supply. The challenge of maintaining the availability and reliability at high levels during the transformation to the FEG remains one of the many facing the transition phase.

For a variety of historical circumstances, but also due to the remunicipalisation programmes of the past 20 years (return to ownership by the "Kommune" or local authorities), the landscape of German distribution system operators (DSOs) is extremely varied, in terms of size, geographical coverage and the different grid levels they manage.

In addition to providing the grid, the four transmission system operators (TSOs) are obliged to maintain the stability of the overall system, using frequency regulation. They act in conjunction with the generators and the suppliers to feed extra energy into the grid or remove excess energy from it, over and above the production volumes established in advance in the form of "timetables", according to the corresponding supply and demand situation. This balancing power is bought and sold mainly via the balancing market. In addition, the TSOs operate the interconnectors to other international grids, through which energy may be imported or exported.

This industrial infrastructure has largely been influenced by the constantly rising demand for electricity over the course of the 20th century, which has led to increasing effects of scale. In turn, these have required the construction of ever larger generation facilities on the supply side. Until the late 1990s, the modern German electricity system, created by the "Elektrofrieden" peace pact agreed among the principal grid operators in 1928, confirmed by the Energy Economy Act (Energiewirtschaftsgesetz) of 1938 and subsequently expanded following the Second World War, was, for macroeconomic and regulatory reasons, a vertically integrated and centrally organised entity. The entire energy supply infrastructure (grids, power plants, etc.) was viewed as a natural monopoly, and was at the same time too important and critical to leave to the vagaries of the market. The price per kWh (kilowatt hour) for tariff-paying customers was set by the individual federal Länder in the scope of the Federal Electricity Tariff Ordinance (Bundestarifordnung Elektrizität) and passed on to the consumers. Other customers were able to negotiate the prices they paid for electricity.

During the late 1990s, the system was overhauled by a process of liberalisation/deregulation, adhering to a disaggregated approach: Now, only the grids (essential facilities/core monopolies) were subject to regulation. All other activities along the energy industry value creation chain are now viewed as having potential for competition. This means that, in particular, there is more than one grid user of the monopolistic infrastructure. Different companies use the grids to service their customers. For this reason, the supply to individual customers must be regulated and controlled more precisely. This is the role of the so-called balancing system.

To simplify matters, "standard load profiles" are used for domestic and commercial customers that consume < 100 000 kWh/year. This means that the risk of supplying a domestic or commercial customer is reduced for the responsible supplier to the extent that, usually, only the question of how much electricity the customer has used overall in a year is important, and the timing of the actual demand is irrelevant. The suppliers feed in specific amounts of electricity per customer to the grid at fifteen minute intervals. These amounts of energy are determined on the basis of the load profile. Within this supply structure, approaches involving time-controlled tariffs for small consumers have been and remain limited to a few special cases, normally in conjunction with a specific application technology (such as off-peak storage heaters). Most German EUCs continue to offer these "off-peak" and "peak" tariffs. For large consumers, in other words industrial customers, there are tariffs that have an effect of attenuating peak loads. In the case of grid charges, there are also special rules on interruptible consumption systems. In section 14a EnWG, the government is redoubling its efforts to make interruptible loads usable for the requirements of the distribution grids. Remote control of loads (for example, public street lighting) and load shedding are further options available to grid operators.

> The realignment of this energy system and the integration of fluctuating renewable energy sources to the extent that these define the system requires the market to be reshaped on consistent and sustainable lines just at the time that a completely new paradigm (competition, unbundling, incentive regulation) is, *in some cases,* being implemented.

In principle, politicians should set targets and framework conditions that allow the markets to establish the best technical and economic solutions in the long term. Whether or not this will work in the energy markets for the construction of new generation facilities via pricing signals at peak load times is not only debatable in theory but has also been demonstrated as obviously problematic by practical experience.

This market paradigm was introduced in the years since 1998, to a system in which many technology decisions have been and continue to be made by politicians (introduction of nuclear power in the 1960s and 1970s, grid expansion). With the Renewable Energy Act (EEG) and the decision to exit from nuclear power generation, significant technology decisions are still being made by politicians rather than by the market.

> Whether and to what extent this dual paradigm shift (fluctuating renewable energy sources, demand-side management (DSM), distributed and therefore fragmented generation on the one hand and the competition paradigm on the other) can be reconciled will be key to the success of the transformation to a future-proof energy system, both at national and at European level.

The respective roles of the market and political control must be discussed without the encumbrances of ideology. Without comprehensive long-term planning of the migration to be followed by the energy system, it will not be possible to achieve any long-term energy policy objectives. The framework conditions that are derived from this should provide as much room for manoeuvre as possible for establishing a market-based equilibrium, while taking account of the fact that first, a market in an energy system may create a large number of white elephants (stranded investments) due to poorly designed incentives and the results of trial and error, and second, energy markets that are undergoing a process of transformation are particularly prone to unintended side effects from intervention. Therefore, chosen market solutions need very strong institutions and a consistent design. At this point, the experiences of California should be considered, where a lack of an agreed way forward was associated with a hike in electricity prices and an increase in power outages. The task is to avoid this scenario as far as possible.

6.2 THE CHALLENGE OF INTEGRATING FLUCTUATING RENEWABLE ENERGY SOURCES

Renewable energy sources as a proportion of overall electricity generation in Germany and Europe have risen considerably over the past five years, and will continue to grow in the future, in order to ensure the transition to a climate-friendly supply system. However, wind and solar energy in particular vary according to the weather conditions, and no increase in prices at the German EEX electricity exchange in Leipzig is going to force the wind to blow any stronger. The supply of electricity, which has so far been based on and oriented towards demand (load-led), is therefore becoming more structurally inelastic. There are four basic options for dealing with this change in fluctuating feed-in, or with this inelasticity combined with random components:

1. Add new cables, storage and power plants to compensate for the inelasticity of supply
2. Reduce the inelasticity of supply
3. Make demand more flexible
4. Strengthen the integration of European markets

6.2.1 ADDING CAPACITY IN ORDER TO COMPENSATE FOR THE INELASTICITY OF SUPPLY

The residual load of a system that comprises a high proportion of fluctuating renewable energy sources can be adjusted on an hourly or daily basis. To maintain the dynamic stability of the grid, it must be possible to purchase a second and minute reserve. In the case of a closed energy system, reserve capacity (around 80 to 95 percent of the capacity, depending on the desired level of reliability required and the primary energy source) must be held for the temporarily limited-availability generating source, which can be accessed when needed. For the German electricity market, which is integrated with the European high-voltage grid, there are three complementary options:

The **power plant pool** is expanded by building new (primarily fossil-fuelled) power plants that can offset the lack of wind or solar energy at short notice. In a system with a high proportion and primacy of renewable energy sources, these power plants are subject to a mixture of high capital costs, very low usage hours and electricity imports as a potential alternative. It is unlikely that these power plants can be financed by extreme market prices for peak load. Either they must therefore probably be financed by capacity payments or a flexibility surcharge.

The **storage capacities** in Germany must be expanded in the long term. As the storage of electricity using traditional technologies is still far from being ready for the market, this option is rather minor in terms of priority for the period of analysis comprising the next five to ten years. In the long term, however, there may be economically attractive alternatives, both distributed, such as using electric vehicles, hydrogen and flywheels, and central, using compressed air or other pumped storage. Power-to-gas, comprising the conversion of excess renewable energy into methane, which is then stored in a gas storage system, is also an interesting option, albeit with no large-scale technical developments as yet.

The transmission grid and interconnect capacity within the European grid system are being expanded. The construction of additional power plant and storage capacity also requires greater expansion of power grid capacities.

The principle is simple – the greater the integration of fluctuating renewable energy sources, the greater the investments required in the grids. In the event that this option is pursued, balancing the system would consist of increasing the known operating resources, rather than introducing a new system of improved quality. Such additional construction *alone* – and therefore continuing on the current path towards system transformation – is simply unsustainable from an economic perspective. In any event, it is first necessary to verify whether all of the flexibilities that are feasibly available in the current system are being exploited. These may be derived from more flexible operation of the existing power plants, improved usage of interconnector capacities, and more flexible use of renewable energy generation.

6.2.2 REDUCING THE INELASTICITY OF SUPPLY

Both the deadweight loss of PV (solar power) technology and the obligations that have arisen for grid expansion have led to increased criticism of the EEG. For that reason, the debate around an unlimited grid expansion must also consider the alternative of **limiting** the grid operating resources.

One option for reacting to this increasingly inelastic supply is the introduction of an incentive regulation that differentiates renewable energy sources according to **system-friendly criteria**.

A criterion for a differentiated funding policy may be the time-variable availability and flexibility of generation capacity. Forms of generation that are more flexible and easier to plan in terms of deployment would be supported financially. This form of "consistency incentive" could increase the financial attractiveness of these technologies, and therefore offset the fluctuating feed-in of renewable energy sources, in particular wind and PV, or at least permit better forecasting. In this way the feed-in of renewable energy can be made more stable.[382] Such an instrument, which was seen positively by companies in the renewable energies sector and rather more sceptically by the Bundesverband der Energie- und Wasserwirtschaft (German Association of Energy and Water Industries; BDEW)[383], is, however, no longer provided for in the pending revision of the EEG. Instead, "market premiums" (only mandatory for large biogas plants) and a flexibility premium for large biogas plants are planned.

A second option for maintaining grid stability in respect of the fluctuating feed-in from renewable energy sources and minimising ad hoc overload, is to **selectively take individual generators that are placing load on the grid offline**. The legislation already allows distribution system operators to control feed-in from EEG plants with rated capacity over 100 kW by remote access. If the grid becomes overloaded the grid operator can reduce the feed-in or take the plants offline. In this case, the system operator is required to treat the plant operator as though the plant were not offline. This had long been considered an interim solution, as the grid operator should reinforce or expand grid capacity to the extent that was economically feasible. The current EEG revision points to a reversal from this little controlled grid expansion policy, however. It foresees a limitation of the maximum effective capacity of small PV installations at the grid interconnect point of 70 percent of the installed peak capacity (section 6 para 2, item 2 letter b EEG 2012), or, as an alternative, demands that the installation is capable of being remotely controlled.

This is sensible in the context of a cost-benefit analysis: Continuing with the unlimited feed-in and resizing of the grid connection to match the manufacturer's rating of the plant, which is only provided occasionally at best, would mean that further grid expansion would simply result in the expenditure of a disproportionately large amount of electricity customers' money for renewable energy plants that were little used, to an extent that was not in relation to the actual grid expansion.

At its core, the objective of the FEG is to achieve efficiency by optimising and shifting load and generation in time and space using intelligent control systems. Not only the quantitative expansion of the installed capacity of renewable energy sources, but also qualitative growth are in the focus – in other words securely and flexibly supplying electricity from renewables.

An FEG creates the technical platform for optimisation of the grids taking account of a high proportion of fluctuating renewable energy sources, and renders some of the grid expansion obsolete. With the transformation of the grid to form a FEG, the optimum (rather than maximum, as has previously been the case) grid capacity and intelligent control must replace the previous paradigm of sizing the grid for 100 percent operation of generating capacity.

Alongside the obligation to connect and expand the grid, the success of the EEG is founded in the priority accorded to feed-in and therefore the maximisation of the time periods in which energy can be fed in and a fee paid. The increasing success of the EEG means that the economic conditions are now in place to allow for the transition from such a deliberately non-market system to the free market.

A debate on the potential instruments for rationing in an FEG and the further development of the EEG is pending – the initial approaches are described in section 6.4.

382 Reiche 2010.
383 BEE 2011.

The listed tools aimed at reducing inelasticity are useful for dealing with a **production surplus** and therefore for finding the macroeconomic optimum limit to local distribution grid expansion, in particular in rural areas, such as for PV in Bavaria and wind power in Lower Saxony and Mecklenburg-Western Pommerania. The next section, **making demand more flexible**, is, in contrast, more sensibly applied against supply for the purpose of inter-regional balancing of the increasingly differing generation and consumption volumes. This "flexibilisation" will occur primarily in sink areas (larger cities and industrial areas).

6.2.3 MAKING DEMAND MORE FLEXIBLE

When it comes to balancing out a surplus (reducing inelasticity), an FEG can help through the aforementioned options relating to feed-in management. In respect of making demand more flexible, the intelligent electricity grid actually represents the best solution, as long as it is not intended to apply rationing instruments such as in the case of the "Flex Alert" used at peak load periods in California. The "Flex Alert" system warns consumers the day before not to use certain electrical appliances during peak load periods. If grid shortages are imminent, electricity users are selectively cut off.

The key element in making demand more flexible is the price design, which provides end-users in industry and domestic households with an efficient indicator of the times at which it is profitable for them to shift their individual demand.

Increasing flexibility among industrial and large consumers
Industrial and large consumers are driven by monetary factors to optimise their generation requirement and explore efficiency advantages and opportunities to shift load, as long as the benefits of such load-shifting offset any disadvantages to their production processes. Corresponding contracts are common practice in this respect. Equally, the activation of additional potential efficiencies, such as the use of large buildings as storage, will work in the same way as incentives, as long as the potential efficiencies can be obtained cheaply.

Increasing flexibility among domestic customers
While the liberalisation of the IT and telecommunications market has led to greater diversification of product offers – from flat-rate, combined Internet and telephone tariffs, to call-by-call options in the scope of a conventional offering – on the electricity market there has, as yet, been no comparable range of different offerings for domestic customers. The existing standard load profiles render such a diversification obsolete, but have the advantage that it is easy to enter the end-customer market even without the supplier having its own highly flexible generation plants that would have to anticipate customer consumption patterns. To ensure the success of new business models (such as that of the "aggregator" which combines the load curves of end users and brings these to the market) it would be necessary to introduce a market design that rewards flexibility and efficiency and creates an offset for the additional risks presented by increased volatility. The price incentives to be achieved, which arise from being able to shift individual demand, are still considered to be too low by most end-consumers to compensate for the logistical effort and added time/complexity of dealing with the shift. A simple economic rule of thumb[384] indicates that finding a tariff that varies according to the time of day (and that is therefore potentially generation-led) is economically uninteresting to domestic customers.

6.2.4 STRENGTHENING THE INTEGRATION OF EUROPEAN MARKETS

During periods of insufficient domestic supply of electricity, increasing use is made of imports of power from neighbouring European countries. Exports can also support and optimise the overall European system. The convergence of the European electricity markets, construction of additional interconnection cables and the objective of achieving Europe-wide harmonised country-specific regulation of the spot markets all combine to facilitate cross-border trading and allow the previously largely autonomously operating markets of the EU Member States to grow even closer together. This provides opportunities to use additional capacities from other power plant pools on a cost-efficient basis.

384 Stoft 2002, p. 13.

The extent to which the generation mix that should be used for imports in such cases is compatible with the corresponding policy objectives in Germany remains unanswered: In the end, the supply made available on the European market to cover the needs of customers or suppliers will be used. This may mean that in addition to supplies from pumped-storage power plants in Norway and Switzerland, and bulk solar power plants in North Africa (DESERTEC), there may also be (a need for) imports from fossil-fuel or even nuclear power plants within the European Economic Area. Political acceptance and the capacity for realisation of such an interconnected system is still unclear. The currently applicable market rules have been designed for a mature system with national markets and base load generation units, not for a system in which there is dense interconnection of grids and markets. Rules must still be drawn up for dealing with the potential interactions and decisions within the overall system. So far, there is no design for an integrated European market supported by the majority of the numerous stakeholders.

6.3 INTELLIGENT DISTRIBUTION GRID AS A PREREQUISITE FOR USEFUL SMART METERS

As yet, no robust cost-benefit analysis of (national) deployment of smart metering systems has been carried out. According to EU law, such an analysis must be completed by 3 September 2012 unless the Member State is willing to accept having to design its legislation such that an "across the board" roll-out must occur quasi automatically, as a result of which 80 percent of all meters must be replaced by 2020.

Some details concerning the FEG[385] suggest that a smart grid and the introduction of smart electricity meters will bring about substantial savings potentials *for the entire system*. Whether these positive externalities are as comprehensive as described in these statements is a matter of doubt in particular for the area of smart meters in Germany. Robust figures on the economics of smart meters prove difficult to obtain and compare. A tariff simulation conducted as part of a study commissioned by the Federal Network Agency (BNetzA) arrived at values between 12 and 50 euros (between 2 and 8 percent based on the annual bill).[386]

Pilot schemes such as the "enercity" test carried in 2008 out by Stadtwerke Hannover AG arrive at a cost-benefit analysis that points to similar results as those calculated by Stoft 2002 in the rule-of-thumb calculation mentioned above. Taking account of the technology costs (software, meters, modules, support) amounting to around 230 euros per meter, the Head of Metering at Stadtwerke Hannover believed that the "savings achieved with smart meters [...] do not balance out the costs." "Without the input of external cash [subsidies]," he explained, "smart meters could not be deployed commercially."[387] In the case of another pilot, comprising cooperation between EWE Energie AG and Fraunhofer-Allianz Energie, in which almost 400 households participated in a test over 2008/2009, the average actual electricity saving per participating household was between 5 and 10 percent, depending on the product package. An analysis and tariff simulation led by the consultancy EnCT[388]has demonstrated that "smart meter products are not worthwhile for customers with low energy consumption since the changes in usage patterns they bring about cannot compensate for an average increase of 65 euros in standing charges." Households that have an annual electricity consumption of 2,000 kWh or less would have to deal with additional costs of between 4 and 11 percent compared with standard meter products, according to EnCT. EnCT has calculated the threshold above which the use of a smart meter will start to pay its way to be equivalent to a minimum consumption of 3,400 kWh per year. Stadtwerke Bielefeld estimates the breakeven point for domestic customers to be around 5000 kWh, while calculations made for the Yello electricity meter go as far as stipulating that consumers would have to shift almost 4,700 kWh of their consumption to off-peak tariff periods in order for the smart meter to pay for itself.[389]

The findings from these pilot projects with very specific groups of customers can only be generalised to a limited extent, and caution should be exercised when drawing conclusions about general cost savings.

385 Pipke et al. 2009.
386 Nabe et al. 2009.
387 Rohlfing 2010a.
388 EnCT 2011.
389 Rohlfing 2010b.

Significant doubts around the business case for smart meters are nevertheless not out of place.[390]

Even BNetzA has indicated that it views smart meters less as a component of the regulated grid operations and more as a component of smart markets, and that it finds a large-scale roll-out (with the consequence of financing exclusively via grid charges) to be inappropriate. This position is apparently shared with the Bundesverband Neuer Energieanbieter (Federal Association of New Energy Suppliers; BNE) and the BDEW.[391]

In respect of the unwanted but potentially inevitable mandatory introduction of smart meters, the currently debated EnGW revision leaves some unanswered questions in the additions to Section 21, which are to be fleshed out in the legal ordinances. Until this happens, the market will continue to suffer from uncertainty. This delegation of basic decision-making to downstream layers is problematic, since it means that a reliable framework is increasingly difficult to pinpoint. If the revision is read such that customers with demand of greater than 6,000 kWh for electricity (not gas) per year should be obliged to install a smart meter system, this would mean that a complete roll-out is not intended. With the statutory requirement for installation of smart meters by major customers, the aforementioned distribution of new business models satisfying the commercial quality will be accelerated, since the necessary infrastructure is already in place for the corresponding customer groups.[392]

In the current structure and format of the electricity market, provisions for Demand Response (DR) do not yet exist. For the metering point operator there are simply not the foundations for the economic success of smart meters above and beyond purely achieving cost savings. First, prerequisites must be put in place in the distribution grid, in a back-end structure and in tariffs for smart metering; any other approach risks putting the cart before the horse. If the costs of a country wide roll-out are to financed on a mass basis by metering charges, then a lack of investment in a more complex FEG runs the risk of faltering investments, in particular if such regulatory policy control is unable to set clear incentives for end-consumers to adjust their consumption patterns.

At the same time, many potential domestic customers are giving voice to their reservations concerning the real-time detection of their consumption data; mechanisms and legislation for effective data protection are still in the process of being explored. The more detailed rules and requirements of the BSI protection profile give rise to the fear that such far-reaching security requirements can only be met by a few providers, and therefore potential market participants (and thus potential for innovation) will be excluded.

In the domestic segment, neither the majority of consumers nor suppliers are prepared to bear the currently (excessively) high costs of installing and operating smart electricity meters. However, since even with quickly falling prices for smart meter technologies and growing automation in the home, the psychological and financial attitudes of most end-consumers to intelligent energy management will still have to be overcome, smart meters will only exist without integration with the FEG in niche segments in the end-consumer area, such as high-tech, auto-generating or high-consumption households. The vast majority of domestic consumers will prefer the usability of an electricity price that is split into two tariffs (e.g. day/night, weekday/weekend). In this case the task of identifying the corresponding consumers and offering services that are tailored to the needs of individual groups of customers can be left to the market. Government intervention here would probably even be a hindrance, and would certainly not be cost

390 Experience from other EU countries and overseas indicates heavily variable savings potentials in the range between 1 and 20 percent, depending on the technology used, customer feedback and the national specific consumption patterns, as well as on the obligation to issue monthly, rather than annual bills. The across-the-board roll-out of bidirectional digital meters in Sweden was brought about by the mandatory introduction of monthly billing. This made it more economical for distribution system operators to configure smart meters. In Italy, the deployment of smart meters while retaining the existing requirement for bimonthly billing and the prevention of electricity theft ("non-technical grid losses") produced cost savings. In the case of an annual billing model with monthly prepayments, as in Germany at the moment, the cost-benefit calculation for smart meters from the meter operator's point of view is negative.

391 Zerres 2011.

392 In addition, the government is moving toward a position of supporting such smart meter systems for EEG plants producing in excess of 7 kW. This policy direction would also be welcomed in the sense of a FEG. The question of how to deal with the large number of old plants that are not subject to this rule and that do not participate in simplified feed-in management according to the most recent EEG revision remains unanswered.

efficient. The government would then simply be responsible for ensuring a fair competitive environment, for example by agreeing standards with new service providers and established energy utilities.

If the optimisation achieved by load shifting is so marginal in the case of more than three quarters of domestic households that it produces barely any actual savings, the introduction of smart metering will be targeted primarily at major industry, industrial customers, commercial customers and domestic households with higher load requirements, in order to achieve the best cost-benefit ratio.

For this reason, currently no regulatory policy measures will be taken to force the mass expansion of the use of smart meters by domestic customers, or to make their installation mandatory in existing buildings.

In the distribution grid, the FEG should be used initially to put in place the prerequisites to allow smart meters to be successful in the long term.[393]

Smart meters are usefully deployed as a further development of the FEG for specific consumer groups, and not as a prerequisite.

Despite this, if roll-out across the board is required for political reasons, care should be taken to ensure that this follows open standards, in particular those that allow the market to test out business models. Standards should not define business models. Moreover, it must also be ensured that smart meters can have new software uploaded easily, since in a developing market and in respect of integration with backend systems, they will probably become outdated quite quickly.

6.4 FUTURE MARKET DESIGN

> A successful, sustainable transformation of the energy system will require a long-term system change in the EEG and in the design of the market, in parallel to the transformation that will result in the FEG.

The debate around this new market design has not yet happened, as specifications, modifications and "clean-up" tasks needed by the market paradigm in the EEG and EnWG are currently being prioritised. An FEG is a long-term task.[394] However, it must be started in good time, since it involves the exploration of new theoretical and practical paths, and the findings must be well prepared before feeding in to a long-lasting institutional and political process.

6.4.1 RENEWABLE ENERGY IN THE MARKET

How could markets be used to achieve improved **use of** renewables feed-in? How can the market deal with renewable energy sources? What market should assume this role? In its current structure, the objective of the EEG is to maximise the amount of kWh in the system with a micro differentiated reward system.

> The EEG is fundamentally incompatible with an FEG, which at its core should lead to optimisation and efficiency, which means the optimum amount of kWh in the system at a given point in time.

Active grid management in the distribution grid may mean that reducing wind power feed-in is more economic for the system as a whole. In contrast, the objective of a feed-in tariff is for each feeder to produce as much as possible. The EEG Experience Report of the Federal Government 2011[395] identified the strategic line: "[…] to hold on to the proven basic principles of the EEG and develop them further." At the same time, however, the report points to the need for a "test of the fundamental further development of the electricity market" in order to "achieve the long-term goal of transforming the energy system." So far, the aim of the EEG has been, and continues to be the introduction of renewable energy sources into a dominant bulk, fossil/nuclear fuelled system, and triggering a long-term system change. While this aim may not yet have been achieved, it is equally no longer at risk. In the future, and especially in a FEG, the question hast to be different: In the new paradigm, renewable

393 This once again confirms the statements made in chapter 4.

394 A good oveview of the positions of various stakeholders was provided in the Annual Conference of the Florence School of Regulation "Future Trends in Energy Market Design" [FSR 2011].

395 DB 2011.

energy sources dominate. This demands a new way of thinking, for the market design too.

When it comes to the "test of the fundamental further development" there will soon be an opportunity – when plants start to fall out of the subsidy scheme. What form should cooperation between the grid operators and plant operators take, in the event that there is no obligation to take their electricity and there is no priority feed-in for renewable energy?

Feed-in tariffs have been and remain necessary, in order to provide renewable energy sources with access to the system. In the medium term, however, fluctuating renewable energy will have to be treated in the same way as all other generators, in order to become compatible with the market. Renewables will have to participate in the markets, deliver timetables, submit offers on the balancing power market, subject to control by grid system operators, etc. Marketing and sales will have to be organised by the plant operators on their own account, and will have to pay their own way. In this respect, the approaches for direct marketing included in the EEG and corresponding market premiums should be welcomed in principle.

There are alternatives to feed-in tariffs. On the international stage the concept of two-part tariffs is being discussed.[396] These make a basic contribution in the form of an "investment aid" and an incentive to become active on the market. Capacity payments for investment in non-fossil fuel generation are structurally equivalent.

Such capacity payments represent the thinking of the old system perspective. In a system dominated by renewable energy sources the problems are exacerbated. Capacity payments would not only be possible and necessary for a transition period: The marginal cost of wind and solar power is zero. When there is plenty of wind, this causes the spot prices on the exchange to fall in a "merit order"[397] system. In a wind-powered system, aggregators of wind power would always offer power to the market at below the known marginal cost of conventional generation. In the event that large amounts of wind power are forecast, all wind providers will approach the market with minimal prices. If the wind blows, in a marginal cost based system the wind farm operator reduces the price by itself (and that of everyone else). Thus the margin on the second part of the two-part tariff is lost. If the wind does not blow, the wind farm operator earns nothing either. The providers of conventionally generated energy, of storage (that is managed at zero marginal cost), of aggregated demand reduction, of load shifting and of imports can all make money in this period.

> The question "How are renewable energy sources to be sufficiently compensated for their price-reducing effect in a wind-dominated system?" remains unanswered.

6.4.2 THE REGULATION PARADIGM AND AN FEG

What form does the regulation of quality and innovation take in a distribution grid consisting of a FEG? The BNetzA, which has been in operation since 2005, has reformulated a regulation paradigm (RPI-X) from the 1980s in the new incentive regulation with great methodological complexity, thus fulfilling the long-declared wish of the government.

> The incentive regulation concept is based on reducing costs in an existing distribution grid, and is specifically not designed to encourage innovation and transition to a FEG.[398]

With incentive regulation, both regulators and grid operators agree ex ante to the permitted costs in terms of defined outputs (SLAs, QoS, grid loss, grid shortages, etc.), to prevent the grid users having to pay

396 Lesser/Sue 2008.

397 The "merit order" determines the sequence in which the power plants are deployed: First the cheap power plants will be used, then the next most expensive, and so on, until market demand is met at the price offered by the final power plant. The costs of energy produced by this power plant set the electricity price.

