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Tobias Menz · Sven-Uwe Müller
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Notice

Preface

by Prof. Dr. Dr. Klaus Töpfer, Executive Director of the Institute for Advanced Sustainability Studies, Potsdam

Source: Schulzendorff

Until 2025, about 250 million people will move to cities in China, where by then there will be 221 cities with more than 1 million inhabitants. They will be clustered in about 11 regions with more than 60 million people each. In order to ensure energy supply with reduced impact on health and the environment a central element of the Chinese governments' five year plan is developing smart eco-cities. With this, the conservation of energy, water, land and materials, reducing pollution, optimizing the transportation, protecting the environment, and improving building comfort, health and safety should be maximized. This will be a critical moment in the acceleration of industrialization, urbanization and rural development providing great opportunities in many respects, business opportunities for the economic sector and saving potential for millions of households.

As China increasingly embraces clean energy, with newly set renewable energy targets and energy efficiency, smart grid capabilities are crucial for achieving and driving the low-carbon transition. With increasing shares of power from renewable energy facilities with their specifics of intermittency, the transformation of the demand and supply sides towards more flexibility is vital. This is recognized in the 12th Five-Year Plan for National Economic and Social Development, where the People's National Congress has set up a goal for the acceleration of smart grid developments. Additionally to balancing the demand and supply sides smart grids can potentially contribute to a reduction in overall need of energy of up to 25 % and reduce the costs of integrating renewable energy into the power system. Doing this will both be useful for the economy, opening up new business models and be a challenge for the regulators, who need to create a supportive framework. Such a regulatory basis should provide incentives and ensure an acceleration of the smart grid development also encouraging competition in order to fuel innovation. Supporting the development of industrial clusters, by creating special industry funds can be one option to fully realize the potential of the economic opportunity of the smart grid development. Considering that China in 2013 for the first time surpassed the spending of the United States on smart grid technologies, accounting for more than a quarter of the worldwide smart grid spending, it is clear that a massive transformation of the country's energy landscape is underway. The potential of being a global leader in the technology development and serving as a role model in smart energy system development however still implies regulatory challenges in order to balance the energy policy goals of reliability, affordability and sustainability – keeping in mind that the social dimension of energy is central to sustainable energy systems.

Sincerely,

Prof. Dr. Dr. Klaus Töpfer

Preface

by Dr. Werner Brinker, Chairman of the Board of the EWE AG, Oldenburg

Europe is committed to the decarbonization of its economy, driven by the European Union (EU) climate and energy policies on renewable energy, low carbon emissions, energy savings and energy efficiency. The further development of the energy sector is pivotal to meeting these objectives, ensuring the transition towards a more sustainable energy system and driving innovation in the energy sector.

While the German energy sector is already well prepared for a successful integration of decentralized power generation from renewable energy sources, Germany is currently heading the necessary legal and regulatory steps to build future-oriented electricity networks, complete the market integration of renewables and ensure at the same time the functioning of electricity markets.

Automation as well as information and communication technology (ICT) are playing an important role in this context. So called *smart grids* are deemed to improve the efficiency, reliability, and sustainability of the production and distribution of electricity. They are able to collect, transmit and use information about the behaviors of electricity producers and consumers in an automated fashion by means of automation and ICT.

In Germany, the transition towards smart grids is driven by a large variety of different institutions and companies interacting on well-functioning markets for electricity and associated products. However, despite all the valuable experiences with regard to the build-up of smart grids, Germany's regulatory framework has not yet been adapted completely to the vision of smart grids. In China, the transition towards smart grids is mainly pushed forward by the government and the politically powerful and vertically integrated grid operators due to the absence of competition in many parts of the energy sector and the non-existence of markets for electricity.

The present study aims to give regulatory recommendations for the deployment of smart grids in China based on German and international experiences and ongoing discussions. I am convinced that the results can help Chinese policy makers to optimize smart grid regulation in China. I am even more convinced that, based on this study, China and Germany have the unique opportunity to link their strengths, overcome weaknesses and withstand threats to maximize overall benefits for the society during the build-up of smart grids. As Germany is already a very important partner for China in Europe and China is of upmost importance for Germany in Asia, it could be important to align and ensure the right legal and regulatory framework as a precondition for a more sustainable energy sector in China.

We as the management of the EWE Group are honored that Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH chose experts from our companies to support the further development of smart grids in China. It was also a pleasure for us to welcome a group of Chinese experts in Oldenburg in April 2013.

Finally, I would like to wish you many new insights during the reading of this study.

Your

Dr. Werner Brinker

Preface

by Dr. TONG Guangyi, Deputy Director General of the Electricity Department

National Energy Administration of the P.R. China, Beijing

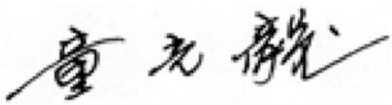
In light of today's environmental challenges, in order to meet the requirements of sustainable development, economic restructuring as well as flexible transmission, distribution and utilization of electricity, optimizing the way we operate our power systems by building a smart grid has become an inevitable trend. Therefore, how to rationally and scientifically lay out a roadmap and at the same time design a sound legal and regulatory framework to promote smart grid development is a major question. This study gives important insights on modern smart grid concepts, policy frameworks and avenues for development in Germany and elsewhere providing us with a wealth of ideas and pathways to choose from.

According to an old Chinese saying "advice from others may help one overcome one's shortcomings". To study the advanced experiences of other countries and learn from their example is of great significance to the development of China's smart grid. This study on "Regulatory Pathways for Smart Grid Development in China" includes an analysis of the current state of smart grid development in China and Germany, summarizes the latest discussion on the regulatory environment for smart grids in Germany and compares it with the current situation in China. Based on this analysis and in accordance with China's overall energy development targets, the study provides seven policy recommendations and three regulatory roadmaps to promote smart grid development in China.

I believe this study provides a useful reference for the healthy development, effective guidance and supervision of China's smart grid. We want to take this opportunity and express our appreciation to Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and the team of experts led by the German side. We thank all the contributors for their rigorous and prudent research approach as well as their professionalism, hard work and dedication in the whole process of writing this report.

At last, I sincerely wish all the best for the future development of smart grids in Germany and China.

Sincerely,



Dr. TONG Guangyi

Preface

by Bernhard Zymla, Head of the Energy Department

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Eschborn

The primary driver for smart grid development in Germany is the integration of a rising share of electricity generated from variable renewable energies into the power system. The German Federal Government's Energy concept for an environmentally friendly, reliable and affordable energy supply of September 2010 and the Package of Energy Laws enacted in July 2011 contain guidelines and objectives related to Germany's future energy system. The government plans express a commitment to sustainable development and environmental protection by setting a target to reduce CO_2 emissions by 40 % compared to 1990 by 2020 and by 80 to 95 % by 2050.

With the German energy transition, the *Energiewende*, the German government has taken ambitious steps and action to tackle the problems related to fossil fuel combustion. To achieve the ambitious targets for reducing greenhouse gas emissions while also gradually phasing out nuclear power until 2022, a rapid expansion of renewable energy is essential. In 2025, 40 to 45 % of gross electricity consumption is to be covered by renewables, with the share planned to rise to 80 % by 2050. An increasing share of intermittent renewables requires a fundamental restructuring of our electricity system, allowing for an effective synchronization of demand with increasingly variable supply, while at the same time maintaining system reliability and stability. To achieve this objective, electricity markets have to be reformed to set the right incentives for an efficient utilization of the system's flexibility resources on the supply and demand side. For this purpose the development of a future-oriented electric power network infrastructure – or smart grid – is indispensable.

Smart grids enable real-time communication between electricity suppliers, grid operators and consumers with the help of modern information and communication technologies facilitating an intelligent grid operation as well as the efficient utilization of all power system components through supply- and demand-side management. Thus, it is possible to integrate a high share of variable renewable energies without compromising the reliability of supply, while cutting peak loads and reducing the need for so-called *baseload* power plants. At the same time, the upgrade of the electric power grid with the help of innovative grid technologies helps to reduce the need for traditional grid expansion avoiding substantial costs. Smart grids lead to the emergence of new business models and new market players together with an increasing spectrum of energy services in the years to come.

The development of smart grids requires a sound legal and regulatory basis that sets the right incentives and clearly defines the roles of different power system actors, the interaction between them and enables a smooth communication between its components. This study presents an overview of China's and Germany's power system as well as each country's view on smart grid development. Built on this foundation recommendations for the adaptation of the policy and regulatory framework were developed aimed at facilitating the development of smart grids in China in order to allow the integration of a rising share of renewable energy in its power system.

We trust you will have an interesting and informative read.

Sincerely,

Bernhard Zymla

Executive Summary

Smart grids – an essential part of China's future electric power system In the past 15 years, a series of reforms have greatly improved the efficiency, reliability, and environmental performance of the Chinese power sector. However, significant challenges remain: rapidly rising electricity demand, concerns about power system reliability and energy security, environmental degradation and climate change [1].

China's government aims at addressing these challenges and set up ambitious development targets for the future electric power system: amongst others, generation and grid capacities are to be expanded substantially, the share of renewable energy sources (RES) in the generation mix is to increase considerably, the number of power outages and supply interruptions is to decrease significantly, and the efficiency of energy and electricity usage is to increase markedly [2], [3]. Moreover, China's government continues to modernize the energy sector regulation: it plans to establish a more effective electricity market system, considers downsizing and further unbundling the integrated electric grid operators, and aims at optimizing the electricity pricing system [2], [4], [5].

The concept of *smart grids* might help to overcome the technological challenges mentioned above. In brief and following the *International Energy Agency* (IEA), smart grids can be defined as:

> *An electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end users. Smart grids co-ordinate the needs and capabilities of all generators, grid operators, end users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimizing costs and environmental impacts while maximizing system reliability, resilience and stability.* [6]

The Chinese government already acknowledged the importance of smart grids: in its *12th Five-Year Plan for National Economic and Social Development*, the People's National Congress explicitly set up the goal of accelerating smart grid developments in China [7]. This goal was also explicitly included in the *12th Five-Year Plan for Energy Development* [2]. In addition, the most influential power sector companies, in particular the large grid operators, and academic institutions are active in promoting their own views on smart grids and developing, testing, and deploying smart grid technologies.

A core motivation for smart grids in China is their intended positive impact on security of supply and operational efficiency, especially at the distribution grid level. Moreover, demand side management enabled by means of smart grid technologies plays an important role for balancing electricity generation and demand. Smart grid technologies are also seen as a means to reduce the costs of integrating RES into the power system which is of critical importance given the ambitious RES expansion targets of China's government.

Though the Chinese government acknowledges the importance of smart grids, considerable challenges exist in adjusting the regulatory environment of China's electric power system to enable an effective and efficient development of smart grids in China.

The importance of new market actors in the smart grid development In Europe and the United States, the trend towards smart grids is driven by the growing importance of new participants in the value chain of the electric power sector, so-called *new market actors* or *third parties*. New market actors in this context are non-incumbents; they can be new competitors on the electricity markets (e. g. operators of RES plants, new power retail companies, energy service companies) or companies from other sectors like the *Information and Communication Technology* (ICT) sector.

The authors of this study are convinced that integrating new market actors in China's electric power sector will significantly contribute to a more rapid and innovative smart grid development in China. The main advantage of liberalizing markets and allowing third parties to participate in the electricity supply chain is the innovation potential that comes with these new actors [8]. In a smart grid context, new market actors create new business models by making use of available power system information and infrastructure in an innovative way. Additionally, new market actors increase competition which generally leads to greater cost efficiency in production, lower price levels and a higher variety of products and services. New market actors can only participate in the electricity sector if equal access to essential facilities (especially the grid and information from smart metering) is guaranteed [9], [10].

One of the main lessons learned from developments in Germany is that liberalization, structural reforms, the development towards smart grids, and the transition to more RES have triggered a massive increase of market entries of new players in the electricity sector. The institutional challenge of smart grids is to facilitate the system-wide interaction of all these players to the benefit of economic efficiency, sustainability, and reliability.

Recommended approaches for smart grid development in China at a glance In the light of the experiences made in Germany and the ambitious government targets for China's electric power system, seven recommendations to promote smart grid development in China have been developed in the present study. *Figure Summary 1* depicts the seven recommended approaches and associates them with different regulatory areas that have been defined in the context of this study. It can be seen that the study's recommendations relate to a broad range of regulatory topics.

The seven recommendations are briefly summarized below and reasonable implementation sequences that take into account the interdependencies between the different recommendations are shortly presented.

Recommendation 1: Define a long-term strategy for the electricity sector and establish an independent and powerful regulator A clearly defined strategy with specific long-term targets for the development of the electricity sector is necessary in order to reduce uncertainty for smart grid investors and manufacturers. Such a strategy should include government targets with regard to the development of electricity generation capacities of different technologies (the so-called *generation mix*) and energy efficiency targets.

Based on German experiences and on recommendations from the *Organisation for Economic Co-operation and Development* (OECD), clearly defined roles and responsibilities concerning the regulation of the electricity sector facilitate the development of smart grids. Specific attention should be paid to the development of an independent and powerful regulator. The regulator should supervise the development of the power grid infrastructure in general as well as smart grids in particular.

Recommendation 2: Create level playing fields for access to power system infrastructure and information Chinese grid operators are still integrated as they own and operate the electric power grids and are responsible for retail. The management of power system data (e. g. grid status

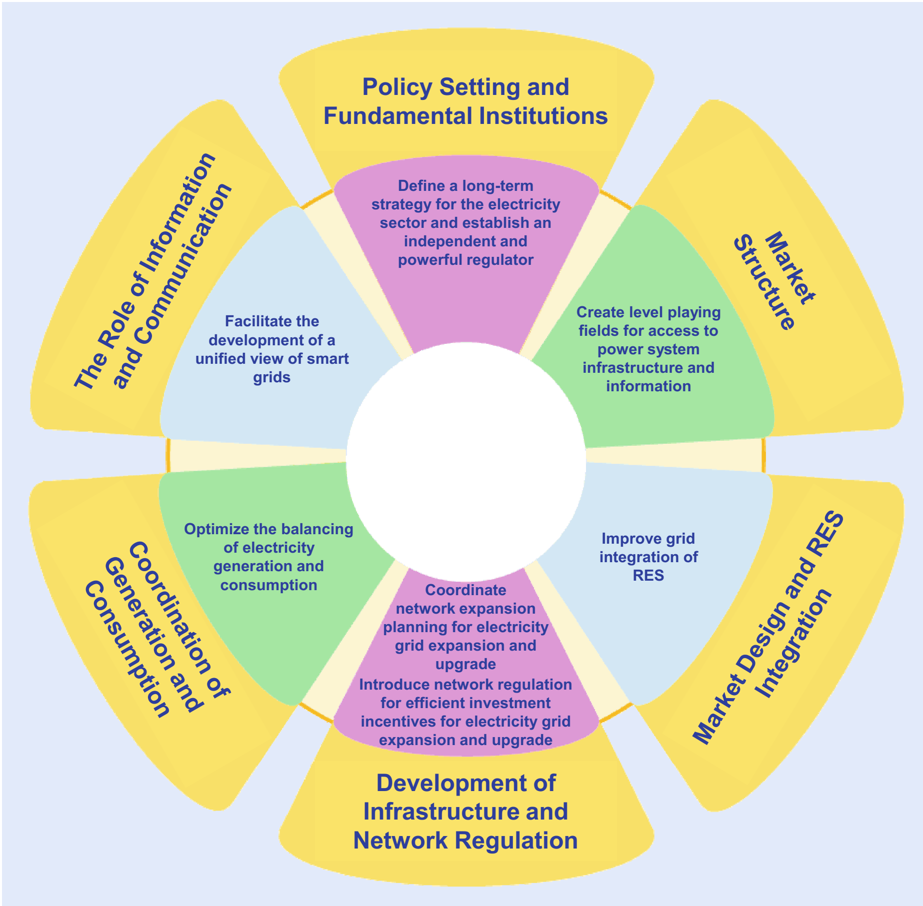


Fig. Summary 1 Overview of this study's recommendations

information or metering data on electricity generation and consumption) is currently their task. As soon as new market actors are to be integrated in the electric power system, power system data management will become more relevant on a broader scale. The non-discriminatory and technology-neutral management of power system-related information and its distribution in smart grids is currently one of the most discussed regulatory topics in Europe and the United States. It is an important finding of these discussions that it is beneficial if a regulator or another government institution develops a governance system, that will ensure provider and technology neutrality and a level playing field for all stakeholders. Non-discriminatory access to power system information in smart grids is of particular importance for new market actors to be able to develop their business models.

Recommendation 3: Introduce network regulation for efficient investment incentives for electricity grid expansion and upgrade At present, there is no explicit price for transmission and distribution (the so-called *network charge*) based on actual costs in China. The source of income of grid operators is the difference between the on-grid (generation) and the retail price for electricity which are both fixed by the government. In contrast, in Europe and many other countries with liberalized electricity markets regulation focuses on the monopolistic parts of the supply chain, i. e. transmission and distribution grids. The other elements of the supply chain, i. e. generation and retail, are liberalized and governed by general competition law only. This approach is referred to as *disaggregated regulation*. Its main advantage is that it avoids misdirected incentives at the non-monopolistic parts of the supply chain. It also widens the profit margin of the commercial businesses (generation and retail) and thus improves the business opportunities for new market actors.

With regard to a network regulation scheme (i. e. a specific method used for calculating network charges) suitable for China, the growing share of RES requires a significant upgrade and expansion of both transmission and distribution grids. On the one hand, regulation should facilitate necessary investments, but on the other, it should also set incentives to avoid unnecessary investments and implement least-cost solutions (e. g. smart grid technologies). In all, regulation should aim for efficient investment incentives. Based on Italian experiences, rate-of-return adders are a specifically interesting approach for projects with a special relevance to the smart grid development in China (e. g. those projects with a high priority for security of supply). It is highly beneficial to analyze their applicability to the Chinese context. Furthermore, profit-sharing mechanisms or innovation bonuses currently applied in the UK could be interesting to increase the diffusion of innovative technologies in China's electricity sector.

Recommendation 4: Coordinate network expansion planning for electricity grid expansion and upgrade China faces an urgent need to expand the existing electricity network within the next few years driven by growing consumer demand for electricity and the integration of RES. Smart grids provide solutions to meet these challenges. With smart grids, the number of potential stakeholders that are relevant for the network development increases. So far, only the incumbent players have been part of the network planning process in China. Evaluating how network development planning could be coordinated in China so that all relevant stakeholders have the possibility of participating in the process is therefore an important step. In this context, China could take advantage of German experience with the network development planning process for transmission grids and evaluate how this approach could be applied to the Chinese context and especially to distribution grids. Clear scenarios about the development of RES, the general electricity mix, and electricity demand in China are needed as a basis for the definition of a network development plan in China. Such scenarios could then serve as a common basis for the network development process.

The development of smart grids calls for effective coordination. Therefore, a long-term network development plan that includes the interests of various stakeholders at an early stage would facilitate the smart grid development in China. Based on German experiences, a stakeholder platform that should be chaired by one of the ministries and serve as a discussion board for the relevant stakeholders can further contribute to the smart grid development process. The stakeholders can exchange their ideas on grid development in general and smart grids in particular at an early stage within the stakeholder platform and jointly provide policy recommendations to the government.

Recommendation 5: Improve grid integration of RES Transparency and a clear division of responsibilities between grid operators and RES investors would encourage the deployment of RES and incentivize new market actors to invest in RES. Experience in Germany illustrates that a fast and efficient grid integration of RES requires a proper definition of grid connection points and clearly defined, transparent, technically sound, and legally binding grid codes (technical standards) for the integration of generation units at all voltage levels. RES need to be assigned a grid connection point (i. e. the point in the electricity grid which is at the nearest linear distance from the location of the RES-installation) on request, so that the interconnection can be installed without delay and according to well-defined technical standards. Whereas plant operators have to comply with the technical standards, grid operators have to bear liability for the grid connection of RES. This is very important, because liability puts a high priority on the establishment of the grid connection and avoids delays on the grid operator's side.

To ensure grid stability, it is necessary to curtail RES in times of critical grid conditions. To provide transparent procedures to the RES operators, detailed processes for curtailment of RES (including documentation, transparency rules, timeframes, involved parties, etc.) have to be defined and the requirements for information exchange within these measures have to be specified.

The integration of RES with regard to ICT is another important aspect in the smart grid context. Only by means of ICT, RES generation can be automatically coordinated with grid capacities and loads at any time. This is the basis for an economic optimum of the power system infrastructure usage and ensures options for action even in times of high wind and solar irradiation. An optimum ICT integration of RES is also a prerequisite for monitoring and controlling RES installations, thereby enabling an economically efficient level of grid curtailment.

Recommendation 6: Optimize the balancing of electricity generation and consumption Balancing generation and consumption of electrical energy is a technical key factor for the stable operation of power systems. In power systems with a high growth rate, such as China, peak loads may cause shortages on the generation side. Peak shaving, i. e. reducing the electrical power consumption during periods of maximum electricity demand, enabled by means of smart grid technologies is crucial for stable and efficient system operation in this case. In power systems with a high share of intermittent renewables, such as Germany, the residual load – the difference between load and renewable generation – is highly volatile. In such systems, residual load shaving during peak consumption times is important in order to reduce the use of conventional sources to cover the residual load.

Balancing mechanisms and technologies like *demand side management* (DSM), *supply side management* (SSM), microgrids, *virtual power plants* (VPP), and energy storage can be employed to facilitate the balancing of electricity generation and consumption. The technical potential for load management in the industrial sector is comparatively high and easy to realize with dedicated ICT solutions. The commercial sector can be included at a later point and the residential sector last, because the potential in the residential sector is smaller and more distributed.

China's government plans to refine the existing time-of-use pricing system and establish time-of-use pricing for all categories of customers. Within such a framework, sufficient differences between peak and off-peak prices for all categories of consumers are of critical importance to incentivize the wider introduction of supply-side management, demand-side management, and energy storage. With more and more RES being introduced, further applications like virtual power plants and microgrids, are recommended. Such applications need to have a clear focus on the security of supply and on economically efficient system development.

Recommendation 7: Facilitate the development of a unified view of smart grids Due to the different strategies of China's grid operators and the absence of a Chinese government vision on smart grids, there is no unanimously accepted vision on the technological and organizational design of smart grids in China. There is accordingly much uncertainty among potential smart grid investors. In Europe, standardization eased the development of a unified view of smart grids. China's government traditionally acknowledges the importance of standardization for industrial development and innovation. In this light, it is suggested to promote the establishment of an organizational arrangement (e.g. similar to the *Smart Grid Coordination Group* in Europe) to coordinate smart grid standardization in China. Within this organizational arrangement, clear organizational structures and processes to foster the understanding of the Chinese smart grid concept should be defined and implemented. In the European smart grid standardization process, which is currently still ongoing, a three-dimensional model of the European smart grid environment, the so-called *Smart Grid Architecture Model* (SGAM) has been created. It can be thought of as a technological, organizational, and functional map showing the boundaries as well as different areas of smart grids. This model has been used to identify smart grid use cases which describe requirements and functions of smart grid technologies. The use cases contribute to the development of a common understanding of smart grids in Europe. Based on this common general understanding of smart grids, a list of smart grid standards is currently being developed in Europe. The standardization process from Europe might serve as a role model for smart grid standardization in China. In this context, the authors of this study specifically emphasize the importance of integrating additional stakeholders (i.e. third parties) into the standardization process.

Regulatory pathways for smart grid development in China There are inherent conflicts between the fundamental energy policy goals of reliability, affordability, and sustainability. As a result, governments have to be aware of the society's energy policy priorities to choose an appropriate energy sector regulation.

The implementation sequence of the given recommendations is not arbitrary with respect to the energy policy goals. In order to give policy makers an impression of how policy goal prioritization influences the timeline in which the recommendations should be implemented, the present study outlines three possible regulatory pathways. Each of these pathways prioritizes one specific goal of the energy policy triangle and develops an implementation roadmap accordingly. These roadmaps are intended to serve as blueprints for policy makers, who have to decide about proper regulation based on the individual Chinese prioritization of energy policy goals.

Figure Summary 2 summarizes the implementation sequences for all three policy goals with recommendations to be implemented in the short term on the left hand side of the figure. Comparing the implementation sequences in all three scenarios reveals that there are two recommended approaches with the highest overall priority. The measures subsumed within these recommendations shall be implemented independently of the underlying scenario:

- *Define a long-term strategy for the electricity sector and establish an independent and powerful regulator,* and
- *Coordinate network expansion planning for electricity grid expansion and upgrade.*

Three of the remaining five recommendations are relevant in each scenario, though with a lower priority:

- The *Improvement of the grid integration of RES* has a very high priority under the *Ecological Sustainability* scenario and is also important for the *Reliability/Security of Supply* scenario. It is somewhat less important in the *Affordability/Competition* scenario.
- The *Facilitation of the development of a unified view of smart grids* is especially important with respect to the *Reliability/Security of Supply* scenario. It is somewhat less important with regard to the *Affordability/Competition* and *Ecological Sustainability* scenarios.

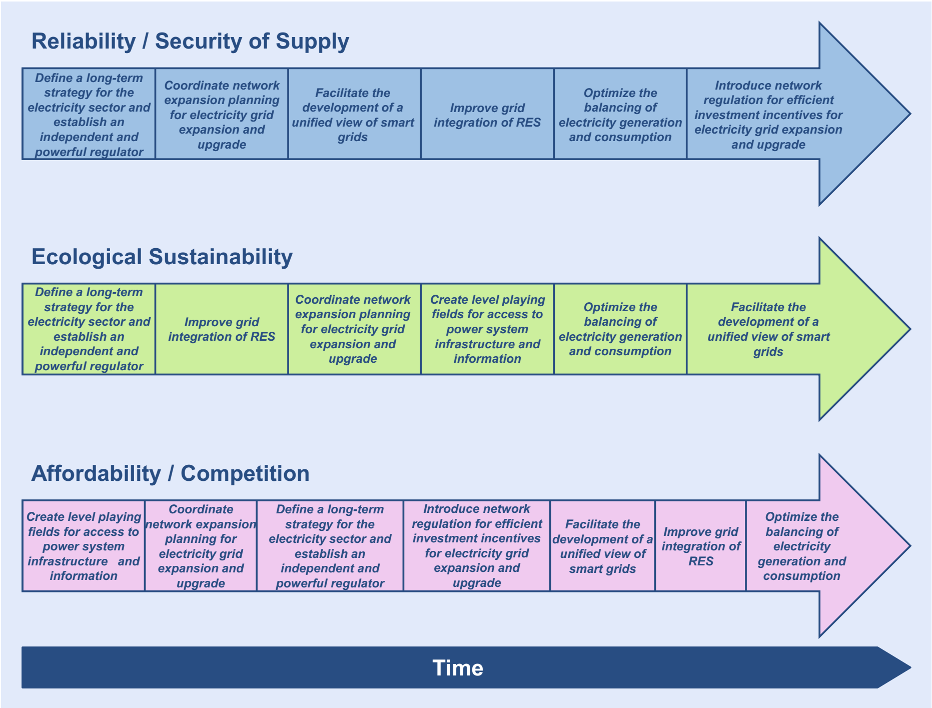


Fig. Summary 2 Overview of proposed implementation sequences for all three scenarios

- The *Optimization of the balancing of electricity generation and consumption* is particularly relevant for the *Reliability/Security of Supply* scenario. The recommendation has a lower relevance in the *Ecological Sustainability* scenario and is ranked last in the *Affordability/Competition* scenario.