398 In 2010, the British regulator OFGEM (Office of the Gas and Electricity Markets) established RIIO (Revenue = Inventives + Innovation _ Outputs), a new regulation paradigm that modifies significant areas of the differentiated incentive regulation in place in the UK since 1990, in order to respond sufficiently to the challenge of system transformation. A core element in this paradigm is the treatment of uncertainty. The approach is not directly transferrable, since setting appropriate output variables for over 900 grid operators in Germany is not possible.

too much. The process of determining these costs is difficult for the new services and new technologies. For this reason, there are regulation periods comprising multiple years, at the end of which the agreed costs are adjusted. However, the output is produced not only in the period in which the investment is made, but also in the subsequent period too. Therefore it is more difficult to achieve an appropriate regulation of investment than of operating costs.

The FEG also means setting the maximum peak load in the grid according to an economic perspective. In other words, the distribution system operator must first invest more in order to receive reduced benchmarking parameters and therefore, probably, lower grid charges. The FEG may, therefore, mean, that the grid operator does not derive the benefits from its investment. This problem of motivation can be resolved by a substantially refined regulatory efficiency benchmark process or alternative forms of payment. Nevertheless, the way in which outputs from the distribution grid should be attributed to inputs, either theoretically or in financial terms, is even more difficult to specify in an FEG than in a modern-day distribution grid. In places where the number of grid operators is small, such as in the UK, this may be possible on the basis of individual negotiations, but with several hundred grid operators that is not a possibility.

The BNetzA must now face the challenge of responding to questions on the FEG against the backdrop of a 25 year old political task. Achim Zerres, Head of Energy Regulation, proposes that the term "smart grid" should be used for "internal" topics (grid control, expansion, management) and that it should be complemented by the term "smart market" which would be used to describe the "modified user patterns due to pricing and incentives in the area of energy exchange". The grid should serve this "smart market", which then will promote innovation, unlike the grid monopoly. The "intelligence gap in the distributed grids can largely be financed from capital flows from the existing grid," by means of "intelligent restructuring". Smart meters are apparently necessary for smart markets, but they have no contribution to make to the smart grid. Such high resolution data is not necessary for operation of the grid As a result, an across-the-board roll-out (with the consequence of financing exclusively through grid charges) is inappropriate.[399] The market rules that apply to this smart market are as yet undefined.

Such a positioning in respect of smart meters should rightly be viewed sceptically, but demonstrates a strong line of argument on the basis of the recently established incentive regulation, avoiding any link to a "fundamental strategy change" in relation to the recognition of innovation in the grid.

The BNetzA has a critical view of both capacity management and time-variable grid charges as an instrument of this management. It believes that time-variable grid charges would be complex to implement, and grid user acceptance would be difficult to achieve. A "strong focus on the existing grid and on insufficient expansion of the grid would hinder the integration of renewable energy and the smart market" – flexibility requires capacity. The grid should be a servant for this smart market.

The strong focus on the established paradigm in this line of argument will underpin the existing grid. An FEG as a services platform for a smart market would also lead to optimum grid capacity utilisation. The debate on the regulation of "optimum grid expansion" and of price signals issued by the grid is still pending.

The current position of the Federal Government and the attitude of the BNetzA is that further development of the already established regulation paradigm is sufficient, but no modification is actually necessary. No position has yet been indicated on the question of how the high investment required in a possible FEG (from the point of view of the grid operator: invest more to reduce grid revenues in the future) should be integrated into the incentive regulation.

It would be necessary to compare the effort and subsequent costs of the conventional solution of grid expansion against the effort and costs of an FEG solution, to allow politicians to weigh up the idea of efficiencies offered by incentive regulation (rewarding cost savings and largely preventing white elephant investments) against a reward strategy that allows the distribution system operator to share more in

399 Zerres 2011.

the overall benefit of grid expansion and grid renewal.[400] In an expert report prepared on behalf of the BDEW, depending on the expansion scenario for renewable energy sources, investments of between 13 and 27 billion euros would be needed within the next ten years, excluding the investments needed for smart grids.[401]

Both the local FEG and the European overlay grid will only achieve a benefit if they are both rolled out widely overall. The extent to which both infrastructures are necessary and require parallel financing, and whether their costs are to be financed by grid charges, remain unanswered questions, which will in all probability be affected by the political feasibility of the options. In both cases, substantial investments are needed which will result in electricity price hikes anyway, even if the marginal costs might fall if the share of renewable energy sources is high.

The BNetzA implemented the RPI-X regulation paradigm in Germany according to a strict methodology and in detail. It could also accompany the debate on modifying this paradigm, if it were to be given the corresponding policy remit. In respect of the third regulatory period (starting in 2018), the expert discussions would have to be increased, enriched with the findings of the ongoing model projects and fed in to the political discussion. This would be the only possibility for incorporating real modifications into the incentive regulation system.

6.4.3 REWARDING FLEXIBILITY

How should flexibility be rewarded (e.g. the non-deployment of generation capacity)? Invest more to produce less. This rationing paradox is characteristic of an FEG and a future energy system:

- More investment in renewable energy, the price of which falls the more it is deployed.
- More investment in grid intelligence, to the extent that this leads to lower charges.
- Optimum investment in grid expansion, which leads to lower charges.

This applies equally to measures designed to produce flexibility. Storage is less problematic: It must cover its costs via arbitrage. It is still unclear how providers of aggregated demand can participate directly in the market. A cement works that moves its production to high-wind days would have to receive compensation for its "negawatts" on wind-free days at the then very high price that conventional generators and providers of power from storage could obtain.

To produce a consistent outline of a future market design, a wide range of questions still need further debate and clarification. The following are simply examples:

- In what volume can cable investments be replaced by investments in "intelligence" (cost-benefit analysis)?
- How can an incentive regulation produce an "optimum grid performance capacity"?
- What are the logical revenue drivers ("outputs") of an FEG in the context of a refined incentive regulation?
- How should the connected output from distributed generation (in rural locations) be handled?
- What is the most efficient method of dealing with this feed-in?
- How can energy savings by consumers be rewarded?
- How can regulation be designed so that the distribution grid can support the upstream TSO in its activities?
- What are the objective roles and responsibilities of the different market participants in a FEG?
- How can the transition be formed sensibly and what are the quick wins?
- How are the costs of buying flexibility handled? How can consumption reduction/reduction of demand on the spot market and intraday market be handled?
- Are negative prices a useful control instrument?
- How are renewable energy sources to be sufficiently compensated for their price-reducing effect in a wind-dominated system?

400 For the further development of incentive regulation, Gerd Brunekreeft has made a suggestion in the scope of the IRIN project, which is supported by the BMWi, based on elements of the revenue=incentives+innovation+outputs (RIIO) paradigm, to establish 2011 as a base year from which to create a "What if" projection with model grid calculations that compare a smart grid with a dumb grid and derives corresponding investment requirements. This would be difficult to accomplish for hundreds of grid operators.

401 E-Bridge 2011.

6.5 INTELLIGENT DISTRIBUTION GRIDS IN A CENTRALISED EUROPEAN TRANSMISSION GRID

With an increasing share of renewable energy in the energy supply, there is a growing need for the provision of sufficient reserve capacity and more active load management. Whether this system balance should occur centrally, locally or through a mixture of both approaches is unclear.

A Europe-wide transmission grid that integrates Norwegian pumped-storage power plants (which would also need further expansion) with wind farms along the Atlantic coast could ensure a balanced system over the course of a day and from season-to-season. Alternatives to the seasonal balancing act are also provided by wider, bulk, large-scale technical options, such as the construction of gas storage, the manufacturing and storage of hydrogen, the use of additional storage options (e.g. CAES – Compressed Air Energy Storage) or the use of the gas grid as storage in a Power-to-Gas system. A pan-European transmission grid, an overlay grid, could synchronise major, primarily renewable energy-based generating plants from Spain to the far north, and possibly even integrate thermal solar power plants and wind power from North Africa into Europe's electricity markets.

At the same time, an FEG at the distribution grid level can produce locally efficient subsystems by intelligently integrating smaller generating plants and providing smart load management functions.

Both in the local FEG and in the European transmission grid, the following dilemma that affects most grid infrastructures must be noted:

> Only a comprehensively expanded FEG is likely to be able to achieve the required effects of scale and efficiency benefits that would simply not arise on the basis of local initiatives.

If all actors invest, the transaction costs will fall and the expenditure on peak load power plants and physical grid expansion will be reduced. In that case, the absence of this investment would result in a market failure in the traditional economic sense, which could be rectified by government intervention. According to this logic a purely microeconomic investment calculation would be insufficient to assess the costs and benefits of a FEG. Instead a long term analysis that evaluated external factors and security and energy independence effects would be required.

6.6 TRANSFORMATION FROM TRANSMISSION AND DISTRIBUTION GRIDS TO AN FEG

> An integrated market design that is supported by a majority of the numerous stakeholders must still be developed for both the European transmission grid and the local distribution grid.

Both at transmission grid and at distribution grid level, the conflicts are similar: On a windy public holiday, what source has priority on the European grid? EEG electricity from Germany or nuclear power providing the base load from France? How should usage of the available grid capacity be optimised across national borders?

This could be decided by a European Independent System Operator (ISO) responsible for system dispatch in the entire system and for optimising the intraday market. Such an ISO would have to have information about the entire system (grid status, plant availability, short-term wind forecasts) and primacy over the European day-ahead and intraday markets, in order to ensure it optimised resource allocation in an overall system with a large proportion of fluctuating renewable energy sources.

A whole package of prerequisites would have to be created around this, including common rules on how exactly renewable energy sources are to be prioritised. Transition to an ISO requires time, central coordination and political will.[402, 403]

Whatever applies to the European transmission grid also applies to any distribution grid that becomes controllable, even if at a different system layer. Who should manage the system and make

402 Neuhoff et al. 2011.
403 Säcker 2007.

decisions to resolve any conflicts that arise? Particularly at distribution grid level, an FEG can create the prerequisite for improving the management of distributed feed-in and demand. The distribution system operator already integrates fluctuating renewables-generated energy at the distribution grid level. It could be used as a regulated enabler for DSM, by aggregating the necessary technical data (including for maintaining voltage in distribution grids) for an optimised, stable overall system. Any excess data for third parties can be presented free from discrimination according to the customers' or third-party's preferences. This, too, could be done by an active ISO in principle. The term coined for this is Smart Area Grid Operator (SAGO). The role has been outlined, but it is still not clear how the business model should work in theory under the current framework conditions. Splitting up the market roles of the current competition paradigm will not facilitate the establishment of a SAGO. The current unbundling measures implemented by the competition paradigm have not been developed specifically for a FEG, but neither do they run counter to it.

6.7 INTERACTION OF AN FEG AND GENERATION

In theory, scarcity prices should attract new investment. In practice, this does not happen, and for a variety of reasons. The secondary conditions of system transformation in the energy sector are such that investors are increasingly less willing to bear the risks for conventional power plants. The more successful the renewable energy sources are, the lower usage hours the conventional power plants will chalk up. This means that many traditional investment computations have become obsolete.

Hedging contracts, capacity payments. Carbon price floors[404] are being discussed around Europe and should issue effective market signals in the long term. An FEG should lead to the formation of intrinsically optimised cells, reducing the demand for bulk feed-in from outside and smoothing out peak loads. This will result in a further reduction in usage hours for conventional power plants and the investment conditions within the existing market design would be further worsened. In addition, there is a negative correlation between wind feed-in and spot market prices: the more capacity is added, the higher the expected price pressure on the spot market.

With the system transformation, there is an accompanying transformation of the role of bulk power plants. Highly flexible gas-fired power plants for use as distributed balancing units are urgently required. However, they are intended to act in a market that would really rather not deploy them at all. For that reason, new regulations are needed to offer security for investment.

6.8 SUMMARY

There are four options for integrating fluctuating renewable energy sources into the energy system:

- Adding new grids, power plants and storage
- Reducing inelasticity by means of feed-in management
- Making demand more flexible
- Strengthening the integration of European markets

Following the transformation from the monopoly to a competitive framework, it is uncertain how and if the market will be able to provide the high level of investment needed for these options. This applies in particular to high investments that have a seasonal balancing as their objective. It is also not clear to what extent the current market design permits multiple possible technical system configurations for major technical interconnection solutions (European overlay grid, Power-to-Gas). Another option would be to isolate grid cells with largely self-sufficient supply, including storage, that require just a small buffer to bridge periods with low wind, for example, or days with little sunlight in winter. An FEG is a prerequisite for the provision of many other balancing options. From such an evaluation, it would be possible to create a "merit order" or balancing options, listing the possibilities for integrating fluctuating energy sources sorted by availability (time) and costs. Similar to the

404 A carbon price floor is a regulatory/control mechanism that ensures that an emitter of CO_2 pays a minimum amount for the right to pollute, even if surplus allocations of emissions certificates result in a very low market price. The minimum price is intended to make investment in efficiency and low-carbon technology attractive in these situations.

abatement curve[405], it could help in the allocation of limited investment resources.

The focus set by the EU on smart metering is counterproductive, at least for Germany. First of all, the prerequisites required for successful smart metering must be met in the distribution grid, in a back-end structure and in the market design. If a cost-benefit analysis for Germany were to confirm that an across-the-board roll-out of smart meters would not be economically efficient for small consumers, this finding could throw into question the obligation demanded by the EU for 80 percent of all households to have installed a smart meter by 2020. Previous studies into the German market have started with a much smaller customer segment, for which a smart meter makes financial sense.
The debate concerning a market design tailored for an FEG at distribution grid level must be started. Such a design must answer the following questions:

- How should investments in rationing and efficiency be rewarded?
- How can aggregated demand and storage participate in the market?
- How can fluctuating renewable energy sources be rewarded for their price-reducing effect?

A price mechanism that fulfils local/regional efficiency and flexibility requirements must cover a measurable and defined grid area in the event of greater penetration of renewable energy sources. The pricing system should reflect the structural conditions for feed-in, storage and exit from individual grid areas.

Against the backdrop of many uncertainties and interactions, the early verification of new approaches and innovation measures is key in the experiment concerning special zones in which exceptions to the wider-ranging regulation principles can be implemented, in order to establish optimum incentive mechanisms, suitable market roles and a market design that will support an FEG with the maximum of consumer benefit.

A market paradigm for the electricity markets in Europe and Germany has only just been established. At the same time, an ever increasing amount of fluctuating renewable energy is being installed remotely from the market through feed-in tariffs. How these renewable energy sources should be moved into the market is still unclear. This three-way contradiction between the paradigms, market – technology selection (EEG) – optimisation (FEG), must be resolved by a new market design. A successful, sustainable transformation of the energy system will require a long-term system change in the EEG and in the design of the market, in parallel to the transformation that will result in a FEG. This applies equally to the further development of incentive regulation in the direction of quality and innovation regulation.

405 Abatement curve: marginal cost abatement curves (MAC) support a range of options for reducing pollution (e.g. in the case of greenhouse gases) in the sequence of their cost and also indicate the potential proportion of the reduction.

7 THE SMART GRID FROM A USER-ACCEPTANCE PERSPECTIVE

This chapter analyses user acceptance, taking a differentiated view on consumer "milieus". Following an initial report and evaluation of the current state of research, the chapter then introduces the milieu approach, and describes the various milieus that are considered. On this basis, the potentials for creating technological acceptance within each milieu are identified, broken down according to a range of linked topics and specific views of the smart grid.

7.1 CURRENT STATE OF RESEARCH

7.1.1 INTRODUCTION

The combination of rising energy prices and an increasing awareness among consumers of energy consumption and its negative consequences for the environment are leading to growing interest in energy management. As a result of the Federal Government's rapid exit from nuclear power following the Fukushima catastrophe, renewable energy sources and therefore more variable electricity usage are quickly gaining in importance. At the same time, away from the perception of the general public, industry and politicians are working on the fundamentals of a new type of electricity supply – the smart grid.

Alongside the legislative and technical aspects, however, it is vital that the views of future, potential users are not ignored. Only by taking account of their needs and requirements will there be broad acceptance and thus rapid establishment of a new "smart" electricity system.

A survey of experts conducted this year revealed that three quarters of them anticipate that the smart grid will achieve market penetration in over 10 years and around one quarter think it will take at least 15 years. While Germany is believed to have the highest levels of competence for this technology, the prospects of realisation are much more critically viewed. Nevertheless, 65 percent of those asked believe that smart grids are the "prerequisite for the integration of renewable energy sources".[406]

In the sections below, however, the views of the technical experts draw less attention. Instead, the focus is on the current state of research into the acceptance of smart grid technology in German households. The knowledge of motives and barriers from the consumers' perspective will provide key starting points from which to ensure successful market introduction, and will prevent an overly technocratic approach, the type of which often ignores customers' needs.

The knowledge of opportunities and barriers from the consumers' perspective will provide key starting points from which to ensure successful market introduction.

7.1.2 STATUS QUO

Within Europe, Germany is a very active (pioneering) role model in matters of environmental protection.[407] Popular surveys reveal a generally high level of understanding of topics involving energy and the environment. For example, 60 percent of Germans believe that energy consumption by domestic households has a negative effect on the environment (cf. 40 percent globally). Furthermore, 80 percent of Germans believe that their knowledge of measures to optimise their household energy usage is sufficient. However, only 31 percent actually know of targeted programs for energy management,[408] which points to a need for greater specific education.

According to an international study, carried out in five different countries, almost 80 percent of those asked believe that intelligent systems ("smart appliances") will play an increasingly important role in the coming 10 years. However, almost all agree that reducing electricity consumption will require significant behavioural changes in domestic households in addition to new technical solutions.[409] A further survey into smart meters reveals that 85 percent of households are already interested in intelligent digital electricity meters and that almost as many are in favour of expanding the distributed energy supply (including the options for own electricity production, which is particularly relevant for those who are

406 VDE 2011, p. 26.
407 EKO 2009.
408 Guthridge 2010, p. 7-9.
409 Mert 2008, p. 17.

homeowners[410]). It should be noted at this stage, however, that declarations of interest should not be equated with specific actions and that there are important barriers to the basic openness to new energy solutions. In the literature, five topic areas can be identified, as shown below:

7.1.3 COST-BENEFIT RATIO

First, a financial advantage is an essential component of considerations to use or invest in smart Energy Management Systems (EMS). For example, end users only look specifically for purchase-related information if electricity prices are rising tangibly or if they are planning to buy a new major household appliance anyway.[411] As the lifecycles of large consumer appliances are relatively long, this consideration normally only occurs once every 10 to 15 years.[412]

An additional factor is the readiness to pay for "smart home" products, such as intelligent refrigerators or other networked household appliances. Multiple studies conducted with end users have proven that the fear of excessive purchase costs is strong and that the costs are often felt to be disproportionate to the benefits.[413] The (financial) savings potential is viewed very critically. While around 50 percent would pay a surcharge of between 50 and 100 euros for intelligent household appliances, they would expect the surcharge to have paid for itself within five years at least.[414] Another study reveals that investment in self-generation of energy is only generally attractive if energy costs can be reduced by 50 percent as a result.[415]

Although the promise of lower energy costs is primarily the key factor when considering whether or not to invest in EMS, after all, almost one third of end users would accept a rise in costs of five percent.[416] Two studies have shown that both experts and consumers consider electricity savings of around 10 percent as realistic.[417] These savings are achieved not only by using intelligent, energy-saving household appliances, but also increasingly by consumers having a greater awareness and understanding of their own energy usage behaviour and the opportunity to optimise their own electricity consumption.[418] This level of monitoring and tracking down "energy guzzlers" are key incentives for end users[419] and would potentially offset the somewhat higher acquisition costs or additional costs of servicing/maintenance.

In this context, many consumers also find the prospect of generating revenue from unneeded electricity very interesting.[420] In this respect, it is possible to state in summary that consumers' knowledge of smart technologies for electricity feed-in and the actual benefits is still too limited to be able to make any realistic statements about private investment propensity just yet.

7.1.4 ELECTRICITY PROVIDERS/DATA PROTECTION

Electricity providers are the first port of call for consumers in relation to energy efficiency topics. The relationship between electricity providers (especially large energy groups) and end users is characterised in Germany especially by a major lack of confidence, however.[421] Even though Germans do not (yet) frequently change electricity provider and do not regard this option as particularly important [422], they still do not want to be bound to a specific provider for too long a period. They fear being technically dependent on their electricity provider if

410 Haastert 2010.
411 Guthridge 2011, p. 12.
412 BMWi 2006b, p. 134.
413 VDE 2011, p. 32 et seq.
414 Mert 2008, p. 33.
415 Valocchi 2007, p. 10.
416 Guthridge 2011, p. 17 et seq.
417 BMWi 2008; VZBV 2010.
418 BMWi 2008, p. 44.
419 VZBV 2010, p. 24.
420 Valocchi 2007, p. 10.
421 Guthridge 2010, p. 13 et seq.
422 Valocchi 2007, p. 9.

the provider also offers smart meter equipment.[423] This (very German) level of distrust represents a potential barrier in terms of the rising level of monitoring by electricity providers and therefore access to personal data. According to a survey, however, this problem is something that is discussed more than it is actually experienced as a barrier in practice. After all, more than 60 percent of respondents state that access by third parties to user data for maintenance or usage optimisation is not an obstacle. This applies in particular when costs can be saved as a result.[424] Scepticism and a certain level of disquiet remain the rule of the day, however.

7.1.5 PERSONAL AUTONOMY

Smart household appliances may mean an increase in usability and energy efficiency, but are also often identified with an unwanted dependency on technology. This is exacerbated by the fear that the technology is too complex and therefore cannot be understood. The presumed difficult and not intuitive operation of such systems thus contradicts the existing level of comfort or desired increase in usability. Moreover, many consumers (on the basis of their own experiences) assume, almost without pausing to think, that the introduction of new products and technologies will (initially at least) be associated with high numbers of technical faults ("teething troubles").

Doubt is also the order of the day in relation to the design of sensors, transmitter boxes and cabling. Aesthetic concerns about the design of individual devices therefore also contribute to the feeling of comfort around their use.[425] If an atmosphere of well-being is interrupted or is no longer as positive, this increases the distance between the user and the product, and reinforces the feeling of there being a third-party determining what happens in the home. In summary, the better a device takes account of or strengthens the user's feeling of self-sufficiency, the greater the acceptance by the user of the EMS in the household. The reverse is naturally also true.[426]

7.1.6 ECOLOGICAL ASPECTS

As already explained above, the greatest motivation for users to inform themselves about energy saving methods is to find out about how to reduce their own electricity costs (around 90 percent). Nevertheless, 70 percent state that reducing environmentally harmful behaviour is also an attractive incentive.[427] Environmental reasons may not be the sole motivation for an investment, but they are certainly seen as a welcome and desirable side effect. The low effective impact of environmental protection as an argument in favour of technology stems potentially from an insufficient explanation of the benefits for the environment and the feeling that end-users are being required to invest while the "big players" in industry, which are viewed as contributing more to pollution, are not being held responsible to a corresponding extent. In part, the actual benefit for the environment is even questioned and viewed as purely a marketing message put out by the provider.[428] Time and time again there is a pattern of scepticism that emerges from the lack of knowledge among the population and that can be remedied in the medium to long term by education.

7.1.7 CURRENT RESIDENTIAL SITUATION

The residential situation is a key factor that helps determine a person's willingness to invest. It should be remembered that more than half the German population[429] lives in rented accommodation, and are thus less likely to share in investments needed to implement energy-saving measures. At the same time, there are many owners/landlords who see too little personal benefit for them to bear the investment costs completely on their own. This dilemma can only be resolved by

423 VZBV 2010, p. 7.
424 Guthridge 2011, p. 32 et seq.
425 BMWi 2006b, p. 133-137.
426 Guthridge 2010, p. 17-21
427 Guthridge 2011, p. 17.
428 Mert 2008, p. 34.
429 TDWI 2011.

taking equal account of the viewpoints of both sets of market participants. A spectrum of tangible (e.g. financial support) and intangible (e.g. prestige) benefits may lead both sides to invest in a future technology without the financial burden falling completely on one side or the other.[430]

Equally, an investment decision is affected by whether the corresponding buildings should be rebuilt or renovated/restored. In the case of new builds there is greater willingness to invest since the technology can be integrated at less effort (i.e. more cheaply), which has a positive effect on the cost-benefit ratio. However in Germany there are more renovations than new builds (the new build trend is actually going down), which is making it more difficult to introduce EMS.[431]

7.1.8 ACCEPTANCE OF SMART HOUSEHOLD APPLIANCES

To make statements on the future distribution and deployment of smart grid technologies in the household, and thus to assess the attitudes and views of end-users, it is worth looking at comparable products that are already on the market and that already enjoy a certain level of awareness. A variety of isolated solutions make ad hoc contributions to obtaining consumer-specific views for the purpose of developing and selling smart grid technologies.

The study "Consumer acceptance of smart appliances" targeted the propensity of users to only use household appliances at times when the electricity is cheap.[432] This investigation demonstrated that smart appliances are generally highly attractive. While the specific method of function is frequently not known, users generally expect increased convenience in the household. In relation to specific household appliances, different levels of attraction can be identified.

Smart heating systems appear extremely attractive, in particular since heating is viewed as very energy-intensive and therefore costly. Innovative approaches in this area are thus especially welcome, although users do not want to hand over control completely.

Intelligent dishwashers are also viewed as extremely feasible and viable by the respondents. For many people, it would not matter if crockery were to remain in the dishwasher for a longer period of time, while the appliance was waiting for a cheaper operating period. Given low operating noise and high safety standards, as are now common in modern equipment, the dishwasher can also operate overnight or while the occupants are not at home.

Intelligent washing machines are also seen as very attractive, and are already available in some guises. However, one fear is raised here: Items of laundry could "suffer" if they are left too long in the washing machine (wear due to fabrics staying damp for too long, creasing). This could be helped by adding a degree of relativity to the intelligence of the appliance, so that it would switch on automatically after at most three hours. Leaving the appliance to run overnight is less well received due to the noise level, which is still considered to be excessively high for this. Moreover, users do not wish to leave wet washing in the washing machine overnight.

A smart tumble dryer is considered less acceptable than the aforementioned appliances. Many do not see the point of it. In addition, on closer analysis, the mere use of a tumble dryer is frequently considered to contradict ecological and economic objectives.

People often find it difficult to imagine a smart refrigerator. The major fear is that food could spoil due to the temperature fluctuations. Mostly, their method of functioning is incomprehensible. This product requires much more information to be provided, as well as an easily visible thermostat that can convince the user that a constant temperature can be maintained despite the intelligent functionality.

"Smart hot water boilers" also tend to meet with resistance. The boiler is used "on demand" and consumers are not prepared to sacrifice comfort. These products are also encumbered by the fear that the higher acquisition costs will reduce the effects of electricity cost savings.

430 Auer/Heng 2011, p. 12 et seq.
431 BMWi 2006b, p. 133 et seq.
432 Mert 2008, p. 17-27

The user of "intelligent air conditioning systems" is viewed very critically in Germany, since the comparably low summer temperatures lead consumers to doubt the need for such a product in general. In other words, the cost-benefit ratio is particularly unfavourable.

7.1.9 INFORMATION PATTERNS/BUYING BEHAVIOURS OF END CONSUMERS

The main sources of information about measures to optimise electricity usage, according to a 2010 accenture study, are consumer and environmental organisations, since these are regarded as highly trustworthy. Manufacturers and providers appear to be insufficiently impartial, since in selling such products they not only have the consumer's interests at heart, but also their own interests.[433] Usually, a personal consultation is desired. In contrast with other European countries, where consultations and purchases primarily take place at the vendor's or provider's offices, German consumers often prefer to conduct business within their own four walls.[434]

In order for smart grid technology to be adopted across the board in German households, all market players must be integrated. Experts view this as a problem. If, as is currently the case, even the craftsmen and architects frequently lack the specialist knowledge to understand the technology (and therefore cannot explain the technology to the end consumer), this makes the consumer uncertain, leading to greater distance and a tendency to wait. It is vital that the technology be presented surely and professionally, to ensure that consumers are won over.[435]

7.1.10 EXCURSUS: CONSUMER GROUPINGS

In the study "Understanding Consumer Preferences in Energy Efficiency", which was conducted in 17 countries in 2010 by accenture, a range of consumer groupings are formed on the basis of factors that are incorporated into decision-making on a smart energy management system. The following six segments were identified: "Proactives" (16 percent), "Eco-rationals" (12 percent), "Cost conscious" (17 percent), "Pragmatics" (21 percent), "Scepticals" (21 percent) and "Indifferents" (13 percent). Germans find above-average representation in the following groups:

- "Pragmatics" (24 percent)
  - little acceptance of energy utility company monitoring
  - dubious of electricity bill savings
  - high propensity to switch to other products and brands
  - wait-and-see approach to new technologies
- "Scepticals" (25 percent)
  - lowest acceptance of energy utility company monitoring
  - least trusting of energy utilities
  - lower electricity bills are less relevant (higher income levels)
  - less social pressure
  - seek out expert advice/information from consumer associations[436]

7.1.11 GENERAL REQUIREMENTS WHEN BUYING AN EMS

Overall, the following expectations can be derived from a consumer perspective on the basis of the different investigations:[437]

- mature technology
- financial support measures
- return on private investment costs within around five years
- permanent reduction in energy costs
- transparency of achieved savings (e.g. information on electricity bill)
- ease of use, attractive design and high level of usability of devices
- ensure personal autonomy during use
- increase level of understanding among all market participants (consumers, consumer groups, installers, architects, etc.)
- one-to-one customer care and tailored solutions

433 Guthridge 2010, p. 14.
434 Guthridge 2011, p. 36.
435 BMWi 2008, p. 43-46.
436 Guthridge 2010, p. 27 et seq.
437 Mert 2008, p. 44 et seq.

7.2 METHODOLOGICAL PROCEDURE: ACCEPTANCE FROM THE PERSPECTIVE OF SINUS-MILIEUS[438]

7.2.1 RESEARCH BACKGROUND

The changes in attitudes to leisure and consumption brought about by a structural transformation and changes to values, including the formulation of new values and lifestyles, are leading to fundamental changes in all markets and presenting new challenges when planning for strategic marketing, products and communications. This requires the development of new, sensitive market models that reflect the increasingly complex reality, i.e. relating to the greater differentiation of desires and needs of people: The person has become the market! It is obvious that with the current breakup of markets and target groups, marketers are required to devise increasingly differentiated strategies. Target-market product development and positioning, successful brand management and communication are only possible today if the marketers assume the lifeworld and lifestyle of the customers who they wish to reach.

In the scope of milieu research, all the key experience areas that affect a person on a day-to-day basis are registered (work, leisure, family, money, consumption, media, etc.). A core finding of this research is that the value priorities and lifestyles that are determined from empirical analysis can be clustered into a basis typology, the Sinus-Milieu. Unlike the traditional stratified divisions, the definition of the milieus comprises a content-based classification. Fundamental value attitudes that determine lifestyle and living strategy are as important in the analysis as everyday attitudes, desires, fears and expectations for the future. In contrast to social strata, Sinus-Milieus describe real existing subcultures in our society that have common contexts and communications structures in their everyday world.

A particular advantage of Sinus-Milieus is their ability to explain specific attitudes and methods of behaviour for each milieu on causal-analytical grounds. In this respect they go beyond being purely descriptive sociodemographic typologies. Value attitudes and mental predispositions that are the result of a person's individual and social development have a major effect on behaviour. These factors, complemented by everyday aesthetic values, are key when associating a person to one of the Sinus-Milieus.

7.2.2 POSITIONING MODEL

The milieu model below (figure 57) shows the current milieu landscape and the position of the various milieus in German society according to social position and basic orientation. The higher the position of a specific milieu in this model, the higher the level of education, income and occupation within it; the further the milieu stretches to the right, the more modern its basic orientation in a sociocultural sense.

Figure 57 also reveals that the borders between the milieus are fluid. The boundaries of lifeworlds are not precisely defined.

For reasons of clarity and ease of reading, the distribution of the milieus has been somewhat simplified in figure 58, compared with figure 57. The following example is a guide to assist understanding: On average, 55.4 percent of those asked agree with a statement (green border). In the Traditionals milieu, however, only 9.6 percent agree (red border). The level of agreement in this milieu is therefore underrepresented in comparison with the total number of respondents, and is therefore coloured grey.

7.2.3 BRIEF CHARACTERISTIC PROFILES OF SINUS-MILIEUS

Upper social milieu

- *Sinus AB12: Established Conservative Milieu (ECO), 10 percent*
  The classical establishment: responsibility and success ethic; aspirations of exclusivity and leadership versus tendency towards withdrawal and seclusion
- *Sinus B1: Liberal intellectual Milieu (LIB), 7 percent*
  The fundamentally liberal, enlightened educational elite with post-material roots; desire for self-determination; an array of intellectual interests

438 "Sinus-Milieu" is a protected mark of Sinus Sociovision GmbH.

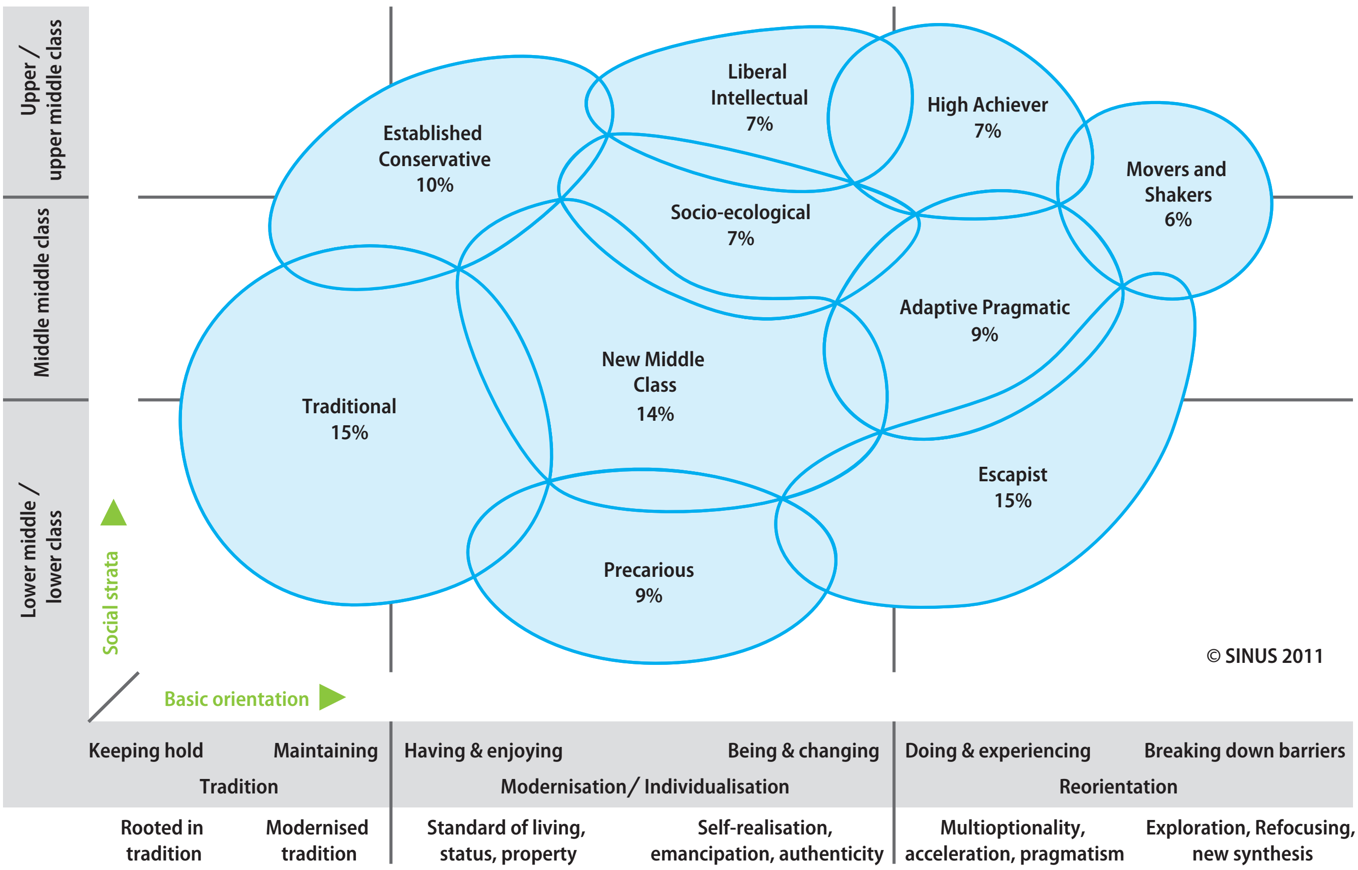


Figure 57: Distribution of Sinus-Milieus in Germany in 2011.

- *Sinus C1: High Achiever Milieu (HAC), 7 percent*
  Multi-optional, efficiency-oriented top performers with a global economic mind-set and a claim to avant-garde style
- *Sinus C12: Movers and Shakers Milieu (MES), 6 percent*
  The unconventional creative avant-garde: hyper-individualistic, mentally and geographically mobile, digitally networked, and always on the lookout for new challenges and change

Mid-social milieus

- *Sinus B23: New Middle Class Milieu (MIC), 14 percent*
  The modern mainstream with the will to achieve and adapt: general proponents of the social order; striving to become established at a professional and social level, seeking to lead a secure and harmonious existence
- *Sinus C2: Adaptive Pragmatic Milieu (PRA), 9 percent*
  The ambitious young core of society with a markedly pragmatic outlook on life and sense of expedience: success-oriented and prepared to compromise, hedonistic and conventional, flexible and security-oriented
- *Sinus B12: Socio-ecological Milieu (SEC), 7 percent*
  Idealistic, discerning consumers with normative notions of the 'right' way to live: pronounced ecological and social conscience; globalisation sceptics, standard-bearers of political correctness and diversity

Lower-middle/lower milieus

- *Sinus AB23: Traditional Milieu (TRA), 15 percent*
  The security and order-loving wartime/post-war generation: rooted in the old world of the petty bourgeoisie or that of the traditional blue-collar culture

- *Sinus B3: Precarious Milieu (PRE), 9 percent*
  The lower class in search of orientation and social inclusion, with strong anxieties about the future and a sense of resentment: keeping up with the consumer standards of the broad middle classes in an attempt to compensate for social disadvantages; scant prospects of social advancement, a fundamentally delegative/reactive attitude to life, and withdrawal into own social environment
- *Sinus BC23: Escapist Milieu (ESC), 15 percent*
  The fun and experience-oriented modern lower class/lower-middle class: living in the here and now, shunning convention and the behavioural expectations of an achievement-oriented society

7.3 IDENTIFICATION OF POTENTIAL TARGET GROUPS IN THE SINUS-MILIEUS

The objective of this milieu analysis is to identify segments of the population that demonstrate a high level of acceptance of intelligent EMS. In order to polarise the views of the various Sinus-Milieus in this respect, factors are analysed that affect the potential acceptance or rejection of intelligent EMS.

This methodology has been selected as so far none of the products are mature or available on the market.

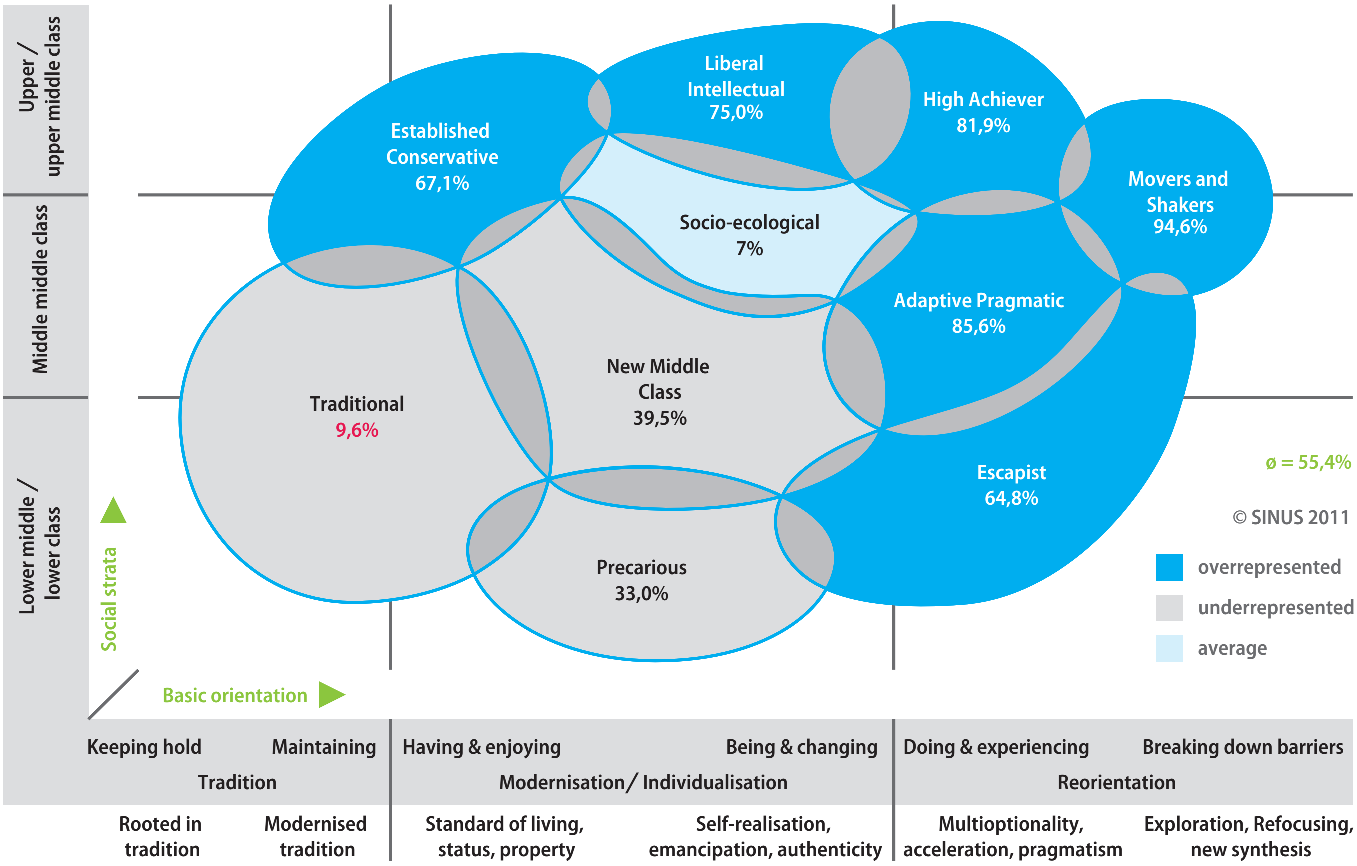


Figure 58: Example for clarification, Sinus 2011.

Pilot projects are currently being run in individual model regions, in order to generate initial indications of factors such as acceptance among consumers. The following six model regions and projects are combined under the umbrella of the "E-Energy: ICT-Based Energy System of the Future" programme:

- eTelligence – Intelligence for energy, markets and power grids, model region of Cuxhaven (Lower Saxony);
- E-DeMa – Development and demonstration of decentralized integrated energy systems on the way towards the E-Energy marketplace of the future, model region of Rhein-Ruhr (North Rhine-Westphalia);
- MEREGIO – The move towards "Minimum Emission Regions", model region of Baden-Württemberg;
- Model City of Mannheim – Model city of Mannheim in the model region of Rhein-Neckar (Baden-Wuerttemberg);
- RegModHarz – Regenerative model region of Harz (Lower Saxony, Saxony-Anhalt, Thuringia);
- Smart W@TTS – Greater efficiency and consumer benefit with the Internet of Energy and the "smart kilowatt-hour", model region of Aachen (North Rhine-Westphalia)

The model projects are funded in a cross-ministry partnership between the BMWi and BMU in a programme that together with the equity of the participating companies amounts to around 140 million euros.[439]

The following aspects are discussed according to the position of the Sinus-Milieus against this backdrop:

- Residential situation and household structure
- Energy and the environment
- Attitudes to and requirements of modern technology
- (Mobile) Internet and Web 2.0
- Data protection
- Dispersion model for product innovations

7.3.1 RESIDENTIAL SITUATION AND HOUSEHOLD STRUCTURE

An obviously decisive factor for the consumption of energy is the structure of households and home ownership. The level of energy consumption is naturally determined by the factors such as number of people in the household and the size of the accommodation.

The logical conclusion is that the more people that are living in the household, the greater is the demand for electricity. Households that comprise more than two people are found primarily in the younger milieus with a more modern orientation. In the on average older milieus, children have already left the house, and in the milieu TRA there is a higher proportion of widows and widowers. Couples living with two children under the age of 18 years are found with disproportionately high frequency in the milieus LIB, HAC, PRA and ESC.[440]

In line with the income structure and life phase, smaller households are primarily found in the milieus PRE and MES. The largest residences (in terms of surface area) are in the milieus ECO and LIB, and to a limited extent in the milieu MIC.[441]

Alongside the size of the home, the ownership situation (owner-occupied vs. rented) also has an impact on energy – particularly in relation to changing the energy used for heating. While tenants only have restricted opportunities to switch to a new form of heating, and are also dependent on the landlord or housing community when it comes to planning even small alterations, home owners or people who own their own apartments have a wider choice.

Those owning their own apartments (see figure 59) can be found primarily in the financially well-off milieus (LIB, HAC). Just over one third (37 percent) of the population own their own house (see figure 60). Both the upper social milieus (ECO, LIB) and the MIC and TRA milieus reveal above average frequency of home ownership

439 BMWi 2009.
440 TDWI 2011.
441 TDWI 2011.

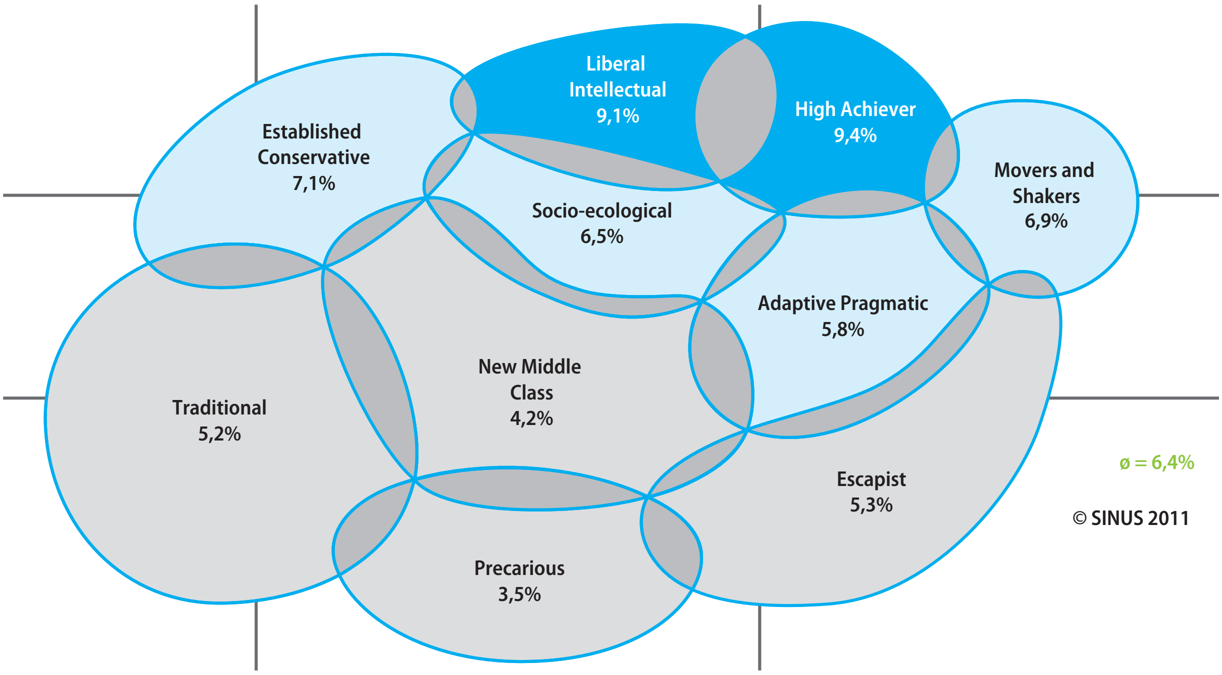


Figure 59: (Own apartment) Typologie der Wünsche 2011 III; Base: German population 14 years and over (20,129 cases).

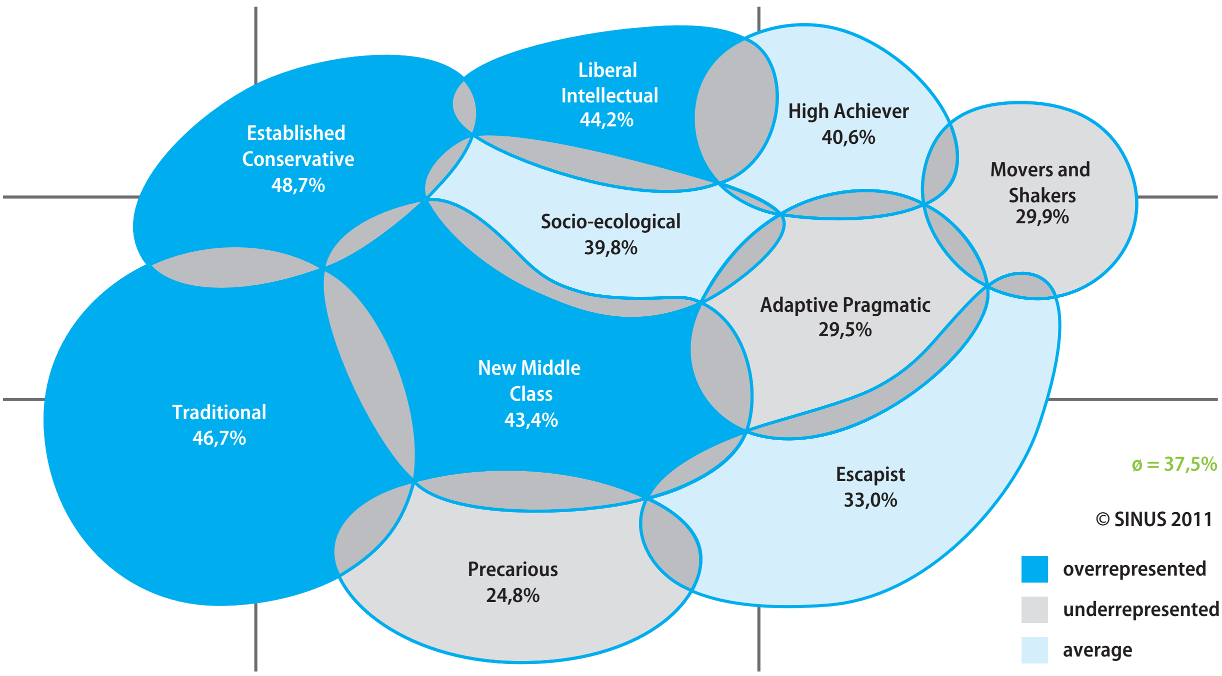


Figure 60: (Own house) Typologie der Wünsche 2011 III; Base: German population 14 years and over (20,129 cases).

(to a limited extent also the SEC milieu) and therefore also have the freedom to make changes to their energy and heating solutions.[442] Considering the milieu structure for tenants in Germany (55 percent), the milieus PRE and PRA have well above average representation. Fewer than half of those in the ECO and LIB milieus live in rented accommodation.[443]

As an indicator of openness towards new and alternative energy systems, home-owners[444] who use renewable energy are analysed in the following sections. In total, this group comprises 14 percent of home owners, or 4.85 million German residents. Above all the milieus representing the modern lifeworld segment (HAC, PRA, MES, ESC) appear particularly committed here, as do the environmentally aware milieus SEC and LIB. The lowest proportion of users of renewable heating energy can be found in the milieus TRA and MIC. These groups rely on traditional, established forms of heating and reject any change to previously less-well established alternatives.[445]

7.3.2 ENERGY AND THE ENVIRONMENT

The level of positive responses to the question, of whether a cost increase of up to five percent would be acceptable in return for environmentally friendly electricity is disproportionately high among the upper social milieus. An additional expense of up to 10 percent is mostly acceptable in the LIB, SEC and HAC milieus. However, the broad majority (64 percent) of German residents are not prepared to pay any more for environmentally friendly power. In particular, the milieus PRE (79 percent) and TRA (76 percent) reject this clearly.[446]

A sustainable use of energy can also be approached from another direction, however, for example by selecting household appliances with low energy consumption. The ECO and SEC milieus in particular pay attention to the energy efficiency class when buying white goods, accepting that they will pay more for the appliance in return. Their better financial situation combines with an awareness for sustainable living. Those in the ESC milieu, however, act according to this principle less often than the average. Here, the exact price of the product plays a much bigger role than the subsequent operating costs. The awareness of efficient, future-oriented energy usage and the readiness to deal with this topic are just as relevant when it comes to smart grids as the general sensitivity for the environment.

7.3.3 ENVIRONMENTAL AWARENESS IN THE SINUS-MILIEUS

Positive attitudes towards the environment and environmentally compatible behaviours are relatively broadly distributed through the upper social milieus (ECO, LIB). This finding is noteworthy insofar as these milieus have a key orientation function for large sections of society. Those in these milieus share a willingness to bear social responsibility and to provide others with a role model based on their own behaviour. In addition, people in these milieus often perform key social functions.

In the milieus HAC and MES, environmental awareness is distinctly less pronounced. This urban, mobile, technology-loving and consumption-oriented group may not at first glance demonstrate a strict environmentally friendly lifestyle, but it is (sometimes very) sensitive to environmental issues, due for example to its members' own social environment and their great hunger for information. They are committed to a "greening" of their lifestyles, but only as long as this does not mean having to set aside their own expectations.

The tendency of the members of the MIC milieu to look to the ECO and LIB milieus should be one, and certainly not the only, reason that even in this large mainstream milieu positive environmental attitudes and corresponding behaviours are spreading. A further obvious reason is the strong desire among members of this milieu for a perfect world in which their family and children in particular can live safely and healthily.

In the SEC milieu, environmental and climate protection are everyday topics that permeate life. These people attach great importance

442 TDWI 2011.
443 TDWI 2011.
444 Owners of detached, semi-detached, terraced houses, multiple occupancy dwellings and office buildings.
445 HBM 2011.
446 HBM 2011.

to living an ecologically aware, health-oriented, sustainable lifestyle. Organic food, natural cosmetics and looking out for environmental and socially acceptable consumer labels are typical of their purchasing habits. In addition, the use of "green" energy is relatively widely distributed. In brief, social-ecological consumers are "critical and consistent consumers".

Typical of the young PRA milieu is a clear orientation towards success and security, an open world view and pragmatism. The pragmatism of this milieu is also apparent in its environmental attitudes. While members strive for a good "eco-balance", specialist knowledge is not widely available and they do not often stop to consider the detailed issues of their own contribution to the environment. They certainly do not want to be considered as an overly zealous "greeny".