The two remaining recommendations are not relevant in every scenario. Rather, they contribute to single energy policy goals. In particular, both of these recommendations are essential for migrating towards smart grids focusing on affordability and competition:

- The *Creation of level playing fields for access to power system infrastructure and information* is the first recommendation that should be implemented if the government strives to develop smart grids focusing on affordability and competition. It is also important if the government chooses to focus on ecological sustainability.

The *Introduction of network regulation for electricity grid expansion and upgrade* is at position four in the implementation sequence of the *Affordability/Competition* scenario. It is also relevant, though at a later stage, in the *Reliability/Security of Supply* scenario.

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Abbreviations

3GThird	Third Generation of Mobile Telecommunications Technology
AbLaV	Verordnung über Vereinbarungen zu abschaltbaren Lasten (Deutschland)/Ordinance on Disconnectable Loads (Germany)
AC	Alternating Current
ACATECH	Deutsche Akademie der Technikwissenschaften (Deutschland)/German Academy of Science and Engineering (Germany)
ACER	Agency for the Cooperation of Energy Regulators
AMI	Advanced Metering Infrastructure
AMS	Asset Management Systems
ARegV	Anreizregulierungsverodnung (Deutschland)/Incentive Regulation Ordinance (Germany)
BDI	Bundesverband der Deutschen Industrie (Deutschland)/Federation of German Industries (Germany)
BImSchG	Bundesimmissionsschutzgesetz (Deutschland)/Federal Pollution Control Act (Germany)
BITKOM	Bundesverband Informationswirtschaft, Telekommunikation und neue Medien e.V. (Deutschland)/Federal Association for Information Technology, Telecommunications and New Media (Germany)
BMAS	Bundesministerium für Arbeit und Soziales (Deutschland)/Federal Ministry of Labor, Social Affairs and Consumer Protection (Germany)
BMUB	Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (Deutschland)/Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (Germany)
BMVI	Bundesministerium für Verkehr und digitale Infrastruktur (Deutschland)/Federal Ministry of Transport and Digital Infrastructure (Germany)
BMWi	Bundesministerium für Wirtschaft und Energie (Deutschland)/Federal Ministry for Economic Affairs and Energy (Germany)
BNetzA	Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen (Deutschland)/Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway (Germany)
CDH	Central Data Hub
CDMA	Code Division Multiple Access
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Organization
CHP	Combined Heat and Power Plants
CO_2	Carbon Dioxide
CSG	China Southern Power Grid Company Limited
DAM	Data Access Point Manager
DC	Direct Current
DIN	Deutsches Institut für Normung (Deutschland)/German Institute for Standardization (Germany)
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
DSM	Demand Side Management
DSO	Distribution System Operator(s)
EC	European Commission
EEG	Erneuerbare-Energien-Gesetz (Deutschland)/Renewable Energy Act (Germany)
EEX	European Energy Exchange
EnLAG	Energieleitungsausbaugesetz (Deutschland)/Energy Network Development Act (Germany)
ENTSO-E	European Network of Transmission System Operators for Electricity
EnWG	Energiewirtschaftsgesetz (Deutschland)/Energy Industry Act (Germany)
ETSI	European Telecommunications Standards Institute
EU	European Union

FACTS	Flexible Control and AC Transmission Systems
FEG	Future Energy Grid
FINSENY	Future Internet for Smart Energy
FNN	Forum Netztechnik/Netzbetrieb im Verband der Elektrotechnik Elektronik Informationstechnik e.V. (Deutschland)/Forum Network Technology/Network Operation in the Association of the Electrical, Electronic and Information Technology (Germany)
GDP	Gross Domestic Product
GW	Gigawatt
GWh	Gigawatt Hour
GSM	Global System for Mobile Communications
GPKE	Geschäftsprozesse zur Belieferung von Kunden mit Elektrizität (Deutschland)/Business Processes for Delivery of Electricity to Customers (Germany)
GPRS	General Packet Radio Service
GWAC	GridWise Architecture Council
GWB	Gesetz gegen Wettbewerbsbeschränkungen (Deutschland)/Act Against Restraints of Competition (Germany)
HV	High Voltage
HVDC	High Voltage Direct Current
ICT	Information and Communication Technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
ITO	Independent Transmission Operator
ITU	International Telecommunication Union
kV	Kilovolt
kVA	Kilovolt Ampere
kWh	Kilowatt Hour
LV	Low Voltage
LTE	Long Term Evolution
MessZV	Messzugangsverordnung (Deutschland)/Metering Access Ordinance (Germany)
MOF	Ministry of Finance of the People's Republic of China
MV	Medium Voltage
MWh	Megawatt Hour
NABEG	Netzausbaubeschleunigungsgesetz Übertragungsnetz (Deutschland)/Grid Expansion Acceleration Act for Transmission Networks (Germany)
NDP	Network Development Plan
NDRC	National Development and Reform Commission of the People's Republic of China
NEA	National Energy Administration of the People's Republic of China
NO_x	Nitrogen Oxides
nTPA	Negotiated Third Party Access
OECD	Organisation for Economic Co-operation and Development
OTC	Over-The-Counter
PAS	Publicly Available Specification
PLC	Power-Line Communications
PV	Photovoltaic
R&D	Research and Development
RES	Renewable Energy Sources

RES-E	Electricity generated by means of RES
ROE	Return on Equity
RPI	Retail Price Index
rTPA	Regulated Third Party Access
SCADA	Supervisory Control and Data Acquisition
SDO	Standards Developing Organizations
SERC	State Electricity Regulatory Commission of the People's Republic of China
SGAM	Smart Grid Architecture Model
SGCC	State Grid Corporation of China
SG-CG	Smart Grid Coordination Group
SGIS	Smart Grid Information Security
SGTF	Smart Grids Task Force
SO_2	Sulfur Dioxide
SOE	State-Owned Enterprise(s)
SSM	Supply Side Management
StromStG	Stromsteuergesetz (Deutschland)/Electricity Tax Act (Germany)
TSO	Transmission System Operator(s)
TWh	Terawatt Hour
UHV	Ultra High Voltage
UMTS	Universal Mobile Telecommunications System
UN	United Nations
UN/EDIFACT	United Nations Electronic Data Interchange for Administration, Commerce and Transport
USB	Universal Serial Bus
USDOD	United States Department of Defense
USDOE	United States Department of Energy
VPP	Virtual Power Plant(s)
WAMS	Wide Area Monitoring Systems
WG FSS	Working Group First Set of Standards
WG RA	Working Group Reference Architecture
WG SGIS	Working Group Smart Grid Information Security
WG SP	Working Group Sustainable Processes
WHO	World Health Organization

Table of Contents

List of Figures

List of Tables

1

Introduction

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1

Smart grids – an innovative solution for upgrading the conventional power grid infrastructure Around the world, power grid operators have to cope with several technological challenges ranging from aging grid infrastructures and fluctuating load levels to the integration of intermittent[1] *renewable energy sources* (RES). These challenges tend to result in supply security problems. The traditional way to deal with such problems is to invest heavily in the conventional (primary) grid infrastructure by installing components like new cables, overhead lines, transformers with higher capacities, additional switch panels, or converter stations.[2]

Several modern technologies have been or are currently being developed which are aimed at reducing investments in the traditional grid infrastructure by increasing operational efficiency, making it possible to fully utilize the capacity of the existing power grid infrastructure and leveraging flexibilities in electricity generation and consumption.

Examples of such innovations designed to upgrade electric power grids[3] are modern information and communication technologies as well as advanced power grid components for metering, measurement and control, and automation. Power grids incorporating these new technologies are commonly referred to as smart grids [1].

Smart grid technologies open up many new possibilities in power grid management and control, e. g. the status of distribution grids can be monitored in real-time when sensoring and communication networks are added. With the help of the information gathered, modern automation and control technologies can be employed to supervise and actively control grids increasing their utilization rate and preventing overloads via grid capacity management [1]. Thus, the need for costly grid expansion may be reduced while the stability of the grid and security of supply can be improved [1].

Challenges to China's current electric power system China faces tremendous challenges with regard to the development of its electric power system. According to China's *12th Five-Year Plan for Energy Development*, massive investments in power generation and grid capacities have to be made to cope with the steadily rising power consumption [2].

Different sources point to a low level of equipment sophistication in parts of the electric power grid in China, especially at the distribution grid level. In some instances, outdated and inefficient distribution transformers are still in operation [3], [4]. This contributes to a considerable number of supply interruptions, despite the fact that significant advancements have been made in recent years. At the same time, requirements of China's quickly modernizing industry with regard to power quality are on the rise and cannot be met at all times [5].

China has to cope with increasing air pollution problems [6] and is the world's largest emitter of *carbon dioxide* (CO_2) [7]. Its power generation sector, which is mainly relying on coal as an energy resource, is responsible for a large share of CO_2 emissions.

Government targets for China's future electric power system In light of these challenges, the Chinese government issued specific targets for the physical and technological development of the power system up to 2015: power generation capacities are to increase from 970 *gigawatts* (GW) in 2010 to 1,490 GW in 2015 [2] and they are projected to attain 1,935 GW in 2020 [8]. Also, the share of power generation from RES and nuclear energy is planned to be increased significantly, with an official target of 11.4 % of total primary energy coming from non-fossil sources by 2015 and 15 % by 2020 [9]. In China, power generation from RES is considered a key instrument to reduce the dependency on coal power, stop the deterioration of air quality,

1 Electricity from an intermittent energy source is not continuously available due to factors outside direct control and cannot be dispatched to meet the demand of a power system. Intermittent RES are tidal power, wind power, or solar power, while biomass, geothermal, and hydro power are dispatchable and non-intermittent RES. Note that the term variable RES is used as a synonym for intermittent RES in the present study.

2 The term conventional grid infrastructure refers to passive electronic components necessary for establishing an electric connection between electricity generators and consumers [1]. Note that this perspective mainly serves an explanatory purpose, because currently no grid is built or operated exclusively with passive components [1].

3 The specific term electric power as well as the general term power are both used as a synonym for electricity in this study. Only if the term energy is used, non-electric power forms such as heat or kinetic energies are referred to.

and reduce the growth rate of CO_2 emissions [9]. The State Council also stipulated that long-distance, inter-regional and inter-provincial transmission of electricity shall be promoted in order to build a nationally integrated backbone grid. In addition, urban and rural distribution grids are planned to be expanded and renovated [2]. Investments in the grid infrastructure are projected to reduce power supply interruptions and to increase power quality. Considering the power consumption side, there are plans to significantly increase the efficiency of power use and to provide access to electric power even in very remote regions of China by 2015 [2], [10].

China's government also plans to make considerable advancements on the organizational level: a modern energy market system is to be established, market-related reforms in key energy sectors are projected to take place, energy pricing mechanisms are to be improved, and the development towards an internationally competitive environmental and energy industry is to be accelerated [2].

To support accomplishment of the government targets for China's future electric power system, the government aims at starting to build up smart grids during the next several years. As has been formulated in the *12th Five-Year Plan for Energy Development*, China's government aims at promoting the development of smart grids [2]. Also, the *Chinese Ministry of Science and Technology* (MOST) released a special plan for technological smart grid improvements in 2012 [11].

Barriers to the implementation of smart grids in China Some aspects of China's technological and regulatory framework may present obstacles to an effective and efficient smart grid development:

- Overlapping responsibilities between different government institutions affect the government's ability to guide and facilitate the development of smart grids [5] [12].
- Compared to the electricity sectors in other countries, the i*nformation and communication technology* (ICT) industry, small-sized power generation companies, and other non-established players like prosumers[4] are underrepresented in (smart) grid development planning in China.
- Due to rather low electricity prices, the current tariff system may not offer sufficient incentives for saving electricity or for shifting electricity demands according to available generation and grid capacities [12].
- A lack of sufficient incentives for grid integration of RES within the existing regulatory framework persists [13].
- Similar to all other countries aiming at developing smart grids, some of the key smart grid technologies in China are not yet fully developed and some equipment specifications and standards are still inconsistent [3], [4], [14].

Idea of the study The aim of the present study is to analyze and discuss regulatory policies supporting the build-up of smart grids in China. The work is based on experiences gathered in Germany and other countries. In the context of the study, the term regulation is not restricted to purely regulatory issues. Rather, government policies such as the promotion of *research and development* (R&D) or standardization issues are also included.

Smart grids follow an evolutionary pathway and their realization depends on the status quo of the existing grid infrastructure. Therefore, this study contains a detailed description of China's and Germany's electric power systems, their most pressing technological challenges, and their regulatory environments. Based on these descriptions, both countries' specific technological views on smart grids are presented.

Regulatory smart grid pathways designed to meet the specific challenges in China are presented subsequently. The pathways include dedicated recommendations that are based on regulatory best practices from Germany and other countries. The recommendations build upon the current situation in China proposing achievable changes to the regulatory framework and relevant policies to promote smart grid development in China.

The structure of the study The structure of the study is visualized in Fig. 1.1 and briefly outlined below:

- ► Chapter 2 presents the conceptual framework of the study. The chapter also introduces

4 Prosumers are end consumers of electricity which also generate electricity, for example by means of rooftop photovoltaic installations.

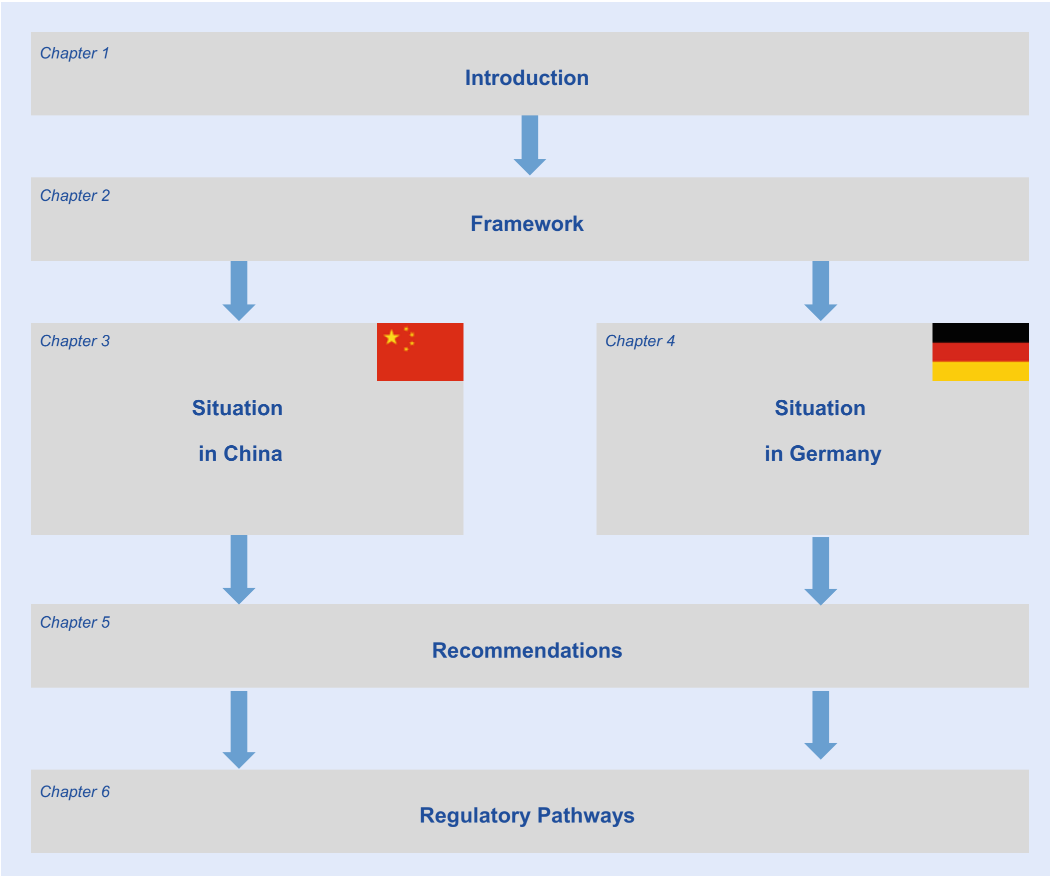

Fig. 1.1 Structure of the study

the so-called *energy policy triangle* covering the three main energy policy goals reliability, affordability, and sustainability. Fundamental premises highlighting the importance of smart grids and explaining the role of the government in the smart grid development process are presented as well. The chapter also discusses the importance of electric power markets and third parties, i. e. new participants in the value chain of the electric power sector, for smart grids.

- ▶ Chapter 3 presents China's electric power system, its recent historical development, its regulation, government targets for China's future electric power system, and the role of smart grids in this context. A clear focus is placed on technological and regulatory challenges for China's electric power system.
- ▶ Chapter 4 contains a description of the German situation focusing on lessons learned and sharing the German experience (corresponding to challenges presented in ▶ Chap. 3).
- ▶ Chapter 5 presents recommendations designed to meet the specific challenges in China. Where appropriate, the recommendations refer to best practices from Germany.
- ▶ Chapter 6 presents three different regulatory pathways (roadmaps) each focusing on a different objective of the energy policy triangle. This offers policy makers an insight of the effects different policy priorities may have on the implementation sequence of the study's recommendations.

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Conceptual framework and background

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Chapter at a glance

- The study's conceptual framework is presented.
- This chapter illustrates the role of regulation and technological progress for the development of the electric power system and introduces the energy policy triangle covering the three main energy policy goals reliability, affordability, and sustainability.
- The concept of and the motivation for smart grids are introduced.
- Fundamental premises highlighting the role of the government and new market actors in the smart grid development process are presented.

2.1 The power sector supply chain and regulatory environment of smart grids

The supply chain model of the electric power sector The delivery of electricity from generation sources to end consumers involves a multitude of technologies, actors, and processes, especially in the context of the development of an intelligent future-oriented power grid infrastructure. Therefore, it is useful to employ a supply chain model of the electric power sector (or electricity system) to structure the debate on smart grids.

In this study, a *smart grid supply chain model* (see Fig. 2.1) is used to structure the discussion on China's and Germany's power systems along with their most pressing problems and challenges as well as their particular approach of how to promote the development of smart grids. The model subdivides all activities/processes, technologies, and actors of the power sector supply (or value) chain into four basic elements:[1]

- ***Power Generation:*** the technical generation of electricity using various kinds of primary energy sources (such as coal, gas, nuclear, hydro, wind, and solar energy) and corresponding ancillary services.[2]
- ***Power Logistics:*** the transmission, distribution, storage, and metering of electricity.
- ***Power Trade & Retail:*** purchasing, trading, and selling electricity, as well as retail and billing services for end consumers.
- ***Power Consumption:*** the end use of electricity by different end-user segments, e.g. rural and urban households, industrial and commercial consumers.

To capture the importance of ICT for transforming the traditional power sector into a smart grid, a corresponding fifth element is added to the model:

- ***Information & Communication:*** operating, monitoring, and controlling power system components, as well as power system-related information exchange between various market actors with the help of ICT along all four stages of the power sector supply chain.

The government plays a pivotal role in the smart grid development process (see ▶ Sect. 2.3) as a guiding and supervising key player affecting processes and businesses across all five supply chain elements.

The regulatory environment of smart grids In the remainder of this study, six regulatory areas will be used to describe the regulatory environments of China's and Germany's power systems.

The six regulatory areas are:

- ***Policy Setting and Fundamental Institutions:*** Government leadership in form of policies, laws, and regulation is essential to promote smart grid development. To practice such a leadership, a governance structure with clearly assigned roles and responsibilities for the field of (smart) grid regulation is of crucial importance.
- ***Market Structure:*** The (market) structure of the electric power sector is characterized by all

1 The smart grid supply chain model being referred to in this study is based on the so-called *Energy Process Management* (EPM) model [16].

2 Ancillary services are functions performed by the equipment and people generating, controlling, transmitting, and distributing electricity with the intention of supporting basic services of generating capacity, energy supply, and power delivery [17]. Examples are load following, scheduling and dispatch, real-power loss replacement, and voltage control (e.g. by means of reactive power supply).

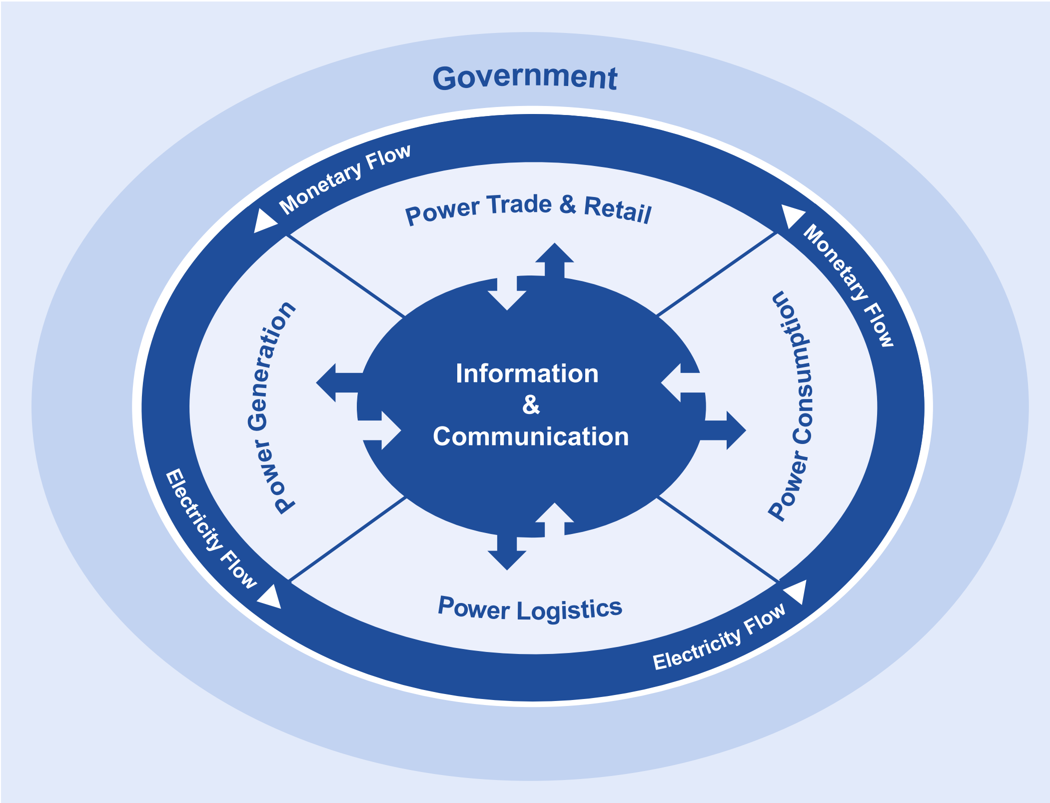


Fig. 2.1 Electric power sector supply chain model

the companies involved in the various stages of the power sector supply chain from *Power Generation* and *Power Logistics* to *Power Trade & Retail* (vertical market structure), the market composition and competitive conditions at different stages of the supply chain (horizontal market structure), and the roles and responsibilities of the market actors.

- ***Market Design and RES Integration:*** Electricity prices (for generation and retail) are of crucial importance with regard to the utilization of different sources of power generation, investment decisions for new generation capacities, power consumption patterns, and investments in power saving technologies. By setting monetary incentives for investments into power generation capacities, generation electricity prices contribute particularly to the long-term coordination of power generation and consumption. At the same time, retail electricity prices have the power to directly affect the patterns of electricity consumption of end users. The formation of electricity prices is heavily affected by the market structure and the underlying market design, the latter of which is generally defined by the government. Feed-in tariffs for RES and associated regulations are also part of the market design because they represent nothing less than prices for electricity generation fixed by the government.
- ***Development of Infrastructure and Network Regulation:*** The regulatory domain explains how investments in the (smart) grid infrastructure can be incentivized through power grid or network regulation. These regulatory practices directly impact the stable and affordable operation of the current grid infrastructure and the investments in the future grid infrastructure.
- ***Coordination of Generation and Consumption:*** In this regulatory area, government policies for

balancing electricity generation and consumption in the short term are described. Many smart grid-related technologies facilitate the balancing of generation and consumption.

- ***The Role of Information and Communication:*** Integration of ICT with power system components across the supply chain is a key factor in smart grid development. This regulatory area covers the relevance of ICT companies, standardization issues, cyber security, and funding of smart grid research.

2.2 The role of regulation and technological progress for the development of electric power systems

Regulation in the electric power sector Competition, where feasible free from government intervention, is generally considered as a very effective way of reducing production costs, improving quality of supply, and increasing product diversity [1], [2]. Yet, competition is not always feasible. Especially where natural monopolies prevail, competition cannot exist and government regulation is necessary [3].

Transmission and distribution grids are such natural monopolies. Having an infrastructure of overlapping power grids from different competitive suppliers would be economically inefficient. Due to economies of scale, a single supplier (the monopolist) is able to offer the services of the electric power grid at lower costs. However, the monopolistic grid operator has a strong incentive to set high prices for its services or to scrimp on quality. Thus, the price and quality of service of the monopolistic grid operator must be regulated to protect grid users against the monopolist's market power [3].[3]

It is common to distinguish two related goals of monopoly regulation [3] which are both typically tasks for the regulator, like the *Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway* (BNetzA) in Germany:

- Control of revenues and prices of the networks (i. e. network charges)
- Secure access to the monopolistic infrastructure (i. e. the network) to facilitate competition among market actors in the commercial parts of the electricity value chain (e. g. generation, trade and retail).

Moreover, the internalization of so-called *externalities* is a frequently cited argument in favor of government intervention even in the non-monopolistic parts of the electric power system:

- ***Negative externalities:*** the generation of electricity is often connected to emissions of environmental pollutants. Without government intervention, neither producers nor consumers of electricity are sufficiently incentivized to behave in an environmentally friendly manner. Therefore, actions of the government such as pollution control laws, energy taxes, and subsidies for environmentally friendly technologies are used to reign in commercial activities and advance the overall societal objectives like environment protection and sustainable development [1].
- ***Positive externalities:*** technological progress critically depends on the creation of new knowledge. After its creation, knowledge can be used over and over by various actors with almost no extra costs. From the perspective of the whole society, companies often do not invest enough in knowledge creation because a significant portion of the benefits related to knowledge creation accrues to outside stakeholders, e. g. other companies, institutions, or citizens. In this light, government actions such as a patent law, a stringent protection of intellectual property rights, or the subsidization of R&D can be employed to incentivize companies to invest in knowledge creation and innovation.

This study adopts a broad understanding of regulation and does not only focus on network regulation

3 Note that, at the beginning of the electrification process, the power generation sector was also recognized as a natural monopoly: in the absence of power transmission lines, competition between power generation units from different cities or regions was not possible. With the rather small electricity demand in separated cities or regions, one larger power plant was able to provide the electric power at lower costs than many small competitive power plants due to economies of scale. However, the gradual deployment of transmission lines allowed competition between large power plants to evolve in such a manner that power generation is no longer considered to be a natural monopoly [3].

but also upon aspects such as RES integration, innovation policies, and standardization.

A stylized history of power system development The historical development of electric power systems dates back to the last decades of the 19th century in the world's most advanced countries of that era. The electrification process in these countries was mostly accomplished by the mid-20th century, when almost the whole population had access to electric power. In less developed regions, the electrification process started somewhat later and progressed at a considerably slower pace. Differences in onset and pace of the electrification process between countries can be explained mainly with technological, economic, political, and regulatory reasons [4].

In developing their electric power systems, many countries followed a similar stylized pathway. At the beginning of the electrification process, the emergence of new technologies and appliances consuming electric power led to a rapidly increasing demand for electricity. Thus, the main objective was to connect a growing number of consumers as quickly as possible to the electric power grid. The build-up process took place in a rather uncoordinated manner with only little government intervention. Thus, various small-sized companies set up overlapping infrastructures such as small-sized power plants and distribution lines. This uncoordinated set-up phase was often associated with low power quality and reliability as well as high costs. Therefore, governments started to regulate the electricity sector with the intention of making power supply more reliable and affordable. Formally assigning monopoly rights to power generation companies and grid operators created economies of scale, which reduced the overall production costs of electric power generation and distribution. After this assignment of monopoly rights, electricity market regulation became a decisive factor to protect consumers against the market power of the newly installed monopolies.