The lower PRE and ESC milieus demonstrate even less environmental awareness and action. Nevertheless, due to their simple lifestyles that are characterised by economy, their day-to-day lives are frequently less environmentally damaging than those of other groups of the population.

The German virtues of discharging one's duties, order and cleanliness are important for TRA milieu. For that reason, their lifestyle is particularly environmentally friendly, even though they do not consider themselves to be particularly environmentally aware. This can be explained by the fact that Traditionalists continue to consider themselves to be very far apart in terms of social groups from those who are pioneers in the ecological movement ("alternative" lifestyle). Due to their own values and also their income levels, Traditionalists are generally not profligate consumers. When they do buy consumer goods, a long lifecycle, quality and efficiency play a key role. While this is not the intention, it nevertheless represents an exemplary environmental attitude. The acceptance that consumers can make a major contribution to protecting the environment through their own behaviour is most strongly held in the LIB and SEC milieus. In particular, members of the PRE milieu are the least likely to hold this view. The same picture is seen in relation to a consistent switch to renewable energy sources: Here once again, the members of the LIB and SEC milieus agree while those in the PRE milieu are underrepresented.[447]

Another aspect of saving energy is the control and management of home technology using IT. Particularly members of the MES and HAC milieus, plus those in the PRA and LIB milieus, see this as an opportunity to reduce energy consumption. The openness (verging on fascination) towards technology that is described further below combines with the value added of doing something good – both for one's pocket and for the environment.

For people in the TRA and PRE milieus, the combination of home technology and IT is not associated with energy savings (see figure 61). As shown in greater detail below, both milieus are rather reticent and sceptical when it comes to new technology, especially in conjunction with IT.[448]

FIGURES IN PERCENT	Ø	ECO	LIB	HAC	MES	MIC	PRA	SEC	TRA	PRE	ESC
I often experience difficulties in interacting with technical equipment.	39	31	30	27	18	43	27	37	62	48	37
I find it increasingly difficult to keep up with technical developments.	53	58	40	34	15	59	34	56	80	71	42

Table 3: VerbraucherAnalyse 2010; German population 14 years and over (31,447 cases) and AACC Study 2009, base: German population 14 years and over (5,030 cases) German population 5,030 years and over (5,030 cases).

447 BMU 2010.
448 BMBF 2009.

7.3.4 ATTITUDES TO MODERN TECHNOLOGY AND REQUIREMENTS OF MODERN TECHNOLOGY

The presence of a certain affinity for technology among consumers is a prerequisite for the successful marketing of smart grid products and services.

When first filtering out those for whom access to new technologies is most difficult, two milieus in particular emerge: TRA and PRE. Both of these frequently experience difficulties in using technical equipment and find it hard to keep up with the speed of technological progress. The majority of the milieus MIC and ECO also demonstrate corresponding, defensive attitudes[449] (see table 3).

In contrast to this, there is a generally positive attitude towards modern technology, especially in the milieus MES and PER, followed by the milieus PRA, LIB and ESC[450] (see figures 62 and 63).

People's self-image as technical experts reveals a similar story (see table 4). Once again, the milieus representing the modern lifeworld segments are most strongly represented here. This proactive group, which is fascinated by technology, embodies a pioneering spirit and always ensures that its equipment is up to date and meets modern requirements. These milieus are also overrepresented when it comes to the "fun-factor" they experience when using computers and other modern electronic equipment.[451]

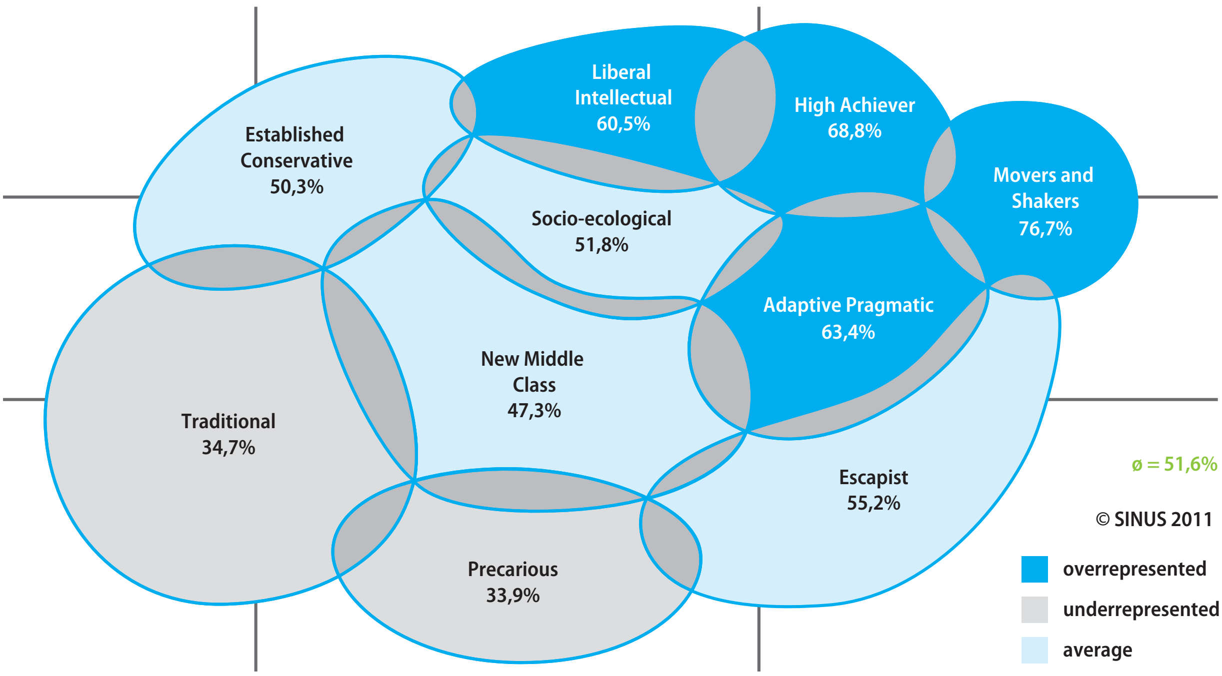


Figure 61: (Systems in the home that are controlled by IT save energy: agree entirely/mostly agree) AACC Study 2009, base: German population 14 years and over (5,030 cases).

449 BMBF 2009.
450 HBM 2011.
451 HBM 2011.

FIGURES IN PERCENT	Ø	ECO	LIB	HAC	MES	MIC	PRA	SEC	TRA	PRE	ESC
I consider myself to be an expert when it comes to new technologies.	11	10	11	21	23	8	14	8	2	4	20
I place high importance on always having the latest technical devices.	43	46	49	68	67	40	53	32	18	26	52
I like computers and other modern electronic equipment.	54	60	67	80	87	44	75	50	16	34	66
I value good looks/design highly in technical equipment.	61	64	71	80	83	62	74	51	35	49	68

Table 4: VerbraucherAnalyse 2010: German population 14 years and over (31,447 cases) and Typologie der Wünsche 2011 III; Base: German population 14 years and over (20,129 cases).

Benefits that are associated with technological further development, such as a wider range of control and programming options, simpler operation of equipment or the avoidance of human error, are particularly widely expected among members of the milieus MES, HAC and PRA. A disproportionately high amount of people in the milieu ESC typically also report that using new devices gives them more enjoyment.

However, among the technology fans, having the latest devices and the fun-factor are not the only important aspects. Their increased acceptance of technology is associated with an expectation that modern products will also feature attractive product design. Accordingly, this group pays particular attention to the design of appliances, which should ideally come in a design that matches the interior design of their homes.[452]

When it comes to the operation of appliances, both the non-technical milieu TRA and also the SEC and modern PRA milieus express above average levels of need for ease of use. They believe in the concept of “less is more”. Appliances that are limited to their core functionality and are not encumbered with numerous, complex additional options are particularly attractive. These three milieus also agree most strongly with the statement that technology should adapt to their habits, and not the other way around (see table 5).

The technologically aware milieus (MES, HAC, LIB, PRA, ESC) see this topic from precisely the opposite angle. They like to be able to make their own customisations and to configure their own settings in software applications, for example. Due to the ease with which they can handle technology, they are most likely to opt for offerings that they can customise[453] (see table 5).

Experience shows that a large amount of self-confidence in using new technologies is associated with the confidence that the advantages of technological progress outweigh the negative aspects. It is not surprising, therefore, that the milieus HAC, MES and PRA consider the changes brought about by further technical development as desirable. The milieus TRA and PRA hold exactly the opposite point of view, and even the SEC milieu views technical progress with a much less

FIGURES IN PERCENT	Ø	ECO	LIB	HAC	MES	MIC	PRA	SEC	TRA	PRE	ESC
Technology has to adapt to my habits, not the other way around.	33	36	37	24	34	33	40	40	41	35	15
All things considered, the changes that further technical developments are bringing about are desirable.	66	64	75	86	93	65	85	54	37	51	75

Table 5: AACC Study 2009, base: German population 14 years and over (5,030 cases)

452 HBM 2011.
453 BMBF 2009.

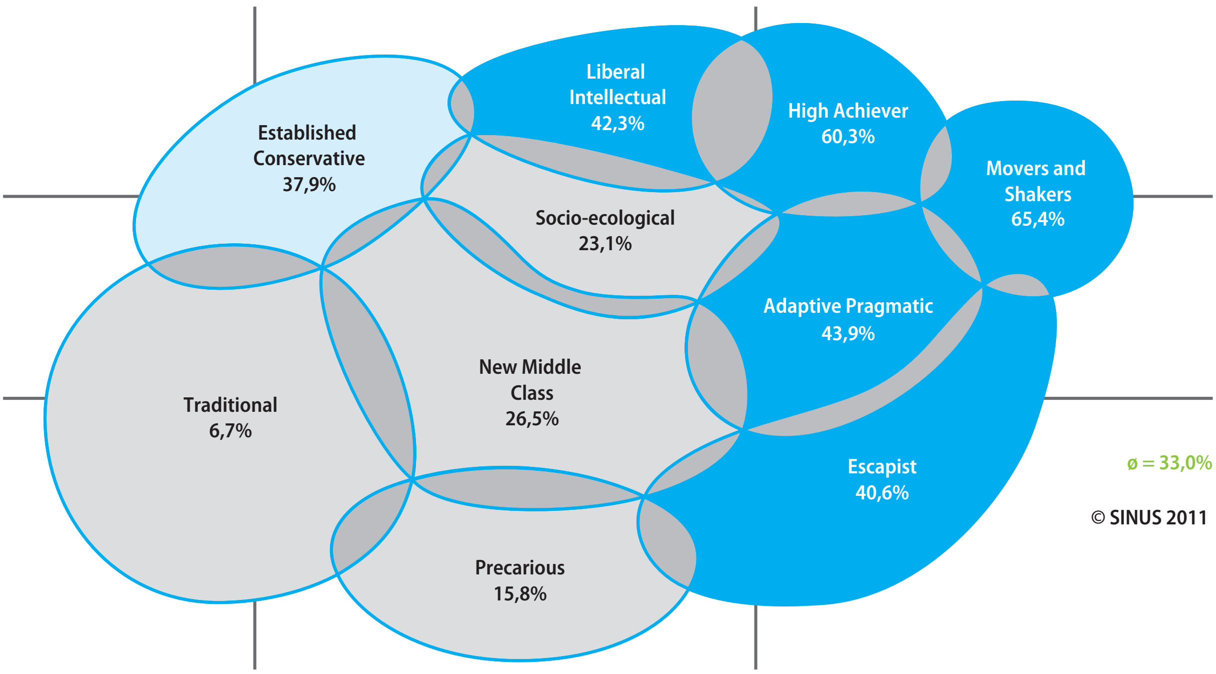


Figure 62: (High technical interest) VerbraucherAnalyse 2010; Base: German population 14 years and over (31,447 cases).

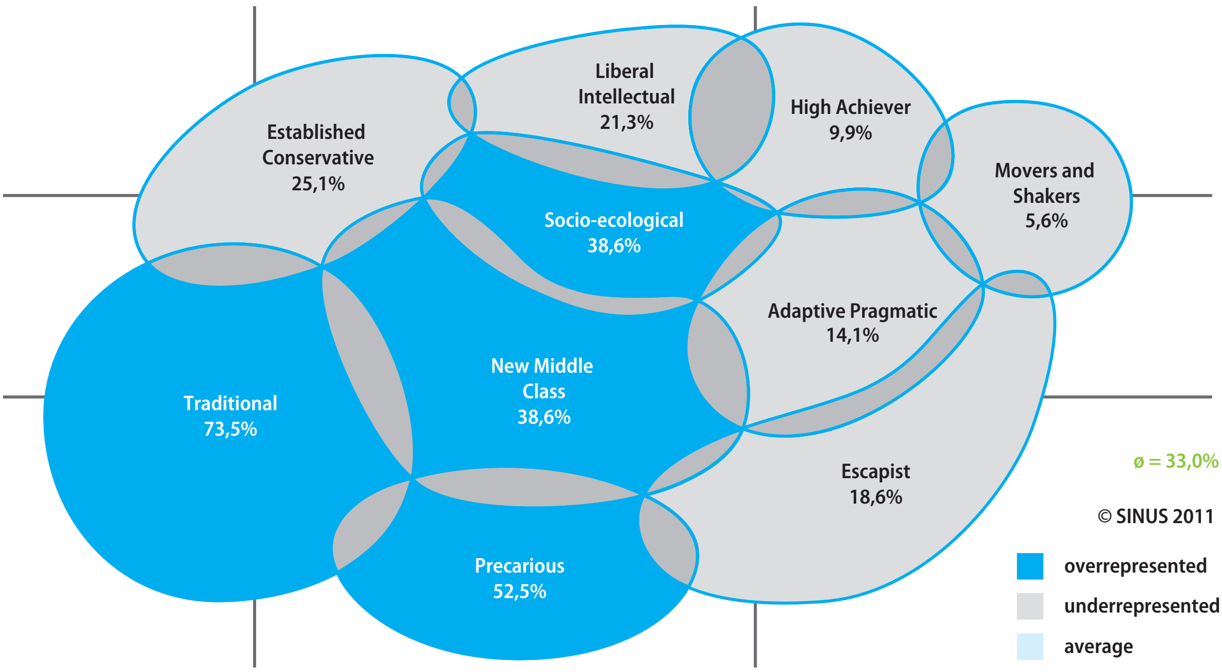


Figure 63: (Low level technical interest) VerbraucherAnalyse 2010; Base: German population 14 years and over (31,447 cases).

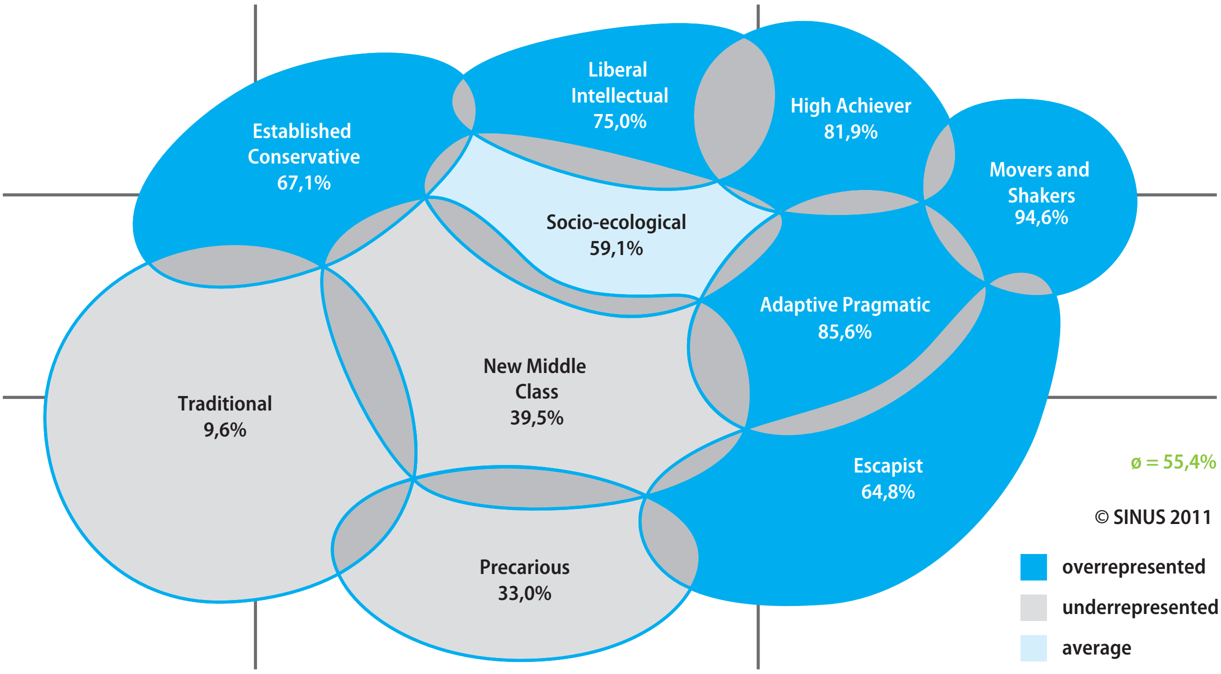


Figure 64: (Use of Internet and World Wide Web) Typologie der Wünsche 2011 III; Base: German population 14 years and over (20,129 cases).

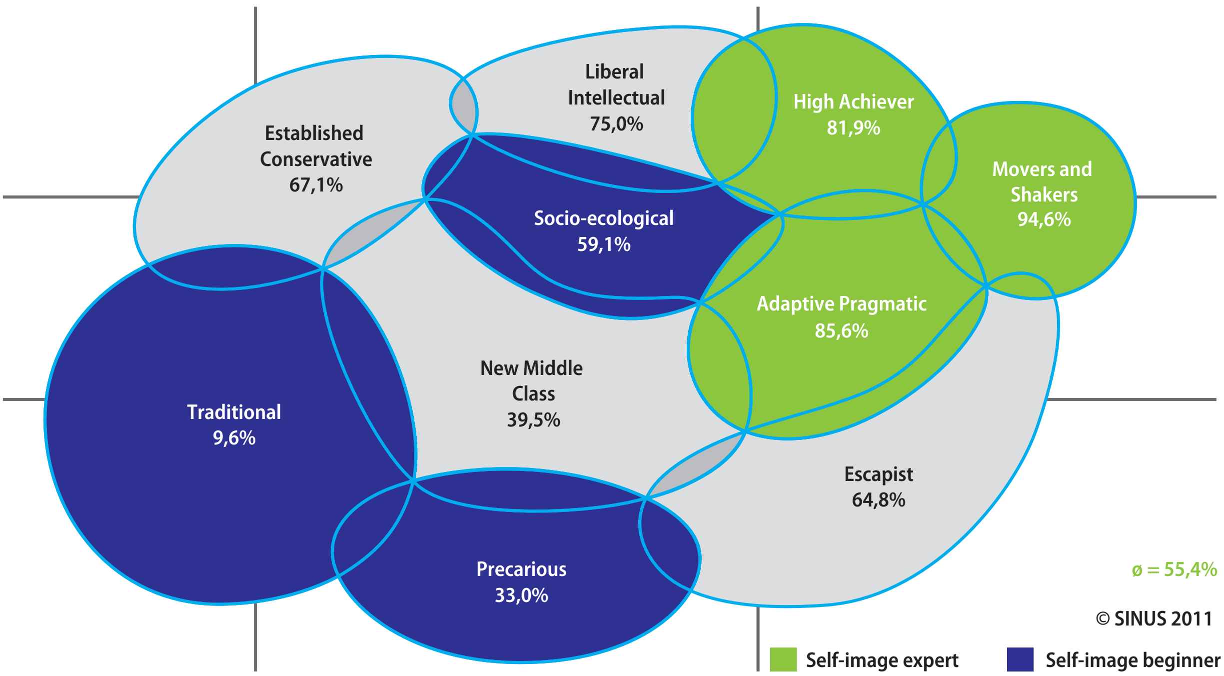


Figure 65: (Self-image Internet usage: expert vs beginner) Typologie der Wünsche 2011 III; Base: German population 14 years and over (20,129 cases).

positive attitude. From their perspective, technical innovation in itself is not positive; it must first prove its maturity for the market, and offer real, useful benefits. These people prefer to wait and observe how new technical products/technologies become established before opting in themselves.[454]

7.3.5 (MOBILE) INTERNET AND WEB 2.0

Alongside competence in using IT equipment, a good knowledge of the Internet, particularly the social web, is a key factor that will allow the potential of individual target groups to be assessed with regard to the greater level of dialog and interaction of the future electricity market. Considering Internet usage in general, the focus is clearly on the young and modern milieus (MES, HAC, PRA). They are growing up with the new opportunities offered by the world wide web (WWW) and, therefore, find it easy to relate to. Thanks to what is in most cases long experience of the medium, they are the mostly likely group to consider themselves as experts in relation to the Internet. Most members of the TRA and PRE milieus see themselves as beginners, although this is also true of the SEC milieu[455] (see figures 64 and 65).

Almost half of the population (47 percent) agree with the statement "I cannot imagine my daily life without the Internet." Most support for the statement is found in the MES and HAC milieus, followed by PRA, ESC and LIB. The opposite viewpoint is held, as usual, by the TRA and PRE milieus, the members of which seek to live their private lives as far as possible from communications technology, an attitude that is reflected in the low level of Internet usage.[456]

In respect of mobile Internet usage using small mobile devices such as smartphones, netbooks, etc., the members of the LIB milieu are overrepresented along with those of HAC and MES. These people are interested in new technological developments and use state-of-the-art equipment with the iPhone and comparable devices clearing the way for broad mobile Internet usage. Nevertheless, they observe certain developments from a critical distance initially, and are not among the early adopters of these devices.[457]

Interactive usage of Web 2.0 offerings primarily attracts members of the HAC, MES and ESC milieus. Even though the spread of major social networks such as Facebook has already reached broad layers of the population, including other milieus, and most Internet users have already visited the YouTube site, truly interactive usage of these sites is primarily in evidence among the groups mentioned first.

Social networking, searching for information in blogs and using fora, chat and mobile applications to interact form a natural part of their communications portfolios[458] (see figures 66 and 67).

7.3.6 DATA PROTECTION

Where the publication of personal information (through Facebook, for example) is already a matter of habit, or people routinely cooperate to produce user-generated content (UGC) on platforms such as YouTube, it can be assumed that the barriers to data transfer in conjunction with smart grid technologies are lower among these people than among those who do not use Web 2.0 products.

Alongside confidence in well-functioning technology, trust that the gathered data will be handled correctly is a key factor, especially when information is transferred via the Internet.

As expected, doubts surrounding security are less frequently articulated among the younger milieus. Security and an indifferent attitude play a role. The HAC, MES and PRA milieus demonstrate the greatest confidence that monitoring instances such as the policymakers will protect citizens against data misuse (see table 4). They delegate a much higher level of protection to the state and the responsible institutions, and are not scared off by repeated data protection scandals.

454 BMBF 2009.
455 TDWI 2011.
456 BMBF 2009.
457 HBM 2011.
458 HBM 2011.

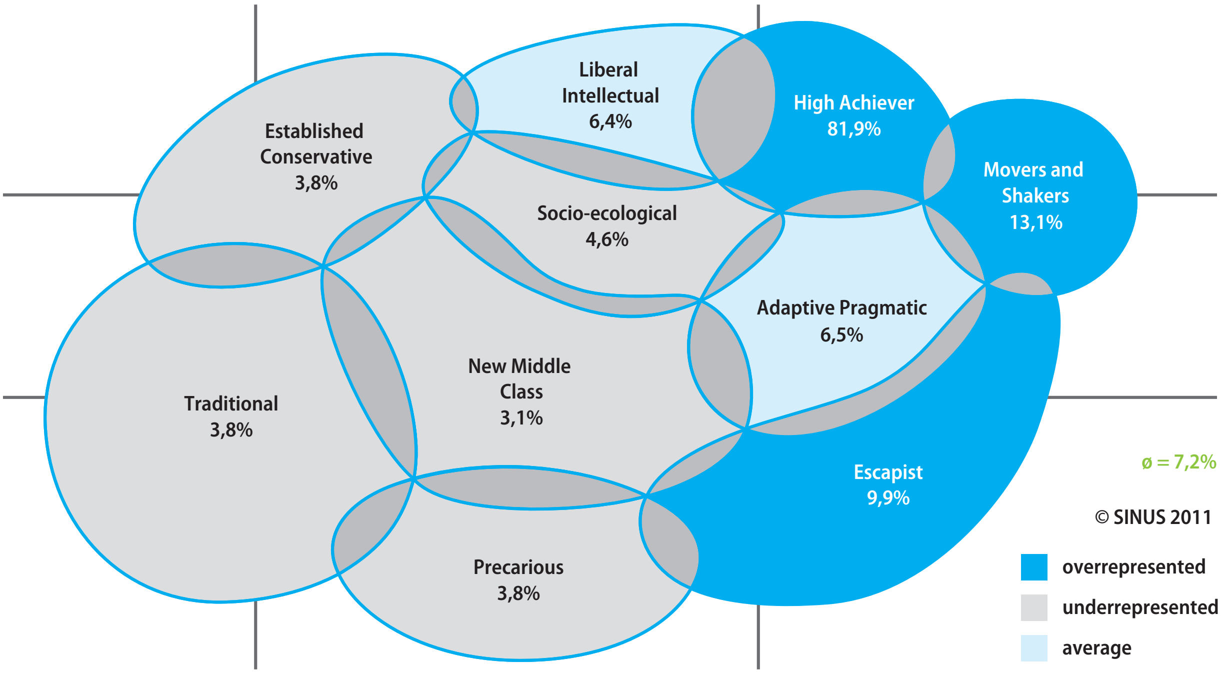


Figure 66: (Read and comment on blogs) VerbraucherAnalyse 2010; Base: German population 14 years and over (31,447 cases).

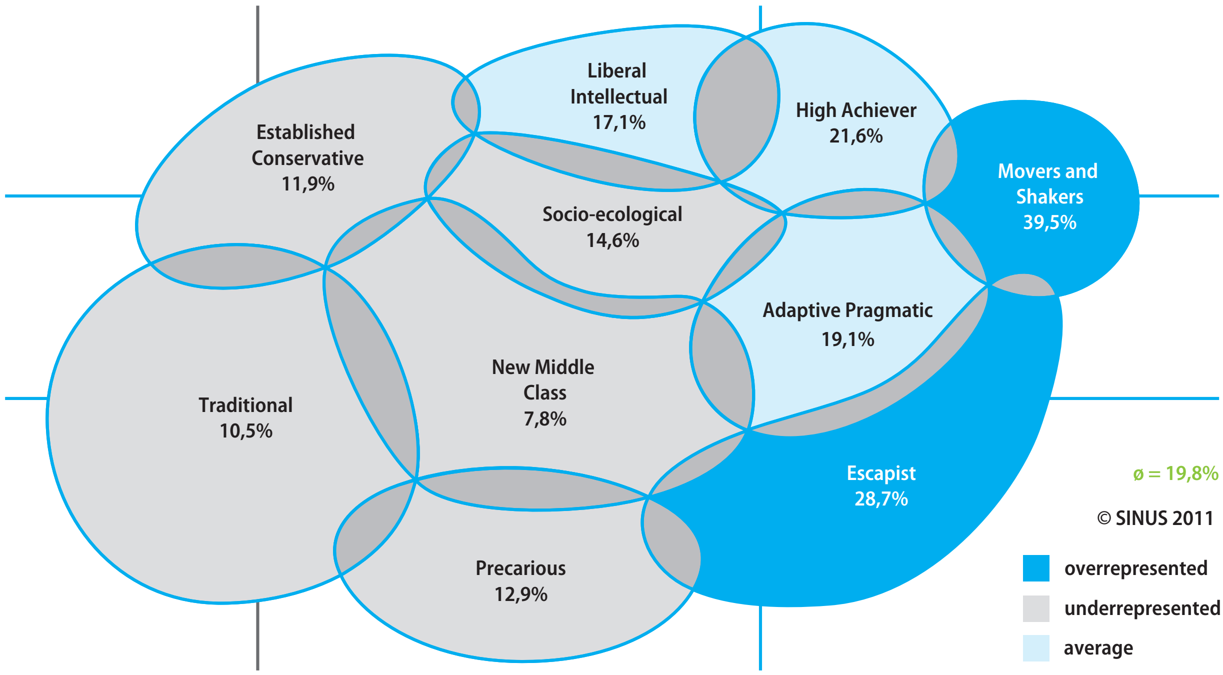


Figure 67: (Have a profile in a social community, for example: Facebook, StudiVZ, Lokalisten) VerbraucherAnalyse 2010; Base: German population 14 years and over (31,447 cases).

A certain degree of resignation also applies – data transfer is a part of everyday life and personal negative experiences do not occur to the extent that they would provoke a counter reaction.

Confidence in data protection is below average among people in the SEC milieu, however (see table 4). Their anti-consumption attitudes are expressed here too: They want to know exactly who has access to which data and what happens to the data that has been collected.[459]

The feeling that individuals' usage is being monitored or tracked is mostly heavily expressed in the TRA and PRE milieus, which are those in which the least access occurs (see table 6). Members of the SEC milieu also once again confirm the basically critical view of society.[460]

milieus (Early adopters). The third phase, relating to the so-called Early majority, mainly contains members of the ECO, SEC, MIC and ESC milieus. The Late majority and Latecomers are then comprised mostly from the TRA and PRE milieus, and the older members of the MIC milieu[461] (see figure 68).

Since intelligent EMS are also electronic devices that are used in the home and are operated by the consumer (at least to a limited extent), these distribution phases can largely be transferred to the distribution of smart grid technologies in households. Even though the degree of operation of the devices differs strongly, the distribution processes in the context of digital entertainments systems seem to provide a plausible analogy.

FIGURES IN PERCENT	Ø	ECO	LIB	HAC	MES	MIC	PRA	SEC	TRA	PRE	ESC
There will be monitoring bodies that will prevent the misuse of data.	61	62	69	79	81	59	74	44	54	45	60
My usage is monitored.	34	36	32	28	21	32	28	47	41	42	26

Table 6: AACC Study 2009; Base: German population 14 years and over (5,030 cases).

7.3.7 DISPERSION MODEL FOR PRODUCT INNOVATIONS

The example of analogue and digital entertainments systems can be used to indicate how product innovations differentiate the Sinus-Milieus. Five groupings of consumers are identified, revealing clear milieu affiliations:

- Innovators
- Early adopters
- Early majority
- Late majority
- Latecomers

Product innovations in the field mentioned above start in the HAC and MES milieus (Innovators) and then continue into the LIB, PRA and ESC

The affiliations of Innovators and the Early majority also converge very closely with the milieu-specific level of agreement with the statement "I will use one or more services that have an IT networked element"[462] (see table 7).

In terms of the future, the expectation that positive changes and new options will occur from technically more mature and more networked information technologies is one most commonly held in the technology-open milieus of the modern lifeworld segment.[463] This is a key finding in respect of smart meters in particular.

Here, too, the members of the MES and HAC milieus, followed by those of the PRA and LIB milieus, demonstrate the greatest openness towards new service products involving IT (see table 5).

459 BMBF 2009.
460 BMBF 2009.
461 TDWI 2011.
462 BMBF 2009.
463 BMBF 2009.

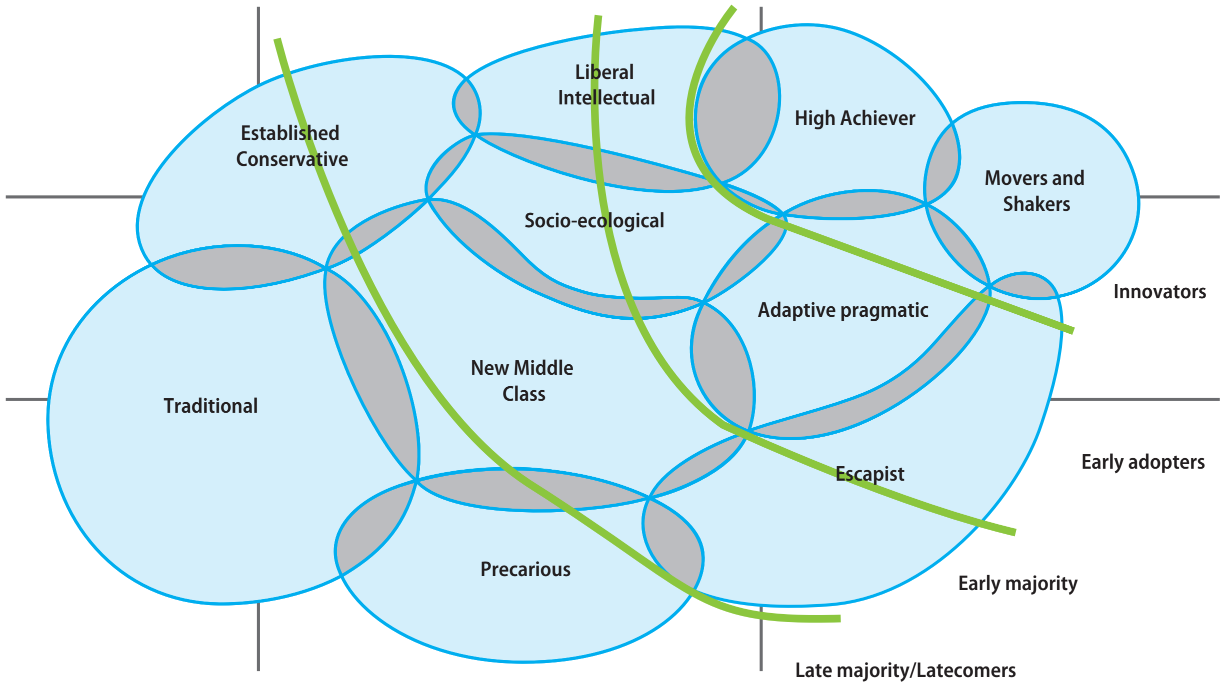


Figure 68: (Adopter model for consumer electronics) Typologie der Wünsche 2011 III; Base: German population 14 years and over (20,129 cases).

FIGURES IN PERCENT	Ø	ECO	LIB	HAC	MES	MIC	PRA	SEC	TRA	PRE	ESC
I will use one or more services that have a networked IT element.	55	59	68	85	91	51	73	50	22	30	60
I am looking forward to the future achievements that will be brought about by ubiquitous and networked IT.	41	34	47	74	84	37	64	26	12	21	52

Table 7: AACC Study 2009, base: German population 14 years and over (5,030 cases).

7.3.8 DEVELOPMENT OF THE SINUS-MILIEUS UP TO 2030

As a final impact variable on strategic planning for the introduction of smart grid technology, the potential futures of the Sinus-Milieus must also be considered. As explained above, the milieu model is not a rigid construct, but rather it changes over time as society develops. On the basis of a single premise (calculation of birth and death rates), the following changes are anticipated:

The TRA segment will shrink by 12 percent by 2030. This milieu is becoming increasingly older, and will thus basically die out. The MIC and PRE milieus will also contract slightly. In contrast, the young PRA and MES milieus will register the greatest growth in the coming years. The ESC and HAC milieus will also increase their shares of the population. The upper social milieus ECO and LIB will remain stable, as will the SEC milieu.[464]

464 Information from the Sinus Institute in 2011.

7.3.9 FINDINGS OF THE ENCT MARKET STUDY

In 2011, the EnCT research institution based in Freiburg published its market study "Kundensegmente und Marktpotenziale" (Customer Segments and Market Potentials). This is a representative survey of 1,100 participants (energy decision makers) in relation to nine smart energy products. The objective was to determine customer interest and potential, and to determine the relevant customer segments for each product class and establish their motivations.

Together with the Sinus Institute, three smart energy products were selected, representing the range from simple, passively used products through to variable systems focused on interaction, and explained to the participants as follows:

- Home display unit:
  "Your energy supplier will provide you with a modern digital electricity meter and a home display unit that indicates your current consumption and consumption by the hour, the day and the week. You can also view your energy costs and your CO_2 emissions, and thus check your energy costs. The data is not transferred to your energy supplier, and remains in your home. This improved transparency and consumption monitoring will allow you to save around five percent of your electricity costs in comparison with the standard tariff."
- Variable tariff and Internet feedback:
  "Your energy supplier will provide you with a modern digital electricity meter that sends the meter data to a data centre via your home Internet connection. You can view the data on your PC using the supplied software or on the Internet. You can also use a smartphone to find out your electricity consumption at any time. In addition, you are granted a variable tariff with a cheaper weekend rate. The daytime tariff is applicable from 8am to 8pm and the cheaper night time and weekend tariff applies during the remaining period on weekdays and around the clock at weekends. You must pay a one-off connection fee for the product. The improved transparency and consumption monitoring will help you save costs, and also shift your consumption from the daytime to the cheaper night time and weekend periods. This will help you achieve a dual reduction in your electricity costs."
- Smart appliances:
  "Your energy supplier will provide you with a package comprising a control panel that doubles up as a home display unit, and a range of different smart devices. These come with a smart plug that measures the energy consumption of the connected appliance and can be activated like a timer-controlled device. The package also contains a smart thermostatic valve that lets you set and control the room temperature remotely. You can access the control panel information and control the devices using your PC or a smartphone. You must pay a one-off connection fee for the product. The improved transparency and consumption monitoring will allow you to cut consumption by around five to ten percent."

The interest in these products was gauged on a six-stage scale to identify customer characteristics that correlate to above-average interest in the products. The objective characteristics with the greatest impact on the evaluation of the energy products were the age of the respondent, household size and ownership of mobile devices. Among the motivating factors, decision-making power, interest in new developments, individualism, reducing costs, and efficiency and interest in technologies were the strongest.

The most sought-after of the three products was the product that was the easiest to understand and the least complex, namely the Home display unit (61 percent interest; 30 percent customer potential), followed by the Smart Home vision (46 percent interest; 18 percent customer potential). Somewhat less customer potential was registered by the Variable tariff with Internet feedback (46 percent interest; 12 percent customer potential).[465]

Expert analysis by EnCT and Sinus on the basis of the empirical data indicates the following probable milieu focuses:

Of the three selected products, the Home display unit makes the least demands in terms of the user's technical understanding, leading to a broad milieu potential (see figure 69). While users still have to find pleasure in new developments and have an affiliation for modern technology, there is no need for any level of technical expertise.

465 Schäffler 2011.

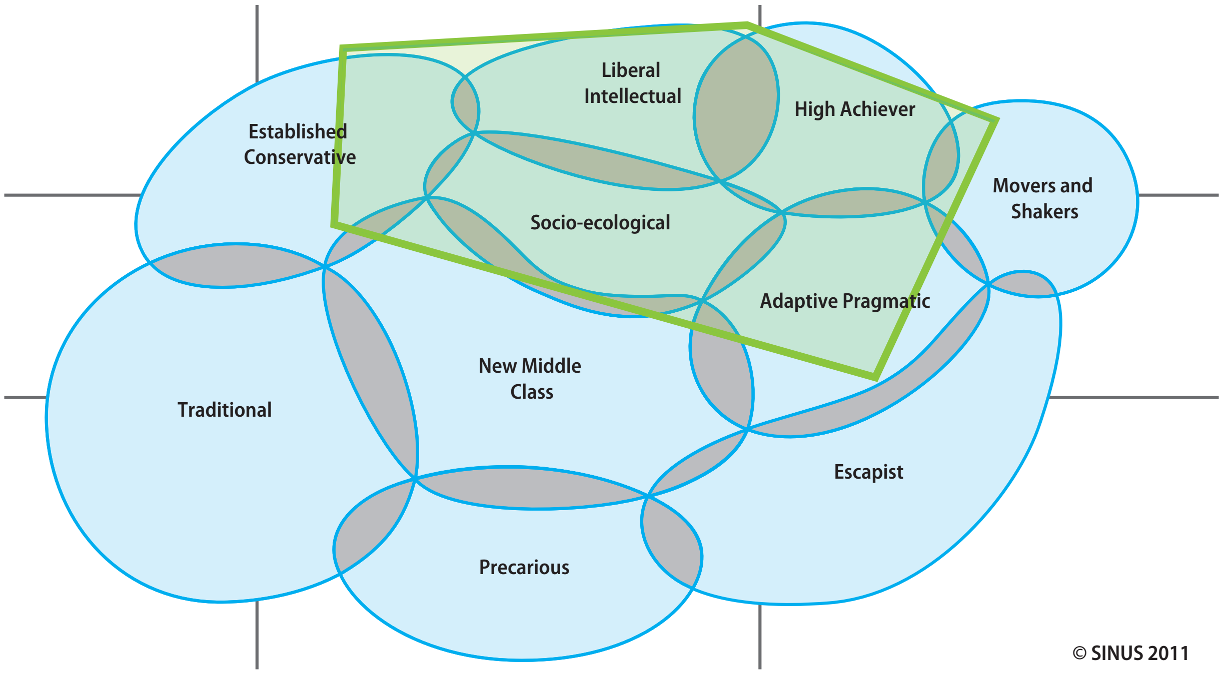


Figure 69: (Home display unit) Expert study by EnCT and Sinus on the basis of the market study "Kundesegmente und Marktpotenziale", 2011.

The principle benefit of the product is the ability to monitor energy consumption, which can be viewed on the display at any time. A variable component here is the display format (euros, kWh or CO_2), although the indication in euros means the most in everyday use. It is not possible to control other devices directly via the display, nor can users access the display from outside the home, for example via smartphone. There is generally a particularly high level of interest in the real time load profile indicator, which shows the effect on consumption of switching on individual appliances, and demonstrates how consumption changes according to everyday usage habits. Above all, users prize the feeling of being in control, and the penny-dropping effect of seeing information on consumption which was previously hidden behind the doors to the fuse box. In the long term, such systems will remain interesting thanks to the monitoring options when consumption varies from the habitual profile.

The emotional value added of this device (prestige, indication of a modern, contemporary lifestyle) is low.

The product that involves the use of a smartphone gives rise to interaction between the energy supplier and the end consumer. In milieus that are used to this process from existing Internet usage, such interaction increases the attraction (see figure 70). Equally, the option for using a smartphone to monitor or control consumption increases the probability of such a solution being deployed.

Positive experience with data transfer generates confidence, but the processes must be transparent, especially for members of the SEC and LIB milieus. However, data protection scandals from other sectors can be problematic here, since despite not being linked to smart grid technologies their impact is negative as they generate a general feeling of distrust. The multifaceted nature of the product and its customisability requires an ability to deal with a high degree of complexity. Users must devote a certain amount of time and effort to coming to terms with the variable tariffs so that they achieve the best possible results. At the same time, the variable pricing provides users with a feeling of co-determination, and reinforces their sense of autonomy.

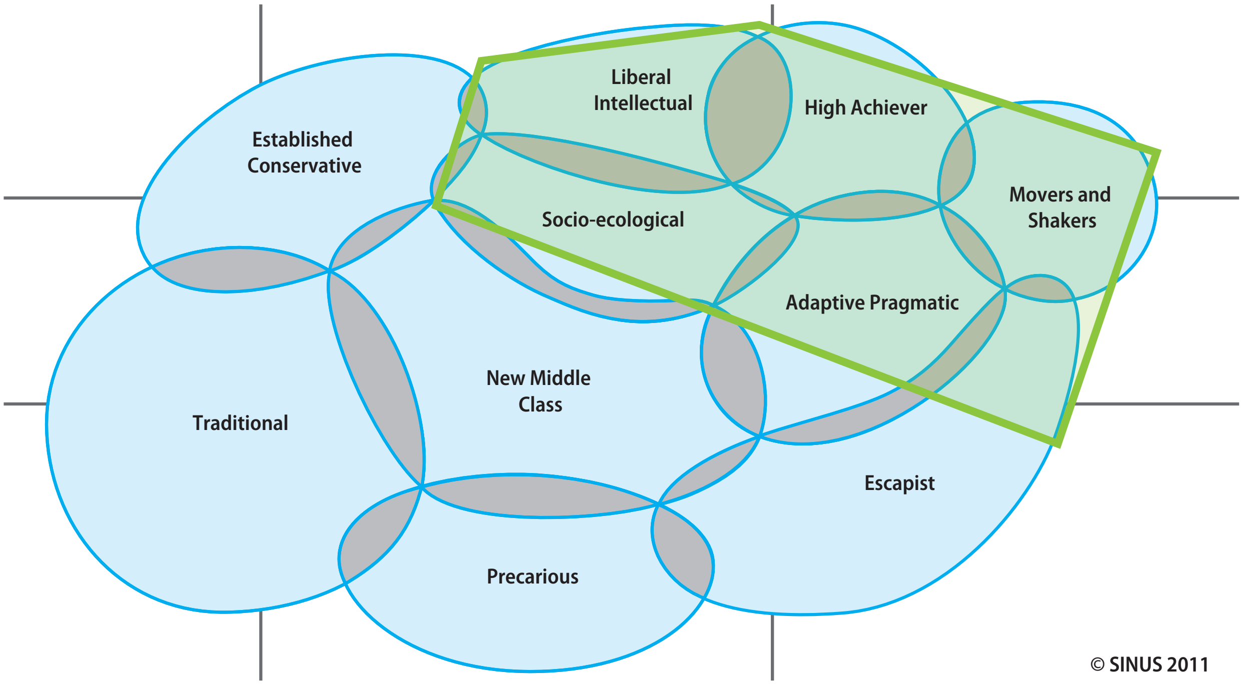


Figure 70: (Variable tariff and Internet feedback) Expert study by EnCT and Sinus on the basis of the market study "Kundensegmente und Marktpotenziale", 2011.

The third product builds on its predecessor, adding the functions to integrate "intelligent" household appliances. The ability to control these modern devices via a control panel is possible both in the house and from outside, using smartphones and computers. Due to the complexity of the solution, a high level of technological expertise and fascination is a prerequisite (see figure 71). Smart homes are primarily suited to (solvent) owner-occupiers, since they must first invest in the infrastructure. As with the Variable tariff with Internet feedback product, this solution also involves data transfer so the topic of trust plays a key role here too. The advantage of "intelligent" devices is that they can operate independently during cheaper tariff periods, and therefore further reduce the financial burden on the consumer.

7.3.10 FOCUSING ON THE TARGET GROUP

Based on the analysis that has been carried out, the following factors are important for acceptance of smart grid products: Home ownership, size of the accommodation, multiple occupancy of the home, environmental awareness, willingness to spend more on "green" energy, competence in using technology and IT, Internet usage, readiness for innovation, and an interest in services offered in conjunction with IT. Clear milieu focuses can be identified for these factors, as shown by the matrix below (see table 8).

This matrix reveals that the LIB and HAC milieus are the most appropriate primary target groups for these offerings. Moreover, the ECO, MES, PRA, SEC and, to a limited extent, ESC milieus are also relevant. These will, however, probably not be active until a later time (see figure 72). The lifestyle of the two primary target groups can be characterised by the following attributes:

The *Liberal-intellectuals* are governed by the concept of quality of life – personally and socially:

- Enjoyment of the finer things of life, receptive to luxury, taste, good service and relaxation;
- Pursue the ideal of a sustainable, environmentally and health-aware lifestyle (e.g. organic and fair trade products, homeopathy), but no missionary zeal;

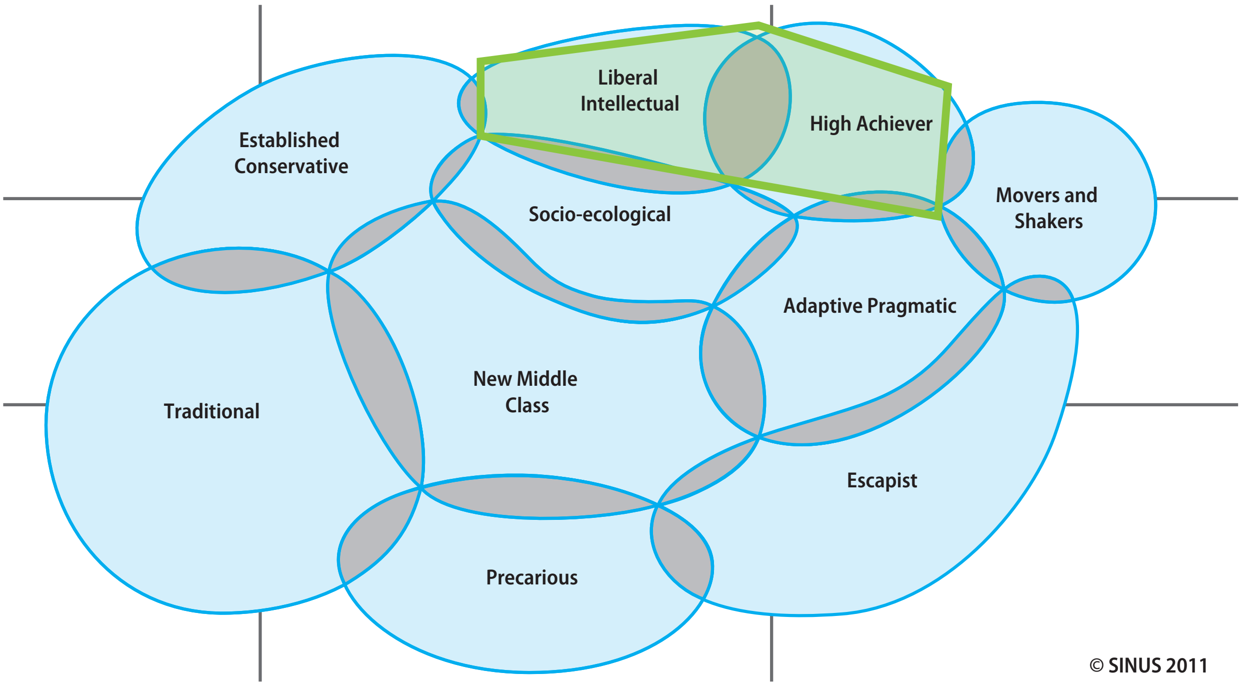


Figure 71: (Smart appliances – Smart home) Expert study by EnCT and Sinus on the basis of the market study "Kundesegmente und Marktpotenziale", 2011.

- Sophisticated and selective consumer patterns ("less is more"), aversion to superficial consumer and media-oriented society, but active information seekers, confident in use of new media;
- Strive for healthy mind, healthy body, work-life balance; Desire for self-improvement and personal development, actively participate in leisure activities;
- Community-based outlook, socially active and committed (clubs, initiatives, politics, church, etc.), networking and in-depth exchange with like-minded people;
- Global outlook, in principle open towards other mind-sets and lifestyles; Wide range of interests, need for intellectual stimulation (art, music, culture), frequently active in the arts themselves;
- Affirmation of enlightenment and emancipation, rejection of traditional roles, orientation toward the ideal of equality and social justice;

The *High Achievers* view themselves as the modern, contemporary elite:

- Thorough definition of their own success criteria, high level of self-confidence, doer mentality: clever, dynamic, visionary, "always on";
- Patchworkers, not confined by conventional lifestyles, multiple options, networking and multitasking as core competences, mixture of work, leisure and social life;
- Natural integration of new media into everyday life, high level of IT and multimedia competence, modern technology as much a toy as a tool to increase efficiency;
- Developed consumer orientation, consumption as a reward for success, high demands in terms of quality and design, desire for special things;
- Avant-garde outlook in terms of style preferences and lifestyle; Pronounced tendency for distinction;
- Fundamentally competitive in all facets of life (job, leisure, sports): Challenge themselves to be the best and have new, deep experiences;
- Great interest in sporting activity (trendy sports, prestige sports, extreme sports), outdoor-oriented leisure (travelling, being active, attending events);

When introducing a product, both the media channels and the tone of the communicative message should be optimised for and focused on these two milieus.

As explained in section 7.3.7, experience with electronic equipment reveals specific processes in the distribution through broad layers of society. Once the smart grid solutions have arrived in the homes of the LIB and HAC milieus and have established a presence there, the neighbouring milieus will become increasingly aware of the technology. The technology will be subject to constant optimisation, while increasingly meaningful experiences with the applications and products will spread out.

Among the members of the ECO milieu the general interest in technology will ensure that they pick up the thread and gather their own experience with the still new technology. Due to their fascination with technology, members of the MES milieu are predestined to integrate smart grid technologies into their modern everyday lives at an early stage.

For people in the young mainstream milieus (PRA, ESC) the simplified method of using the devices and the prospect of saving energy and, more importantly, money, will be particularly desirable.

For those in the SEC milieu, the focus is on the opportunity to save energy and therefore make a contribution to environmental protection. Technological toys are less pertinent here.

7.4 SUMMARY

The aim of this chapter was first to assess the current state of research into consumer acceptance of smart grid technologies. Second, the aim was to shed light on the factors that will be key to increasing acceptance and consequently to achieving the strongest possible spread of smart grid technologies among end users.

In chapter 2 potential developments in the energy market in relation to smart grids were presented. The three scenarios outline different visions of the electricity market in the future. The "Sustainable & economic" scenario has characteristics that have also arisen in the findings above.

Research into consumer acceptance of smart grids is at a relatively early stage, overall. While a great deal of expertise has been acquired regarding technological developments and technical and statutory frameworks in Germany, Europe and the rest of the world, knowledge of consumer attitudes is still rather limited.

A prerequisite for the rapid spread of smart grids is that the real advantages are communicated, with the awareness that these differ according to target group.

	Ø	ECO	LIB	HAC	MES	MIC	PRA	SEC	TRA	PRE
Home ownership	++	+	O	-	o	-	o	+	--	--
Size of accommodation	++	++	++	o	+	o	o	-	--	O
Two or more people in household	+	+	+	+	+	++	+	--	-	+
Environmental awareness	+	++	+	o	o	+	++	-	--	-
Readiness to spend more on "green" energy	+	++	+	o	o	o	++	--	--	-
Competence in using technology and IT	o	+	++	++	o	+	-	--	-	+
Internet usage	+	++	++	++	-	++	o	--	--	+
Readiness for innovation	o	+	++	++	-	+	o	--	--	+
I will use one or more services that have an IT networked element.	+	++	++	++	o	++	o	--	-	+
Milieu development	o	o	++	+	-	++	o	--	-	+
PRIORITY	2.	1.	1.	2.	3.	2.	2.	3.	3.	2.

"++" disproportionately strong/large; "--" = disproportionately weak/small

Table 8: Prioritisation of the ten milieus in respect of a potential communication sequence.