When a certain level of wealth and economic development had been achieved, the awareness of environmental protection increased in many societies.[4] Therefore, more emphasis was put on ecological sustainability of the electric power system and many governments introduced environmental protection policies.

The energy policy triangle The schematic history presented above reveals that different objectives and regulations were prioritized at different development stages of the power system. Whereas the provision of widespread and reliable access to electricity was often the initial motivation, affordability of electric power emerged as a second driver of energy policy after the initial build-up phase. Finally, the ecological sustainability of the electric power system has often been formulated as a third important priority.

Today, governments strive to incorporate all three objectives in their power sector regulation. They (1) want to provide a reliable and secure electricity supply for their economies, (2) simultaneously promote economic development by ensuring affordable electricity prices while (3) also achieving ecological sustainability. The three goals *reliability*, *affordability*, and *sustainability* are commonly referred to as the *energy policy triangle* (see ◘ Fig. 2.2).

Conflicting nature of the energy policy triangle There are inherent conflicts between the goals of the energy policy triangle. A government forcing owners of fossil-fuel power plants to install filter technologies for the sake of improving air quality, for instance, is accepting that costs of power generation increase. Another government using expensive domestic resources for electricity generation instead of lower-priced resources available on world markets accepts higher generation costs for the sake of independent and predictable energy supply.

The complete and simultaneous achievement of all three policy goals is virtually impossible. Therefore, most countries place a priority on one or sometimes two policy goals, trying to achieve or maintain acceptable levels with regard to the non-prioritized policy goals. In recent years, the Chinese government, for example, prioritized (1) providing a reliable and secure electricity supply and (2) keeping electricity prices for the population at an affordable level. On the other hand, it has accepted high levels of environmental pollution. The German government, in contrast, has been placing a strong

4 The positive correlation between economic development and environmental preferences has been well documented during the last two decades [18].

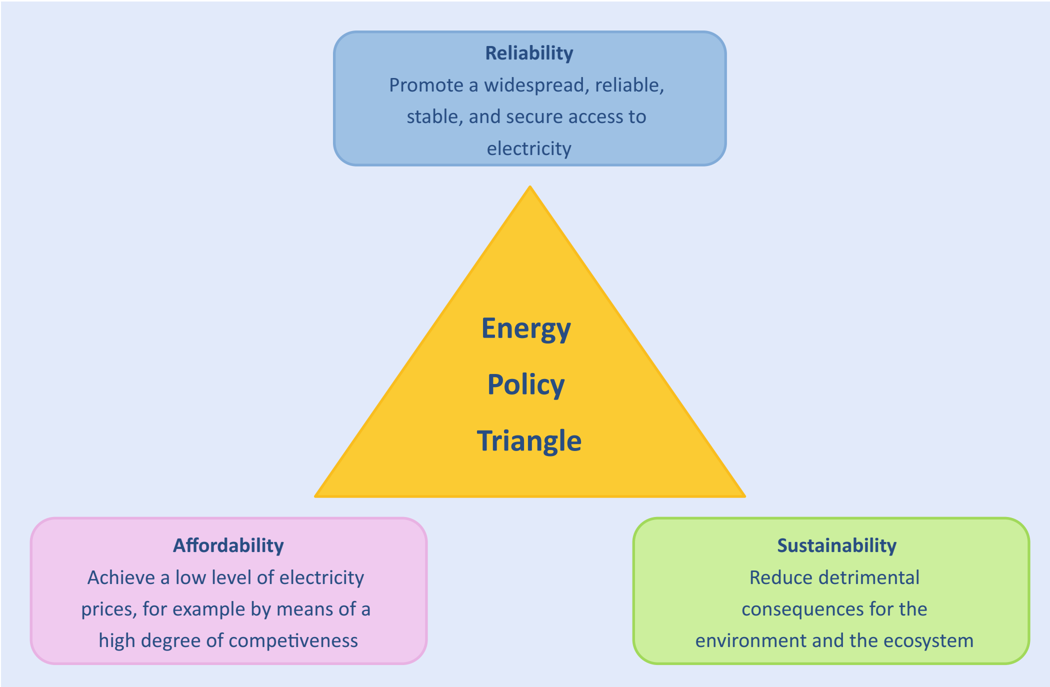


Fig. 2.2 Energy policy triangle

emphasis on ecological sustainability since the end of the 20th century. A prominent strategic decision in this context was the build-up of RES generation capacities so that currently approximately one fourth of Germany's electricity comes from RES [5]. The high share of RES in Germany currently leads to increasing challenges with regard to the policy goals of reliability and affordability. However, both conflicts may be mitigated by means of technological progress as well as smart design of policies and regulatory framework:

- In most cases, electricity generated by means of RES, so-called *RES-E*, is still more expensive than electricity generated in fossil fuel-fired power plants. This difference in generation costs has contributed significantly to climbing end consumer prices for electricity in recent years. Nonetheless, RES-E is often already cheaper than electricity retail prices (known as *grid parity*) depending on the characteristics of location and end-user segment. The costs of RES-E have decreased considerably during the last few decades and are projected to decrease even more with further technological advancement and economies of scale through worldwide deployment [6]. Someday, the costs of renewably generated electricity will consequently fall below those of electricity generated in conventional power plants. From that time on, investments in RES will increase both sustainability and affordability of the power system provided that the power system and market design allow for a minimizing of grid integration costs.
- With a rising of electric power generated by variable RES, more and more efforts have to be undertaken to guarantee the high stability and reliability of the power system. Below, two examples of temporary RES penetration in Germany, a power system with electricity loads commonly ranging from 40 to 80 GW, are presented: on December 5th 2013, a particularly windy day, roughly 27 GW of feed-in was generated by means of wind turbines in Germany [7]. On March 9th 2014, a very sunny day, *photovoltaic* (PV) installations alone fed a

peak power of almost 22 GW into the grid [7]. Technological progress as well as adaptations to the existing design of the electricity market in Germany are essential to limit the cost of the ongoing transition towards a low carbon economy.

2.3 Smart grids – promising technological innovations

The concept of smart grids The capabilities of conventional power grids to cope with many of today's technological challenges, e. g. the integration of a large share of electricity generated by means of intermittent RES, are limited or can only be maintained with significant investments. In this light, smart grids represent a promising new technological concept. Today, the general understanding regarding the concept of smart grids seems to converge on a global level. A definition of smart grids which has found widespread acclaim in the professional community comes from the *International Energy Agency* (IEA) [8]:

> *An electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end users. Smart grids co-ordinate the needs and capabilities of all generators, grid operators, end users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimizing costs and environmental impacts while maximizing system reliability, resilience and stability.*

Another explanation of the smart grid concept comes from the *International Electrotechnical Commission* (IEC) [9]:

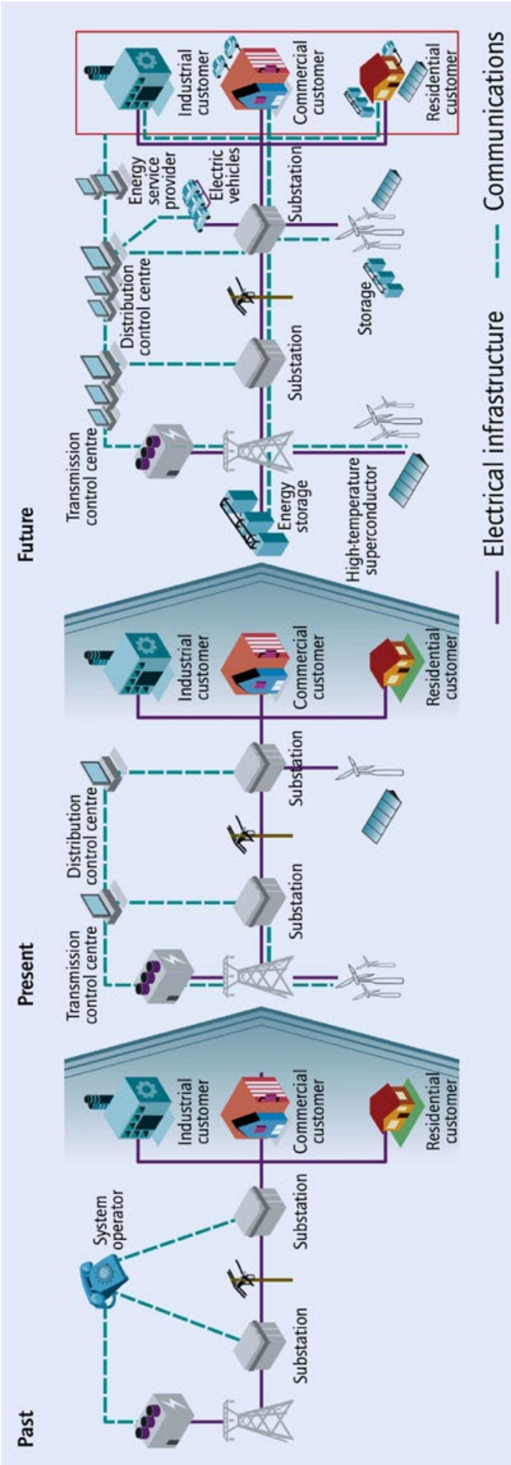
> *The general understanding is that the Smart Grid is the concept of modernizing the electric grid. The Smart Grid comprises everything related to the electric system in between any point of generation and any point of consumption. Through the addition of Smart Grid technologies the grid becomes more flexible, interactive and is able to provide real time feedback.*
>
> *It is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies.*

Irrespective of the common general understanding of smart grids, the specific vision of smart grids differs substantially from case to case and from country to country. Technologies that are included in one smart grid concept are not necessarily included in another.

Motivation for smart grids Smart grids are generally expected to cope with the most pressing problems and challenges of many power systems more effectively and efficiently than conventional grid technologies. Smart grids primarily aim at delivering enhanced levels of reliability and security of supply, facilitating the balancing of electricity generation and consumption, increasing the utilization rate of power system components, and reducing investments in the conventional (primary) grid infrastructure. Smart grid technologies can be used, for example, to

- monitor and control electric power grids more effectively,
- facilitate the grid connection and operation of generators of all sizes and technologies,
- help to integrate electricity generated from intermittent RES,
- allow industrial, commercial, and residential consumers to play a part in optimizing the operation of the system by adjusting electricity consumption behavior according to supply, and
- provide consumers with greater information on their electricity consumption enabling electricity conservation [9].

The evolutionary character of smart grids Smart grids are not built from scratch. Rather, they evolve from conventional power grids which are upgraded with different kinds of innovative technologies and components. These technologies and components will be deployed at different periods in time depending on commercial attractiveness, compatibility with existing technologies, regulatory policies, and



■ **Fig. 2.3** Development of smarter power systems (© OECD/IEA [8])

investment frameworks. The evolutionary pathway of smart grid technologies is similar to that of other innovations: after major R&D efforts, smart grid technologies are developed further in specific demonstration projects, tested in model cities or regions, and finally deployed on a larger scale.

Today's smart grid technology landscape is highly diverse with some technologies reaching already high levels of maturity and others still in a development process. Smart grid-related technologies with high levels of maturity are, for example, power plant communication and control modules, grid control systems, and *advanced metering infrastructures* (AMI). On the other hand, technologies such as wide area monitoring and control, distribution management, or electric vehicle charging infrastructure require more progress before they are mature enough for large-scale deployment [8].

■ Figure 2.3 visualizes a stylized evolutionary pathway of smart grids: in the past (left part of the illustration), electric power was mainly generated in thermal power plants. The status of high, medium, and low voltage grids was not remotely monitored. System operators were able to supervise substations at different voltage levels via rudimentary telecontrol or by means of manual patrol teams.

In the present (middle part of the illustration), large wind farms complement thermal power plants feeding in electricity at the *high voltage* (HV) level. The status of transmission grids and the associated substations is remotely monitored. The resulting status information is received in the transmission control center and can be used to monitor and control the grid. *Medium voltage* (MV) and *low voltage* (LV) grids, however, are not yet equipped with sophisticated monitoring technologies. The distribution control center only monitors the associated substations via telecontrol or by means of manual patrol teams. For the first time, small-sized wind farms and PV installations are being connected to distribution grids.

In the future (right part of the illustration), power grids at all voltage levels are expected to be equipped with sophisticated monitoring and control technologies. Status information, e. g. on electricity generation and consumption, will also be available for distribution grids. RES, energy storage installations, and electric vehicles will become an integral part of the future electric power system and will be able to exchange status information with the grid.

The role of governments in the smart grid development process Given the evolutionary character of smart grids and the low maturity levels of some smart grid technologies, both a systematic guidance and specific government support policies are essential to promote the development of smart grids. Exemplary government policies in this context are:

- Setting up a government long-term strategy for the development of the future electricity system to reduce investment risks for potential investors in R&D and deployment of smart grid technologies.
- Establishing network regulation for transmission and distribution grid operators which incentivizes them to invest in smart grid technologies.
- Promoting a non-discriminatory and technology-neutral management of and access to power system data to enable companies to develop innovative business models making use of this data.
- Partial government funding of R&D to increase the maturity level of smart grid technologies.
- Supporting smart grid-related standardization, defining technical guidelines and regulations to reduce the costs for deployment and integration of different smart grid components by ensuring interoperability.
- Promoting the exchange and collaboration between different government organizations, power sector companies, academia, associations, and other relevant actors to create a common understanding of smart grids.

The role of new market actors in the smart grid development process In Germany and many other countries, one important trend associated with the migration towards smart grids and the transition to an electricity system relying to an increasing extent on RES-E is a rise in the number of market actors in the electricity sector. New market actors (*third parties* or *non-incumbents*) can expand the horizontal market structure by entering into competition with established companies (*incumbents*) with regard to existing products or services (e.g. operators of renewable energy plants or new power retail companies). New market actors can also expand the vertical market structure by being pioneers offering products and/or services in new market sectors or niches (e.g. energy service companies or virtual power plant operators[5]) or in using existing knowledge and/or infrastructure from other sectors in an innovative way upgrading products and services in the electric power sector (e.g. ICT companies).

New market actors offer innovative products and services that were not supplied by established market actors before. In a smart grid context, non-incumbents create new business models and offer new products and services by making use of available power system information and infrastructure in an innovative way. To give some tangible examples for the power sector innovations that may be driven by third parties, ► Sect. 4.4.2 highlights how non-incumbents in Germany create new business models in the smart grid development process. Note that the German evidence elaborated in ► Sect. 4.4.2 also demonstrates that new market actors might emerge due to government policies aimed explicitly at the promotion of competition.

In expanding the horizontal market structure, third parties contribute to an increased level of competition. Higher competition levels are usually considered to drive innovation, enable greater efficiency in the allocation of resources, increase cost efficiency of power sector enterprises with regard to their operations and investments, contribute to lower retail price levels, and stimulate innovation resulting in a higher variety of competitively priced products and services offered to the customer:

- With regard to the electric power sector, IEA analyzed the market liberalization process in several of its member countries and came to the conclusion that higher competition levels in the electric power sector contributed to a reduction of electricity prices for industrial consumers [10].
- With respect to the telecommunication sector, various empirical studies (including data from industrial and developing countries) found

5 Both new market actors are introduced in more detail in Sect. 4.4.2.

2

that high competition levels significantly increased the overall sector performance and led to more landline and mobile telephone connections, lower tariffs, and more connection capacity [11], [12], [13]

- In the general economic literature, the relationship between competition and innovation has been examined in many theoretical and empirical studies. It is usually found that there is a kind of optimal market structure for R&D-spending, innovation and diffusion. Neither very low nor very high competition levels are an innovation-friendly environment. A competitive market with a limited number of companies seems to promote innovation best [14].

Economic efficiency of smart grids The economic evaluation of smart grids is still ongoing. However, early evidence suggests that smart grids are an attractive solution compared to conventional grid expansion measures. A recent study summarizes the results of twelve smart grid cost-benefit analyses published between 2004 and 2012 in the United States, the UK, the Netherlands, Denmark, and the Czech Republic [15]. This overview shows that benefits of the investigated smart grid concepts outweigh costs in ten of twelve cases (with costs outweighing benefits in Denmark and the Czech Republic). Only four of these studies compared their results to costs and benefits of conventional grid expansion measures (increasing the grid capacity by traditional network expansion). These studies come to the conclusion that, from an economic point of view, investments in smart grid technologies are preferable to conventional expansion measures.

Key findings

- Governments strive to provide a reliable, affordable, and sustainable electricity supply for their economies. Yet, there are inherent conflicts between these three energy policy goals.
- Smart grids can be seen as an advanced way of operating grids supported by a broad set of new technologies in the areas of communication, metering, control, and automation. Smart grid-related operation concepts, technologies, and components can be used to upgrade the existing grid infrastructure and offer many new possibilities in grid management and control. Smart grids will be deployed at different periods in time depending on requirements of the particular power system, compatibility with existing technologies, regulatory policies, and investment frameworks.
- Recent evidence has shown that investments in smart grid technologies are economically preferable to conventional grid expansion measures. Moreover, smart grids represent a promising concept that could increase reliability and security of supply, facilitate the balancing of electricity generation and consumption, ease the grid integration of electricity generated from variable RES, and increase the utilization rate of power grid assets.
- Given the evolutionary character of smart grids and the still low maturity levels of some smart grid technologies, both systematic guidance and specific government support policies are essential to promote the development of smart grids.
- New market actors in the electric power sector are of crucial importance to promote innovation in the electric power sector and speed-up the development of smart grids.

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China's way from conventional power grids towards smart grids

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3

Chapter at a glance

- The chapter gives an overview of the existing electric power system, the envisaged development of smart grids, and the regulatory environment in China. The main aspects emphasized in this chapter serve as a guideline for the description of the German background in ► Chap. 4 and the recommendations and regulatory pathways in ► Chaps. 5 and 6.
- ► Section 3.1 gives an overview of the more recent development of the power sector to lay a solid foundation for identifying the challenges currently facing the sector.
- ► Section 3.2 presents an overview of the physical structure of China's current electric power system and discusses in detail the main technological challenges in this context.
- ► Section 3.3 introduces the Chinese smart grid vision resulting from the specific technological challenges. In this respect, the role of the government and the ICT industry in developing the Chinese smart grid vision is especially emphasized.
- ► Section 3.4 describes the regulatory framework of the electric power system in China on the basis of the regulatory areas defined in ► Sect. 2.3. A clear focus is thereby on regulatory circumstances representing a barrier to smart grid development in China.

3.1 Historical perspective

Towards a reform of the power sector In the past 15 years, a series of reforms have greatly improved the efficiency, reliability, and environmental performance of the Chinese power sector. However, significant challenges remain: rapidly rising electricity demand, concerns about power system reliability and energy security, environmental degradation and climate change [1].

Historically, all stages of China's power sector value chain – from generation, transmission and distribution to retail – were owned and operated directly by the central government. By the mid-1980 s, in the wake of China's opening up policy, a first set of reforms allowed new market actors, mostly provincial and local governments, to invest in power generation. This created a boom of so-called *independent power producers* (IPP), thereby alleviating power shortages. Today, IPP make up more than half of China's power generation assets.

In 1997, the former *Ministry of Electric Power* (MoEP) was dissolved and the generation, transmission and distribution assets previously under direct government control were transferred to the newly formed *State Electric Power Corporation* (SEPC). This marked a significant step towards the separation of market functions fulfilled by *state-owned enterprises* (SOE) and government regulatory authority.

In 2002, the *State Council of the People's Republic of China* promulgated a landmark reform for restructuring the Chinese power sector by separating power generation from grid operation (transmission & distribution). In the course of the reorganization, the vertically integrated SEPC was dismantled and its assets divided into eleven new SOE: two grid operators, five power generation companies, also known as *Big Five* (China Huaneng Group, China Datang Corporation, China Huadian Group, China Guodian Corporation, China Power Investment Corporation), and four power service companies providing advisory and ancillary services. At the same time, the State Council established a ministerial regulatory authority, the *State Electricity Regulatory Commission* (SERC), to oversee the developing competitive market structure and further push power sector liberalization and market-based reform. The aim of this major power sector reform was to:

- break-up the power sector monopoly and introduce fair competition (mainly on the generation side) within the framework set by the regulator,
- improve economic efficiency and reduce costs,
- rationalize the electricity tariff system and optimize resource allocation,
- promote the development of the power industry and push ahead nationwide interconnection,
- set up an open, orderly and well- developed power market based upon the principles of separation of governmental oversight and power sector enterprises.

In retrospect, the reforms are considered a significant step towards the diversification of China's power sector market structure. However, the market-oriented reform of the power sector – as it had originally been envisaged by the State Council – stalled after these initial steps. No progress was made in unbundling the grid operators' transmission and distribution assets or in introducing more market-based electricity prices. This lack of progress despite ambitious plans for further reforms may be attributed in part to a lack of power and independent decision-making authority of the newly established regulator SERC, which suffered from very limited jurisdiction, capacity and resources. The *National Development and Reform Commission* (NDRC) is a successor to the *State Planning Commission* (SPC), which was renamed to *State Development Planning Commission* (SDPC) in 1998. In March 2003 the SDPC merged with the *State Council Office for Restructuring the Economic System* and parts of the *State Economic and Trade Commission* to form NDRC, which remained the most powerful policymaker for the power sector, retaining competence over electricity pricing and major energy project approval. The emergence of the newly formed *State Grid Corporation of China* (SGCC, in charge of 80 % of China's electricity grid) as a powerful influence in national energy policies further hampered the stride towards liberalization of the sector. In the most recent government restructuring in March 2013, the SERC was integrated into the *National Energy Administration* (NEA), an institution responsible for energy planning under the NDRC.

The trend towards low carbon development For a long time, progress in the electrification process together with the provision of a reliable and affordable power supply were the main priorities of China's government in its efforts to promote industrial and economic development. In the last two decades, questions relating to the sustainability of the electric power system have steadily gained increasing importance in China.

Energy efficiency and environmental protection were first put forward as a prominent policy objective for power sector development in China's general energy law – the 1995 *Electric Power Law* [2]. On the one hand, the law aimed at legalizing the status of power generation companies as commercial entities and at establishing the legal basis for private ownership [3]. On the other hand, the law stressed the importance of the environmental sustainability of the development of the power system by stipulating that

> » *the construction, production, supply and utilization of electric power shall protect the environment according to law, adopt new technologies, minimize discharge of poisonous waste, and prevent pollution and other public hazards. The state encourages and supports electricity generation by using renewable and clean energy resources.* [4]

The shift towards environmental protection was reiterated in the 1998 *Energy Conservation Law* and the 2006 *Renewable Energy Law*, which respectively aim at promoting energy efficiency and deploying RES. The *Renewable Energy Law* has laid a solid legal foundation that has since been followed by a number of key implementation guidelines detailing national renewable energy targets, a mandatory connection and purchase policy, a national feed-in tariff system for wind and solar energy as well as arrangements for cost-sharing and funding of renewable energy incentives.

China put forward aggressive measures to reduce the energy intensity of its economy: in its 11th (2006–2010) Five-Year plan, China set a target of reducing its energy intensity, measured as energy consumption per unit of *gross domestic product* (GDP), by 20 %. At the world climate conference in Copenhagen in 2009, China complemented this target with an overarching goal to reduce carbon intensity, the measure of carbon dioxide emissions per unit of GDP, by 40 % to 45 % by 2020 compared to 2005 levels. The targets are backed up by comprehensive plans featuring numerous measures to facilitate increased energy efficiency and reduced emissions across different sectors. One of these efforts is the *Small Plant Closure Program* established in the 11th Five-Year Plan. It focused on closing down small and inefficient power plants and replacing them with larger state-of-the-art facilities. In the period from 2006 to 2010, more than 70 GW of coal-fired power generation capacity was shut down in the context of this program [5]. The program not only targeted power plants, but also facilitated the shut-

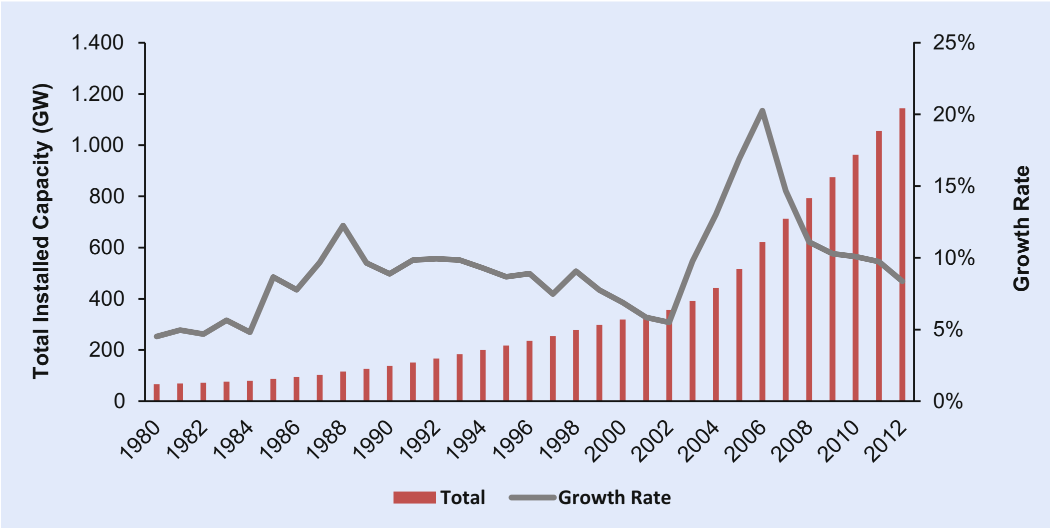

Fig. 3.1 China's power generation capacities from 1980 to 2012, data from [10]

down and replacement of a large number of outdated small factories of energy-intensive industries, e.g. in the iron and steel and cement sectors. More recently, small coal mines and inefficient pulp and paper mills have been subject to this government policy promoting consolidation and modernization of its heavy industry.

The *Top 1000 Enterprises Energy Saving Program* was another measure of the 11th Five-Year Plan to improve industrial energy efficiency by targeting China's largest energy consuming companies, which accounted for almost half of total industrial energy consumption and one third of total primary energy consumption in China. The program reportedly realized total energy savings of 150 million tons of coal equivalent, 50 % more than originally planned [6]. The ambitious targets and extensive efforts to promote energy efficiency and adjust China's energy mix through the deployment of renewable energies are evidence of China's commitment to decouple its economic growth from the growth of energy demand and emissions – to reduce the carbon intensity of its economy and fight pollution.

An increasing factor influencing China's energy and industrial policy is the increasing public awareness of environmental pollution and its detrimental effects on the ecosystem and on people's health. In particular, the extreme levels of air pollution in major Chinese cities may be seen as a potential source of social unrest and has thus been given great attention by the Chinese government, especially after the serious pollution events in Beijing in January 2013 saw particulate matter air pollution levels rise to figures exceeding the 24-hour mean level recommended by the *World Health Organization* (WHO) by more than 30 times.

3.2 Today's power system and its most pressing challenges

3.2.1 Power generation

Compared to international averages, China's per capita reserves of coal, petroleum, and natural gas are rather low, a situation which in recent years has resulted in an increasing dependence on the import of fossil fuels [7]. In contrast, China is endowed with large renewable energy resources – estimated at 250 GW and 750 GW for onshore and offshore wind respectively, plus significant solar energy resources [8]. Since the 1980 s, China's power generation capacity has been steadily expanding (see Fig. 3.1). From 2006 to 2012, total installed capacity almost doubled, increasing from 621 GW to 1,147 GW [9].