Away from the milieus construct, the following conclusions for (future) consumer acceptance can be drawn on the basis of these analyses and evaluations covering the smart grid environment:

- A large proportion of the population believes that it is well informed about its own contribution to protecting the environment and saving energy. This belief is, however, often betrayed by the actual level of knowledge. Awareness of options and programmes that are already available to support more energy-efficient household management is frequently low or they are seldom fully implemented. Therefore, there is a need for a programme of education that targets end users. Experience demonstrates that greater awareness of and improved competence in handling a technology also contribute to improved propensity to invest. Once the knowledge deficit has been cancelled out and confidence has been restored, the true potentials for consumers and their individual life situations are fully visible and can therefore be accessed.
- It should be noted that this information is not only provided by electricity suppliers or vendors of corresponding products to the end user. Some components of smart grid technologies view the consumer as an opportunity to monitor and gather data. For this reason there is sometimes considerable distrust of the industry in particular (providers and vendors). Collaboration with consumer organisations and environmental organisations is therefore advisable in order to build confidence.
- Security is a core concern of the end consumers. Data protection must, therefore, be accorded the highest priority and must also play a key role in outward communications. It should also be ensured that key public-facing personnel, such as energy advisors and heating installers, have sufficient information and can explain the smart grid components competently to the end users.
- For many consumers, technology in itself is the greatest barrier. It is perceived as being overly complex and therefore prone to faults, although usually this perception is based on assumptions and preconceptions, rather than on actual experience using the equipment. As described, however, there are sections of the population that are strongly interested in state-of-the-art technology and typically are the first to buy and try out new product offerings

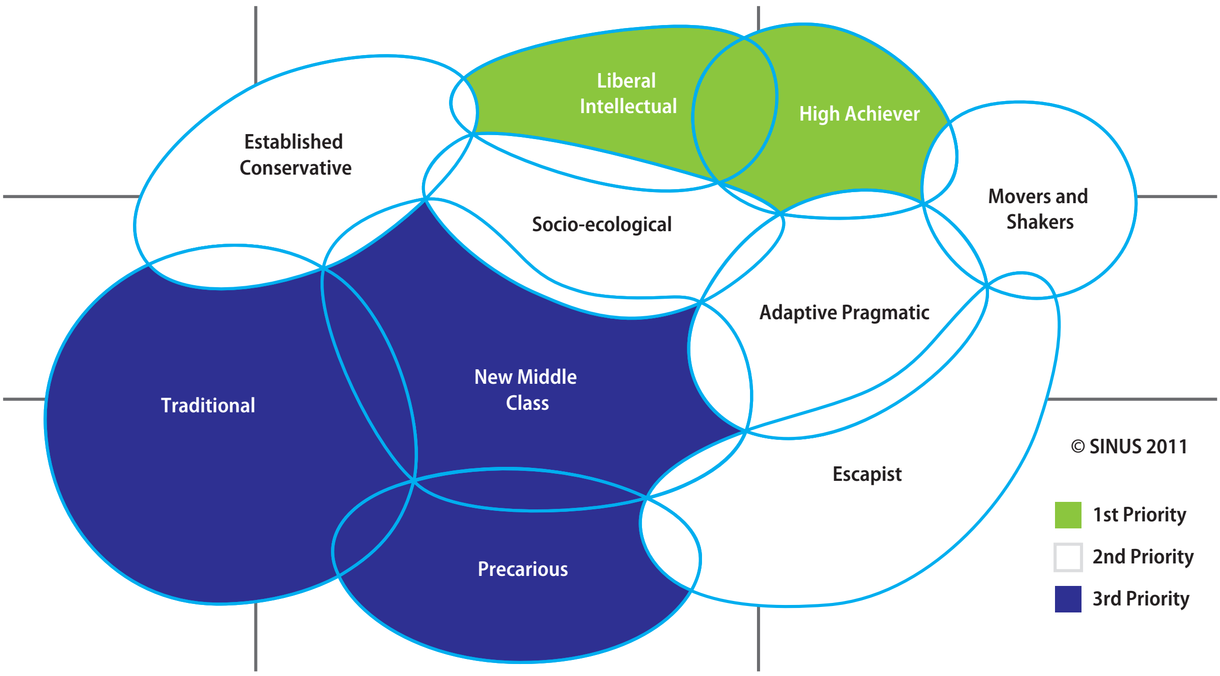


Figure 72: (Milieu prioritisation) Expert study by Sinus, 2011.

(Innovators). The milieus in which these people are primarily located are very important entry points, as they open the door to other customers (Early adopters) who look to Innovators and follow the trends they set.

- Nevertheless, a large proportion of consumers does not want to be dominated by technology. While intelligent household appliances and innovative systems should increase comfort and provide advice on how to use energy more efficiently, the consumers should still have the feeling of retaining control of the data flows and being able to customise the process flows to suit themselves. For this reason, specific prerequisites must be met, such as the option to operate the devices manually.
- Fear of the technology can also be reduced, if not entirely beaten, by offering customised solutions. Especially those users who are somewhat unsure about the technology require a tailored solution that is perfectly adapted to their home situation. They wish to be involved in the decision-making processes, although a demonstration of the technical capabilities may assist here.
- As already mentioned, first and foremost smart grids must be financially viable. More efficient usage of electricity and a positive effect on the environment are generally not sufficient in order to convince consumers about smart household appliances. The true savings potentials and additional costs must be clearly and transparently communicated. Higher initial costs are acceptable if the long-term potential for savings is tangible. The end user should be able to read the electricity savings on the appliances themselves, and savings should also be clearly detailed on the electricity bill.
- In order for smart grid technologies and the associated transfer of data to receive widespread popular support in broad layers of society, the risks and corresponding preventive measures must be thoroughly thought through and communicated sensitively. The feeling of being monitored and watched must be avoided, as must the impression that the collected data will not be handled with care. Equally, the possibility of linking to other data sources without permission must be excluded, where this could result in determining the individual usage patterns of third parties or gaining unauthorised access to the data.
- A major factor in the acceptance of smart grids will be confidence in the security of the transfer of data between end users and the energy supplier. Due to the transfer of household data it is key that the end-user's security is taken seriously in order to build confidence. The types of data protection scandals seen in other sectors must be prevented and the possibility for data misuse must be clearly excluded from the offering.
- As a modern communication technology, the Internet is a good source of information on the futuristic technology of smart grids. In particular, the representatives of the modern and Internet-savvy milieus will expect to find information there.
- A further important factor described in the "Sustainable & economic" scenario as a means of ensuring a rapid distribution of the smart grid technology in the future is the liberalisation of the energy market. Competition between a variety of actors will increase the attraction of the offerings for end users, and the increasing interaction between all market participants will accelerate the spread of the technology. Equally, the sensitisation of end users to their electricity consumption from ecological and financial perspectives will have a positive effect on the take-up of smart grid technologies.
- In order for the introduction and embedding of the smart grid technologies to be successful, consumers must be fully involved. The first approaches, such as the "Bürgerdialog" (Citizens' Dialog) on the topic Energy Technologies of the Future[466] that was held in Berlin in July 2011, point to a potential way forward. The public debate between all participants including citizens is key to including the views of end users in developments and decisions. It is recommended that such discussion processes be professionally moderated so that targeted, realisable results can be achieved. As described in the "Sustainable & economic" scenario, the objective should not simply be to gain the passive support of citizens. Rather, the aim should be for citizens to participate actively in the electricity market themselves, and help shape the Internet of Energy.
- To achieve this, further research is required into the expectations and demands for smart grid technologies among end users. A technology will only gain the confidence and acceptance of users and therefore exploit its future potential successfully if the requirements, desires and hopes of the people are clearly recognised.

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8 SUMMARY AND OUTLOOK

The aim of this study is to identify the factors in the development of the smart grid in Germany, to reveal the key technologies and functionalities, and how they interact and depend on each other, and finally from that to draw out specific technological migration paths to reach the Internet of Energy. As part of this process, three scenarios were developed leading up to 2030, and analysed in respect of the ICT (information and communication technologies) and energy-technology specific developments that are required to reach them. Alongside the technical analysis, the areas of market regulation and technical acceptance among consumers were also explored in order to obtain as comprehensive as possible a view of the smart grid topic area. An international benchmarking exercise in relation to current and future developments in Germany also enabled a comparison to be made with selected countries from Europe and the rest of the world.

To determine the scenarios for the German electricity supply system of the future (see chapter 2), the scenario methodology developed by Jürgen Gausemeier was adapted for the purposes of the Future Energy Grid project and applied. The selected time horizon was set to 2030 – a period that appears to remain transparent for the issues under investigation. First, expert workshops were held to establish the determining factors for the development of the energy system, and to evaluate the potential impact of each on future smart grid development. For reasons of clarity, the many different factors were summarised into eight key factors. Up to four extreme properties were then prepared for each key factor. By combining the different properties and applying cluster and consistency analyses it was then possible to create the scenarios that are described in sections 2.4 to 2.6. In formulating both the properties and the subsequent scenarios, as much effort as possible went into ensuring that extremes were chosen so as to obtain the widest possible spectrum of developments. The selected scenarios "Sustainable & economic", "Complexity trap" and "20th Century" cover the development of ICT in the electricity supply system over the entire corresponding futurespace.

Chapter 3 is concerned with the current and future role of ICT in the context of the energy supply. The current state of affairs is described in section 3.2 and describes the standardisation activities in the ICT domain. In order to provide some structure to the complex energy supply system, section 3.3 identifies three system layers and explains their importance. These provide a classification for the technologies that are analysed, in relation to their use in the closed system layer, the networked system layer and the ICT infrastructure layer which joins the previous two. Building on this, and additional expert surveys, the literature was researched with the objective of identifying technology areas that are of major importance for ICT (see section 3.4). These 19 technology areas are distributed throughout the closed system layer (5), the networked system layer (10), and the ICT infrastructure layer (1), with the remaining three comprising the cross-cutting technologies. The cross-cutting technologies are not assigned to any of the three system layers, and play a role in each of them. These areas consist of integration technologies, data management and information security. Using the Smart Grid Maturity Model (SGMM) as a guide, up to five development stages were derived for each technology area. These relate exclusively to the functional development of the technology and therefore take account of neither the time factor nor regulatory nor social conditions. Finally, in section 3.5 the three scenarios are compared with the development stages of the individual technology areas. The degree to which a technology area must develop to allow full realisation of the overall system described in the corresponding scenario is investigated.

Once the scenarios, technology areas and their interaction are known, chapter 4 describes the Migration Paths to which the study owes its title. In the first instance (section 4.2), the relationships between the technology areas are mapped out. Once again, this process is based on expert workshops. It reveals clearly how the individual development stages of the technology areas are interlinked. In each case, the prerequisites that must be put in place in order for the next development stage to be reached in a technology area are revealed. It is important to note that a development stage corresponds to the market-mature introduction of a functionality item, and therefore may have already been implemented in prototype form or as part of another system, and also that a certain level of experience of deployment is available. Equally, the identified dependencies are not to be viewed as the sole solution, but as the opportunity that is currently assumed to be the most logical and consistent. These dependencies result in a complex dependency map for each scenario. The maps are analysed in section 4.3. In this context, the most technologically developed scenario "Sustainable & economic" is selected as the target scenario. For this reason, when assessing the migration paths, this scenario is considered along with a timescale for development. The timescale divides the migration process into three phases, namely the Concept phase (2012 to 2015), the Integration phase (2015 to 2020) and the Fusion phase (2020 to 2030). At this point it becomes very clear that the developments of the technology areas in the closed system layer are developed in the Integration phase, while the technology areas of the open system layer are more typically developed in the Fusion phase. During all of the phases, development of the ICT infrastructure layer forms the backbone of the entire development.

Chapters 5 to 7 are concerned with the framework conditions for technological developments: Comparison of Germany in an international context, the energy-policy and statutory frameworks and the social acceptance of a selected area of application. Chapter 5 establishes Germany's position among other selected countries. This positioning is determined on the basis of brief country profiles, which compare ten selected countries (including Germany) that have model-like characteristics in respect of their current situation and their development in relation to smart grids. The position is also determined by the findings of a questionnaire. The questionnaire is concerned with assessments by experts of the situation in the individual countries. Finally, core statements are produced for Germany, indicating, among other findings, that demonstration projects for smart grid technologies will help provide access to international markets.

The energy sector framework described in chapter 6 discusses in particular the conditions that must be created in order to realise a highly developed scenario such as "Sustainable & economic". It also takes account of the key factor "Political conditions". Smart metering and the intelligent distribution grid are considered separately in order to distinguish between economic and regulatory factors. Alongside the challenges that arise from attempting to integrate fluctuating feed-in, potential future market designs are also considered. The study reveals the conditions that must be put in place to ensure the transformation from today's transmission and distribution grids to a future-proof overall system.

Chapter 7 addresses the social context of the future energy supply. Taking the specific example of household Energy Management Systems (EMS), it focuses on the topic of consumer acceptance. Using the established tool of Sinus-Milieus as assistance, it considers the results of completed acceptance studies in its investigation of increasingly complex household EMS. The findings demonstrate that the groups Liberal-intellectuals and High achievers are particularly well suited as target groups for the use of household EMS. The chapter also describes the processes by which other milieus may be won over for the household EMS solution.

The results confirm the massive complexity of the Energy Revolution project from the point of view of ICT. It is clear that the construction of a smart grid requires many different actors, technology developments and statutory measures to interact in as ordered a fashion as possible. If the smart grid is to make a major contribution to the success of the energy revolution, there is a need for rapid development of certain vital system technologies, and for a tailored political framework process that ensures the project remains on track.

The study also clarifies the need for a range of actions. In particular when using new, ICT-near technologies, a strict plan must be adhered to:

– Assuming that the "Sustainable & economic" scenario represents the target scenario, the phase schedule outlined in section 4.3 may serve as a monitoring tool. It is possible, for example, to integrate other roadmaps and legislative projects in order to verify that the development remains on track to achieve the stated aims. Thus, milestones such as the smart meter roll-out may be mapped on to the time scale by highlighting the technological developments that are required for this.
– The study has revealed that there are certain "critical paths" for the migration. These paths identify the steps that must be taken as a priority in each system layer in order to achieve the stated aim. In particular, AMS-WAMS in the closed system layer, forecasting systems, plant communications and control modules, business services and AMI in the networked system layer and ICT connectivity technologies have all been revealed as neuralgic, systemic technologies. Without the development of these technologies, the construction of a smart grid will be impossible or extremely difficult. Therefore, research, development and applications should focus on these technology areas.
– In many areas, significant R&D efforts and pilot projects are necessary. Many of the technologies required are still being developed or are only just entering a laboratory phase. Since most

of the technologies are only deployed in the networked system, R&D projects and subsequent demonstration projects will be needed in order to achieve the next development stage of a given technology area.

- In the scope of the study, the many different types of challenges associated with the smart electricity supply system were considered. Expansion of the study to look at other energy infrastructures would have gone far beyond the established scope. However, as the next steps, it will be necessary to conduct similar studies to provide an integrated analysis of all energy grids, for example the gas grids, heating grids and also the transport system, and to consider how they might, together, be optimised. By using existing infrastructure and the opportunities it provides for storing power generated by renewable energy forms, it might be possible to reduce the overall macroeconomic costs of the energy revolution significantly. This is a topic that must be investigated closer to the time.
- A further candidate for investigation, which was only considered implicitly in this project, is electric mobility. As already mentioned in the study, consideration of electric mobility is covered by implication of the technology areas. It will help make demand for electricity more flexible, and may become a key component in the field. It also opens up possibilities for inclusion of the transport system, as well as offering potential for electricity storage.

Based on the analysis of the statutory conditions, acceptance and the international ranking, the following steps have been established for the short to long term:

- The international comparison revealed how Germany is positioned in the world for selected countries that are considered as prototypical. In respect of smart grid technologies, countries such as Japan and Spain, and countries in North Africa, represent niche markets in which German companies can participate. The same applies for the model projects that were considered and which in Europe are largely already listed in summary in a catalogue.[467]
- The legislation around the energy sector was looked at in a very condensed fashion in this study. The focus has been on the required technological developments relating to ICT. In respect of regulation in particular, Germany's very specific situation was clear: The requirements in this area are extremely complex and must be adapted due to other related changes, such as the liberalisation of the markets and the nuclear exit strategy. The results of the investigations show that more detailed examination of the regulatory situation is needed. Many unresolved problems were discovered. However, there is currently a lack of both specific ideas, on how the interaction of the roles in the system should be regulated or left to the market, and of knowledge of what form the effects of potential regulation might take.
- Issues of acceptance will be of key importance for the future, when smart grid technologies are being or must be realised. Projects such as Stuttgart 21 or the expansion of transmission grid cabling demonstrated that major projects only succeed in Germany when consensus is reached with the population at large. In the energy sector there will continue to be protests, in particular against the construction of overhead cables, onshore and offshore wind farms and CCS technologies, even though it is clear that the energy revolution will not succeed without these systems. This type of acceptance issue has not been considered in this ICT-focused study, but will have to be investigated in conjunction with smart grids. It will be necessary to verify how the findings on consumer acceptance can be transferred in order to launch corresponding investigations. Alongside the domestic customers it will also be necessary to involve the major commercial and industrial customers. High acceptance levels will facilitate the realisation of concepts such as DSM and DR for domestic customers. Industrial major customers already use tools such as DSM and DR today. Additional potential can be found here in particular in the further optimisation of individual processes, and the opening up of new business models.

On the basis of the findings presented here, acatech has derived recommendations that are targeted at representatives of the worlds of politics, industry and science. The acatech POSITION paper *Information and Communication Technologies for the Path towards a Sustainable and Economic Energy System*[468] discusses and introduces these recommendations in detail.

467 ECJRCIE 2011
468 acatech 2012

LITERATURE

AA 2009
Auswärtiges Amt (pub.): *Indien - Energiepolitischer Jahresbericht*, New Delhi, 2009.

acatech 2010
acatech (pub.): *Wie Deutschland zum Leitanbieter für Elektromobilität werden kann* (acatech BEZIEHT POSITION, no. 6), Heidelberg, etc.: Springer Verlag, 2010 (acatech bezieht Position, no. 6).

acatech 2012
acatech (pub.): *Future Energy Grid. Informations- und Kommunikationstechnologien für den Weg in ein nachhaltiges und wirtschaftliches Energiesystem* (acatech POSITION), Heidelberg, etc.: Springer Verlag, 2011.

accenture/WEF 2009
accenture/World Economic Forum (pub.): *Accelerating Smart Grid Investments,* Davos: 2009.

AEEG 2010
The Italian Regulatory Authority for Electricity and Gas: Annual Report to the European Commission on Regulatory Activities and the State of Services in the Electricity and Gas Sectors, N.p., 2010.

AGEB 2011
AGEB AG Energiebilanzen e. V. (pub.): *Energieverbrauch in Deutschland im Jahr 2010*. Retrieved on 12 Oct. 2011. http://www.ag-energiebilanzen.de/viewpage.php?idpage=62.

AHAM 2009
Association of Home Appliance Manufacturers (AHAM) (pub.), *Smart Grid White Paper*, 2009, retrieved on 12 Oct. 2011. http://www.aham.org/ht/a/GetDocumentAction/i/44191.

AHK 2011
German-Russian Chamber of Industry & Commerce (pub.): *Russland 2010 – Auf dem Weg zur Modernisierung*, Moscow: 2011.

AIM/Liander 2011
Amsterdam Innovation Motor/Liander: *Amsterdam Smart City*. Retrieved on 23 Sept. 2011. http://www.amsterdamsmartcity.nl/#/en.

Amelin/Soder 2010
Amelin, M./ Soder, L.: "Taking Credit". In: Power and Energy Magazine, Vol. 8 No. 5 (2010), p. 47-52.

Angenendt/Boesche/Franz 2011
Angenendt, N./Boesche, K./Franz, O.: "Der energierechtliche Rahmen einer Implementierung von Smart Grids". In: Recht der Energiewirtschaft, no. 4-5 (2011), p. 117-164.

Appelrath et al. 2011
Appelrath et al. (pub.), *Forschungsfragen im „Internet der Energie"*, retrieved on 12 Oct. 2011. http://www.acatech.de/de/publikationen/materialienbaende/uebersicht/detail/artikel/internet-der-energie.html.

Athesiadruck 2010
Athesiadruck GmbH (pub.): "Sauber und lokal: Unsere Energie". In: Radius, Magazin für die Europaregion Tirol, no. 8 (2010), p. 6-7.

ATW 2010
Holger Ludwig/Tatiana Salnikova/Ulrich Waas: *Lastwechselfähigkeiten deutscher KKW*. Retrieved on 12 Oct. 2011. http://www.atomforum.de/kernenergie/documentpool/Aug-Sept/atw2010_09_waas_lastwechselfaehigkeiten_kkw.pdf.

Auer/Heng 2011
Auer, Josef/Heng, Stefan: *Smart Grids – Energiewende erfordert intelligente Elektrizitätsnetze*, Frankfurt am Main: Deutsche Bank Research, 2011.

Backhaus 2006
Backhaus, K. et al.: *Multivariate Analysemethoden – Eine anwendungsorientierte Einführung*, 11th edition, Berlin: Springer Verlag, 2006.

Balzer/Schorn 2011
Balzer, G./Schorn, C.: *Asset Management für Infrastrukturanlagen – Energie und Wasser,* Berlin: Springer Verlag, 2011.

BCB 2009
Banco Central do Brasil (pub.): *Produto Interno Bruto e taxas medias de crescimento*, Sao Paulo: 2009.

BDEW 2008
Bundesverband der Energie- und Wasserwirtschaft e. V. (pub.): *Technische Richtlinie Erzeugungsanlagen am Mittelspannungsnetz – Richtlinie für Anschluss und Parallelbetrieb von Erzeugungsanlagen am Mittelspannungsnetz*, Berlin: BDEW, 2008.

BDEW 2011a
Bundesverband der Energie- und Wasserwirtschaft e. V.: *Energiedaten*. Retrieved on 30 Aug. 2011. http://www.bdew.de/internet.nsf/id/DE_Energiedaten.

BDEW 2011b
Bundesverband der Energie- und Wasserwirtschaft e. V. (pub.): *Energiemarkt Deutschland 2011 – Zahlen und Fakten zur Gas-, Strom- und Fernwärmeversorgung*, Berlin: BDEW, 2011.

BDI 2011
Bundesverband der Deutschen Industrie e. V. (pub.): *BDI Agenda*. Retrieved on 29 Oct. 2011. http://www.bdi-online.de/BDIONLINE_INEAASP/iFILE.dll/X434E4CE448D145C3B17B54DB5FCCFAD6/2F252102116711D5A9C0009027D62C80/PDF/BDI_Agenda_24_Januar_2011_small.PDF.

BEE 2011
Bundesverband Erneuerbare Energie e. V. (pub.): *Maßnahmenpaket zur System – und Marktintegration Erneuerbarer Energien*. Retrieved on 11 Oct. 2011. http://www.bee-ev.de/_downloads/publikationen/sonstiges/2011/110321_BEE_Position_Direktvermarktung_Systemintegration.pdf.

Beenken et al. 2010
Beenken, P./Rohjans, S./Specht, M./Uslar, M.: *Towards a standard compliant Smart Grid through Semantic Web Technologies concerning interoperability, security and SOA, Proceedings of the Power Grid Europe*, Amsterdam: 2010.

BITKOM 2010
Bundesverband Informationswirtschaft, Telekommunikation und neue Medien e. V. (BITKOM) (pub.): C*loud Computing Leitfaden*, retrieved on 19 Aug. 2011. http://www.bitkom.org/de/publikationen/38337_66148.aspx.

Bitsch 2000
Bitsch, Rainer: *Perspektiven im Energiemanagement bei Stromversorgungsnetzen mit dezentraler Einspeisung*. Kasseler Symposium Energie-Systemtechnik, Kassel: 2000.

BMBF 2009
Bundesministerium für Bildung und Forschung (pub.): *Anytime, Anywhere, Communication and Computing (AACC)*, Berlin: SINUS Markt- und Sozialforschung GmbH 2009.

BMBF 2011a
Bundesministerium für Bildung und Forschung (pub.): *Energietechnologien der Zukunft*. Retrieved on 5 sept. 2011. http://www.buergerdialog-bmbf.de/energietechnologien-fuer-die-zukunft/index.php.

BMBF 2011b
Bundesministerium für Bildung und Forschung (pub.): *7. FRP im Überblick*. Retrieved on 22 Sept. 2011. http://www.forschungsrahmenprogramm.de/frp-ueberblick.htm.

BMBF 2011c
Bundesministerium für Bildung und Forschung (pub.): *Bürgerdialog zum Thema Energietechnologien für die Zukunft.* Bonn, Berlin: 2011. Retrieved on 12 Oct. 2011. http://www.bmbf.de/pub/energietechnologien_fuer_die_zukunft.pdf .

BMJ 2010
Bundesministerium der Justiz (pub.): *Verordnung über die Entgelte für den Zugang zu Elektrizitätsversorgungsnetzen (Stromnetzentgeltverordnung – StromNEV)*, Berlin: Bundesministerium der Justiz, 2010.

BMU 2009
Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (pub.): *Langfristszenarien und Strategien für den Ausbau erneuerbarer Energien in Deutschland.* Retrieved on 12 Oct. 2011. http://www.bmu.de/files/pdfs/allgemein/application/pdf/leitszenario2009_bf.pdf..

BMU 2010
Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (pub.): *Umweltbewusstseinsstudie*, Berlin, Bonn: 2010.

BMU 2011a
Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (pub.): *Erneuerbare Energien in Zahlen. Nationale und internationale Entwicklung*, Berlin: 2011.

BMU 2011b
Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (pub.): *Nationaler Aktionsplan für erneuerbare Energie gemäß der Richtlinie 2009/28/EG zur Förderung der Nutzung von Energie aus erneuerbaren Quellen*. Retrieved on 28 Mar. 2011. http://www.bmu.de/files/pdfs/allgemein/application/pdf/nationaler_aktionsplan_ee.pdf.

BMWi 2006a
Bundesministerium für Wirtschaft und Technologie (pub.): *Energiedienstleistungsrichtlinie (2006/32/EG).* Retrieved on 15 Nov. 2010. http://www.bmwi.de/BMWi/Redaktion/PDF/E/edl-richtlinie,property=pdf,bereich=bmwi,sprache=de,rwb=true.pdf.

BMWi 2006b
Bundesministerium für Wirtschaft und Technologie (pub.): *Potenziale der Informations- und Kommunikations-Technologien zur Optimierung der Energieversorgung und des Energieverbrauchs*, Berlin: 2006.

BMWi 2008
Bundesministerium für Wirtschaft und Technologie (pub.): *Zukunft & Zukunftsfähigkeit der deutschen Informations- und Kommunikationstechnologie*, Berlin: 2008.

BMWi 2009
Bundesministerium für Wirtschaft und Technologie (pub.): *Parlamentarischer Staatssekretär Otto eröffnet ersten E-Energy Jahreskongress.* Retrieved on 27 Sept. 2011. http://bmwi.de/BMWi/Navigation/Presse/pressemitteilungen,did=321584.html?view=renderPrint.

BMWi 2010a
Bundesministerium für Wirtschaft und Technologie/Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (pub.): *Energiekonzept für eine umweltschonende, zuverlässige und bezahlbare Energieversorgung*, Berlin: 2010. Retrieved on 12 Oct. 2011. http://www.bmwi.de/BMWi/Redaktion/PDF/Publikationen/energiekonzept-2010,property=pdf,bereich=bmwi,sprache=de,rwb=true.pdf.

BMWi 2010b
Bundesministerium für Wirtschaft und Technologie (pub.): *Das Energiedienstleistungsgesetz tritt in Kraft.* Retrieved on 15 Nov. 2010. http://www.bmwi.de/BMWi/Navigation/Presse/pressemitteilungen,did=368034.html.

BMWi 2010c
Bundesministerium für Wirtschaft und Technologie (pub.): *Gesetz zur Umsetzung der EU-Energiedienstleistungsrichtlinie*. Retrieved on 15 Nov. 2010. http://www.bmwi.de/BMWi/Redaktion/PDF/J-L/gesetz-umsetzung-richtlinie-eu-edl-g,property=pdf,bereich=bmwi,sprache=de,rwb=true.pdf.