Coal is currently the primary source of electricity generation in China; in 2012 it accounted

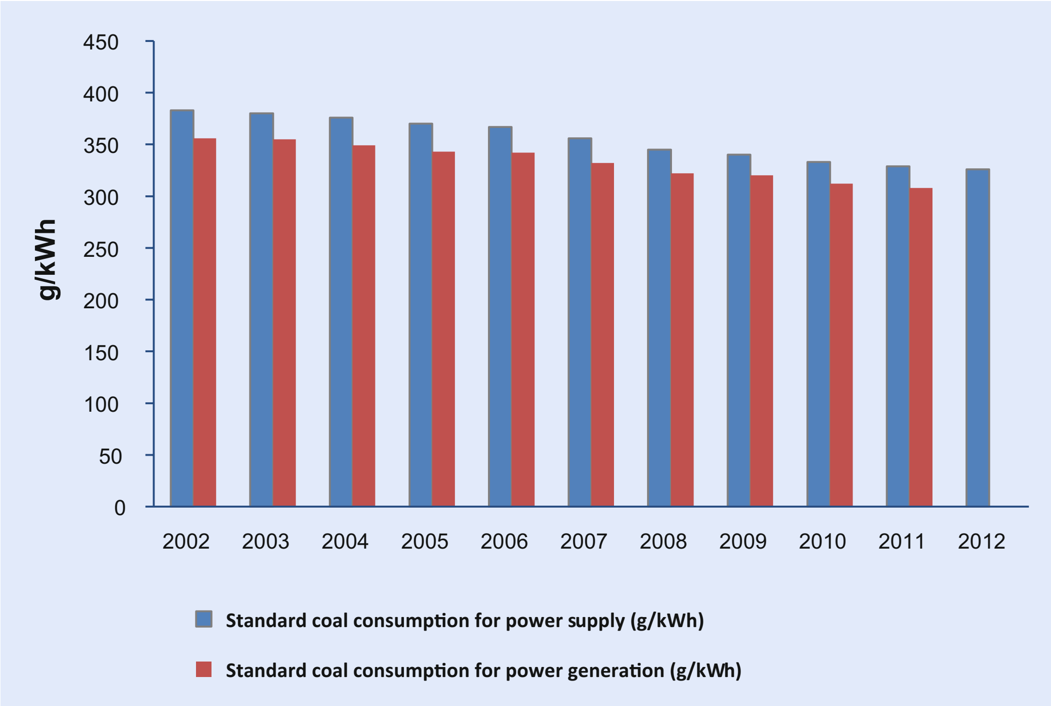

Fig. 3.2 Standard coal consumption (2002–2012), data from [10]

for close to 80 % of total electricity generation [9]. This massive reliance on coal for power generation and industry makes China the biggest CO_2 emitter worldwide [11]. The second pillar of China's electricity generation mix is hydro power, which has a share of roughly 17 % of total electricity generation. Nuclear and wind power contribute a share of roughly 2 % each. Other sources, such as gas, solar, and biomass power, with shares of less than 1 % each, currently play no more than a minor part in China's power mix [9].

Although China's generation mix has been relatively stable over the past two decades, the composition of the country's coal-fired power plants has undergone a significant shift toward larger and more efficient units, especially during the 11th Five-Year Plan. By implementing the policy of replacing small-size units by large and efficient plants, the share of units with 300 MW and above rose from 42.67 % of total thermal generating capacity in 2000 to 89.1 % by the end of 2010. As a result, the standard coal consumption per kWh generated has been reduced significantly (see Fig. 3.2).

With the introduction of the *Renewable Energy Law* in 2006, China triggered a boom in the expansion of renewable energy development (Fig. 3.3). China has since become the world's largest producer of wind power, with approximately 13 GW installed in 2012 reaching a total installed and grid-connected capacity of 61.4 GW. With the introduction of financially attractive feed-in-tariffs in 2013, China has also recently become the world's biggest market for solar PV with record installations of around 14 GW, more than 11 GW of which is grid-connected [9].

China's electricity system, however, is not well-prepared for such a rapid increase of intermittent wind and solar generation units. Due to the lack of gas-fired power plants in China, coal-fired power plants are mainly employed for load-following and peak generation. These activities require a significant cycling reducing the operational efficiency of coal-fired power plants [12]. Also, limited inter-regional transmission capacities often complicate the usage of hydro power plants for load-following and peak generation. This contributes to high grid

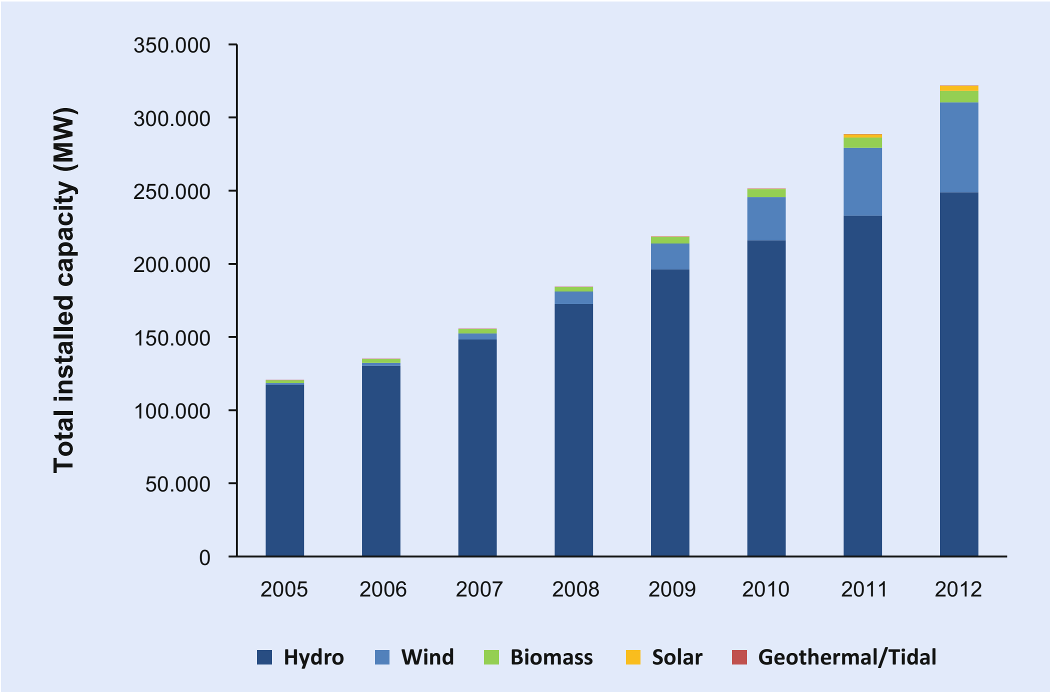

Fig. 3.3 Installed capacities of renewable energies (2005–2012), data from [10]

integration costs for wind and PV power in China [12].

Another challenge of the rapid build-up of renewables is that grid connection is lagging behind. Wind turbines are erected much faster than power lines are built. Realizing this problem, the government has made efforts to slow wind power expansion in order to reduce the share of wind power capacity which is installed but not grid-connected (by year-end) from 30 to 20 % in 2012. Due to the heavy concentration of wind power in remote regions with rich wind resources and in so-called *wind power bases* with 10 GW and more capacity, curtailment due to grid congestion has become an important issue: 20 TWh of wind power had to be curtailed in 2012 [13], representing about 20 % of total electricity generation from wind [14]. Since financial losses due to curtailment are not reimbursed to RES owners, wind power developers exposed to the negative impact of curtailment are increasingly building wind farms in lower wind speed regions with less network congestions.

Challenges in China's power generation sector

- China is not particularly well endowed with fossil energy resources in per capita terms. A system relying on fossil-fueled generators may create an increasing dependence on foreign energy sources.
- China's heavy reliance on coal for power generation and industrial processes is contributing to high air pollution levels and CO_2 emissions.
- Employing coal-fired power plants for load-following and peak generation reduces the efficiency of their operation.
- Renewable energy deployment is poorly coordinated with grid development, so that grid connection is lagging behind the construction of renewable power plants and significant quantities of wind power are being curtailed due to grid congestion.

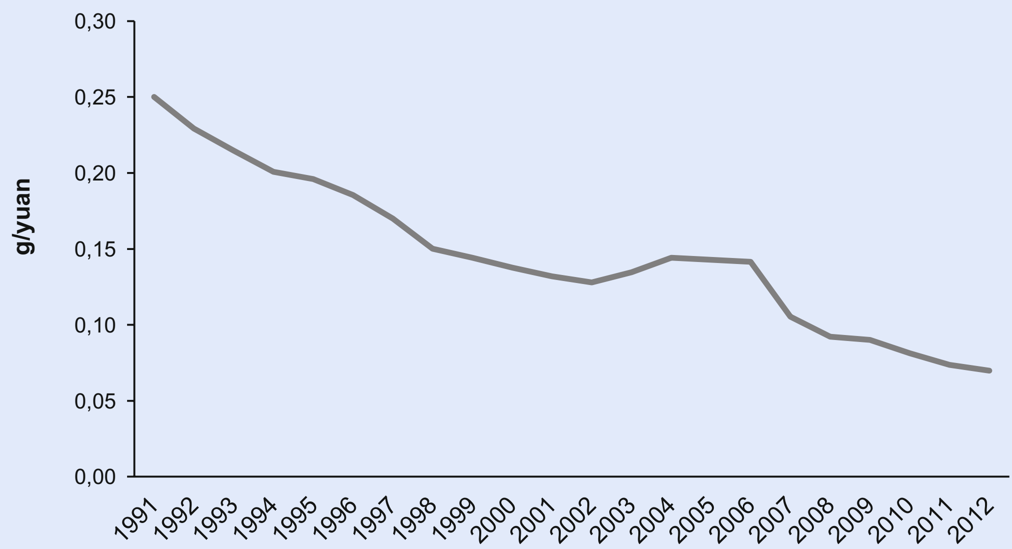

Fig. 3.4 Energy intensity per unit of GDP (1991–2011), data from [10]

- The high proportion of large coal-fired power plants and lack of gas-fired generators makes the Chinese power system less flexible. At the same time, an increasing share of electricity generated from intermittent renewable energy is increasing the demand for system flexibility.

3.2.2 Power consumption

Since the 1980 s, the increase in China's power consumption has been mainly driven by industrial growth. In 2011, more than 70 % of China's electricity was consumed by the industrial sector [15]. The residential sector accounted for approximately 12 % and the commercial sector for 3 % (see Table A.1 in the appendix). One reason for the high proportion of industrial loads in China is the focus on producing and exporting energy-intensive materials and goods [7]. While it is still relatively high in comparison to countries with a focus on less energy-intensive sectors [16], China's overall energy intensity of production (defined as energy consumption per unit of GDP) has been decreasing consistently due to a number of government measures to promote energy efficiency (see Fig. 3.4).

China's economy is gradually shifting away from heavy industry towards high value-added industries, such as information technologies and the service sector [12]. The composition of the electricity consumption is projected to change in the coming decades. Shares of residential and commercial electricity consumption are expected to increase. As a consequence, a predicted increase in load variability and range of fluctuation will soon require a higher flexibility of electric power generation [12]. In addition, industrial demand for reliable and high-quality electricity is expected to increase due to the growing importance of information technology in all economic sectors.

Challenges in China's power consumption sector

- The efficiency of energy and electricity use is low.
- Future energy demand from high value-added industries will require high power quality and reliability. Also, future demand

will be more variable in nature, thus requiring a higher degree of flexibility in the Chinese power system.
- There is a mismatch between the current power generation system with its limited flexibility and an increasing demand for flexible generation due to a projected shift in electricity consumption patterns towards more variability in demand.

3

3.2.3 Power logistics

Disparity between power generation and consumption Coal supplies are mainly located in the northwestern, northern, and northeastern parts of China (sometimes referred to as "Three Norths"). Similarly, wind resources are concentrated in the three northern regions as well as along China's coast. Solar energy resources are abundant in the west and north of China. Hydro power is concentrated in the southwest and in the upstream areas of the Yellow River. While energy resources are most abundant in China's north and west, regions that are typically remote and less economically developed, the load is concentrated in the economic and industrial centers along China's eastern coast. This discrepancy presents a major challenge for power logistics (transmission) as well as for the physical transportation of fossil resources and puts a heavy strain on power grid and road/railway infrastructure.

Grid infrastructure The regional disparity between energy resource distribution and load profile on the one hand and between the geographical location of electricity generation facilities and major centers of consumption on the other means that electricity has to be transported from north to south and from west to east. However, China does not have a nationally integrated electricity network. Its network is fragmented into six regional grids with limited interconnection operated by three grid companies: SGCC, *China Southern Power Grid* (CSG) and the Inner Mongolia Grid Company (for a more comprehensive overview of China's power lines please refer to Table A.2 in the appendix).

Aside from the limited capacity of interconnectors between the regional networks, interregional electricity trade is also heavily impeded by administrative barriers. Regional grids are made up of provincial grids, where dispatch decisions are made with the aim of balancing supply and demand within the boundaries. For cross-border power trading, provinces have to conclude bilateral contracts specifying the annual amount of electricity transmitted in each direction typically netting close to zero [17]. This way of restricting interregional trade makes it difficult to leverage the power system's inherent flexibility potential across regional borders, e. g. the use of dispatchable hydro power capacities for peak generation and ancillary services in other regions [12].

Around the turn of the century, in an effort to speed up nationwide grid integration and to connect regions with significant hydro power, solar, and wind capacities with the load centers on the east coast, China started to construct *Ultra High Voltage* (UHV) power transmission lines. Today, China is considered a global leader in UHV transmission and transformation technology [18]. Specifically, UHV *alternating current* (AC) lines are used for transmitting electricity generated in coal-fired power plants or by means of RES from China's northern and western regions to the load centers. UHV *direct current* (DC) lines are used for transmitting hydro power from South and Central China to the east coast.

Asset utilization and supply security Compared to other countries, for instance the United States, average utilization rates of the grid infrastructure in China are low in spite of the rather flat load curve [19]. Major transmission lines, for example, seldom reach a high utilization rate. In 2011, for instance, two 800-kV lines for which data are available reached utilization rates of less than 35 %. Only five of eleven trans-regional lines with 500- and 660-kV achieved utilization rates above 50 % [20]. At the level of distribution grids, average utilization rates of 10-kV lines and transformers are even lower and only seldom reach values above 30 % [19].

In principle, low utilization rates point to a large margin for grid operation often resulting in a high level of system stability and security. In the specific case of China, average annual outage times of urban users during the last years exceeded seven hours (see Table A.3 in the appendix) and those of rural users even ten hours [19]. In Germany, to give a reference value from an industrialized country, average annual outage times were only approximately 15 minutes in 2010. This evidence points to low levels of equipment maturity in parts of the electric power grid (see also [21], [22]). In recent years, investments in distribution grids have been considerably smaller than those in transmission grids [12]. Most line losses and power outages in China occur in the distribution grid [19] pointing to less sophisticated equipment in the distribution grid compared to the transmission grid (see also [21]).

Investment needs in the grid infrastructure In the coming years, massive investments will have to be made in the electric power grid in order to cope with the steadily rising power consumption, increase supply security, and facilitate the integration of wind and PV power. It is projected that, in 2020, the total length of power lines of 110 kV and above will reach 1.76 million kilometers with an associated transformer capacity of 7.9 billion kVA [23]. This represents a considerable increase compared to line length and transformer capacities in 2010 (see Table A.2 in the appendix).

Challenges in China's power logistics sector:

- The regional disparity between power generation and consumption in combination with barriers to interregional electricity exchange imposes a constraint on the efficient use and delivery of energy resources.
- The barriers to interregional electricity exchange make it difficult to fully exploit the flexibility potential inherent in the power system.
- Asset utilization rates of China's electric power grids are below those of highly industrialized countries such as the United States in spite of China's rather flat load curve.
- Supply security in China is considerably lower than in highly industrialized countries. There is evidence that a large part of power outages and line losses in China originate from distribution grids. This indicates that distribution grid equipment is less mature and sophisticated than transmission grid equipment.

3.3 Smart grid development in China

3.3.1 Motivation for smart grids in China

Smart grids for increasing supply security A core motivation for smart grids in China is their suspected positive impact on supply security. In China, especially distribution grids with voltage levels of 10-kV and less are limiting reliability for urban end-user's, causing roughly 80 % of all power blackouts [19]. Due to missing sensoring and monitoring technologies, it often takes a long time to analyze the respective line, locate and isolate the fault, and re-establish electricity supply [19].

Enhancing distribution grids with smart grid technologies such as advanced sensoring and control technologies is often seen as a means to improve the reliability of the whole electric power system in China (see e. g. [19]).

Smart grids for facilitating peak shaving The rapid growth of electricity consumption reflected in very high peak loads may cause shortages on the generation side and network congestions. Also, the rising importance of residential electricity consumption compared to industrial electricity consumption will lead to a more pronounced load curve. This trend could be further accentuated by China's continuing urbanization process [24]. With low gas generation capacities and limited transmission capacities, coal-fired power plants are mainly employed for load-following and peak generation in China. This reduces their operational efficiency. Peak shaving is of critical importance as it contributes to a reduction of peak loads and thus helps to avoid peak generation. Peak shaving might also reduce potential network congestions when demand peaks occurring in periods of network congestions are reduced via demand side management. As such, it should be seen as an important factor towards a more reliable power system in China. In addition, by reducing the maximum grid load, peak shaving helps to increase average utilization rates of the grid infrastructure, thus reducing investment needs and increasing the affordability of electricity supply.

To enable peak shaving and demand side management it is necessary to deploy an ICT infrastructure for two-way communications between end-users – or so-called prosumers if they also generate electricity – and grid operators. Together with other smart grid technologies facilitating real-time data exchange, visualization of information as well as control of devices, this infrastructure enables the grid operator to have a clear picture of electricity consumption and generation at any given time, while allowing end-users to receive price signals to adapt their electricity consumption to the variable supply.

Smart grids for preparing extensive integration of RES China has aggressively expanded RES generation capacities within an extremely short time frame. Grid connection of RES is currently lagging behind and a considerable amount of RES-E is curtailed. In this context, smart grid technologies are often seen as a means to reduce RES integration costs:

- Large-capacity battery storage systems facilitate the integration of centralized large-scale intermittent RES generation capacities of the type that are currently focused upon in China.[1]
- Due to frequent network congestions at the local level, a considerable quantity of electricity generation from RES has to be curtailed. More effective grid capacity management using smart grid technologies could reduce curtailment of RES.
- Smart grid technologies such as microgrids and virtual power plants ease the integration of RES at the local level.
- The grid connection itself might be more effective with smart grid technologies. One aspiration expressed in this area is that RES might be integrated into grid operation via standardized ICT connectors so that the integration of standard RES plants might become as easy as connecting external devices with computers via *universal serial bus* (USB) interfaces (plug-and-play integration) [25].

3.3.2 China's technological view of the smart grid

The development of smart grids in China An early form of smart grids was proposed in 1999 by Lu and Mei [26] in their article *Basic research on vital scientific problem with collapse prevention and optimal operation of large scale power systems* [27]. Five years later, distributed computing was applied in a research project for a real-time simulation of the entire power grid [27]. In 2007, the *East China Grid Company*, a subsidiary of SGCC, carried out a feasibility study on smart grids that examined the promotion of digital substations and build-up of a unified enterprise platform for power system data [27].

The grid operator's view on smart grids Since then, China's smart grid development has mainly been pushed forward by China's grid operators, SGCC and CSG. In 2009, SGCC proposed the strategic goal of building strong and smart grids with Chinese characteristics. SGCC focuses on the nationwide integration of provincial and regional grids by means of a strong UHV AC backbone. The first objective of this backbone grid is to ease the balancing and power exchange between different regions, the second to integrate large-scale generation from RES. CSG, on the other hand, envisages a smart grid with a more decentralized focus using primarily *high voltage direct current* (HVDC) links as backbone systems. CSG intends to integrate remote energy sources, especially hydro power. HVDC development will lead to separated asynchronous provincial grids. The nationwide synchronization of China's power grids is not one of CSG's main goals. Comparing both strategies reveals that the two grid

1 One example for the trend towards large-capacity battery storage are the activities of BYD. The Chinese manufacturer of automobiles and rechargeable batteries built one of the world's largest lithium-ion battery energy storage systems, a 36-megawatt-hour system, located in Zhangbei, Hebei [52].

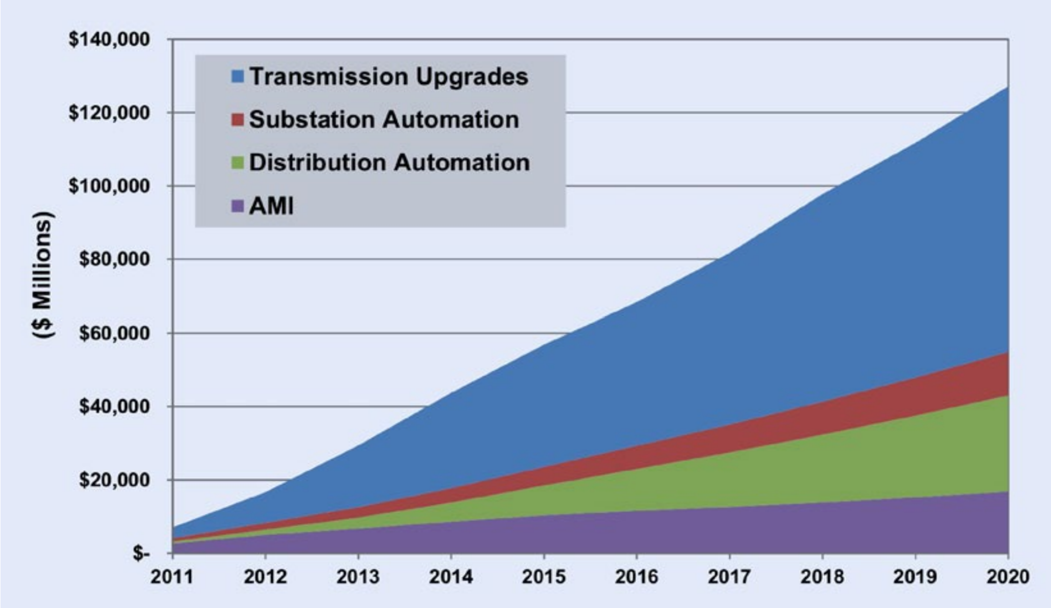

Fig. 3.5 Annual overall smart grid revenue of main smart grid technologies in China (© Navigant Research [28])

operators pursue different approaches with regard to the type of transmission technology and the nationwide synchronization of China's power grids.

In spite of this disagreement, the smart grid visions of both grid operators concentrate mainly on the upgrade of transmission grids: a look at the total annual smart grid revenues from the most important smart grid technologies in China reveals that currently more than 50 % of revenue is related to upgrades of transmission grids. Substation and distribution automation technologies are responsible for no more than a low share of overall smart grid revenues (see Fig. 3.5). According to markets forecasts for 2020, the absolute increase in smart grid revenues related to transmission upgrades is significantly higher than the increases of revenues from substation automation, distribution automation, and AMI (see Fig. 3.5).

The government's view on smart grids China's government has already acknowledged the importance of smart grids for China's future energy system. In its *12th Five-Year Plan for National Economic and Social Development*, the *People's National Congress* explicitly set the goal of accelerating smart grid developments in China (see [27]). In the Decision *of the State Council on Accelerating the Fostering and Development of Strategic Emerging Industries*, the State Council also underlined the importance of speeding up the development of smart grids (see [27]).

In addition to the general commitment to smart grids, NEA also issued a general definition of smart grids:

> *Smart grid technologies have the purpose to integrate new energy, materials and equipment as well as advanced technologies in information, automatic control and energy storage for realizing digital management, intelligent decision-making and interactive transaction in power generation, transmission, distribution, consumption and storage. Furthermore, smart grid assets optimize the resource allocation and satisfy diverse needs of customers as well as ensure the safety, reliability and cost-efficiency of power supply. Finally, the new technology [in the sense of smart technology] bridges the constraint of environmental protection and the development of the power market.*

Moreover, the Chinese government supports the technological development of main smart grid technologies by means of innovation policies such as standardization and R&D funding (see ► Sect. 3.4.6). However, in contrast to both grid operators, the Chinese government has not yet developed a perspective of its own on the technological and organizational design of China's smart grids. As a result, the discussion of such aspects is still dominated by the grid operators and there is currently no unanimously accepted comprehensive view of smart grids in China.

This lack of common understanding among the main stakeholders is the cause of many controversies and basic disagreements on the key aspects of smart grid development [27]. The absence of such a common vision increases uncertainty for potential smart grid investors because the profitability of their investments critically depends on whether a strong and smart or a decentralized smart grid will be realized. Thus, the lack of a comprehensive smart grid vision has to be viewed as an obstacle towards the development of smart grids in China [27].

Main challenges with regard to the technological view of smart grids

- Due to the contrary strategies of China's grid operators on the subject of smart grid development and the absence of a Chinese government view on smart grids, there is still no unanimously accepted vision on the technological and organizational design of smart grids in China. As a result, there is much uncertainty among potential smart grid investors regarding the future development.

3.3.3 This study's view on smart grids in China

The present study has a clear focus on proposing regulatory policies supporting the evolution of smart grids in China. The creation of a widely accepted technological smart grid vision is beyond the study's scope. Nonetheless, a common understanding of desirable smart grid developments during the next years is necessary to determine the general direction of the regulatory recommendations. Given the missing unanimously accepted smart grid vision in China, a pragmatic three-sided approach was employed to develop such a common understanding:

- Following a bottom-up approach, China's future smart grid is considered to comprise a broad portfolio of ICT together with various modern technologies for power generation, transmission, distribution, storage, and consumption.[2] This also includes modern grid technologies such as UHV transmission grids or heat-resistant wires. A recent literature review supports this view by underlining that smart grids in China focus on all sections of the power system, including smart power generation, transmission, deployment, usage and storage. Specifically, the integration of RES should also be understood as part of the topic of smart grids in China [27].
- The smartness of the current electric power grid as well as the desirable smartness of the power grid in 2020 was assessed. In particular, the current levels of system integration of single power system components as well as the projected levels in 2020 were described. In this context, system integration refers to the extent to which power plants, wind farms, transmission grids, distribution grids, and power consumers are expected to be remotely monitorable, controllable, or even autonomously controllable (self-healing).[3]
- Given the government's will to establish energy markets, the study compares market elements used in China today with those projected for 2020.[4]

This three sided-approach has led to the following conclusions:

- China has in recent years made important breakthroughs in the development of smart grid technologies. Examples for such technolo-

2 Please refer to appendix B for a complete overview of all modern technologies that are subsumed under the smart grid label in this study.

3 Please refer to appendix C for a complete overview of the results.

4 Please refer to appendix C in for a complete overview of the results of this discussion.

gies are UHV transmission grids and large-capacity battery energy storage technology.[5]

- On the other hand, a big leap forward with regard to many smart grid technologies is indispensable at all stages of the smart grid supply chain.[6] Like in many other countries engaged in the development of smart grids, some of China's key smart grid technologies are still immature and have somewhat inconsistent component specifications and standards [21], [22], [27].
- In 2020, market elements such as regional energy marketplaces and virtual power plants are intended to be used much more intensively than today. They will be introduced at least on provincial level.

With the study's focus on regulatory issues in mind and in light of the conclusions described above, the regulatory pathways presented in this study aim specifically at:

- facilitating the widespread deployment in 2020 of those smart grid technologies which have already achieved high maturity levels today. In this context, smart grid technologies also include modern grid technologies which are not necessarily included in smart grid concepts of other countries;
- promoting technological innovations of rather immature smart grid technologies and increase their maturity;
- promoting the development of so-called smart markets (see ► Sect. 4.3.2 for more details on smart markets). In this context, an important prerequisite is the integration of third parties. They are seen as key players in smart markets.

5 Please refer to appendix B for a complete list and description of these technologies.

6 Please refer to appendix C for an overview of the necessary technological advancement during the next years.

3.4 The regulation of China's electric power system

3.4.1 Policy setting and fundamental institutions

Policy Setting

Government leadership is essential to promote smart grid development. The general strategy of policy-makers towards the development of the future power system, often containing quite specific targets for short-term and long-term development, is important for companies and other stakeholders in the electric power sector: indeed, this government strategy serves as an important basis for smart grid investment decisions of both companies and households.

The Chinese government has set quite specific targets with regard to the development of the energy system until 2015. However, there are no explicit targets beyond this point in time. The most important government targets for 2015 are briefly summarized below:

- From 2010 to 2015, generation and grid capacities are planned to increase by roughly 50 % in order to cope with the steadily growing demand.
- RES generation capacities are expected to increase out of proportion – their share in the electricity mix will increase significantly.
- Average utilization rates of the grid infrastructure and supply security are targeted to increase. Specifically, power outages on the level of distribution grids, are expected to be reduced.
- The efficiency of energy use and particularly of electricity use is planned to improve considerably.

A detailed overview of government targets for China's future electric power sector is given in ► Sect. 6.1 in the context of the regulatory pathways.

Fundamental institutions

To realize the government agenda, ministries and other government institutions issue laws and ordinances, monitor compliance with these laws and ordinances, propose major technological standards, and promote innovations. The question regarding whether the different government practices can be executed effectively largely depends on the governance structure of ministries and government institutions.

Governance structure The governance structure of China's energy system, and in particular the power sector, has been subject to frequent reorganization and currently comprises a broad variety of ministries and institutions. The fragmentation of responsibilities among a multiplicity of different stakeholders makes conflicts of competence inevitable and a coherent and continuous governance of the power sector difficult [2].

Figure 3.6 presents a graphical overview of the main authorities of China's power sector governance (Table A.4 in the appendix further specifies influences, roles, and responsibilities of main governmental institutions). There are four main government authorities involved in China's power sector policy:

- **The *State Council* (SC)** is the highest executive organ of the People's Republic of China. With regard to the electricity sector it sets the political agenda, takes the lead for major reforms and is in charge of promulgating major plans like the Five-Year Plan for energy development.
- **The NDRC** is an agency under SC exerting broad administrative and planning control over the Chinese economy. It is the most important government authority for power sector regulation. Its powers include the regulation and setting of energy and electricity prices, the approval of major power sector projects, as well as energy efficiency policy.
- **The NEA** proposes the energy development strategy, drafts energy development plans as well as energy-related policies, provisions and laws to be adopted by NDRC or SC. NEA also advises on power system reform and market regulation. In addition to these political functions, NEA is the regulatory authority for the power sector in charge of regulating power system construction, power safety, power supply and service, as well as tariff and information disclosure.
- **The *State-owned Asset Supervision and Administration Commission of the State Council* (SASAC)** supervises the performance of SOE such as the grid operators and the major power generation companies. SASAC exerts its power through the right to appoint, dismiss and evaluate the performance of executives, the right to audit as well as to approve key decisions.

The existing literature on China's governance structure in the electric power sector (see for example [2], [3], and [30]) often stresses several regulatory challenges potentially preventing an effective development towards smart grids in China:

- There is a significant fragmentation as well as overlap of responsibilities of the various government bodies involved in power system regulation, negatively affecting the efficiency of the sector's governance.
- In international comparison, China's major institutions governing the energy sector have a rather low number of employees, staff numbers not always being adequate to fulfill the responsibility of regulating an electricity system the size of China.
- The importance of the previous aspect even increases when the size and the power of China's major grid operators are taken into account. The grid operators' stakes are so high that it always pays off for them to hire consultants, lawyers, and lobbyists to argue their case. To address these claims, the regulator needs to be equipped with a sufficient number of highly qualified employees.
- Essential instruments to steer power sector development, like electricity pricing, remain under the authority of NDRC. The concentration of power within NDRC limits the ability of NEA to drive power sector reform.

Regulatory challenges in the area of policy setting and fundamental institutions

- Efficient governance of the power sector is impeded by overlapping responsibilities and conflicts of interests between different government authorities.

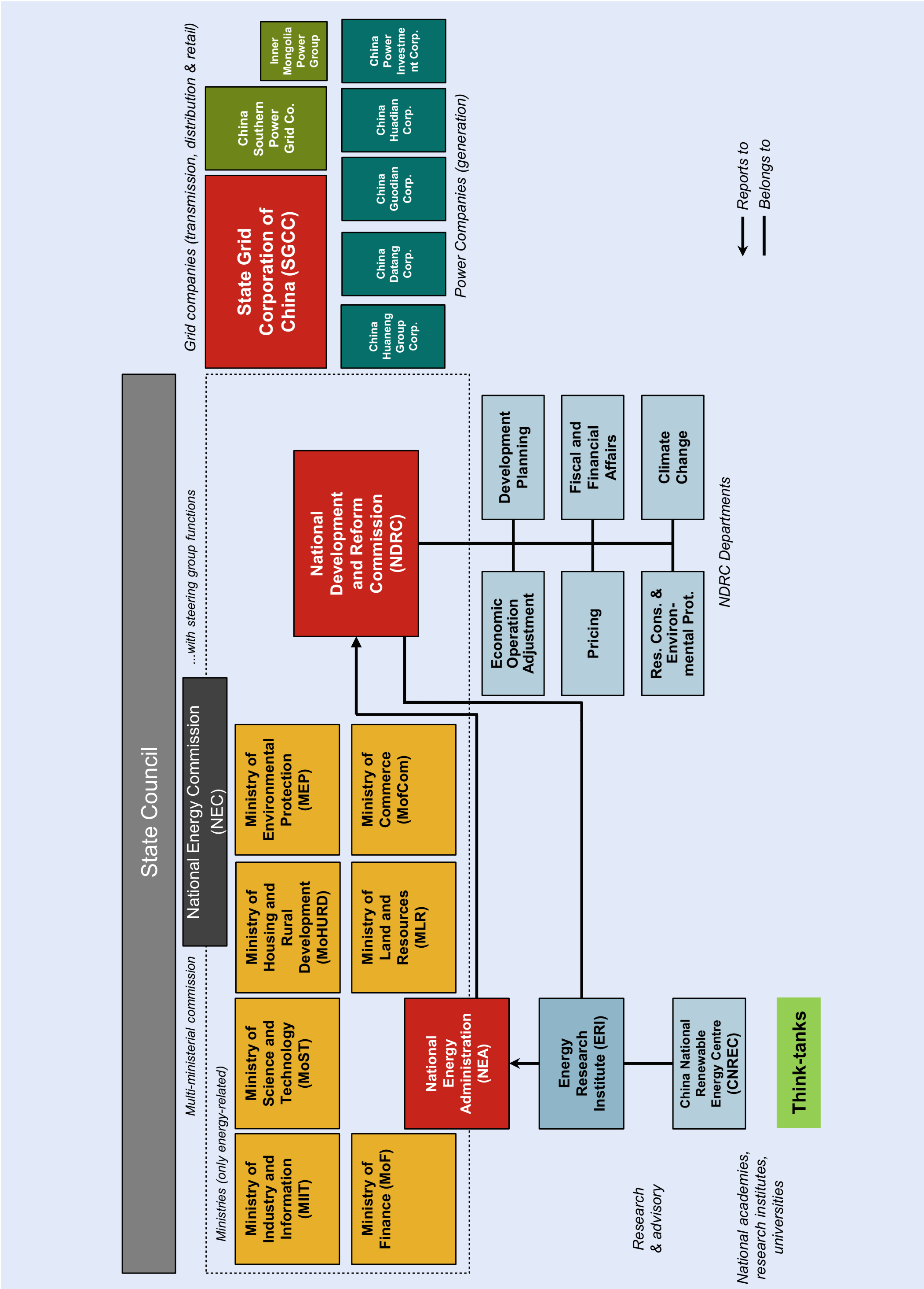

Fig. 3.6 Key Actors of China's Power Sector Governance, (© GIZ [29])

3

- In international comparison, NEA is understaffed, underfunded and without sufficient power to make independent decisions. The lack of independence and law enforcement authority has a negative effect on regulatory performance.
- The concentration of power within NDRC limits the ability of NEA to drive power sector reform.

3.4.2 Market structure

The market structure and especially the involvement of new market actors is a critical factor with regard to the innovation potential in the smart grid development process. The following paragraphs will describe the governance structures between the companies at the various stages of the supply chain (vertical market structure) and the competitive conditions for the companies in each part of the supply chain (horizontal market structure).

Vertical market structure The competences and responsibilities of China's power system supply chain have been tightly bundled over a long period of time. The main electricity sector reform of 2002 mandated the separation (or unbundling) of the state-owned vertically integrated utility into five big power generation companies, two major grid operators handling transmission, distribution and retail as well as four power service corporations.

All of them are SOE. Under this market structure, the grid operators are assigned regional monopolies acting as single buyers from generation side as well as being the only seller with the electricity retail monopoly within their geographic area.

Horizontal market structure In the field of power generation, the five major power generation companies, the so-called *Big Five* are responsible for roughly 50 % of China's electricity generation. By means of its project approval process, NDRC tries to balance generation capacities between them [31]. Due to their size, the *Big Five* have a significant lobbying force contributing to China's power system governance together with the government and the grid operators. The remaining part of China's power is generated by thousands of smaller local and regional generation companies. In addition, there are specialized generation companies mainly focusing on power generation from one energy source, e.g. hydro or nuclear power. China's power generation sector can be described as liberalized, as it potentially allows competition between the different companies. However, compared to local governments or state-owned companies, private and foreign investors still face significant legal and administrative barriers restricting the development of a diverse ownership structure [2].

Power transmission, distribution and retail are currently vertically integrated and operated by two major SOE with geographical monopolies including electricity retail: SGCC controls the eastern, central, northwestern, northern and northeastern grids; while CSG is in charge of the southern grid. In the sparsely populated province of Inner Mongolia, an independent grid operator, the *Inner Mongolia Electric Power Corporation,* controls the western part of the grid while SGCC controls the eastern part. Due to their importance for the development of China's power system, both SGCC and CSG are briefly introduced below:

- ***State Grid Corporation of China*** **(SGCC)**, an SOE, is the 7th biggest company in the world according to the 2012 Fortune Global 500 list, with almost 1.6 million employees [32]. SGCC is responsible for power transmission, distribution, and retail in all five major regions of China with the exception of South China. Its operations cover 26 provinces, autonomous regions and municipalities – 88 % of the national territory – and 83 % of the national power consumption [33] (see Table A.5 in the appendix for a list of affiliated grid operators). The company has ministry-like status and is a powerful force in power sector governance [34].
- ***China Southern Power Grid*** **(CSG)**, also an SOE, ranks at position 152 on the Fortune Global 500 list and has roughly 300,000 employees. CSG is responsible for power transmission, distribution, and retail in the five provinces of South China, covering 12 % of

the national territory and 17 % of the national power consumption [33].

Both grid operators are currently expanding their business portfolios across the value chain: SGCC has taken over domestic engineering firms and leading electric power equipment manufacturers, raising concerns about conflicts of interests and a threat to competition due to the concentration of multiple roles within one company (i. e. roles standard setting, manufacturing equipment, transmitting and selling electricity).

At the same time, SGCC is pursuing a "going global" strategy targeting the acquisition of assets abroad [35]. The advancing vertical integration of SGCC has caused discussion as to whether its mergers and acquisitions go against China's power sector reform policies of downsizing and unbundling grid operators. Recently a potential separation of grid operators into transmission and distribution companies or into smaller, regional businesses has been subject of debate [34].

Regulatory challenges in the area of market structure

- Transmission, distribution and retail of China's electricity are in the hands of two grid operators. There is no competition in the power retail sector.
- The acquisitions of grid operators in other segments of the value chain (e. g. equipment manufacturing and services) threaten fair competition in these sectors.
- The size and power of grid operators makes it difficult to regulate them.

3.4.3 Market design and RES integration

The question regarding how electricity markets are designed is highly important for the development of smart grids because market design affects electricity pricing. Pricing mechanisms, including feed-in tariffs for RES, are of crucial importance with regard to the utilization of different generation sources, investment decisions for new generation and grid capacities, day-to-day power consumption patterns, and investments in power saving technologies.

General market design Prices for energy resources, power system equipment and electricity were fixed by the government for a long period of time. In the 1980 s, the government started to gradually liberalize coal prices. Coal is currently at least partly traded at variable market prices, either depending on spot market rates or on individually negotiated contracts [31].

Irrespective of market liberalization tendencies, China still lacks a formal and transparent mechanism for linking real costs and prices of electricity [12]. Electricity markets with prices based on supply and demand do not exist in China. Two types of electricity prices exist in China:

- On-grid prices are the prices power generators receive from their grid operator for each kWh generated.
- Retail prices are the prices grid operators (which are also responsible for retail) charge to end consumers for each kWh consumed.

Both prices are fixed by the price department of NDRC and adjusted every 18–24 months.[7]

Setting on-grid prices NDRC determines on-grid prices for power generation using two different approaches:

- On-grid prices for thermal generators are set using a price benchmark for generators within the same technology class. Each power plant is contractually guaranteed a certain capacity factor (number of full load hours) equal to comparable facilities. The equal capacity factor is based on an estimate of annual power output as well as on average fixed and variable costs.
- On-grid prices assigned to owners of hydro power and nuclear power plants differ from facility to facility. They are the sum of the

7 Jointly with local and provincial price bureaus, the price department of NDRC is responsible for the formulation, inspection, approval and establishment of the tariff, as well as for the supervision and inspection of the tariff implementation. In addition to NDRC, the NEA may put forward suggestions to the price department of NDRC.

plant's generation costs, governmental taxes and surcharges, and profits attributed to the plant owner [2] [12].

To give a short overview of the results of these price-setting mechanisms, the following list shows on-grid prices for electricity stemming from different conventional generation technologies in 2012 (prices from [31]):

- Gas-fired power plants: 0.395–0.710 RMB/kWh
- Coal-fired power plants: 0.311–0.520 RMB/kWh
- Nuclear power plants: 0.414–0.471 RMB/kWh
- Hydro power plants: 0.145–0.411 RMB/kWh

Consequences of on-grid price setting Both price setting approaches ensure that plant operators usually earn revenues sufficient for the repayment of their investment costs within one decade [2]. That is, in principle, both approaches are sufficient to incentivize investments in power generation capacities. However, such price setting approaches based on costs are often viewed quite critically in the economic literature (see e.g. [36], [37], and [38]): for example, they are quite time-consuming for the regulator. In China, the following aspects have to be emphasized with regard to the setting of on-grid prices:

- Due to the fact that coal prices are flexible while on-grid electricity tariffs for coal-fired power plants are strictly regulated and adjusted rather infrequently, power companies are not able to directly pass on changes in fuel costs. During periods of high coal prices, power companies have seen their revenues squeezed to such an extent that they have restricted generation in order to limit their losses. This behavior further aggravates the problem of missing generation capacities and contributes to the emergence of power outages.
- The approach used to set on-grid prices of hydro power and nuclear power plants gives few incentives to save costs, because potential cost savings in one specific power plant would lead to lower on-grid prices for the plant within 18–24 months. Even more, such approaches give an incentive to exaggerate generation costs by means of creative financial accounting to receive higher on-grid prices [38].

Setting of retail prices Retail prices are amended from province to province to account for policy goals and status of economic development. They are also differentiated according to end user groups. The current national averages of electricity retail prices for different consumer groups are:

- Commercial: 0.863 RMB/kWh,
- Non-residential lighting: 0.791 RMB/kWh,
- Industrial use: 0.698 RMB/kWh,
- Residential: 0.498 RMB/kWh,
- Agriculture: 0.419 RMB/kWh,
- Irrigation in poor areas: 0.201 RMB/kWh.

Retail tariffs are subject to cross-subsidization in certain market segments to account for differences in income and to ensure social stability. Tariffs for residential, agriculture, irrigation and drainage use, together reflecting about 20 % of the Chinese power consumption, are lower than average generation costs. It is notable that industrial users generally pay higher tariffs than households.

Consequences of retail price setting The main disadvantage of low retail prices is that a low price level does not incentivize consumers to use power more efficiently. There is evidence that residential electricity consumers in China are quite sensitive to changes in electricity price levels [39]. Thus, increasing electricity prices would probably lead to significant reductions of electricity consumption among Chinese households. However, increasing electricity prices for residential consumers is not a political option in China given the government's intention to keep prices for residential consumers low. Therefore, China currently employs a number of other retail pricing policies that serve to align economic and environmental targets of the electricity sector [1]:

- A three-tiered pricing system has been applied to residential consumers since mid-2012. Electricity prices are set in blocks with higher rates for customers with a large electricity consumption (referred to as *inclining block pricing*).
- In addition, China has implemented a policy differentiating the electricity tariffs based on

the energy efficiency of industrial processes. The policy, which is applied to eight energy-intensive industries, aims at phasing out outdated industrial capacities or incentivizing upgrades.

Promotion and integration of RES Feed-in tariffs have proven to be an efficient instrument to promote RES in China. They are paid to RES generation installations depending on the type of renewable energy and location of the installations. Feed-in tariffs for RES generation are considerably higher than on-grid prices for hydro power and coal-fired power plants. In 2012, the ranges for feed-in tariffs of different RES generation types in 2012 were [31]:

- Solar: 1.00 RMB/kWh
- Biomass: 0.56–0.77 RMB/kWh
- Wind: 0.51–0.61 RMB/kWh

The *Renewable Energy Law* obliges grid operators to feed in renewably generated electricity. The resulting costs are socialized through a renewable energy surcharge levied on all electricity users in China [31].[8] Since the initial publication of the 2006 *Renewable Energy Law*, the renewable energy surcharge has been adjusted three times, with the last increase from 0.008 to 0.015 RMB/kWh taking place in September 2013. To ensure that the grid companies do not misuse the surcharge, it is turned over to the *Ministry of Finance* (MOF) in a first step. The grid companies then apply to MOF and NEA for the disbursement of these funds with supporting documentation [40]. This procedure causes a delay in the reimbursement of grid operators' expenses for purchasing power generated from renewables, which in turn results in a lack of operating capital with serious effects on the whole supply chain. Grid operators delay payments to wind power developers, who in turn are unable to pay renewable energy equipment manufacturers (e. g. wind turbines), resulting in delayed payment of component suppliers. This situation is expected to be alleviated with the recent doubling of the renewable energy surcharge. From the grid operator's perspective, delays in reimbursement may be seen as a reason to delay the grid connection of renewable energy generators.

8 Note that agricultural uses and power consumers in Tibet are excepted from the surcharge [43].

Regulatory challenges in the area of market design and RES integration

- On-grid and retail electricity prices do not reflect actual costs and are adjusted only infrequently.
- The approach used for setting on-grid prices of hydro and nuclear power plants gives only few incentives for cost savings. Rather it gives incentives to exaggerate costs to achieve a higher on-grid price.
- Although a system of tiered prices has been introduced for residential consumers, the low overall level of retail electricity prices does not provide sufficient incentives for consumers to use power more efficiently.
- Delays in the disbursement of RES funds leads to a lack of operating capital along the renewable energy value chain and provides a disincentive for grid operators to connect RES plants to the grid.

3.4.4 Development of infrastructure and network regulation

This section explains how grid planning is done in China and how investments in the (smart) grid infrastructure are incentivized. The pertinent regulatory practices directly impact the stable and affordable operation of the current grid infrastructure and the investments in the prospective smart grid infrastructure.

Network expansion planning The government's key target is cost-efficient extension and development of the power grid in order to cope with the steadily increasing electricity consumption and minimize supply interruptions.

Targets on the development of grid infrastructure and grid operators' performance are specified by the government in a top-down process. However, little information is publicly available on official grid expansion plans [41]. As a result, the document *Framework and Roadmap for Strong and Smart Grid Standards,* published by SGCC in 2010 [42], serves as an unofficial (smart) grid development plan in

China [41]. With respect to grid expansion planning, there is little guidance from the government and little coordination among existing power system stakeholders.

3

Network regulation At present, there is no explicit price for transmission and distribution (network charge) based on actual costs. The source of grid operators' income is the difference between the on-grid and the retail price for electricity. This amount covers all costs of the grid operators: grid operation and maintenance, grid upgrade and expansion, management, metering and billing, etc. The remainder makes up the profits of the grid operator. The government targets a rate-of-return for the grid operators in the range of about 8 to 10 % [43]. This practice, in combination with the rather infrequent adjustments of the retail electricity tariffs, has an impact on the ability of grid companies to quickly and predictably recoup costs. In turn, the grid companies may exhibit little motivation to invest and assume costs related to the implementation of government policies and regulations, e. g. for investments related to renewable grid connection and integration, investments in end-use energy efficiency or distributed generation [1]. Moreover, the cost structure of power sector companies lacks transparency and power sector data and information available to the public is very limited. Opaque costs affect the government's ability to regulate and inform the setting of electricity prices.

There are no clear rules for accounting of costs, revenues, and profits and no transparent administrative process for setting allowed revenues. Without this foundation the government is unable to audit companies' accounting records or exact penalties for noncompliance with reporting obligations, information requests or other government requirements [1].

Regulatory challenges in the area of development of infrastructure and network regulation

- Grid expansion planning is organized in a top-down process with low transparency and little involvement of players other than government authorities and grid operators.
- The price-setting mechanism with respect to wholesale and retail prices together with the rather infrequent adjustments of retail prices reduces the ability of grid companies to quickly recoup costs. This might reduce their willingness to incur costs related to other government policies (for instance related to RES integration).
- A lack of transparency of costs impedes the efficient and informed regulation of power sector companies.

3.4.5 Coordination of generation and consumption

The following paragraphs describe general responsibilities for coordinating electricity generation and consumption. Government measures implemented in this context are also presented.

Long-term coordination of generation and consumption China's rapid economic growth has resulted in a steadily increasing electricity consumption. The Chinese government promotes the expansion of generation and grid capacities. In addition, the role of energy efficiency as an instrument to decouple the rise of power consumption from economic growth has been recognized. Numerous policies to promote energy efficiency have been promulgated: for instance, national targets for energy intensity, differential pricing for energy-intensive industries and energy efficiency obligations requiring Chinese grid companies to realize energy conservation targets (e. g. through end-user energy efficiency programs).

Short-term coordination of generation Historically, dispatch of power plants in China is organized by means of a so-called *equal shares dispatch* or *generation quota system*. China allocates operating hours equally among the coal-fired generators that constitute the bulk of China's generating capacity. This system is intended to give each generator an equal chance to recover capital costs and achieve a reasonable return-on-investment, but it largely ignores the fact that plants within the coal fleet vary significantly in terms of efficiency and environmental performance [44]. Annual operating hours for generators are set administratively by *Provincial Economic and Trade Commissions* (PETC) and approved nationally by NDRC. As a result, the overall performance of the power system has suffered significantly in terms of cost, environmental performance, and distorted investment decisions. The dependence of each coal-fired generator on running a similar guaranteed number of hours has become a major barrier to reforming dispatch in China.

In 2007, China started to pilot a so-called *energy efficient dispatch system*. This system sets a dispatch order prioritizing generators on the basis of heat and emissions rates favoring renewable and low carbon generation sources, with coal-fired power plants dispatched according to their thermal efficiency. This order is based on the *priority order table* created by PETC and is updated quarterly based on changes in generator parameters and the addition of new units [45]. Hence, the power generation quotas of power generation facilities are no longer guaranteed [46]. Since on-grid prices are calculated on the basis of a fixed estimate of annual operating hours, generators will face a revenue shortfall if average operating hours fall below the projected level [44]. One of the main drawbacks of the policy was a lack of compensation of power and grid companies for lost revenues due to the changes in dispatch. The pilot has proved to be difficult to implement and has not spread to the whole country [47].

Regardless of whether a generation quota or an energy-efficient dispatch system is used, the specific day-to-day dispatching is in the hand of dispatch centers under the authority of national, regional, provincial, or local grid companies. The dispatch centers take into account factors like load forecasts, the availability of power plants, and constraints for system reliability. On this basis, the dispatch centers set day-ahead commitment plans for the power plants. Power generation companies are subsequently obliged to supply power as required [44].

Short-term coordination of consumption Like in all other regions of the world, China's intraday power generation follows intraday power demand. However, early attempts have been made to influence the hourly pattern of China's power consumption and to shift power consumption from peak times to off-peak times: since the 1990 s, many provinces have started to coordinate power consumption by means of interruptible loads and time-of-use prices:

- Interruptible loads refer to a pricing mechanism in which large industrial consumers are paid for curtailing their loads in times of network congestions. This *demand response* (DR) mechanism has been piloted and regionally applied in China [12].
- Time-of-use pricing means that the electricity price varies depending on the time-of-day when electricity is provided. In times of network congestions prices tend to be high to incentivize electricity consumers to reduce their consumption. With the *2005 Interim Provisions for the Administration of Power Selling Prices*, the Chinese government stressed the role of time-of-use prices to reflect real costs at different day times [2]. Time-of-use pricing has been implemented mainly for industrial and commercial users [48]. In some regions, time-of-use pricing is also applied to residential customers. The Chinese government has recently announced that it will introduce time-of-use pricing for residential consumers on a national level by the end of 2015 [49]. Overall, it is still questionable whether the existing incentives are actually sufficient to induce customers to shift electricity consumption to off-peak times [2].

Regulatory challenges in the area of coordination of generation and consumption

- The generation quota system ignores the fact that power plants within the coal fleet vary significantly in terms of efficiency and environmental performance. As a result, the overall performance of the system has suffered significantly in terms of cost, environmental performance and distorted investment decisions.

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- The dispatch model is closely linked to the electricity pricing mechanism; no dispatch reform can be introduced without a reform of electricity pricing, and such a reform would have to compensate coal power plants whose revenue is calculated on the basis of the existing dispatch model.
- China has made remarkable progress with regard to the introduction of time-of-use pricing. Such pricing mechanisms are planned to be applied to all categories of customers in 2015. However, it is unclear whether the specific design of time-of-use prices actually sets sufficient incentives for shifting electricity use among all groups of customers.

3.4.6 The role of information and communication

The government's role in promoting smart grid-related ICT The Chinese government promotes innovations surrounding smart grids mainly by focusing on the supply of smart grid technologies: on the one hand, the Chinese government counts on public enterprises as main drivers of smart grid innovations. On the other hand, it allocates significant financial funds to promote R&D activities or to build up demonstration sites [50]. Specifically, in 2012 the MOST released a special plan for smart grids focusing on R&D and considering the 12th five-year period (from 2011 to 2015). The smart grid special plan focuses on three main strategic goals:

- It is forward-looking and sets the agenda for the Chinese smart grid development after 2015. It promotes the development of so-called *cutting-edge* smart grid technologies which might be deployed after 2015.
- It aims at ensuring that existing modern technologies such as those listed in appendix B are introduced very fast into the Chinese energy system.
- It highlights that China must keep up with world-class smart grid research developments and should carry out cutting-edge smart grid technology research.

The general idea behind the smart grid special plan is that the development of smart grids should be business-orientated and primarily rely on the innovation capacity of domestic companies, which are intended to achieve international technical dominance by 2020. This will require a more profound and more effective involvement in international research cooperation and standardization processes.