BMWi 2011a
Bundesministerium für Wirtschaft und Technologie (pub.): *Monitoring-Bericht*. Retrieved on 4 Mar. 2011. http://www.bmwi.de/BMWi/Redaktion/PDF/M-O/monitoringbericht-bmwi-versorgungssicherheit-bereich-leitungsgebundene-versorgung-elekrizitaet,property=pdf,bereich=bmwi,sprache=de,rwb=true.pdf.

BMWi 2011b
Bundesministerium für Wirtschaft und Technologie (pub.): *Akzeptanz, schnellere Genehmigungsverfahren, Smart Grids – Brüderle gibt offiziellen Startschuss für die Plattform „Zukunftsfähige Netze“*. Retrieved on 4 Mar. 2011. http://www.bmwi.de/BMWi/Navigation/Presse/pressemitteilungen,did=381382.html.

BMWi 2011c
Bundesministerium für Wirtschaft und Technologie (pub.): *Zahlen und Fakten Energiedaten – Nationale und Internationale Entwicklung*, Berlin: 2011.

BMWi 2011d
Studie für das Bundesministerium für Wirtschaft und Technologie (pub.): *Potenziale der Informations- und Kommunikations-Technologien zur Optimierung der Energieversorgung und des Energieverbrauchs (eEnergy).* Retrieved on 28 Mar. 2011. http://www.bmwi.de/BMWi/Redaktion/PDF/Publikationen/Studien/e-energy-studie,property=pdf,bereich=bmwi,sprache=de,rwb=true.pdf.

BMWi 2011e
Bundesministerium für Wirtschaft und Technologie (pub.): *Monitoring-Bericht des Bundesministeriums für Wirtschaft und Technologie nach § 51 EnWG zur Versorgungssicherheit im Bereich der leitungsgebundenen Versorgung mit Elektrizität*, Berlin: 2011.

BMWi 2011f
Bundesministerium für Wirtschaft und Technologie (pub.): *Wirtschaftsraum Europa*. Retrieved on 22 Sept. 2011. http://www.bmwi.de/BMWi/Navigation/Europa/wirtschaftsraum-europa,did=118988.html.

BMWi 2011g
Bundesministerium für Wirtschaft und Technologie (pub.): *Energiedaten – nationale und internationale Entwicklung*. Retrieved on 12 Oct. 2011. http://www.bmwi.de/BMWi/Navigation/Energie/Statistik-und-Prognosen/energiedaten,did=176654.html.

BNetzA 2009
Bundesnetzagentur (pub.): *Monitoringbericht 2009*. Retrieved on 20 Oct. 2011. http://www.bundesnetzagentur.de/cae/servlet/contentblob/152206/publicationFile/7883/Jahresbericht2009Id18409pdf.pdf.

BNetzA 2010a
Bundesnetzagentur (pub.): *Monitoringbericht 2010*. Retrieved on 29 Oct. 2011. http://www.bundesnetzagentur.de/cae/servlet/contentblob/191676/publicationFile/9834/ Monitoringbericht2010Energiepdf.pdf.

BNetzA 2010b
Bundesnetzagentur (pub.): A*nzahl Lieferantenwechsel 2006-2009*. Retrieved on 18 Feb. 2010. http://www.bundesnetzagentur.de/cae/servlet/contentblob/191768/publicationFile/9320/S43_Strom_pdf.pdf.

Bothe et al. 2011
Bothe, D., et al. „Ökonomisches Potenzial spricht für Wahlfreiheit von Haushalten bei Smart Metern". In: *Energiewirtschaftliche Tagesfragen*, Vol. 6 (2011).

BP 2010
Beyond petroleum (pub.): *BP Statistical Review of World Energy*, London, 2010.

BUND 2011
Bundesregierung (pub.): *Der Weg zur Energie der Zukunft – sicher, bezahlbar und umweltfreundlich*. Retrieved on 12 Oct. 2011. http://www.bundesregierung.de/Content/DE/__Anlagen/2011/06/2011-06-06-energiekonzept-eckpunkte,property=publicationFile.pdf.

Cassin 2011
Cassin, F.: *The French planning exercise – Regional Wind Plan – (Schéma régional éolien – SRE) – Perspectives and Reality*, Brussels: EWEA, 2011.

CDG 2007
China Development Gateway (pub.): *Medium and Long-Term Development Plan for Renewable Energy in China*. Retrieved on 22 Sept. 2011. http://en.chinagate.cn/reports/2007-09/13/content_8872839.htm.

CEC 2009
Commission of the European Communities (pub.): *A Technology Roadmap for the Communication on Investing in the Development of Low Carbon Technologies (SET-Plan),* Brussels, 2009.

CGDD 2010
Commissariat général au développement durable (pub.): *Bilan énergétique de la France pour 2009*, Paris, 2010.

Chakrabarti et al. 2009
Chakrabarti, Saikat/Kyriakides, Elias/Bi, Tianshu/Cai, Deyu/Terzija, Vladimir "Measurements get together". In: *Power and Energy Magazine*, 7, (2009), no. 1 (2009), p. 41-49.

CIA 2011
Central Intelligence Agency (pub.): *The World Factbook – Brazil.* Retrieved on 22 Sept. 2011 . https://www.cia.gov/library/publications/the-world-factbook/geos/br.html.

Crastan 2009
Crastan, Valentin: *Elektrische Energieversorgung*, 2nd edition, Berlin/Heidelberg: Springer Verlag, 2009.

Cross 1997
Cross, R.: Revenue Management: *Hard-Core Tactics for Market Domination*, New York: Broadway Books, 1997.

CSO 2010
Central Statistics Office (pub.): *Energy Statistics 2010.* Cork: 2010.

DB 2011
Deutsche Bundesregierung (pub.): E*rfahrungsbericht 2011 zum Erneuerbare-Energien-Gesetz (EEG-Erfahrungsbericht),* Berlin: 2011.

DDN 2011
Dutch Daily News (pub.): *Amsterdam Smart City wins European award.* Retrieved on 23 Sept. 2011. http://www.dutchdailynews.com/amsterdam-smart-city/.

DDWB 2011
Delegiertenbüro der Deutschen Wirtschaft Beijing (pub.): *CDM Newsletter,* 6 (2011).

DEA 2007
Danish Energy Authority (pub.): E*nergy Policy Statement 2007.* Retrieved on 22 Sept. 2011. http://193.88.185.141/Graphics/Publikationer/Energipolitik_UK/Energy_policy_Statement_2007/index.htm.

DEA 2010
Danish Energy Authority (pub.): *Energy Statistics 2009,* Copenhagen: 2010.

dena 2008
Deutsche Energie-Agentur GmbH (pub.): *Länderprofil Dänemark*, Berlin: 2008.

dena 2009a
Deutsche Energie-Agentur GmbH (pub.): *Länderprofil USA,* Berlin: 2009.

dena 2009b
Deutsche Energie-Agentur GmbH (pub.): *Länderprofil China*, Berlin: 2009.

dena 2009c
Deutsche Energie-Agentur GmbH (pub.): *Länderprofil Brasilien,* Berlin: 2009.

dena 2009d
Deutsche Energie-Agentur GmbH (pub.): *Erneuerbare Energien in Russland.* Retrieved on 23 Sept. 2010. http://www.energieforum.ru/de/nachrichtenarchiv/erneuerbare_energien_in_russland_527.html.

dena 2009e
Deutsche Energie-Agentur GmbH (pub.): *Länderprofil Russland*, Berlin: 2009.

dena 2010a
Deutsche Energie-Agentur GmbH (pub.): *Länderprofil Indien*, Berlin: 2010.

dena 2010b
Deutsche Energie-Agentur GmbH (pub.): *dena-Netzstudie II, Integration erneuerbarer Energien in die deutsche Stromversorgung im Zeitraum 2015–2020 mit Ausblick 2025*, Berlin: Deutsche Energie Agentur (DENA), 2010.

dena 2011a
Deutsche Energie-Agentur GmbH (pub.): *Länderprofil Frankreich*, Berlin: 2011.

dena 2011b
Deutsche Energie-Agentur GmbH (pub.): *Länderprofil Italien*, Berlin: 2011.

dena 2011c
Deutsche Energie-Agentur GmbH (pub.): *Russlands Energiestrategie bis 2030.* Retrieved on 23 Sept. 2010. http://www.energieforum.ru/de/nachrichtenarchiv/russlands_energiestrategie_bis_2030_764.html.

De Oliveira 2007
Oliveira, A., de: "Political economy of the Brazilian power industry reform". In: Victor, D. G./Heller, T. C. (pub.): *The Political Economy of Power Sector Reform. The Experience of Five Major Developing Countries*, Cambridge: Cambridge University Press, 2007, p. 31-75.

DESERTEC 2011a
DESERTEC Foundation (pub.): *The DESERTEC Concept.* Retrieved on 22 Sept. 2011. http://www.desertec.org/en/concept/.

DESERTEC 2011b
DESERTEC Foundation (pub.): Retrieved on 03 Mar. 2011. http://www.desertec.org/.

Destatis 2010
Federal Statistical Office (pub.): *Haushalte.* Retrieved on 20 Oct. 2010. http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE/Navigation/Statistiken/Bevoelkerung/Haushalte/Haushalte.psml.

de Winter et al. 2009
Winter, J. C. F., de:/Dodou, D./Wieringa, P.A.: "Exploratory Factor Analysis With Small Sample Sizes". In: *Multivariate Behavioral Research* 44, 2009, p. 147–181.

DGEMPOE 2008
Direction Générale de l'Énergie et des Matières Premières Observatoire de l'énergie (pub.): *Scénario énergétique de référence DGEMP-OE*, 2008.

DKE 2010
DKE (pub.): *Die deutsche Normungsroadmap E-Energy/Smart Grid*, 2010.

DoE 2009
U. S. Department of Energy (pub.): *Modern Shale Gas – Development in the United States: A Primer*, Pittsburgh: 2009.

DONG 2007
DONG Energy (pub.): *Nachhaltigkeitsbericht 2006,* N.p., 2007.

Du/Liu 2011
Du, J./Liu, Y.: *Unprecedented power shortages expected.* Retrieved on 22 Sept. 2011. http://europe.chinadaily.com.cn/business/2011-05/24/content_12567865.htm.

DW 2011
Deutsche Welle: O*bama hält am Bau neuer Atomkraftwerke fest.* Retrieved on 22 Sept. 2011. http://www.dw-world.de/dw/article/0,,14912210,00.html.

E-Bridge 2011
E-Bridge Consulting GmbH (pub.): *Abschätzung des Ausbaubedarfs in deutschen Verteilungsnetzen aufgrund von Photovoltaik- und Windeinspeisungen bis 2020,* retrieved on 12 Oct. 2011. http://www.bdew.de/internet.nsf/id/C8713E8E3C658D44C1257864002DDA06/$file/2011-03-30_BDEW-Gutachten%20EEG-bedingter%20Netzausbaubedarf%20VN.pdf.

EC 2009
European Commission (pub.): *M/441 Standardisation mandate to CEN, CENELEC and ETSI in the filed of measuring instruments for the development of an open architecture for utility meters involving communication protocols enabling interoperability,* Brussels: 2009.

EC 2010a
European Commission (pub.): *M/468 Standardisation mandate to CEN, CENELEC and ETSI concerning the charging of electric vehicles. Radiation protection dosimetry,* Brussels: 2010.

EC 2010b
European Commission (pub.): *Energy 2020 – A strategy for competitive, sustainable and secure energy,* 2010. Retrieved on 12 Oct. 2011. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0639:FIN:EN:PDF.

EC 2011
European Commission (pub.): *M/490 Standardization mandate to European Standardisation Organisations (ESOs) to support European Smart Grid deployment.* Networks, Brussels: 2011.

ECC 2011
European Commission CORDIS (pub.): *Seventh Framework Programme (FP7).* Retrieved on 22 Sept. 2011. http://cordis.europa.eu/fp7/home_en.html.

ECE 2011a
European Commission Environment (pub.): *Smart Grids Task force.* Retrieved on 4 Mar. 2011. http://ec.europa.eu/energy/gas_electricity/smartgrids/taskforce_en.htm.

ECE 2011b
European Commission Energy (pub.): *European strategy.* Retrieved on 22 Sept. 2011. http://ec.europa.eu/energy/strategies/consultations/20110307_roadmap_2050_en.htm.

ECE 2011c
European Commission Energy (pub.): *Overview of the secondary EU legislation (directives and regulations) that falls under the legislative competence of DG ENER and that is currently in force.* Retrieved on 22 Sept. 2011. http://ec.europa.eu/energy/doc/energy_legislation_by_policy_areas.pdf

ECE 2011d
European Commission Environment (pub.): *Green Cities Fit for Life 2010 – Stockholm.* Retrieved on 23 Sept. 2011. http://ec.europa.eu/environment/europeangreencapital/winning-cities/stockholm-european-green-capital-2010/index.html.

ECJRCIE 2011
European Commission Joint Research Centre Institute for Energy (pub.): *Smart Grid projects in Europe: lessons learned and current developments*, Brussels: 2011.

EEGI 2010
The European Electricity Grid Initiative (pub.): *Roadmap 2010-18 and Detailed Implementation Plan 2010-12.* Retrieved on 16 Aug. 2011. http://www.smartgrids.eu/documents/EEGI/EEGI_Implementation_plan_May%202010.pdf.

EKE 2010
European Commission Eurostat (pub.): *Energy production and imports.* Retrieved on 22 Sept. 2011. http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Energy_production_and_imports.

EKO 2009
European Commission (pub.): *Eurobarometer 313, Dezember 2009.* Retrieved on 12 Oct. 2011. http://ec.europa.eu/public_opinion/archives/ebs/ebs_313_en.pdf.

EKO 2010a
European Commission (pub.): *Energieinfrastrukturprioritäten bis 2020 und danach – ein Konzept für ein integriertes europäisches Energienetz,* 2010. Retrieved on 12 Oct. 2011. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0677:FIN:DE:PDF.

EKO 2010b
European Commission, Europe in figures. *Eurostat yearbook 2010.* Retrieved on 20 Oct. 2010. http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-CD-10-220/EN/KS-CD-10-220-EN.PDF.

EKO 2010c
European Commission (pub.): *Energy 2020: A strategy for competitive, sustainable and secure energy.* Retrieved on 05 Mar. 2011 <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0639:FIN:en:PDF.

EnCT 2011
Schäffler, Harald (pub.): *Marktstudie Kundensegmente und Marktpotentiale 2011,* Freiburg: Research Group Energy & Communication Technology (EnTC), 2011.

Energinet.dk 2011
Energinet.dk: *Market regulations – Regulations for the wholesale and retail markets.* Retrieved on 22 Sept. 2011. http://www.energinet.dk/EN/El/Forskrifter/Markedsforskrifter/Sider/default.aspx.

ENTSOE 2011
European Network of Transmission System Operators for Electricity: *We are the European TSOs*. Retrieved on 22 Sept. 2011. https://www.entsoe.eu/.

EP 2008
European Parliament: "20 / 20 / 20 by 2020": *MEPs give first reactions to climate change and energy package.* Retrieved on 22 Sept. 2011. http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+IM-PRESS+20080122IPR19355+0+DOC+XML+V0//EN.

EPE 2007
Ministério das Minas e Energia/Empresa de Pesquisa Energética (pub.): *Plano Nacional de Energia 2030*, Rio de Janeiro: 2007.

EPE 2008
Ministério das Minas e Energia/Empresa de Pesquisa Energética (pub.): *Balanço Energético Nacional 2008:* Ano base 2007. Resultados, Rio de Janeiro: 2008.

EPRI 2011a
Electric Power Resarch Institute (EPRI): *Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid, 2011.* Retrieved on 10 Oct. 2011. http://my.epri.com/portal/server.pt?space=CommunityPage&cached=true&parentname=ObjMgr&parentid=2&control=SetCommunity&CommunityID=404&RaiseDocID=000000000001022519&RaiseDocType=Abstract_id.

EPRI 2011b
Electric Power Resarch Institute (EPRI): *EPRI Intelligrid Initiative.* Retrieved on 07 Oct. 2011. http://intelligrid.epri.com/.

Europa 2011
Emissions Transit. Emissions Trading: *Q & A following the suspension of transactions in national ETS registries for at least one week from 19:00 CET on Wednesday 19 January 2011.* Retrieved on 24 Aug. 2011. http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/11/34.

EUROSOLAR 2010
The European Association for Renewable Energy (pub.): *Appreciation Region of Puglia.* Retrieved on 23 Sept. 2011. http://www.eurosolar.de/en/index.php?option=com_content&task=view&id=427&Itemid=128.

FAZ 2009
Frankfurter Allgemeine Zeitung: *China baut größtes Solarkraftwerk der Welt.* Retrieved on 22 Sept. 2011. http://www.faz.net/artikel/C31151/innere-mongolei-china-baut-groesstes-solarkraftwerk-der-welt-30007306.html.

FAZ 2011a
Frankfurter Allgemeine Zeitung: *Was folgt aus dem Abschalten der Kraftwerke?* Retrieved on 22 Sept. 2011. http://www.faz.net/artikel/C32436/atomkraft-debatte-was-folgt-aus-dem-abschalten-der-kraftwerke-30331417.html.

FAZ 2011b
Frankfurter Allgemeine Zeitung: *Italien entscheidet über Kernenergie.* Retrieved on 23 Sept. 2011. http://www.faz.net/artikel/C31151/mitte-juni-volksabstimmung-italien-entscheidet-ueber-kernenergie-30330486.html.

FSR 2011
Florence School of Regulation (pub.): *FSR Annual Conference, 2011 Edition.* Retrieved on 11 Oct. 2010. http://www.florence-school.eu/portal/page/portal/FSR_HOME/ENERGY/Policy_Events/Annual_Conferences.

FTD 2011
Financial Times Deutschland: *Fünf Jahre nach Fertigstellung – Drei-Schluchten-Staudamm sorgt für neuen Ärger.* Retrieved on 22 Sept. 2011. http://www.ftd.de/wissen/technik/:fuenf-jahre-nach-fertigstellung-drei-schluchten-staudamm-sorgt-fuer-neuen-aerger/60054418.html.

Gausemeier et al. 1996
Gausemeier, J./Fink, A./Schlake, O.: *Szenario-Management – Planen und Führen mit Szenarien,* 2nd edition, Munich/Vienna: Carl Hanser Verlag, 1996.

Gausemeier et al. 2009
Gausemeier, J./Plass, C./Wenzelmann, C.: *Zukunftsorientierte Unternehmensgestaltung – Strategien, Geschäftsprozesse und IT-Systeme für die Produktion von morgen*, Munich/Vienna: Carl Hanser Verlag, 2009.

Ginter 2010
Ginter, A.: *The Stuxnet Worm and Options for Remediation,* Industrial Defender, Inc. 2010.

Goerten/Clement 2007
Goerten, J./Clement, E.: "Strompreise für private Haushalte und industrielle Verbraucher zum 1. Januar 2007". In: *Statistik kurz gefasst, Umwelt und Energie* 80, 2007.

Götz 2004
Götz, R.: *Rußlands Energiestrategie und die Energieversorgung Europas, Stiftung Wissenschaft und Politik (SWP)-Studie,* Berlin: 2004.

Gross 2010
Gross, D.: "Spotlight on Singapore: Smart Grid City". In: Cleantech magazine, July/August 2010.

GTAI 2007a
Germany Trade and Invest (pub.): *Energiewirtschaft Indien 2006/2007,* Berlin: 2007.

GTAI 2007b
Germany Trade and Invest (pub.): *Hoher Kapitalbedarf in Indiens Elektrizitätssektor,* Berlin: 2007.

GTAI 2011
Germany Trade and Invest (pub): *Wirtschaftstrends kompakt Jahresmitte 2011 VR China,* Berlin: 2011.

Guthridge 2010
Guthridge, Gregory, S.: *Understanding Consumer Preferences in Energy Efficiency – Accenture end-consumer observatory on electricity management*, Amsterdam, 2010.

Guthridge 2011
Guthridge, Gregory, S.: *Revealing the Values of the New Energy Consumer – Accenture end-consumer observatory on electricity management.* Amsterdam, 2011.

Haastert 2010
Haastert, Robert: *Ergebnisse einer repräsentativen Umfrage zum Potenzial von Smart Metern und dezentraler Energieversorgung in Deutschland,* Berlin: Accenture GmbH, January 2010.

Häger/Lehnhoff/Rehtanz 2011
Häger, U./Lehnhoff, S./Rehtanz, C.: A*nalysis of the Robustness of a Distributed Coordination System for Power Flow Controllers,* Stockholm: IEEE-Press Proceedings of the 17th Power Systems Computation Conference 2011.

HBM 2011
Hubert Burda Media (pub.): *VerbraucherAnalyse 2010.*

HER 08
Herger, Karl: „Evergreen in der Netzleittechnik". In: *ew – das Magazin für die Energie Wirtschaft* 107 (2008), vol. 23, p. 36-45.

Hiroux 2005
Hiroux, C.: *The Integration of Wind Power into Competitive Electricity Market: The Case of the Transmission Grid Connection Charges. 28th annual IAEE International Conference,* Taipei: 2005.

Hoss 2010
Hoss, F.: *Smart Grid Data Management: 7 Tips from the Trenches*. Retrieved on 08 Sept. 2011. http://www.smartgridnews.com/artman/publish/Business_Strategy_Resources/Smart-Meter-Data-Management-7-Essential-Tips-from-the-Trenches-2445.html.

Hüttel/Pischetsrieder/Spath 2010
Hüttl, R./Pischetsrieder, B./Spath, D. (pub.): *Elektromobilität – Potenziale und wissenschaftlich-technische Herausforderungen,* Heidelberg, etc.: Springer Verlag, 2010.

ICDSV 2007
Innovation Center Denmark Silicon Valley (pub.): *New Energy Plan from the Danish Government: Double Energy from Renewable Sources,* Silicon Valley: 2007.

IEA 2010a
International Energy Agency (pub.): *World Energy Outlook 2010,* Paris: 2010.

IEA 2010b
International Energy Agency (pub.): *Key World Energy Statistics,* Paris: 2010.

IEA 2011a
International Energy Agency (pub.): *Statistics & Balances*. Retrieved on. http://www.iea.org/stats/index.asp. 22 Sept. 2011

IEA 2011b
International Energy Agency (pub.): *Technology Roadmap Smart Grids,* Paris: 2011.

IEA 2011c
International Energy Agency (pub.): *Technology Roadmap Smart Grids,* 2011. Retrieved on 10 Oct. 2011. http://www.iea.org/papers/2011/smartgrids_roadmap.pdf.

IEC 2009
International Electrotechnical Commission (pub.): *62357 Second Edition: TC 57 Architecture – Part 1: Reference Architecture for TC 57 – Draft*, 2009.

IG 2010
Indian Government: *Jawaharlal Nehru National Solar Mission Towards Building SOLAR INDIA,* New Delhi, 2010.

ISTT 2011
IEEE Spectrum Tech Talk: *Fukushima's Impact on Nuclear Power*. Retrieved on 24 Mar. 2011. http://spectrum.ieee.org/tech-talk/energy/nuclear/fukushimas-impact-on-nuclear-power/?utm_source=techalert&utm_medium=email&utm_campaign=032411.

ITER 2011
ITER Organization: *Iter the way to new energy*. Retrieved on 22 Sept. 2011. http://www.iter.org/.

Josuttis 2007
Josuttis, N. M.: *SOA in Practice,* O'Reilly: 2007.

JRC 2011
European Commission Joint Research Centre Smart Electricity Systems: *Smart grid catalogue – The first comprehensive inventory of Smart Grid projects in Europe*. Retrieved on 22 Sept. 2011. http://ses.jrc.ec.europa.eu/index.php?option=com_content&view=article&id=93&Itemid=137.

Kaiser/Rice 1974
Kaiser, H. F./Rice, J.: "Little Jiffy". Mark IV. In: Educational and Psychological Measurement 34, no. 1 (1974), p. 111–117.

Kost/Schlegl 2010
Kost, C./Schlegl, T.: *Stromgestehungskosten Erneuerbare Energien, Studie des Fraunhofer Instituts für Solare Energiesysteme, Renewable Energy Policy Innovation. 2010.* Retrieved on 13 Oct. 2012. http://www.juwi.de/fileadmin/user_upload/de/PK_2011/Hintergruende/FIS-Stromgestehungskosten.pdf..

Kurbel et al. 2009
Kurbel, K./Becker, J./Gronau, N./Sinz, E./Suhl, L.: *Enzyklopädie der Wirtschaftsinformatik,* Munich: Oldenbourg Wissenschaftsverlag, 2009.

Lesser/Sue 2008
Lesser, Jonathan A./Sue, Xuejuan: "Design of an economically efficient feed-in tariff structure for renewable energy development". In: *Energy Policy*, no. 36 (2008), p. 981-990.

Liebig 2011
Liebig, D.: *Änderungen AtG.* Retrieved on 22 Sept. 2011. http://www.buzer.de/gesetz/6234/l.htm.

Loske 2010
A. Loske: "Industrial Smart Grids". In: *e|m|w Zeitschrift für Energie, Markt, Wettbewerb*, 5 (2010).

Lukszo/Deconinck/Weijnen 2010
Zofia Lukszo/Deconinck, Geert/Weijnen, Margot P. C.: *Securing Electricity Supply in the Cyber Age,* Heidelberg, etc.: Springer Verlag, 2010.

Mattern/Flörkemeier 2010
Mattern, F./Flörkemeier, Ch.: "Vom Internet der Computer zum Internet der Dinge". In: *Informatik-Spektrum* 33, no. 2 (2010), p. 107-121.

Matthes/Harthan/Loreck 2011
Matthes, C./Harthan, R./Loreck, C.: *Schneller Ausstieg aus der Kernenergie in Deutschland.* 2011. Retrieved on 12 Oct. 2011. http://www.oeko.de/oekodoc/1121/2011-008-de.pdf.

Mayer et al. 2010
Mayer, C., et al.: *IKT – Integration für Elektromobilität in einem zukünftigen Smart Grid,* VDE Kongress, 2010.

McLuhan/Nevitt 1972
McLuhan, M./B. Nevitt: *Take Today: The Executive as Dropout,* New York: Harcourt Brace Jovanovich 1972, p. 4.

MC 2011
Masdar City: *Masdar City.* Retrieved on 23 Sept. 2011. http://www.masdarcity.ae/en/.

MED 2010
Italian Ministry for Economic Development (pub.): *Italian National Renewable Energy Action Plan,* Rome: 2010.

MEEDDM 2009
Ministère de l'Ecologie, de l'Energie, du Développement Durable et de la Mer (pub.): *National action plan for the promotion of renewable energies 2009-2020,* Paris: 2010.

Merck 2011
Merck KGaA: *Gesamtwirtschaftliche Situation.* Retrieved on 23 Sept. 2011. http://merck.online-report.eu/2010/gb/lagebericht/gesamtwirtschaft.html.

Mert 2008
Mert, Wilma: *Consumer acceptance of smart appliances, Smart-A project, Inter-university Research Centre for Technology (IFZ),* Graz: 2008.

MNRE 2009
Ministry for New and Renewable Energy (pub.): *Wind Power Program*, New Delhi: 2009.

MoP 2008
Ministry of Power (pub.): *Annual Report 2007-2008,* New Delhi: 2008.

Nabe et al. 2009
Nabe, C., et al.: *Einführung von lastvariablen und zeitvariablen Tarifen,* 2009. Retrieved on 10 Oct. 2011. http://www.bundesnetzagentur.de/cae/servlet/contentblob/153298/publicationFile/6483/EcosysLastvariableZeitvariableTarife19042010pdf.pdf.