The promotion of smart grid standards is another important channel for the government to influence the evolution of Chinese smart grids. One example for such activities is the work of the State Council, which has issued a plan for modifying and promoting the power equipment manufacturing industry [50]. Another example is the China Electric Power Research Institute directly emitting standards on *Low Voltage Power Line Carrier Communication* or *Intelligent Control Network Data Terminal* [50].

Policies focusing on the demand for smart grid technologies are of rather low importance for the Chinese government in its efforts to promote smart grids [50]. Note that this prevalence of supply-side policies together with the rather low importance of demand-side policies in China are a sign that, much like the situation in other countries, China's smart grid industry is still in the initial phase of its development [50].

The role of the ICT industry in promoting smart grids China's ICT sector is representative of the massive changes in China's industry and economy. Since the economic reforms in 1978, it has been growing rapidly with large inward and outward foreign direct investment flows and export-led activities [51]. Today, most of China's ICT companies are private companies that are not owned by the state. Many of them have been founded by foreign investors or companies. The Chinese strategy of building national champions has already yielded the creation of several ambitious companies which became global players [51]: *Huawei Technologies*, *Lenovo*, and *ZTE* are good examples of such companies. Huawei and ZTE are major players in the *Global System for Mobile Communications* (GSM), *Code Division Multiple Access* (CDMA), Optical and *Digital Subscriber Line Access Multiplexer* (DSLAM) equipment markets. Huawei Technologies in particular has emerged as a leading provider of telecommunications networks that increasingly challenges established competitors like *Siemens*, *Cisco*, and *Alcatel* [51].

Irrespective of the increasing importance of China's ICT sector, most ICT companies have few stakes in the strategic development of China's smart grid vision. Even though these companies act as component and technology suppliers, they are less engaged in the strategic development process, which is mainly pushed forward by the government, the grid companies, and the power generation companies.[9]

Regulatory challenges in the area of the role of information and communication

- There is a need for cutting-edge smart grid technology research to keep up with international level smart grid research developments.
- China's ICT industry consists of many ambitious and competitive companies, some of them global players. However, ICT industry is currently underrepresented in the strategic development of smart grids in China. Therefore, the large innovation potential of the ICT sector risks not being fully integrated in the Chinese smart grid development.

Key findings

- In the past 15 years, a series of reforms have greatly improved the efficiency, reliability, and environmental performance of the Chinese power sector. However, significant challenges remain: rapidly rising electricity demand, concerns about power system reliability and energy security, low average utilization rates of the grid infrastructure, environmental degradation and climate change.
- A core motivation for smart grids in China is their suspected positive impact on supply security and operational efficiency, especially on the distribution grid level. Peak shaving enabled by means of smart grid technologies plays an important role to increase supply security and operational efficiency. Smart grid technologies are also seen as a means to reduce RES integration costs, which is of critical importance given the Chinese government's aggressive RES expansion targets.
- Due to the absence of a common smart grid view in China and the contrary strategies on smart grid development among China's grid operators, there is still no unanimously accepted technological and organizational concept of smart grids in China. As a result, the uncertainty of potential smart grid investors regarding the future technological development is high.
- Some regulatory aspects of China's electric power system represent barriers for the effective and efficient development of smart grids in China:
  - The absence of government guidelines for the long-term development of the electric power sector, overlapping responsibilities and conflicts of interests between different government authorities, and the lack of independence and law enforcement of the regulatory authority point to insufficient government leadership with regard to smart grid development.
  - The market structure is dominated by China's grid operators, who are responsible for transmission, distribution, and retail. Innovative and new market actors, and specifically the ICT industry, are hardly involved in the smart grid development process.
  - On-grid prices, retail prices, and the operating hours of power plants are fixed by government authorities. Grid operators' income depends on the difference between retail and on-grid prices – network charges are not explicitly calculated. Such a market design sets only few incentives for operational efficiency and does not incentivize investments in an efficient way.
  - Grid expansion planning is organized in a top-down process with low transparency and little involvement of players other than government authorities and grid operators.

9 They seem to show even less engagement in China's smart grid development than international players such as Cisco or IBM.

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Germany's way from conventional power grids towards smart grids

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4

Chapter at a glance

- This chapter gives an overview of Germany's electric power system, its physical infrastructure, the regulatory environment, and the vision for smart grid development. The main topics presented were selected with the intention of providing examples of lessons learned and of sharing the German experience in the area of the main technological and regulatory challenges presented in the previous chapter.
- The chapter contains a detailed description of the historical development and current design of German electricity markets with a special emphasis on market liberalization policies. It also focuses on the effects of aggressively expanding RES generation capacities in the context of such markets. The evidence presented here might be insightful for Chinese policy-makers given their will to promote the establishment of electricity markets and to increase RES generation capacities.

4.1 Historical perspective

Reliability and affordability as the first policy goals In the first decades of the electrification process, Germany's electricity system developed rather independently from governmental regulation. Power generation units and electric power grids were built up in a decentralized manner and operated by a variety of local and regional companies. After World War I, 220-kV transmission grids were constructed to interconnect local and regional power grids. The trend towards a nationally integrated electric power grid contributed to increasing competition between companies from different regions which in turn resulted in a pronounced market consolidation.

The time of little government interference ended in 1935, when the German government issued the *Energy Industry Act* (EnWG). The main objective of this law was to pave the way for the effective and efficient development of a nationally integrated and reliable electricity grid. This goal was supposed to be achieved by incentivizing investments in generation units and in the grid infrastructure by formally assigning monopoly rights to predominant companies. Monopolistic structures were deemed more suitable to guarantee a reliable power grid and to operate the grid in a cost-efficient manner taking advantage of economies of scale.

As a result of regional monopoly rights, EnWG created an electricity system with a high degree of vertical integration and a low degree of competition. Electricity generation and transmission assets were owned and operated by integrated utilities, while electricity distribution and retail was in the hand of integrated municipal utilities. The municipal utilities were owned either by local governments or by the integrated utilities responsible for generation and transmission, which then combined all stages of the electricity supply chain into a single company. To protect consumers against the market power of the newly installed monopolies, EnWG obliged the companies to provide electricity to every end consumer; the Act also regulated construction and expansion of power plants in order to ensure system stability.

Sustainability as a more recent policy goal One important shift in Germany's electricity market regulation regime had its origin in the 1970 s, when environmental protection gained momentum as a new policy goal [1]. Due to high levels of local and regional air pollution caused by the combustion of fossil fuels for electricity generation, the German government issued the *Federal Pollution Control Act* (BIMSchG) in 1974. This law and its ordinances obliged power plants to install filter technology in order to reduce, for instance, *sulfur dioxide* (SO_2) or *nitrogen oxides* (NO_x) emissions. In the 1990 s, the German government further strengthened the role of environmental protection:

- The 1991 *Act on the Feed-In of Electricity from Renewable Sources into the Public Grid* and its more prominent successor, the *Renewable Energy Act* (EEG) of 2000, had the objective to incentivize investments in renewable energies by guaranteeing investors financially attractive feed-in tariffs.
- Another example of Germany's regime shift to environmental protection is the *Electricity Tax Act* (StromStG) of 1999 which, amongst other objectives, had the aim of inducing consumers to consume less electricity by raising electricity prices.

Public acceptance – towards a fourth energy policy goal The increasing importance of sustainability is generally supported by the German population. However, citizens are more frequently opposed to new energy infrastructures near residential areas if these infrastructures are related to visible, audible, or olfactory effects. In the light of Germany's rather high population density, the build-up of distributed and renewable energy sources has of late entailed rising public opposition. An increasing number of citizens disapprove of investments in new wind farms, biomass power plants or transmission lines [2]. During the last few years, a certain number of energy projects – for instance new transmission lines or demonstration sites for carbon capture and storage – have failed to be realized owing to public opposition against them [3], [4]. As a consequence, public acceptance has recently gained prominence in the discussion as a fourth general energy policy goal in Germany, since it is only with a high level of public acceptance that the government and the companies are able to realize their investment plans [2]. Experiences in Germany reveal that three elements are important to ensure the support of the population for investments in energy infrastructure:

- There has to be transparency on costs, benefits, and risks of new investments and technologies while the underlying motivations of the stakeholders involved in a project have to be communicated to the public.
- The public has to be included in the entire planning process of new projects. Private citizens and other public stakeholders must be able to communicate their position and may also be allowed to invest financial funds of their own in the project.
- Given that some conflicts cannot be solved unanimously, specific institutions or procedures for mediation and reconcialiation of interest are necessary to reduce number of court-cases [2].

A short summary of market liberalization tendencies since 1996 For a long time, Germany's electric power system was characterized by a high degree of vertical integration and a low degree of competition. Today, the different stages in the supply chain are in a state of far-reaching unbundling, and competition has been established in the generation and retail sectors.

The market liberalization process on the European level began in 1996 with the *First Electricity Directive* [5], which was issued by the *European Union* (EU) and motivated by two main objectives [6]:

- To open the electric power sector for third parties and to prevent discriminatory behavior towards generation companies by grid operators.
- To allow end consumers to choose their retailer in an effort to increase the affordability of electricity through more competition. Thus, the protected supply areas (regional monopolies) of the incumbent retail companies were abandoned in favor of retail competition.

Based on this directive, the German government in 1998 revised EnWG and started to liberalize Germany's electricity sector. After a short period of promising results with market entries of independent retail companies and decreasing retail prices, retail prices increased again. In addition, the market concentration did not decline significantly. Questions emerged regarding whether competition in generation and retail could be achieved as long as grid operators still had ownership in generation. Accordingly, the *Second Electricity Directive* issued by the European Union in 2003 contained a package of requirements to achieve *legal unbundling*. Legal unbundling can be described as an unbundling of accounts, operations, and information. It requires that transmission and distribution grid operators are independent from each other, as well as from generation and retail. In practice, legal unbundling requires a functional unbundling by guaranteeing independence in terms of legal form, organization/management and decision-making.

Based on the 2007 inquiry into the energy sector, the *European Commission* (EC) stated that, in spite of legal unbundling, the level of competition in the European energy market was still too low [7]. Major challenges were identified with respect to market concentration and vertical foreclosure.[1]

1 Vertical foreclosure refers to a situation in which a company buys a supplier that supplies both the company and its competitors in order to discriminate against the competitors.

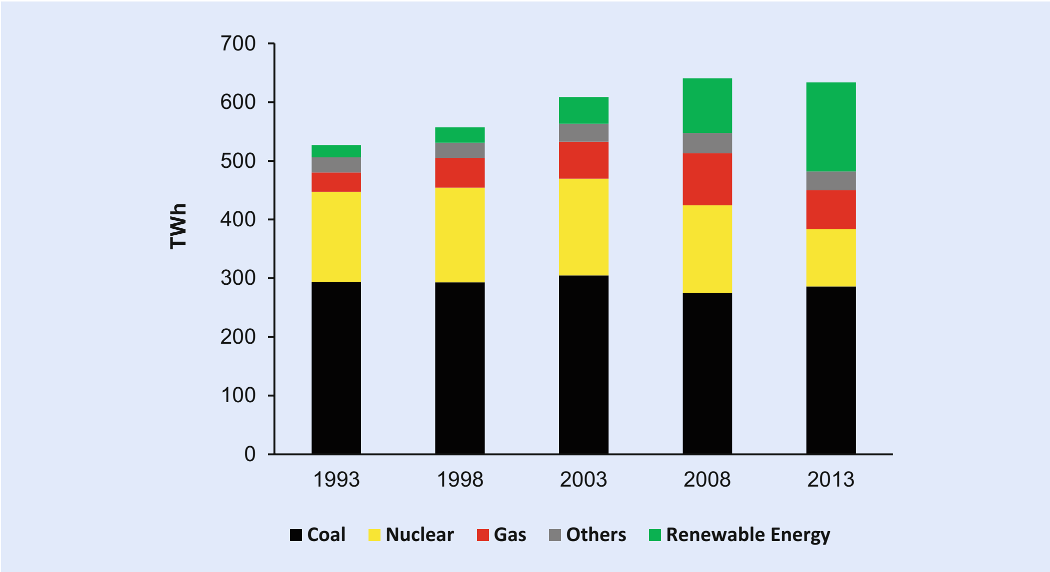

Fig. 4.1 Electricity generation in Germany from 1993 to 2013 in TWh, data from [11]

This document criticized the fact that with legal unbundling, a utility might still be able to discriminate against competitors or even restrict access of new market actors to the infrastructure. In addition, the Commission Paper stated that a grid operator involved in competitive sectors might be able to cross-subsidize its activities in the market with the revenues generated from the monopoly part of its business [8]. Furthermore, the European Commission was concerned about insufficient incentives for network investments, especially across borders. Generally speaking, markets for electricity were organized on a national basis and there was only a weak relation between the various national markets, as shown by grid congestions at most borders. The Commission argued that incumbents might postpone investments into interconnector capacities in order to protect their own market against cheaper electricity imports. This behavior is known as *strategic investment withholding* by locally integrated utilities [9].

In 2009, the EU's *Third Electricity Directive* introduced a compromise with three different options for unbundling on the transmission level. Basically, the aim of this rule was to separate the transmission grid from the other stages of the supply chain. The three options were:

- ***Full ownership unbundling*** prohibits ownership of network and generation or retail assets by one and the same firm.
- A model based on an ***Independent System Operator*** requires that an entity independent from the transmission grid owner takes over grid operation. With an independent system operator, network ownership can remain within an integrated company which also owns generation assets.
- A model based on an ***Independent Transmission Operator (ITO)*** allows companies to retain both network ownership and management, but it puts strong limitations on cross involvement of employees in order to ensure network independence (please refer to [10] for further explanations on this model). In effect, the ITO model is similar to legal unbundling, though in a stronger form.

In Germany, the ITO model was applied. It had to be ensured that the transmission system was owned and operated by the ITO, which is legally independent from the commercial businesses of electricity generation and retail. Currently three out of the four *transmission system operators* (TSO) in Germany apply full ownership unbundling; the fourth is a genuine ITO.

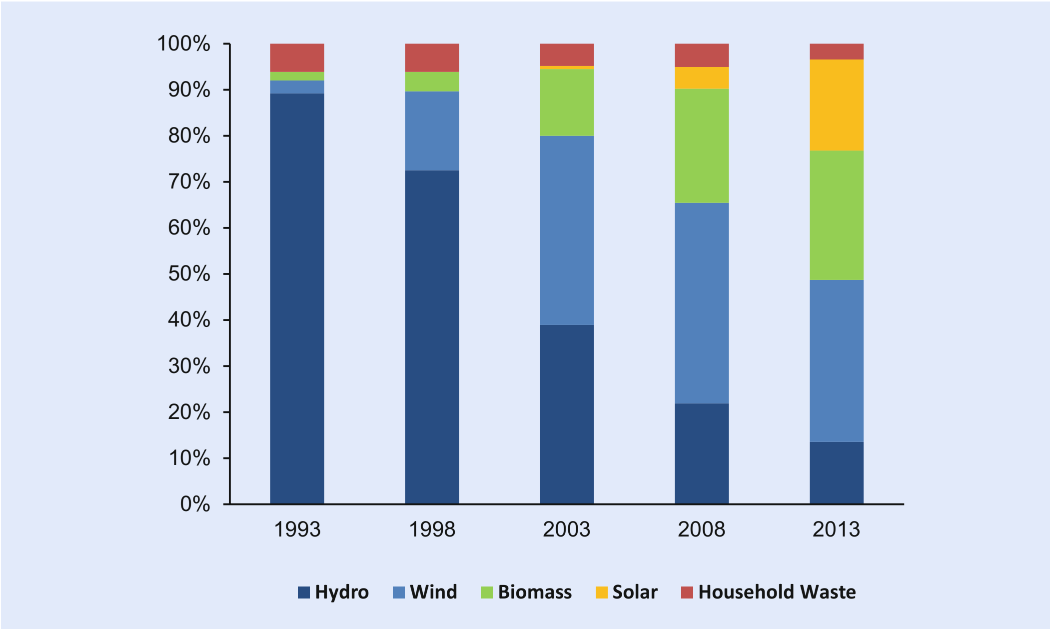

Fig. 4.2 Composition of the RES generation mix from 1993 to 2013, data from [11]

Distribution grids are currently subject to legal unbundling requiring administrative separation similar to the ITO model though in a less restrictive form. The objective is to ensure that no commercially sensitive information is exchanged between the power grid and other parts of the supply chain within one integrated company. Note that administrative unbundling is only applied for *distribution system operators* (DSO) with more than 100,000 customers. DSO with fewer customers do not have to unbundle and can remain an integrated part of a utility. This exception is known as the *de-minimis rule*.

4.2 Today's power system and its most pressing challenges

4.2.1 Power generation

In 2013, Germany's gross electricity generation amounted to roughly 634 TWh. Coal is currently Germany's predominant primary energy source, accounting for more than 45 % of total electricity generation.[2] Nuclear power and gas are the second and third most important generation sources, accounting for approximately 15 % and 11 % of overall electricity generation respectively. Roughly 24 % of total electricity generation comes from RES, with wind accounting for 8.4 %, biomass for 6.7 %, solar for 4.7 %, hydro for 3.2 %, and household waste for 0.8 % [11].

During the last 20 years, overall electricity generation increased only slightly (see Fig. 4.1). However, the composition of the electricity mix has changed significantly owing to two specific governmental policies: the promotion of RES initiated in the 1990 s and the nuclear phase-out promulgated in 2002. As a consequence, there has been a steady decline in the proportion of electricity generated by means of nuclear power from 29.2 % in 1993 to 15.4 % in 2013, and coal, from 55.7 % in 1993 to 45.2 % in 2013, while the share of RES in the electricity mix has increased from 4.0 % in 1993 to 23.9 % in 2013 [11].

The rise in the share of RES generation went along with a considerable shift of the importance of different RES generation sources. While hydro power was by far the most important RES generation source in 1993, it plays no more than a minor part in 2013. Wind, biomass, and solar power, virtually non-existent in 1993, are the most important RES generation sources in 2013 (see Fig. 4.2). Elec-

2 In the German context, coal refers to both hard coal and lignite. These two fuels are used in roughly equal amounts.

Table 4.1 Electricity consumption in Germany in 2013, data from [14]

Consumer	Electricity Consumption in TWh in 2013	in % of Total
Mining and Industry	241	45.6
Residential Sector	139	26.3
Wholesale, Retail, Trade	76	14.4
Public Sector	51	9.7
Transport	12	2.3
Agriculture	9	1.7

tricity generation from PV has seen large growth in recent years (from 4.4 TWh in 2008 to 30 TWh in 2013).

A large part of Germany's RES installations are distributed generation sources such as small rooftop PV installations, single wind turbines, or biomass plants. A look at PV installations, for example, reveals that more than 60 % of all installations feed in electricity in a decentralized manner at the level of low voltage grids [12]. The focus on distributed energy sources is reflected in a diverse ownership structure. More than 40 % of all RES installations in Germany are owned by private investors, with project developers and financial institutions following with 14 % and 13 % respectively [13]. Note that only roughly 12 % of RES installations are owned by power generation companies [13].

4.2.2 Power consumption

Germany's electric power consumption amounted to about 528 TWh in 2013 [14]. The difference between gross electricity generation and consumption results from power plants' own consumption, from electricity exports to other countries, and from line losses. Industry is the main consumer of electricity and is responsible for approximately 46 % of national electricity consumption (see Table 4.1). The residential sector follows with 26 % while the commercial and public sectors consume about 14 % and 10 % respectively. The transport and agricultural sectors play no more than minor roles with shares of roughly 2 % [14].

In comparison to China, the shares of residential and commercial loads are significantly higher in Germany. This results in a load curve with more pronounced peaks and valleys. The ancillary services necessary to cope with this pronounced load curve are mainly offered by gas-fired power plants in Germany. Neither total electricity consumption nor the relative importance of different types of consumers has changed significantly in recent years.

The increasing share of electricity generated from intermittent sources like wind and PV led to the question of how power consumption can adapt to fluctuating generation. The potential for load shifting, which is relatively easily accessible at reasonable costs, lies in Germany's industrial sector with its large electricity consumers. Table 4.2 presents the maximum power which can be disconnected (neg.) or connected (pos.) for a short period of time in the residential, commercial, or industrial sectors according to different studies. The numbers have to been seen in relation to the German overall peak load of 80 GW.

4.2.3 Power logistics

Disparity between generation and consumption Power generation and consumption are not equally distributed in Germany. The load centers are situated in western and southern Germany, both regions with strong industrial bases. Since the amount of electricity generated in nuclear and coal-fired power plants in these regions is generally not sufficient, they often have to import electricity from other parts of Germany or from neighboring countries. In contrast, Germany's north and east, with their significant wind capacities, quite regularly generate more electricity than they consume. Thus, both regions frequently transfer electricity to southern and western Germany.

Grid infrastructure Germany's electric power grids can be classified into four different categories:

- ***Extra high voltage grids (220-kV to 380-kV)*** form the German transmission grids. In ad-

Table 4.2 Demand side management potential according to German studies and sector

Study	Residential	Commercial	Industrial
Stadler [15]	–68 GW (pos.)/28 GW (neg.)		
Klobasa [16]	20 GW	–	2.8 GW
Dena II [17]	7–32 GW	2.4 GW (pos.) 14.3 GW (neg.)	3.9 GW (pos.) 6.5 GW (neg.)
TU Dortmund University [18]	5.0 GW (pos.) 6.3 GW (neg.)	3.0 GW (pos.) 18.1 GW (neg.)	0.9 GW (pos.) 11.2 GW (neg.)

dition to the transmission of electricity, they are responsible for the electricity feed-in of large generators such as nuclear and coal-fired power plants, or offshore wind farms. The transmission grid is mainly characterized by suspended above-surface cables with visible electricity pylons. There are currently approximately 35,000 km of transmission grids with 1,100 electricity transformers in Germany [19], [20].

- ***High voltage grids (35-kV to 110-kV)*** are the highest voltage level of distribution grids. They act as a redistribution system at the regional level. Furthermore, high voltage grids provide electricity to large industrial consumers and are also employed to feed in electricity from smaller power plants, wind farms, and large PV parks. There are approximately 95,000 km of high voltage grids and 7,500 electricity transformers at this level [19] [20].
- ***Medium voltage grids (10-kV to 30-kV)*** represent the subordinate level of distribution grids. They distribute electricity to the connected low voltage levels, provide electricity to connected bulk consumers, and feed in electricity from small PV parks or single wind turbines. The medium voltage level is characterized by underground cables; it is roughly 507,000 km in length and contains 560,000 local substations [19] [20].
- ***Low voltage grids (230-V to 400-V)*** are typically also characterized by underground cables and distribute electricity from local substations to households and collect electricity from rooftop PV modules. It has an approximate length of 1,150,000 km [19].

An increasing amount of network congestion at times of peak generation is caused by small distributed rooftop PV installations on the low voltage level and rising feed-in from large wind farms at the high voltage level [21]. Due to the rapid build-up of RES generation capacities, grid capacities are not always sufficient to absorb RES-E. As a result, grid curtailment rates of solar and wind power have increased significantly within the last few years. In Schleswig-Holstein, a windy region in the north of Germany, 3.5 % of the total wind generation had to be curtailed in 2012 [22].

The curtailment of RES-E at times of peak generation can reduce the need for network investments. A recent study suggests that curtailing 30 % of PV peak production and 20 % of wind peak production could reduce infrastructure investments by 10 % between now and 2030 while a total of only 2 % of the annual electricity production from RES would be curtailed [23].

Through the transmission grid, Germany's electric power system is well interconnected with those of neighboring countries (please refer to Fig. A.1 in the appendix for a snapshot of Germany's transmission grids). All German TSO are members of the *European Network of Transmission System Operators for Electricity* (ENTSO-E), which was established in 2011 in order to

» *promote the completion and functioning of the internal market in electricity and cross-border trade and to ensure the optimal management, coordinated operation and sound technical evolution of the European electricity transmission network* [24].

Table 4.3 Frequently used measures to maintain supply security in the presence of RES, data from [27]

	Supply Security Issue		
Measure	**Grid Overload**	**Critical Voltage Variation**	**Power Quality**
Direct connection of RES to a substation		X	X
Upgrade of grid circuit conductors	X	X	X
Upgrade of upstream transformer capacity	X	X	X
Reduction of the grid circuit length		X	X
Set point adjustment of transformer automatic voltage control		X	
Using reactive power capabilities of RES		X	
Construction of a new substation	X		

Supply security in Germany In comparison with other European countries, Germany's electric power system is characterized by a very high level of security of supply with, on average, only about 15 minutes of annual interruptions on the household level [25] [26].

The increasing feed-in of RES generation imposes challenges for the stability and reliability of Germany's distribution grids. Three technical challenges for network stability caused by RES integration into distribution grids in Germany are presented in Table 4.3, together with the measures most frequently used to overcome them.

Investment needs in the grid infrastructure Securing a high level of supply security in spite of the increasing share of electricity generated by variable RES requires significant investments in transmission and distribution grids. On the transmission grid level, it is estimated that roughly 3,600 km of 380-KV AC overhead lines will have to be installed between now and 2023 [23]. This represents a total investment of EUR 21 billion [28]. On the distribution grid level, the pressure is even higher: between 135,000 and 193,000 km will have to be added to the existing network by 2030. In addition, between 21,000 and 25,000 km of the existing distribution grid will have to be modernized in the same period of time. According to a recent study, these numbers add up to a total investment need of roughly EUR 42.5 billion on the distribution grid level [18].

4.3 Smart grid development in Germany

4.3.1 Motivation for smart grids in Germany

The rising importance of intermittent RES generation is the main smart grid driver in Germany. Today, the general opinion of most energy market experts in Germany is that building a smart grid, especially a smart distribution grid, is a cost-efficient way of ensuring security of supply in the presence of large-scale integration of intermittent RES [29], [30].

The challenge of fluctuating RES in extra high voltage grids Germany's transmission grids (380-kV/220-kV grid) have already achieved a high degree of smartness and are equipped with sophisticated real-time monitoring and control technologies. The increasing amount of wind power from large wind farms creates a need for more grid control. Sophisticated generation forecasts, for example, are needed to adequately react to the pools of fluctuating generators and maintain the 50 Hz grid frequency within its narrow tolerance range of ± 0.2 Hz.

The challenge of fluctuating RES in high voltage grids The 110-kV high voltage grid also requires high availability and near-real-time monitoring and control. The main challenge within high voltage grids is to maintain voltage levels and loads within a technically viable band. In the event of overloads, for example arising from a high volume of RES-E, electricity has to be transferred to the higher voltage level. Bidirectional flows of electrical power are an additional challenge at the level of 110-kV high voltage grids. If overloads cannot be transferred to the higher voltage level, generation has to be curtailed or additional loads have to be activated.

The challenge of fluctuating RES in medium voltage grids Supply quality, specifically with regard to voltage maintenance, constitutes a major technical challenge in medium voltage grids due to the fluctuating and distributed generation from RES. The degree of utilization of ICT in medium voltage grids is limited. Continuous load measurement, for example, is used only for customers with consumption levels exceeding 100 MWh/a. As prescribed by the *Electricity Network Access Ordinance* (StromNZV), these customers' average power consumption must be measured in periods of 15 minutes and this information delivered to the distribution grid operator which then uses the measurement data to compute a specific load profile. The measurement equipment is operated by the DSO or by the metering system operator. Like at the 110-kV level, wind and PV plants may result in inverted flows of electricity to the higher voltage level in order to avoid an overload of grid assets, especially in rural areas with a more limited infrastructure.