NDR 2011
Norddeutscher Rundfunk: *Höchster Verbrauch vor den USA – Chinas Energiehunger ist am größten.* Retrieved on 22 Sept. 2011. http://www.tagesschau.de/wirtschaft/energieverbrauch112.html.

Neuhoff et al. 2011
Neuhoff et al.: Europe's Challenge: *A Smart Power Market at the Centre of a Smart Grid. CPI Smart Power Grid Project,* Project Overview January 2011.

Nikolei 2007
Nikolei, H.-H.: "China überschüttet Frankreich mit Aufträgen – Schlag gegen Dollar". In: *greenpeace magazin*, 2007.

NIST 2010
NIST (pub.): *NIST Framework and Roadmap for Smart Grid Interoperability Standards*, Special Publication 1108, Release 1.0., Washington: 2010.

NIST 2011
NIST (pub.): *The NIST Definition of Cloud Computing (Draft)*, Washington: 2011.

Nitsch et al. 2010
Nitsch, Joachim et al.: *Leitstudie 2010.* Retrieved on 23 Aug. 2011. http://elib.dlr.de/69139/1/Leitstudie_2010.pdf.

Østergaard 2006
Østergaard, J.: *European SmartGrids Technology Platform-Vision and Strategy for Europes Electricity Networks of the Future,* Brussels: 2006.

Oettinger 2011
Oettinger, G.: *Towards competitive, sustainable and secure energy?* Retrieved on 12 Oct. 2011. http://ec.europa.eu/commission_2010-2014/oettinger/headlines/speeches/2011/01/doc/20110125.pdf.

OFFIS/SCC Consulting/MPC management coaching 2009
OFFIS, SCC Consulting, und MPC management coaching: *Untersuchung des Normungsumfeldes zum BMWi-Förderschwerpunkt ‚E-Energy – IKT-basiertes Energiesystem der Zukunft',* Oldenburg: 2009.

PDO 2008
People's Daily Online: C*hina's electricity consumption increases 6.67 % year-on-year.* Retrieved on 22 Sept. 2011. http://english.people.com.cn/90001/90776/90884/6557978.html.

Pike 2011
Pike Research: *Smart Appliances to be a $ 26.1 Billion Global Market by 2019.* Retrieved on 12 Oct. 2011 www.pikeresearch.com/newsroom/smart-appliances-to-be-a-26-1-billion-global-market-by-2019

Pipke et al. 2009
Pipke, H./Hülsen, C./Stiller, H./Seidel, K./Balmert, D.: *Endenergieeinsparungen durch den Einsatz intelligenter Messverfahren, 2009.* Retrieved on 10 Oct. 2011. http://www.kema.com/Images/KEMA%20Endbericht%20Smart%20Metering%202009.pdf doc.

Prahalad/Ramaswamy 2000
Prahalad, C. K./Ramaswamy V.: "Co-opting Customer Competence". In: *Harvard Business Review*, Jan.-Feb. 2000, p. 79-87.

Rastler 2010
Rastler, D., *EPRI, Electricity Energy Storage Technology Options, 2010.* Retrieved on 07 Oct. 2011. http://my.epri.com/portal/server.pt?space=CommunityPage&cached=true&parentname=ObjMgr&parentid=2&control=SetCommunity&CommunityID=404&RaiseDocID=000000000001020676&RaiseDocType=Abstract_id.

Rehtanz 2003
Rehtanz, Christian: *Autonomous Systems and Intelligent Agents in Power System Control and Operation,* Heidelberg, etc.: Springer Verlag, 2003.

Reiche 2010
Reiche, Katherina: *Neues Energiekonzept der Bundesregierung – welche Spielräume für Unternehmen?* (Jahreskonferenz Erneuerbare Energie), Berlin: 2010. Retrieved on 11 Oct. 2011. http://www.bmu.de/reden/katherina_reiche/doc/46683.php.

REW 2005
Renewable Energy World: *Authorized Release: The Renewable Energy Law. The People's Republic of China.* Retrieved on 22 Sept. 2011. http://www.renewableenergyworld.com/assets/download/China_RE_Law_05.doc.

Rohjans et al. 2010
Rohjans, Sebastian et al: "Survey of Smart Grid Standardization Studies and Recommendations". In: *First IEEE International Conference on Smart Grid Communications*, Gaithersburg: 2010.

Rohjans et al. 2011
Rohjans, Sebastian et al.: "Towards an Adaptive Maturity Model for Smart Grids". In: *17th international Power Systems Computation Conference*, Stockholm: 2011.

Rohlfing 2010a
Rohlfing, Dirk: Hannover: *Bilanz des Smart-Meter Piloten.* Retrieved on 12 Oct. 2011. http://smart-energy.blog.de/2010/07/06/.

Rohlfing 2010b
Rohlfing, Dirk: *EnCT Studie bestätigt Erfahrung der Stadtwerke Bielefeld.* Retrieved on 12 Oct. 2011. http://smart-energy.blog.de/2010/05/05/.

Schwab 2006
Schwab, Adolf: *Elektroenergiesysteme*, Berlin/Heidelberg: Springer Verlag, 2006.

Schwab 2009
Schwab, A. J.: *Elektroenergiesysteme,* Karlsruhe: Springer Verlag, 2009.

SD 2011
Statistics Denmark: *Statistical Yearbook 2011,* Statistisches Amt Dänemark, Kopenhagen: 2011.

SEN 2010
SEN Group GmbH: *Russlands Energiewirtschaft.* Retrieved on 23 Sept. 2011. http://senmedia.net/index.php?option=com_content&view=article&id=255&Itemid=.

SGCC 2010
State Grid Corporation of China: *SGCC Framework and Roadmap for Strong and Smart Grid Standards,* Beijing: 2010.

SGMM 2010
The SGMM TEAM: *Smart Grid Maturity Model – Model Definition – A framework for smart grid transformation,* Pittsburgh: 2010.

SGN 2011
Smart Grid News: *Energy-Efficiency Policy Opportunities for Electric Motor-Driven Systems*. Retrieved on 22 Jun. 2011. http://www.smartgridnews.com/artman/uploads/1/EE_for_ElectricSystems_1.pdf.

SMA 2011
SMA Solar Technology: *Sunny Sensorbox*. Retrieved on 12 Oct. 2011. http://www.sma.de/de/produkte/monitoring-systems/sunny-sensorbox.html.

SMBSG3 2010
SMB Smart Grid Strategic Group: *IEC Smart Grid Standardization Roadmap,* Geneva: 2010.

Sommerville 2010
Sommerville, I.: *Software Engineering* [paperback], 9th revised edition, International Version Amsterdam: Addison-Wesley Longman, 2010.

Spiegel 2007
SPIEGEL ONLINE GmbH: *Rasmussen rühmt Dänemark als Musterland.* Retrieved on 22 Sept. 2011. http://www.spiegel.de/wissenschaft/natur/0,1518,470802,00.html.

Spiegel 2011
SPIEGEL ONLINE GmbH: *Drei-Schluchten-Damm*. Retrieved on 22 Sept. 2011. http://www.spiegel.de/thema/drei_schluchten_damm/.

SRS 2011
Stockholm Royal Seaport: *Stockholm Royal Seaport.* Retrieved on 23 Sept. 2011. http://www.stockholmroyalseaport.com/.

Stern.de 2010
Stern.de: *Stromausfälle in den USA und Kanada – Dunkle Zeiten in Amerika.* Retrieved on 22 Sept. 2011. http://www.stern.de/politik/ausland/stromausfaelle-in-den-usa-und-kanada-dunkle-zeiten-in-amerika-1580736.html.

Stewart 1981
Stewart, D. W.: "The Application and Misapplication of Factor Analysis in Marketing Research". In: *Journal of Marketing, Research* 18:1 (1981), p. 51-62.

Stoft 2002
Stoft, S.: *Power System Economics,* New York: John Wiley & Sons 2002.

sueddeutsche.de 2007
sueddeutsche.de GmbH: *Atomwaffensperrvertrag: Das indische Problem.* Retrieved on 22 Sept. 2011. http://www.sueddeutsche.de/politik/atomwaffensperrvertrag-das-indische-problem-1.889347.

TDWI 2011
Axel Springer AG/Bauer Media Group (pub.): *Typologie der Wünsche.* Berlin, Hamburg: 2011.

Thompson 2004
Thompson, B.: *Exploratory and Confirmatory Factor Analysis: Understanding Concepts and Applications,* Washington DC: American Psychological Association, 2004.

Tremblay et al. 2010
Tremblay, Monica et al.: "Focus Groups for Artifact Refinement and Evaluation in Design Research". In: *Communications of the Association for Information Systems* 26/27 (2010).

UBA 2008
Umweltbundesamt (pub.): *Politikszenarien für den Klimaschutz IV – Szenarien bis 2030,* Berlin: 2008.

UNEP 2008
United Nations Environment Programme: *Human Development Report 2007/2008 Fighting climate change: Human solidarity in a divided world,* New York: 2008.

UNITY 2011
UNITY AG: *Szenario-Software.* Retrieved on 07 Oct. 2011. http://www.unity.de/de/vorrausschau-szenarien/szenario-software.html.

U. S. Government 2011
U. S. Government: *The Recovery Act.* Retrieved on 22 Sept. 2011. http://www.recovery.gov/About/Pages/The_Act.aspx.

Uslar 2010
Uslar, Mathias: *Ontologiebasierte Integration heterogener Standards in der Energiewirtschaft.* Edewecht: Olwir Verlag Oldenburg, Computer Science Series XIII, 2010.

Uslar et al. 2010
Uslar, Mathias et al.: „Survey of Smart Grid Standardization Studies and Recommendations - Part 2". In: *IEEE Innovative Smart Grid Technologies Europe*, Gothenburg: 2010.

Valocchi 2007
Valocchi, Michael et al.: P*lugging in the consumer, Innovating utility business models for the future – IBM Institute for Business Value,* IBM Global Business Services, Somers: 2007.

VDE 2009
Verband der Elektrotechnik Elektronik Informationstechnik e. V.: *Energiespeicher in Stromversorgungssystemen mit hohem Anteil erneuerbarer Energieträger, 2009.* Retrieved on 12 Oct. 2011. http://www.vde.com/de/fg/ETG/Arbeitsgebiete/V1/Aktuelles/Oeffentlich/Seiten/Studie-Energiespeicher.aspx.

VDE 2011
Verband der Elektrotechnik Elektronik Informationstechnik e. V. (pub.): *VDE-Trendreport 2011 Elektro- und Informationstechnik Schwerpunkt: Smart Grids,* Frankfurt am Main: 2011.

VDN 2007
Verband der Netzbetreiber (pub.): *TransmissionCode 2007 – Netz- und Systemregeln der deutschen Übertragungsnetzbetreiber,* Frankfurt am Main/Berlin/Heidelberg: VDEW 2007.

VZBV 2010
Verbraucherzentrale Bundesverband e. V. (pub.): *Erfolgsfaktoren von Smart Metering aus Verbrauchersicht*, Berlin: 2010.

WBG 2005
World Bank Group: *From Transition Economy to Development Economy,* Washington D. C.: 2005.

WNA 2011a
World Nuclear Association: *Nuclear Energy in Denmark.* Retrieved on 23 Sept. 2011. http://www.world-nuclear.org/info/inf99.html.

WNA 2011b
World Nuclear Association: *Nuclear Energy in Denmark.* Retrieved on 23 Sept. 2011. http://www.world-nuclear.org/info/default.aspx?id=342&terms=Italy.

WWEA 2011
World Wind Energy Association: *World Wind Energy Report 2010*, Bonn: 2011.

WZ 2011
Viennaer Zeitung: *EU-Energie-Binnenmarkt soll bis 2014 stehen*. Retrieved on 22 Sept. 2011. http://www.wienerzeitung.at/nachrichten/politik/europa/29320_EU-Energie-Binnenmarkt-soll-bis-2014-stehen.html.

ZEIT 2011
ZEIT ONLINE GmbH: *Wüstenstromprojekte, die sich ergänzen müssen*. Retrieved on 22 Sept. 2011. http://www.zeit.de/politik/ausland/2010-07/Desertec-Mittelmeer-Solarplan.

Zerres 2011
Zerres, Achim: *Smart Grids: Die Sicht der Bundesnetzagentur. Präsentation auf dem Workshop zum Energierecht*, FU Berlin, 30 Jun. 2011. Retrieved on 12 Oct. 2011<http:// www.enreg.de/content/material/2011/30 Jun. 2011.Zerres.pdf.

Zhang/Rehtanz/Pal 2005
Zhang, X.-P./Rehtanz, C./Pal, B.: *Flexible AC Transmission Systems: Modelling and Control*. Berlin: Springer Verlag, 2005.

ZPRY 2010
Zpryme Research & Consulting: *Smart Grid Insights: Smart Appliances*, März 2010. Retrieved on 19 Aug. 2011. http://www.zpryme.com/SmartGridInsights/2010_Smart_Appliance_Report_Zpryme_Smart_Grid_Insights.pdf.

ZVEI 2010
Zentralverband Elektrotechnik- und Elektronikindustrie e. V. (pub.): *Nachrichten – Electrical Industry News – Indien – Wirtschaft boomt*. Retrieved on 22 Sept. 2011. http://www.zvei.org/index.php?id=2049.

APPENDIX I: ABBREVIATIONS

AAL	Ambient Assisted Living
ADFEC	Abu Dhabi Future Energy Company
AIM	Amsterdam Innovation Motor
AMI	Advanced Metering Infrastructure
AMM	Advanced Meter Management
AMR	Automated Meter Reading
AMS	Area Management System
ANA	Autonomous Low-Voltage Grid Agent
API	Application Programming Interface
ARegV	(German) Incentives Regulation Ordinance
ARRA	American Recovery Reinvestment Act
ATSOI	Association of the Transmission System Operators of Ireland
BALTSO	Baltic Transmission System Operators
BDEW	German Association of Energy and Water Industries
BMBF	Federal Ministry of Education and Research
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BMWi	Federal Ministry for Economics and Technology
BNE	Federal Association of New Energy Suppliers
BNetzA	Federal Network Agency
BSI	Federal Office for Information Security
BÜM	New middle class milieu
CAES	Compressed Air Energy Storage
CCS	Carbon Capture and Storage
CEN	Comité Européen de Normalisation
CENELEC	Comité Européen de Normalisation Electrotechnique
CFC	Continuous Function Chart
CHP	Combined Heat and Power plant
CHP	Combined heat and power
CIM	Common Information Model
COSEM	Companion Specification for Energy Metering
CPS	Cyber Physical System
CRM	Customer Relationship Management
CSP	Concentrating Solar Power
CSS	Customer Self Service
DEA	Danish Energy Authority
dena	German Energy Agency
DER	Distributed Energy Resource
DERA	Danish Energy Regulatory Authority
DFC	Decision Field Component
DIN	German Institute for Standardization
DKE	German Commission for Electrical, Electronic & Information Technologies of DIN and VDE

DLMS	Device Language Message Specification
DoE	Department of Energy
DR	Demand Response
DSL	Digital Subscriber Line
DSM	Demand Side Management
DSO	Distribution system operator
EAI	Enterprise Application Integration
ECG	Electrocardiogram
EDIFACT	Electronic Data Interchange For Administration, Commerce and Transport
EDM	Energy Data Management
EDP	Electronic Data Processing
EEG	German Renewable Energy Act
EEGI	European Electricity Grid Initiative
EEX	European Energy Exchange
EMA	Energy Market Authority
EMS	Energy Management System
ENEA	Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (Italian agency for new technologies, energy and sustainable economic development)
ENTSO-E	European Network of Transmission System Operators for Electricity
EnWG	Energy Economy Act
EPE	Movers-and-shakers milieu
EPRI	Electric Power Research Institute
EPS	Emergency Power System
ERP	Enterprise Ressource Planning
ESB	Enterprise Service Bus
ETP	European Technology Platform
ETSI	European Telecommunications Standards Institute
ETSO	European Transmission System Operators
EU	European Union
EUC	Energy Utility Company
EWA	European Wind Energy Association
FACTS	Flexible AC Transmission Systems
FEG	Future Energy Grid
FYP	Five-Year Plan
GDP	Gross Domestic Product
GeLi Gas	German Business processes for switching gas supplier
GIS	Geo Information System
GPKE	German Business Processes for Electricity Suppliers
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications

HED	Escapist milieu
HVDC	High voltage direct current transmission
IaaS	Information as a Service
ICT	Information and Communication Technology
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
IES	Intelligent Energy System
INGV	Istituto Nazionale di Geofisica e Vulcanologia (Italian Institute for geophysical and volcanic research)
IoE	Internet of Energy
IP	Internet Protocol
ISO	Independent System Operator/International Standardisation Organisation
IT	Information Technology
ITU	International Telecommunication Union
KAV	German Concession Levy Ordinance
KEMIN	Klima- og Energiministeriet (Danish Ministry of Climate and Energy)
KET	Established-conservative milieu
KWKG	German Combined Heat and Power Act
LIB	Liberal-intellectual milieu
LTE	Long Term Evolution
MaBiS	Market rules for accounting grid billing
MDS	Multidimensionale scaling
MessZV	German Measurement Access Ordinance
MIST	Masdar Institute of Science and Technology
MIT	Massachusetts Institute of Technology
MSP	Mediterranean Solar Plan
MUC	Multi Utility Communication
NC	National Committee
NDRC	National Development and Reform Commission
NGO	Non-Governmental Organization
NIST	National Institute of Standards and Technology
NREAP	National Renewable Energy Action Plan
OSI	Open Systems Interconnection
OT	Off-peak tarrif
OTC	Over-the-counter
PER	High-achiever milieu
PLC	Power Line Communication
PLC	Programmable logic control
PMU	Phasor Measurement Unit
PPC	Production Planning and Control system
PQ	Power quality

PRA	Adaptive-pragmatist milieu
PRE	Precarious milieu
PT	Peak tariff
PV	Photovoltaic
QoS	Quality of service
R&D	Research and development
RFID	Radio Frequency Identification
RIIO	Revenue=Incentives+Innovations+Outputs
RTU	Remote Terminal Unit
SAGO	Smart Area Grid Operator
SAIDI	System Average Interruption Duration Index
SCADA	Supervisory Control and Data Acquisition
SDLWindV	German Ordinance on System Services from Wind Power Plants
SET	European Strategic Energy Technology
SFC	Sequential Function Chart
SGCC	State Grid Corporation of China
SGMM	Smart Grid Maturity Model
SIA	Seamless Integration Architecture
SLA	Service Level Agreement
SMB	Small and medium-sized businesses
SML	Smart Message Language
SMS	Short Message Service
SOA	Service Oriented Architecture
SÖK	Socio-ecological milieu
SQL	Structured Query Language
StromNEV	German Electricity Grid Charging Ordinance
StromNZV	German Electricity Grid Access Ordinance
TC	Technical Committee
TCP	Transmission Control Protocol
TFEU	Treaty on the Functioning of the European Union
TKG	German Telecommunications Act
TR	Technical Report
TRA	Traditional milieu
TSO	Transmission system operator
UBA	Federal Environment Agency
UCTE	Union for the Coordination of Transmission of Electricity
UK	United Kingdom
UKTSOA	UK Transmission System Operators Association
UMTS	Universal Mobile Telecommunications System
UPS	Uninterruptible power supply
V2G	Vehicle to Grid

VDE	Association for Electrical, Electronic & Information Technologies
VDEW	Association of the Electricity Industry (taken over in 2007 by BDEW)
VPP	Virtual Power Plant
WAMS	Wide Area Measurement System
WAN	Wide Area Network
WASA	Wide Area Situational Awareness
WLAN	Wireless Local Area Network
WWW	World Wide Web
XML	Extensible Markup Language

APPENDIX II: GLOSSARY

Active power	The portion of electrical power that can be used for transformation into other power forms.
Apparent power	Comprises reactive power and active power.
Back-up power plant	Generation facilities that are ready to balance out the effects of a long-term failure of other generation facilities.
Backward compatibility	The ability for a new or updated version of a technology to be used (easily) with a previous version.
Bidirectional plug & play	Bidirectional means that the system to which the device is connected is recognised by the device and that the device behaves accordingly.
Bluetooth	Standard for wireless data communications over short distances
Breakeven point	The point at which the revenue and costs of a value process are equal and by which the profit zone is separated from the loss zone.
CCS technology	Carbon Capture and Storage (technology to capture and store CO_2)
Churn rate	The annual churn rate defines the percentage of customers who change provider, by dividing the number who switch by the total number of customers.
Concentrated Solar Power	The group of technologies that exploit the principle of concentrating the sun's rays to produce electricity.
Condition monitoring	Automated, digital measurement and analysis of functional parameters of operating resources within the electricity infrastructure.
Customer Self Service	Products and services to which customers can help themselves independently, via interactive media.
Data hub	A directory service containing information on generating and consumer systems.
Data lineage	The individual sources used to provide data for a specific pool.
Data provenance	See "data lineage"
Day-ahead market	Market for buying or selling electricity for the following day.

DESERTEC	A concept for generating electricity from solar power and wind power in desert areas of North Africa, supported by an initiative bearing the same name.
Distributed energy resources (DER)	Resources for generating electricity that are distributed throughout the grid systems.
Distribution grid	Entire set of grid components in the high, medium and low voltage levels with the purpose of regional distribution of electricity to consumer locations.
EEBus	Interface supporting standardised exchange of services between energy utilities and households in order to increase energy efficiency.
E-Energy initiative	Funding programme for smart grid projects in Germany, financed by the BMWi and BMU, running from 2008 to 2012.
Enabler	Technology or product or framework that makes a significant contribution to or is a basic prerequisite for achieving an objective.
Energy Management System (EMS)	Functionality that allows the user to optimise energy consumption and procurement in terms of efficiency and costs.
Forward compatibility	The ability for an older version of a technology to be used (easily) with a newer version.
Front loading	Model-based enhancement of the product design process that helps to optimise functionality of the product before it is tested in practice. Also referred to as Front-end loading (FEL).
Grid control desk	A central point that receives, processes and analyses grid operational data and from which grid operations within a specific grid segment are controlled.
Grid frequency	The European interconnection grid operating on AC has a target constant voltage frequency of 50 Hz.
High voltage direct current transmission	Long distance electricity transmission using direct current at voltages > 100 kV, normally > 700 kV.
Intraday market	Market for buying or selling electricity (provided capacity) for the same day or the following day.
Load	Electricity consumption or demand for power at a given point in time. See also Residual load

Maintenance forecast Forecast of the time, type and intensity of maintenance of assets.

Merit order Sequence in which power plants are deployed as load increases.

Methanisation The chemical conversion of carbon monoxide or carbon dioxide into methane, using hydrogen.

Microgrid Geographically restricted, normally regional system comprising small-scale and even smaller generation facilities located directly adjacent to consumption units, normally connected using smart grid technology.

Middleware Middleware is distinct ICT layer that acts as an application-neutral agent between two different applications, encapsulating the complexity and infrastructure of the applications within an interface.

Minute reserve Alongside primary and secondary regulation measures, the minute reserve forms an integral component of the measures used to maintain grid stability (frequency). Power plants with adjustable output increase or reduce their power to balance out fluctuations between supply and demand in the short or medium term.

North Sea Power Wheel Offshore transmission grid in the North Sea that serves to integrate offshore wind farms and pumped-storage power plants with the European interconnect system.

Offshore (Wind farms) located at sea, in coastal waters.

Onshore (Wind farms) located on land, both at the coast and in other areas.

Overlay grid An inter-regional, possibly even Europe-wide grid for long-distance transmission of electricity at very high voltage (> 750 kV) or using HVDC.

Peak shaving Methods and measures to reduce (frequency, level) of peak loads.

Peak/off-peak tariffs Flexible and dynamic electricity pricing using peak and off-peak tariffs for the purpose of load management.

Phasor Measurement Unit (PMU) Technology to record grid operational data (phase angle between current and voltage).

Plug & play Simple, user-friendly connections between ICT systems (USB is a common example).

Power quality	The reliability of supply.
Power to gas	Technology that uses power (from renewables) to sythesise energy-rich gas (usually methane) for the purposes of energy storage or alternative usage.
Powerline Communication	Transmission of data using electricity cables.
PQ data	Data recorded concering the power quality.
Primary control	Very short-term measures to maintain grid stability (frequency) in the European interconnection grid. Power plants with adjustable output increase or reduce their power to balance out fluctuations between supply and demand.
Programmable logic control	Programmable devices that can measure and control.
Prosumers	Portmanteau word formed from producer and consumer: (Energy) producer and consumer
Reactive power	The portion of power carried by a cable that the consumer is unable to use, in contrast to active power.
Remote control systems	Technology located in switchgear (within a substation) that is installed to enable communications with the managing substation (remote control computer).
Remote diagnostics	The ability to diagnose faults, etc., from a remote location.
Remunicipalisation	The return of energy utility responsibilities to local authorities (Kommune).
Repowering	The replacement of old generation equipment by new plants with higher output and/or higher efficiency (generally for wind power).
Residual load	Power in the distribution grid that results as the difference between consumption and distributed generation, also referred to simply as load.
Retrofitting	The process of expanding, renovating or replacing old power generation plants for the purposes of increasing efficiency or reducing emissions.
Scenario method	(Strategic) process of developing, analysing and possibly evaluating future possibilties.

Secondary control	Short-term measures to maintain grid stability (frequency) between different regulated segments.
Security patterns	Reusable draft designs that can be applied to ensure the security of a system.
Service Oriented Architecture (SOA)	An architecture paradigm from the world of IT that structures and uses services from a range of systems.
Shale gas	Natural gas formed from being trapped within shale (clastic sedimentary rock) formations.
Smart meter	An "intelligent" digital meter.
Software-as-a-Service (SaaS)	A element of cloud computing, in which software and IT infrastructure are offered externally and used by customers in the form of a service.
Special contract customers	Customers who have been able to negotiate individual pricing with the electricity utility due to their significantly above average level of consumption (> 100,000 kWh/year).
Star grid	A grid formation in which cables radiate out in a star pattern from a single feed-in point.
Substation control system	Equipment located in power facilities to communicate between digital protection systems and local substation control systems.
Supervisory Control and Data Acquisition (SCADA)	Monitoring and control system for technical processes.
Supply Side Management	Measures to ensure the efficient, safe and matched generation, transmission and distribution of electricity.
Sym2	Synchronous modular meter
System Average Interruption Duration Index (SAIDI)	Average amount of downtime per supplied electricity consumer. Indicates the reliability of an energy utility company.
TFEU	Treaty on the Functioning of the European Union
Transmission grid	Here: Entire set of grid components at HV (high voltage) and EHV (extra-high voltage) levels for the purpose of inter-regional, long-distance transmission of electricity (in general: also for gas).

Unbundling	Break up of ownership of electricity production and wholesale companies on the one side and electricity transportation and distribution on the other.
Unidirectional plug & play	Unidirectional means that the system to which the device is connected is able to recognise and use the device with its interfaces and services.
Voltage range	Tolerated range within voltage may fluctuate in the various voltage levels of the electricity infrastructure.
Wholesale trading	Competing generators offer electricity to wholesalers, who then offer this electricity at different prices on the market.
Wide Area Situational Awareness	Technologies that are used to improve monitoring of the electricity infrastructure over large geographical areas.
WLAN	Wireless local area network.
Workshop	Moderated educational activity.
Zigbee	Wireless networking standard for household appliances.
Z-Wave	Wireless communications standard for home automation, produced by Zensys.

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