The challenge of fluctuating RES in low voltage grids Today, ICT-based grid operation is very rarely installed at the level of low voltage grids, where rooftop PV represents a major challenge in terms of voltage maintenance and can cause a more rapid aging of grid assets. Grid operators currently handle these challenges by expanding the grid infrastructure with new cables or local substations. In the future, electric mobility may further increase the necessity for active control of low voltage grids. It should be noted that the control of assets in low voltage grids is especially difficult due to the large number and high heterogeneity of the connected assets (e.g. households, rooftop PV modules, local substations, electric vehicles). Thus, standardization of control interfaces is viewed as one of the key issues for assets being installed in low voltage grids [31].

4.3.2 Germany's technological view of the smart grid

The development of smart grids in Germany In Germany, smart grid technologies have been described, combined, tested, and implemented in a bottom-up process by research institutions, companies from the electric power sector, component suppliers, and ICT companies.

The primary driver for smart grid development was the integration of RES into the operational environments of grid operators. Their integration mainly relies on large monolithic *supervisory control and data acquisition* (SCADA) systems. Small amounts of renewables were controlled in parallel to the overall grid operations, often in so-called *distributed energy management systems* (DEMS). In terms of communications, the systems used existing communication infrastructure and heterogeneous proprietary data models and protocols. The need to integrate RES in daily grid operations led to a change in the paradigms on how to design and control RES. Aspects relating to the connection between different assets were the first to be focused upon – *general packet radio service* (GPRS), GSM, *universal mobile telecommunications system* (UMTS), and currently *long term evolution* (LTE) or IP-based open networks such as the internet have been used. After this initial focus on connectivity, more emphasis was put on the semantics and syntactical aspects of communication.

The government's view on smart grids As in China, different stakeholders in Germany have developed different views on smart grids. The primary goal of the German government, especially via the *Federal Ministry for Economic Affairs and Energy* (BMWi) and BNetzA, is to guide the debate and support convergence of the various stakeholders' smart grid visions. BNetzA, in late 2011, published a position paper called *Smart Grid and Smart Market* [32] (see [33] for an English summary of this document).

The main objective of this document was to introduce a clear-cut criterion on how smart grids and so-called *smart markets* can be differentiated and to discuss the regulatory consequences. BNetzA points out that electricity volumes and related services have traditionally been traded on electricity markets independently from the available grid capacity.[3] In a power system based on smart grids, however, information on current grid status can be taken into account in market transactions. Markets allowing the trade of electricity volumes and related services based on available grid capacities are referred to as smart markets. Depending on the available grid capacity, smart markets can either operate without restriction – in case of sufficient grid capacity, or – in case of grid congestion – the grid operator has the right to intervene in the market to ensure grid stability and e. g. shut down power plants or cut off consumers [33]. One example for smart markets are regional energy market places.[4] Within a specific region, industrial, commercial, and domestic customers are given the option of trading electricity volumes and/or ancillary services in a market place. By trading ancillary services, power consumption schedules, and power generation (feed-in) schedules, market participants are exposed to price signals serving as an economic incentive to balance electricity supply and demand and thus stabilize the grid.

The position paper *Smart Grid and Smart Market* discusses relevant topics along six key concepts:

- The first key concept, named *Grid capacity and energy volumes as distinguishing criteria for grid and market,* explains how grids and markets can be separated by identifying the main topics involved. All aspects relating to grid capacity (as measured in kW, MW, GW, etc.) refer to the grid whereas all topics relating to energy volumes (as measured in kWh, MWh, GWh, etc.) refer to the market.
- The second key concept, *Clarification of the discussion about the energy future through the terms of smart grid and smart market,* follows-up on the first key concept. It clarifies that the term smart grid can be related to network issues while the term smart market can be related to energy volume issues.
- The third key concept has the somewhat cumbersome title *The energy future requires more responsibility on the market and more negotiated solutions. The grid should play a predominantly service role and should be separated from competitive activities as far as possible.* It discusses the importance of new market actors in smart markets and underlines that competitive functions, especially those in smart markets, should not be attributed to grid operators. Grid operators are considered responsible only for the (smart) grid itself. Smart grids are seen as a platform for smart markets. Grid operators are consequently viewed as playing a supporting role for smart markets.
- The fourth key concept, entitled *Smart meters are part of, but not an absolute prerequisite for, the energy future*, states that grids can be made smart without a widespread rollout of smart meters. The main argument is that it is sufficient to measure data on grid conditions in local substations or to install only some smart meters at potentially critical junctures in the grid.
- The fifth key concept, named *The smart grid is a part of an evolutionary, not a revolutionary, process*, emphasizes that smart grids are not built from scratch but evolve in a gradual process. In the light of the heterogeneity of the various grid operators in Germany, BNetzA consequently stresses that a kind of uniform smart grid concept applicable to every grid operator does not exist and should not be promoted by means of regulation.
- The sixth key concept is named *If targets for the use of renewable energy are to be met it is essential that these producers, too, respond to*

3 However, system operators have the possibility of correcting market outcomes in the case of insufficient grid capacities. Nonetheless, grid capacity itself is not taken into account in the decisions of the market participants.

4 Regional energy markets have been tested in several demonstration projects in Germany, e. g. in the *eTelligence* project. A detailed overview of the results from *eTelligence* can be found in [62].

market signals and grid exigencies. It underlines the importance of integrating RES more effectively in wholesale markets, potentially by redesigning the feed-in priority for RES.

Smart grids according to a recent study by the German Academy of Science and Engineering In 2012, under the guidance of the *German Academy of Science and Engineering* (acatech), representatives of the electric power sector, equipment manufacturers sector, ICT sector, and from academia and research institutions developed a smart grid model for Germany: the *Future Energy Grid* (FEG) model [30]. The model complements the BNetzA view on smart grids by developing a conceptual and technological foundation for the separation of smart grids and smart markets. In particular, FEG can serve as a best practice example of how to develop and formulate a comprehensive smart grid vision. FEG is a systematic and comprehensive top-down approach that can be used to evaluate the current smartness of grids and to define a smart grid vision. It systematically addresses specific problems and challenges in Germany's electric power system and introduces a model of system layers (see Fig. 4.3) and technology areas (see Fig. 4.4). The system layers represent different functions and requirements regarding the application of ICT in the power system. They were chosen in reference to a model adapted by the *European Electricity Grid Initiative* (see [34]).

In total, FEG comprises the following three system layers (see Fig. 4.3):

- The innermost layer, referred to as the *closed system layer*, contains the critical infrastructure and power system equipment that serves as the backbone of the system and requires a high level of security and safety. Therefore, external access to the resources within this layer is restricted and may be limited to the grid operator or to an equivalent actor. Central (bulk) power generation, transmission and distribution grids, and the corresponding ICT-based control systems are components of this layer.
- The outermost layer is referred to as the *networked system layer*. It contains heterogeneous power system components (distributed power generators, power storage units, consumers, marketplaces, meters, control applications, etc.) which are characterized by a high level of communication and information exchange. In contrast to the closed system layer, much of the value within this layer is created by interactions between the different participants on smart markets. As the exchange of sensitive power system information, e.g. real-time data on power generation and consumption, is of particular importance in this context, strict ICT and data security protocols have to be applied to ensure individual privacy rights are respected and overall power system security is guaranteed.
- The *ICT infrastructure layer* enables communication within and between the two other layers. It contains the communication networks and associated components that provide ICT interface functionalities. In order to ensure that different components of each layer can communicate with each other, interoperability is a key factor. Interoperability is achieved with the help of standardization of system interfaces and communication protocols.

In the study *Future Energy Grid*, a smart grid vision based on the three system layers described above and nineteen technology areas is outlined (see Fig. 4.4, for a detailed description refer to appendix D).

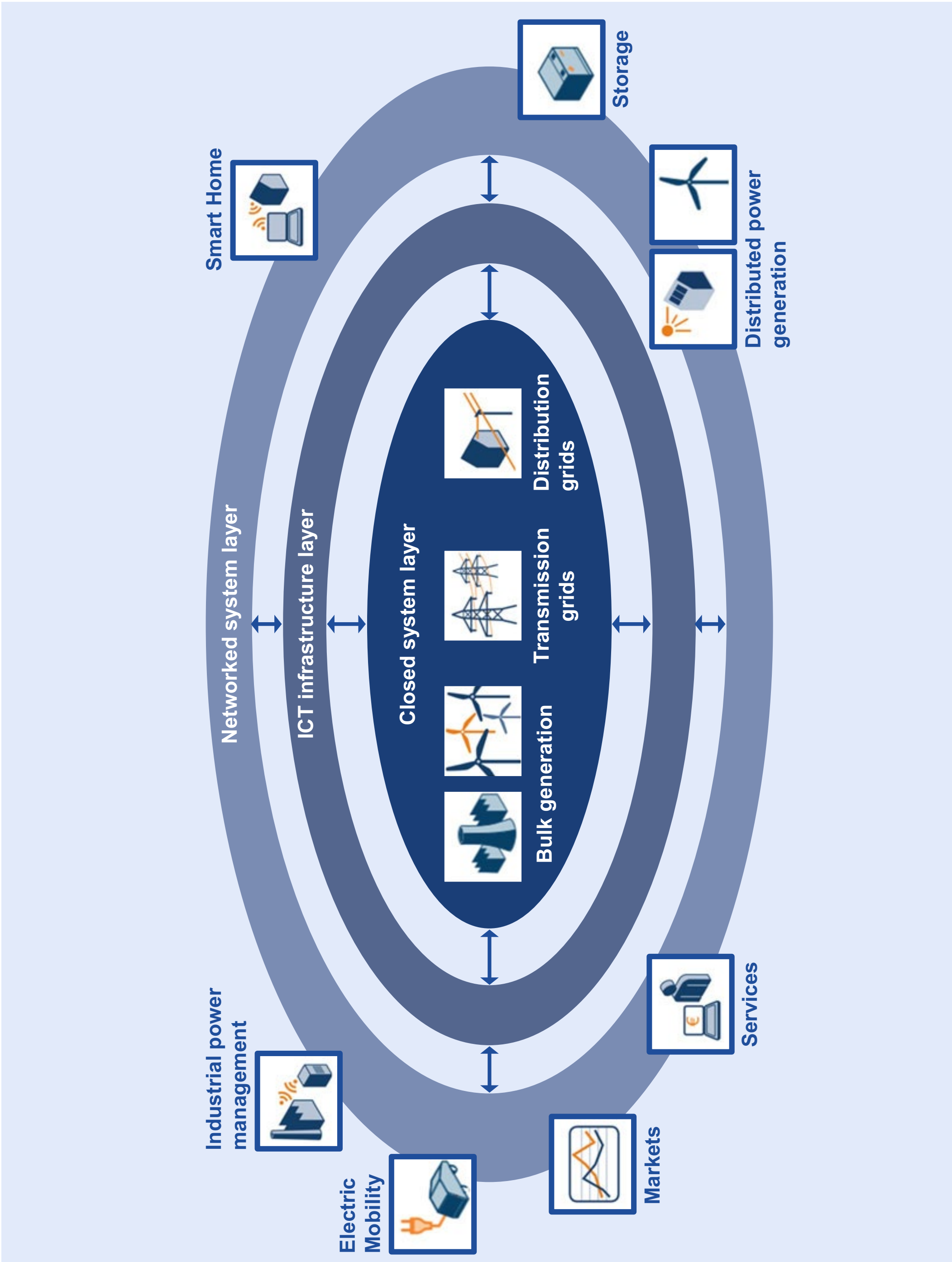

Fig. 4.3 Abstract smart grid system model regarding the application of ICT within three distinct layers, translated from [30]

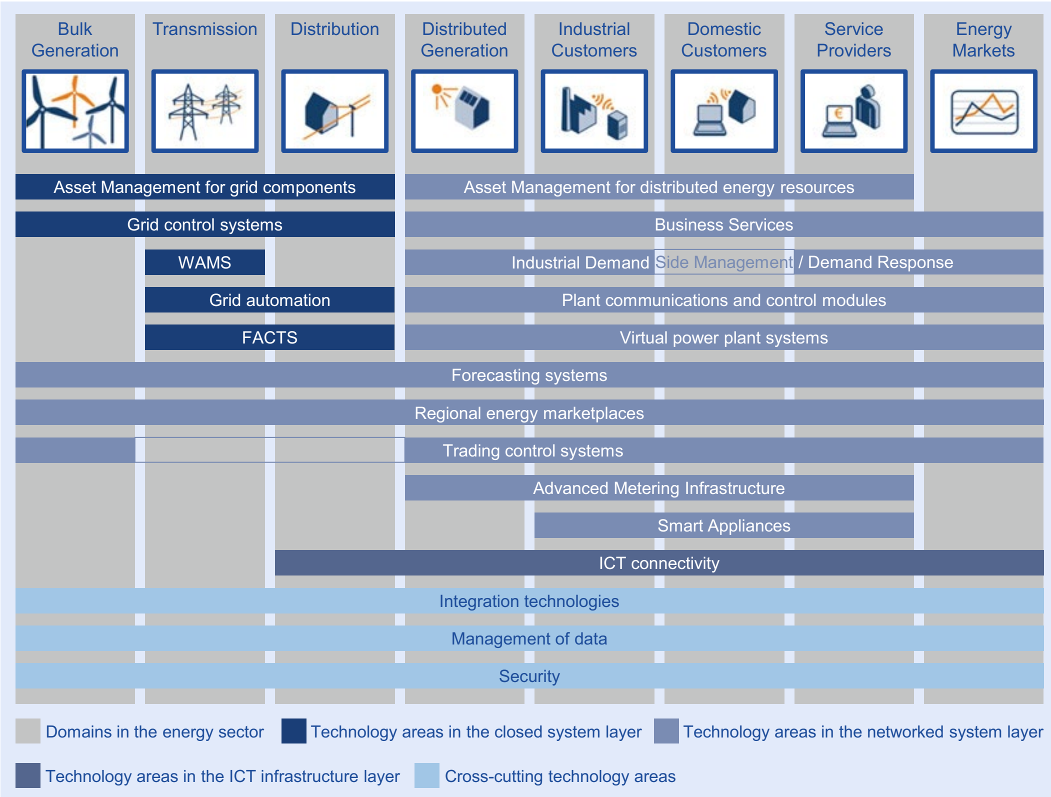

Fig. 4.4 Technology areas regarding ICT aspects of smart grid implementation in Germany, translated from [30]

4.4 The regulation of Germany's electric power system

4.4.1 Policy setting and fundamental institutions

Policy setting The *Federal Government's Energy concept for an environmentally friendly, reliable and affordable energy supply* of September 2010 *and The road to the energy of the future – safe, affordable and environmentally friendly (Key Elements of an energy policy concept)* of June 2011 [35] contain guidelines and objectives relating to Germany's future energy system. In particular, the trend towards more environmental protection is explicitly expressed by government plans to reduce CO_2 emissions to 60 % of the 1990-level by 2020. It is planned to further reduce emissions to 20 % of the level of 1990 until 2050 [35].

These cuts in CO_2 emissions are to be achieved by reduced energy use for transport and heating (see Fig. 4.5): e. g. energy consumption for room heating purposes should be reduced by 20 % between 2008 and 2020 and 80 % by 2050. For the power sector, the government's objective is to generate 35 % of electricity with RES in 2020 and to increase the share to 80 % by 2050 [35] as shown in Fig. 4.5. At the same time, in the aftermath of the nuclear disaster in Fukushima, the German government decided to completely phase out nuclear power generation by 2022 [35].

Many specific objectives with regard to the development of Germany's power system are subordinated to the general goal of achieving more sustainability and the specific goal of increasing the importance of RES: for instance, the German government wants to expand transmission grids in the north-south direction, thus allowing a more effective transport of wind power from the north to the load centers in the south of the country. Other government goals such as improving energy efficiency and promoting energy storage technologies

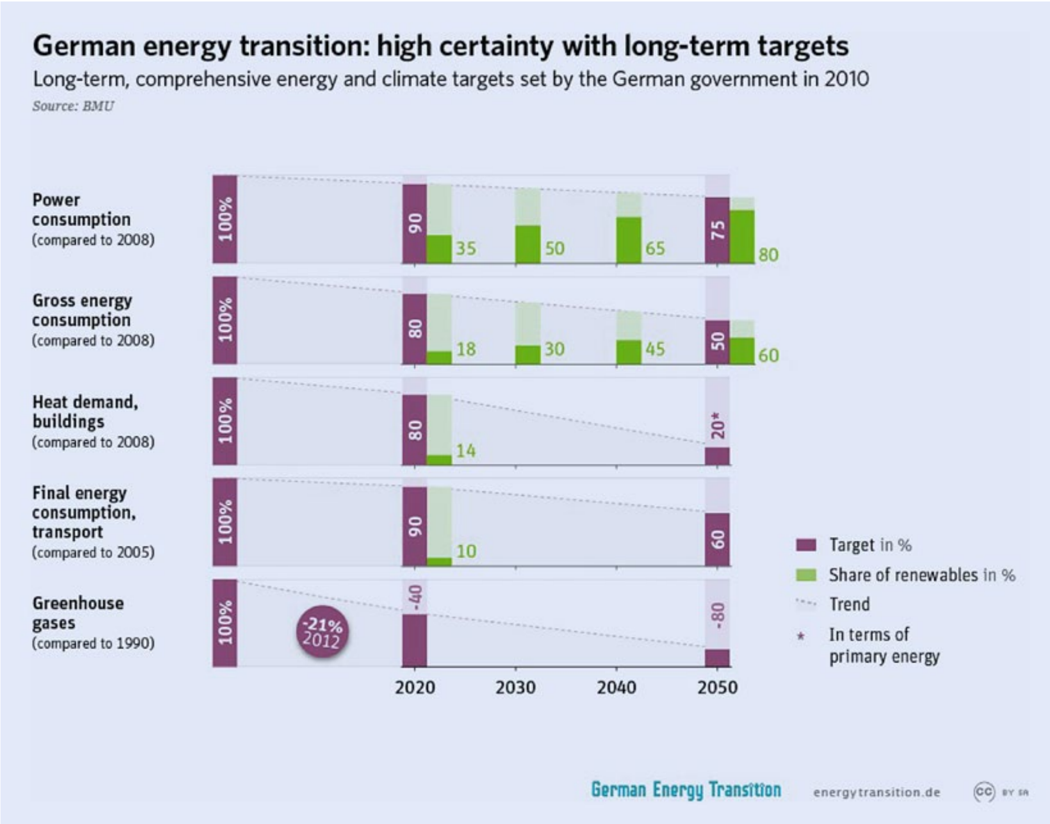

Fig. 4.5 Long-term targets for Germany's energy sector (© Heinrich-Böll-Stiftung e.V. [36])

and electric vehicles are also related to the broad government plan of increasing the sustainability of Germany's power system.

General governance structure The governance structure of Germany's energy system comprises several ministries and independent institutions. The ministries are responsible for enacting laws and ordinances that then have to be applied by independent institutions. This means that the ministry concerned can neither interfere in day-to-day business nor expand or restrict the competences of the institutions. Nonetheless, these institutions and the ministries cooperate closely.

Ministries responsible for Germany's energy policy There are currently two ministries at the core of the governance structure of the German electricity system:

- The *Federal Ministry for Economic Affairs and Energy* (BMWi) has the main responsibility for formulating and implementing energy policy, including renewable energy, and is responsible for issues related to security of supply and competition policy.
- *The Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety* (BMUB) is responsible for those energy policy issues which are directly related to environmental protection, e.g. CO_2 reduction, and energy efficiency in the building sector.

The market design of the electricity sector is a responsibility shared by BMWi and BMUB. Other relevant ministries in the context of energy and electricity sector policy and smart grids are:

- The *Federal Ministry of Transport and Digital Infrastructure (BMVI)* takes responsibility for

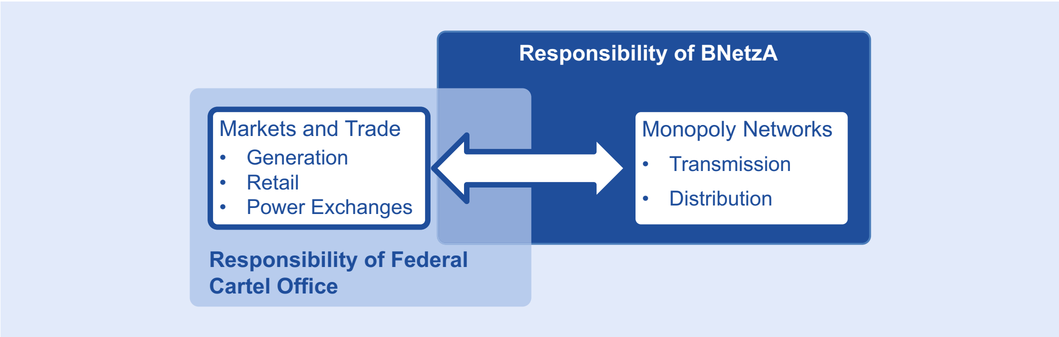

Fig. 4.6 Responsibilities of BNetzA and of the Federal Cartel Office

transportation and mobility issues as well as for the expansion of digital communication infrastructure, which is especially important as a backbone for smart grids.

- The *Federal Ministry of Labor, Social Affairs and Consumer Protection* (BMAS) focuses on social issues related to energy.

Institutions responsible for Germany's energy policy The following three government authorities are of particular relevance with regard to the regulation of Germany's electric power system:

- The *Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway* (BNetzA) is responsible for regulation of the networks which are natural monopolies, including the electricity grid (see Fig. 4.6). The existence and competences of BNetzA are laid down in laws such as EnWG and the *Grid Expansion Acceleration Act for Transmission Networks* (NABEG).[5] While BNetzA is in charge of national and interstate regulation it cooperates closely with regulatory counterparts on the level of the federal states. State regulators are responsible for DSO with less than 100,000 customers and BNetzA for all TSO and for DSO with more than 100,000 customers or with operations in more than one state.
- The *Federal Cartel Office* is responsible for general competition matters (see Fig. 4.6). If competition problems are related to natural monopoly networks, the Federal Cartel Office can authorize BNetzA to handle the issue. The existence and competences of the Federal Cartel Office are laid down in the *Act Against Restraints of Competition* (GWB).
- The *Monopoly Commission* advises on competition and monopoly issues. Its advice is non-binding and it does not have decision-making powers. Nonetheless, the Monopoly Commission plays a vital role in checking and evaluating the regulator's work. The tasks of the Monopoly Commission are also laid down in GWB.

A brief history of BNetzA The liberalization of European electricity markets began with the EU's *First Electricity Directive* of 1996. A so-called *negotiated Third Party Access* (nTPA) was allowed as an option alongside *regulated Third Party Access (rTPA)*. nTPA meant that access to the electricity networks, including network charges, had to be negotiated between network owners (grid operators) and network users (power companies). The directive did not explicitly prescribe a regulator and ultimately this approach failed to secure non-discriminatory network access and to deliver fair and reasonable network charges (cf. e.g. [37], [38] for an analysis and further literature).

The EU's *Second Electricity Directive* of 2003 contained significant changes: rTPA became the only option making non-discriminatory network access conditions a requirement by law. The Directive also demanded the establishment of an electric-

5 The NABEG describes the precise steps and more importantly the timing of these steps to be fulfilled after a connection request. With this, it avoids unjustified delays with network connection. The role of BNetzA within this process is specified, for example, in paragraphs 5, 7, 8, and 9 of this law.

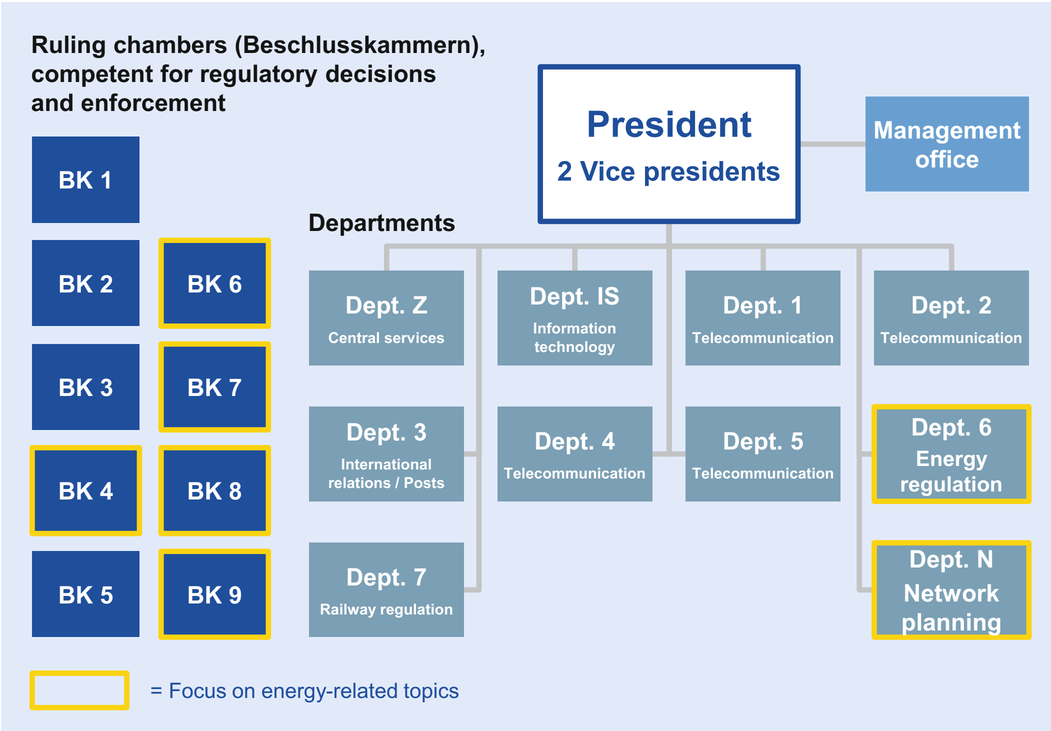

Fig. 4.7 BNetzA organization chart, adapted from [40]

ity sector regulator and the creation of a regulatory framework for fair and reasonable network charges. In Germany, EnWG was amended to satisfy these demands, resulting in the establishment of BNetzA as a federal regulator for monopolistic networks and the development of incentive regulation (see ▶ Sect. 4.4.4 for more information on incentive regulation). The regulatory competences of BNetzA were based on the competences of its predecessor, which was the *Regulatory Agency for Telecommunications and Post Services*. Competences relating to electricity and gas were added, and the agency was renamed to BNetzA. Later on, the task of regulating the railway infrastructure was added as well.

The EU's *Third Electricity Directive* of 2009 did not change the arrangements on rTPA or regulation. Instead, it strengthened the arrangements relating to unbundling rules. For the TSO, this led to the ITO approach while for DSO the unbundling rules stayed as they were in the *Second Electricity Directive* (see ▶ Sect. 4.1). BNetzA is also responsible for implementing the unbundling rules and monitoring compliance with them. Lastly, the *Third Electricity Directive* led to the creation of an *Agency for the Cooperation of Energy Regulators* (ACER). In a nutshell, ACER is responsible for cross-border issues and provides a platform for cooperation between various European regulators.

Main tasks and competences of BNetzA The mission of BNetzA is to regulate the monopolistic part of the supply chain – the grid or network infrastructure by:
- guaranteeing an affordable, consumer-friendly, efficient and environmentally friendly supply of electricity and gas,
- ensuring an effective and undistorted competition in the supply of electricity and gas as well as securing a reliable operation of electricity and gas grids,
- transposing and implement EU law in the field of grid-bound energy supply and
- facilitating efficient approval processes to adapt the German high-voltage transmission grid to

the needs of a rising share of renewable energy [39].

In this context, the two main tasks of the BNetzA are:
- to secure non-discriminatory access to the network and
- to regulate network charges.

This is reflected by the organizational structure of BNetzA (see Fig. 4.7). BNetzA consists of several departments. Two of them (Department 6 and Department N) focus on energy and network regulation. The decision process within BNetzA takes place within so-called *ruling chambers*. BNetzA has nine ruling chambers with decision-making powers, with five of these relating to electricity and gas:
- network development and approval of individual network charges (ruling chamber 4 in Fig. 4.7),
- access to electricity networks (ruling chamber 6 in Fig. 4.7),
- access to gas networks (ruling chamber 7 in Fig. 4.7),
- regulation of electricity networks (ruling chamber 8 in Fig. 4.7), and
- regulation of gas networks (ruling chamber 9 in Fig. 4.7).

Note the focus on and restriction to networks as the core monopoly part of the supply chain. BNetzA is not responsible for the markets, where these are not related to the networks. Strictly speaking, BNetzA is not responsible for general competitive conditions, for example merger policy, which is one of the tasks of the Federal Cartel Office. In practice, however, the Federal Cartel Office and BNetzA cooperate closely. Moreover, BNetzA monitors market development in a so-called *Monitoring Report,* which is published on an annual basis.

Additional tasks of BNetzA In addition to securing non-discriminatory access to the network and regulating network charges, further BNetzA tasks are:
- ensuring consumer protection in retail issues (e.g. rules for switching the power retail company),
- implementing and monitoring unbundling rules,
- evaluating the *network development plan* (NDP),
- approving network expansion plans and helping to accelerate licensing procedures for network expansion, as arranged by NABEG,
- exchanging information with other European regulators, formally or informally, and cross-border issues (e.g. the interconnectors),
- providing support for technical standards, and
- providing data on power plants and electricity networks to the public.

Competences of BNetzA It is of critical importance for the regulator to be powerful enough to impose sanctions on the grid operators. In Germany, this is regulated in § 29 to § 33 EnWG, which define the competences of BNetzA and the possible range of penalties it can impose:
- § 29 EnWG lists all discriminating behaviors of grid operators which can be penalized by BNetzA.
- According to § 30 EnWG, BNetzA can force grid operators to stop any discriminating behavior against other market participants.
- According to § 31 EnWG, information on discriminatory behavior of a grid operator can be provided to BNetzA by any legal or natural person.
- § 32 and § 33 EnWG specify how fines and compensation payments are to be settled in case of misconduct by a grid operator.

4.4.2 Market structure

Vertical and horizontal market structure As described in ► Sect. 4.1, the stages in the supply chain of Germany's electric power sector are in a state of far-reaching unbundling: transmission grids, for example, are owned and operated by fully unbundled companies that are independent from other parts of the supply chain. Distribution grid operators are legally unbundled from generation and retail companies so as to ensure that, within the same utility, no commercially sensitive information is exchanged between the power grid and other parts of the supply chain.

Competition in power generation has been increasing significantly in Germany since the EU's *First Electricity Directive*. Before 1996, generation was mo-

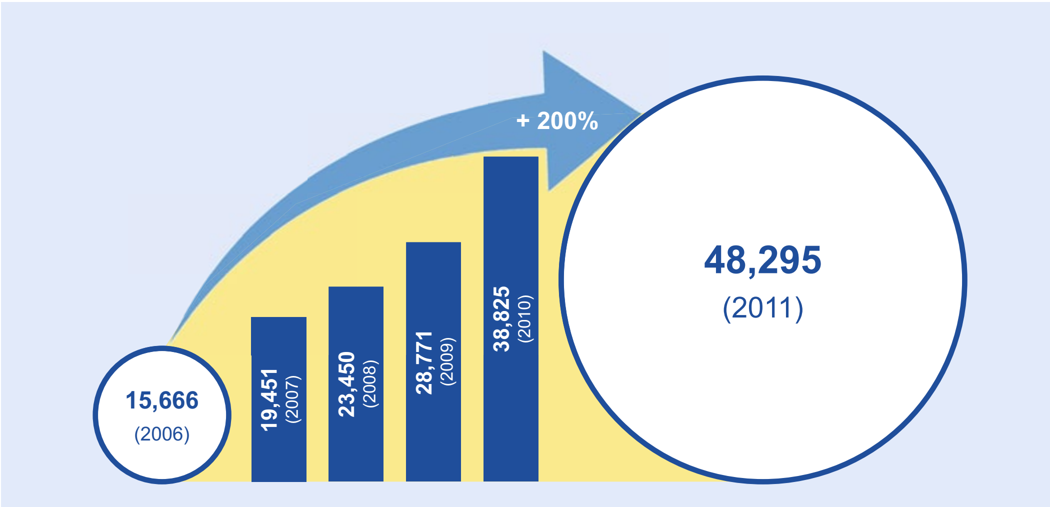

Fig. 4.8 Number of companies active in the German energy sector, data from [43]

nopolized by four major companies (RWE, E.ON, Vattenfall Europe, and EnBW). Meanwhile, these four companies together represent a market share of no more than roughly 44 % of total installed electricity generation capacities [41]. The decreasing market share of the former monopolists is also a result of the nuclear phase-out and the increasing share of distributed generation from RES. The growing importance of RES in particular has served as a key driver for competition in the generation sector. While investments into conventional power plants are a capital-intensive business, investments into RES have become profitable for small investors due to the guaranteed feed-in tariffs for renewables. As a result, there are currently some 300 smaller generation companies with capacities starting at 1 MW up to hundreds of MW.

The situation is similar in the retail sector. The market share of the four former monopolists has been continuously decreasing from 50 % in 2008 to 45 % in 2011 [19]. Most German retail companies have a regional focus with a high market share within their established service areas. Consumer switching rates to other retailers are still quite low due to the end consumers' tendency to remain with the incumbent regional suppliers. In 2012, for example, only about 7.8 % of all households in Germany changed their electricity supplier [19].

The ownership structure on the transmission and distribution level is as follows: on the transmission level, four TSO own the infrastructure while roughly 900 DSO own parts of the distribution grid. Since electricity networks are a natural monopoly with network charges regulated by BNetzA, there is no competition for markets and customers between the different grid operators.

The emergence of new market actors The unbundling process, the legally enforced trend towards more competition, as well as the migration towards smart grids and RES have contributed to the emergence of new market actors in Germany. Their growing importance can be considered as the most profound change in Germany's electricity market structure during the last few years. A considerable number of new players have entered the supply chain of the electric power system: Figure 4.8 shows that the number of companies active in the German energy sector (including electricity, gas, heat, etc.) increased from 15,666 in 2006 to 48,292 in 2011 [42]. This represents an increase of more than 200 % within five years. Especially companies with less than nine employees, often innovative start-ups and energy service providers, have contributed to this increase. Their number increased from 14,545 in 2006 to 46,967 in 2013 [43].

Figure 4.9 presents an exemplary overview of established and new market actors in smart grids, as they are present or emerging in Germany, classi-

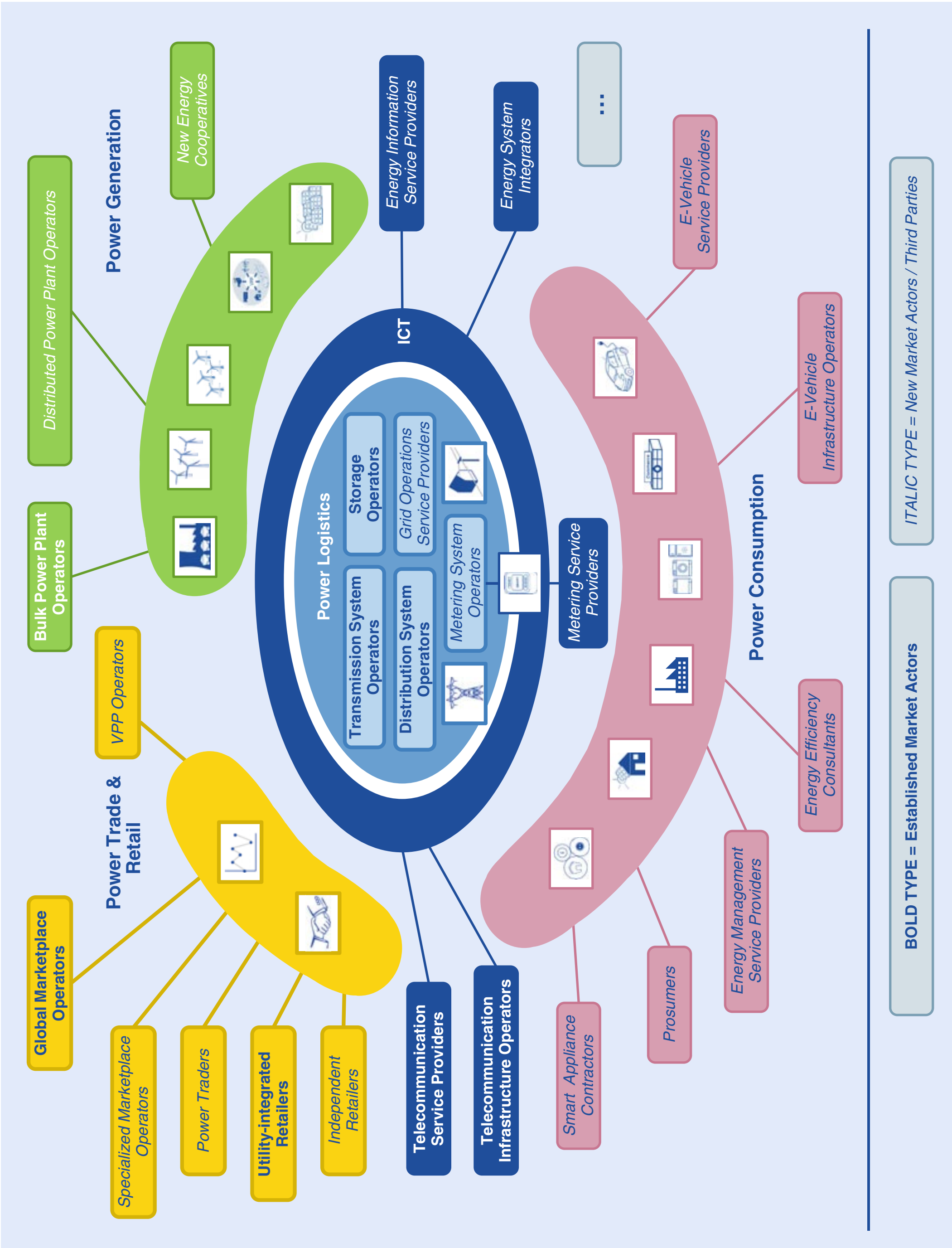

Fig. 4.9 Examples of established and new market actors in smart grids in Germany

fied into the different smart grid supply chain areas *Power Generation*, *Power Logistics*, *Power Trade and Retail*, *Power Consumption*, and *Information and Communication*. In the following, some examples of new market actors depicted in Fig. 4.9 are described together with a brief explanation on their role in the smart grid development process:

- ***Power Generation:***
  - *RES operators:*
    Traditionally, power plants in Germany were exclusively owned and operated by large utilities. Due to the financial support codified in EEG (see ▶ Sect. 4.4.3), a number of more than 1,500,000 RES plants, especially onshore wind, PV and biomass plants, has been installed so far. The largest part of these plants is operated by households as well as small and medium-sized companies: in 2013 for example, 6 % of all German households had their own RES generation units, especially small rooftop PV installations [44]. Companies in the manufacturing industry have also long since started to build their own RES generation units. By 2005, roughly 5 % of all German manufacturing companies owned RES. This number has more than tripled since, reaching roughly 18 % in 2012 [45].
  - *New energy cooperatives:*
    In the tradition of cooperatives founded in Germany in the beginning of the 20th century to develop the first power supply systems, new energy cooperatives have emerged in recent years. These associations allow individual citizens or civil society to pool their financial resources and jointly invest in power system components otherwise exceeding the financial resources of their individual members. In Germany, 650 energy cooperatives with roughly 130,000 members invested more than one billion euros in power plants based on RES until 2012 [46].

- ***Power Logistics:***
  - *Grid operations service providers:*
    This type of company specializes in offering services to operate smart grids for small-sized or municipally owned German DSO. The business model of grid operation service providers works out, since the small DSO often do not have the highly specialized personnel required for smart grid operation (i. e. with deep knowledge of ICT capabilities and with the required level of grid automation knowledge). A single grid operation service provider may operate the smart grids of several small DSO.

- ***Power Trade & Retail:***
  - *VPP operators:*
    A virtual power plant is a network of decentralized, small to medium-scale power generating units such as biomass plants, *combined heat and power* (CHP) units, wind farms and solar parks. The interconnected units are partly operated through central control of the virtual power plant but nevertheless remain independent in their operation and ownership. *Virtual power plants* (VPP) deliver electricity products, such as balancing power, that can be traded on electricity market places. Product requirements, e. g. the minimum volume of the delivered power, are restrictive and usually cannot be met by single small scale power plants, like e. g. a single wind farm. VPP therefore bundle (aggregate) several small scale power plants and often even add other generation capacities and/or flexible loads, to fulfil the product requirements of the energy market places. Thus, the power generation of the units in the virtual power plant is bundled – or aggregated – and sold by a single trader on the energy exchange or other energy market places (e. g. market for balancing power). As a result, VPP can gradually take over the role of traditional power plants – selling their output in the wholesale markets. Today, in Germany, about 20 medium sized companies operate VPP.
  - *Specialized marketplace operators:*
    These market actors operate market places e. g. for ancillary services or for electricity from well-defined sources. The concept of specialized market places has been piloted in several research projects of the German *E-Energy* program (see ▶ Sect. 4.4.6 for more information on the *E-Energy* program).
  - *Power traders:*
    A person or entity that buys and sells energy goods and services in an organized electricity market (electricity or power exchange) or *over-*

the-counter (OTC). Power traders offer dedicated electricity wholesale services to other market actors, e.g. industry companies or power retailers companies or larger end-users (like energy-intensive industry). Due to the complex nature of electricity markets, trading requires specialist knowledge and expertise, comparable to financial service providers. In Germany, power trading services are offered by some 50 companies [19].

- *Independent retailers:*
  Liberalization of the energy market in Europe led to the establishment of mostly medium-sized power retail companies that are independent from the established utilities. These companies offer their customers heterogeneous energy-based retail products, e.g. regional tariffs, time-of-use pricing or electricity with a low CO_2-footprint. These products are widely accepted both by the population and by enterprises.

Power Consumption:

- *Smart appliance contractors:*
  Households as well as enterprises operate a growing multitude of power-consuming appliances like heating equipment, cooling devices or home electricity storage (so-called *smart appliances*). For these clients, smart appliance contractors offer individual services such as financing, installation, operation, maintenance, support and appliance replacement. Other contractors act as full-service providers and offer volume-based heating, cooling or load management services.
- *Prosumers:*
  The term prosumer is merged from the terms producer and consumer. Besides consuming power, these new market actors deliver surplus power to the grid, e.g. through small-scale rooftop PV or *combined heat and power* (CHP) plants.
- *Energy management service providers:*
  Energy management service providers deliver energy monitoring and controlling services to industry and large commercial companies. With their service portfolio they contribute to continuous improvement of energy procurement and use in smart grids.
- *Energy efficiency consultants:*
  These typically small-sized companies analyze the energy consumption of private households, enterprises, industry and municipalities in order to identify potentials for energy savings and energy efficiency improvements and consult the clients in efficient power usage. In a typical business model the advisory is paid for with a share of the savings generated from energy efficiency improvements. In Germany, a number of nearly 12,500 companies carried out more than 400,000 consulting projects in 2011 [47].
- *E-Vehicle infrastructure operators:*
  Electric vehicles need charging stations. These are built and/or operated by a growing number of infrastructure operators.
- *E-Vehicle service providers:*
  These new market actors are typically big-sized or mid-sized companies. E-Vehicle service providers operate pools of electric vehicles and rent them to companies and private consumers.

Information & Communication:

- *Metering system operators:*
  These companies install and operate electricity metering equipment. Metering system operators are an example for a new market role that has been created by the German government. Their role is described by EnWG (§ 21) and the *Metering Access Ordinance* (MessZV).
- *Metering service providers:*
  Metering service providers offer the service of reading out meter systems and delivering the gathered data to power retailers as a basis for billing. Their role is also described by EnWG (§ 21) and the *Metering Access Ordinance.*
- *Energy information service providers:*
  All market actors in smart grids require energy-related information to carry out their tasks and businesses, e.g. current or historical grid status data, metering data or weather data. Energy information service providers collect raw data from multiple sources, analyze and refine the data and then offer specialized information services to their customers. One example of an energy information service is wind and PV power generation forecasts,

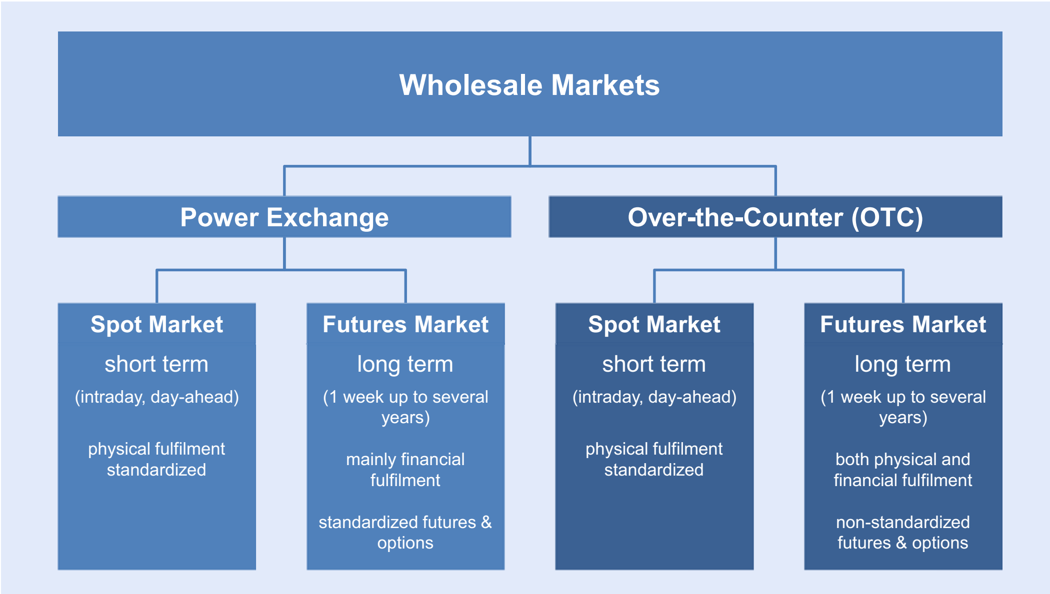

Fig. 4.10 Electricity wholesale markets in Germany

which are typically derived from a multitude of different weather data sources.

- *Energy system integrators:*
  Energy system integrators are established or new companies which develop ICT-based system solutions in all segments of the smart grid supply chain for their customers, e.g. solutions for advanced distribution system management and grid maintenance solutions for DSO, smart metering solutions for metering service providers or virtual power plant management solutions for VPP operators. The ICT sector in Europe has increasingly been participating in the development of smart grids and is involved in approximately 60 % of all related research projects [48]. The ICT-related smart grid concepts developed by energy system integrators contribute to the general understanding of smart grids among established and new market actors, public decision-makers, and the general public.

4.4.3 Market design and RES integration

General market design German electricity wholesale markets bring together roughly 300 power generation companies, about 50 power trading companies, and approximately 1,110 power retail companies [19]. A high level of liquidity indicates that electricity wholesale markets are functioning well [19]. The German wholesale market is currently separated into two major energy-only markets (see Fig. 4.10):

- The *European Energy Exchange* (EEX) with two products: spot (short-term) and future (long-term) markets for electricity. In contrast to China, there is only one uniform wholesale price for electricity in Germany irrespective of the power source, production technology, or age of the power plant under consideration. The market price – for all generators – at any given time is determined by the marginal costs of the last power plant required to satisfy total electricity demand. This nationally integrated market leads to a situation in which, at any point in time, only those power plants with the lowest marginal costs of production are able to sell their electricity on the market.
- The *over-the-counter* (OTC) market gives suppliers and buyers of electricity the opportunity to bilaterally trade electricity and to negotiate contracts and prices irrespective of standardized contracts or prices at the power exchange. Like the EEX, OTC contracts offer the pos-

sibility for spot and future trades. Products on both markets can be the same, e.g. short-term contracts with direct physical fulfillment can be either traded via the exchange or negotiated directly with another party on the OTC spot market.

Most of Germany's electricity is traded bilaterally between generation and retail companies. In 2012 for example, 7,000 TWh of electricity were traded in OTC transactions, whereas only approximately 1,200 TWh were traded at the EEX [19].[6] The attractiveness of OTC trading results from the fact that OTC products can be designed more flexibly according to the specific needs of the parties involved. Nonetheless, EEX prices are very important because they serve as a reference value for OTC trading.

While generation and retail companies use the power exchange to trade electricity especially for short-term contracts (physical fulfillment), most of the trade at the power exchange is focused on the exchange of futures. Here electricity traders focus on financial exchanges. Traders expect to gain benefits through the arbitrage between different future periods. Retail companies have to pay the generators for the electricity produced and the grid operator for the transport of the electricity. The generation company needs to inform TSO in advance about the exact electricity volume that its facility will produce within a certain period of time and to which customer (e.g. power retail companies) the electricity needs to be transported.

Promotion and integration of RES To subsidize the development of RES, a fixed feed-in tariff which is significantly above market prices is paid to RES owners. The EEG, which regulates the promotion of RES, was enacted in 2000 on the basis of the former *Act on the Feed-In of Electricity from RES into the Public Grid*, itself enacted in December 1990. The EEG regulates a feed-in system that comprises four key elements:

- ***Fixed feed-in tariff:*** for each kWh produced and fed into the grid, a fixed price is paid which is higher than the wholesale market price for electricity.
- ***Take-up obligation:*** grid operators must buy the electricity from RES at all times and pay the feed-in tariff independently from current market prices.
- ***RES priority:*** RES has priority over non-RES in case of network congestion.
- ***RES curtailment in last resort:*** in case of network congestion, conventional power supply needs to be curtailed as much as possible before RES can be curtailed as well.

Feed-in tariffs at a glance The feed-in tariffs are usually paid for electricity stemming from hydro power, landfill gas, gas from purification plants, mine gas, biomass, biogas, geothermal power, onshore wind, offshore wind, small-sized rooftop PV installations, and large-scale PV parks. With regard to the specific design of the feed-in tariffs, three aspects must be considered:

- First, feed-in tariffs differ depending on the power source under consideration.
- Second, feed-in tariffs for installations using the same power source often depend on the installed capacity with higher feed-in tariffs applying to smaller installations.
- Third, feed-in tariffs are paid for a period of 20 years and the feed-in tariff paid for each installation at the moment of its commissioning is guaranteed over the whole period.[7]

Feed-in tariffs for new installations have been steadily adjusted downwards since the implementation of the EEG in 2000, reflecting technical progress and the declining costs of RES. However, feed-in tariffs for installations that went into service before the adjustments remain at their originally guaranteed level. To facilitate planning for RES investors, future reductions of the feed-in tariffs are already known today and recorded in specific reduction schemes that are part of governmental supplements

6 Note that the quantity of electricity virtually traded either via OTC or EEX is considerably higher than the physical quantity of electricity generation and consumption. This is due to hedging or arbitrage activities of market participants.

7 Wind power represents an exception to this general framework: tariffs for wind farms are not constant over the whole period but are slightly elevated during the first years of the operation. Also, feed-in tariffs for wind farms do not decrease with the size of the wind farm.

to the EEG. Depending on the capacity and some other characteristics of the installations, the following ranges of feed-in tariffs for the power sources with the highest relevance were paid in 2012 [49]:

- Hydro: 0.034 €/kWh–0.127 €/kWh
- Onshore wind: 0.0893 €/kWh–0.0991 €/kWh
- Offshore wind: 0.15 €/kWh–0.19 €/kWh
- Biomass: 0.06 €/kWh–0.143 €/kWh
- PV: 0.1794 €/kWh–0.2443 €/kWh

Financial burden caused by feed-in tariffs Electricity generated by means of RES (RES-E) is traded on wholesale markets irrespectively of the feed-in tariffs. RES-E enters Germany's wholesale markets in the following way:

- Generators of RES-E receive the feed-in tariff from their respective distribution grid operator, who in turn gets an equivalent compensation from the transmission grid operator.
- The transmission grid operator sells RES-E on a wholesale market, frequently receiving a price considerably lower than the governmentally fixed feed-in tariff.
- To avoid financial burdens for transmission grid operators as a result of this practice, the difference between the fixed feed-in tariffs and the market prices for electricity is refunded in full to the transmission grid operator.
- The financial capital for this compensation stems from the electricity consumers, who have to pay a surcharge for the promotion of RES on their electricity bill (renewable energy surcharge). The amount of the surcharge depends on the type of consumer (with high discounts for industrial consumers) but does not depend on the consumer's geographic location.

The financial burden caused by this compensation has increased significantly in the course of the past years. In 2000, approximately one billion euros was necessary to cover the difference costs of RES feed-in tariffs.[8] This figure increased to approximately EUR 16 billion in 2012 and is projected to amount to roughly EUR 20 billion in 2014 [50]. Owing to the increasing share of RES in Germany's electricity mix, the renewable energy surcharge rose from 0.0008 €/kWh in 2000 to 0.0528 €/kWh in 2013 [51]. Germany has made the experience that setting up a system with feed-in tariffs financed by means of a surcharge that does not vary in different regions redirects purchasing power from regions with high loads towards regions with high RES capacities. Berlin, with its more than 3 million inhabitants (roughly 4.1 % of Germany's total population), received only 0.1 % of all RES connected payments, whereas Schleswig-Holstein, a federal state in Northern Germany with less than 3 million inhabitants (about 3.5 % of the population), received 7.0 % of all RES connected payments [51]. However, Berlin's population did not pay less than the population in Schleswig-Holstein to finance the RES funds. This means that purchasing power was implicitly redirected from Berlin to Schleswig-Holstein owing to the RES financing mechanism.

8 Difference costs refer to the total amount of feed-in tariffs paid to investors minus the revenues from RES-E on wholesale markets.

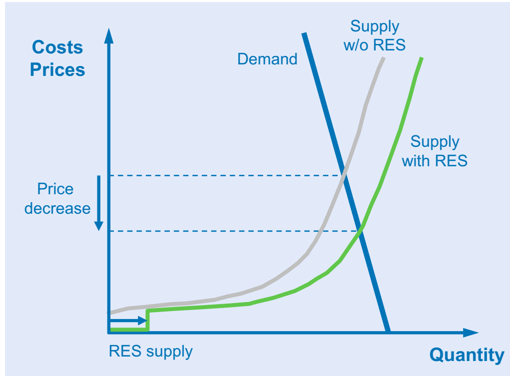

Fig. 4.11 Effects of RES supply on the wholesale electricity prices

The effects of RES on wholesale electricity prices The price on the wholesale electricity market is determined by the marginal costs of the last power plant required to satisfy total electricity demand setting the price which is applied to all generators at that point in time. The power plants are ranked according to their marginal costs of electricity generation (merit order), with the plants with the lowest marginal costs necessary to meet demand dispatched first and the ones with the highest marginal costs brought online last.

TSO are mandated by law to prioritize the feed-in of RES before other conventional generation technologies. Once installed and connected to the grid, wind and PV installations can produce electricity with almost zero marginal costs, while costs of electricity generation from fossil fuel-fired power plants depends on the price of the combustibles used (fuel costs). Thus, electricity generated from RES enters the wholesale markets at the beginning of the merit order (at zero marginal costs) and is dispatched first. As a consequence, average wholesale prices decrease as the generation technologies with higher marginal costs are displaced by an increasing volume of RES-E. Thus, large-scale integration of RES-E suppresses wholesale electricity prices. This is known as the so-called *merit order effect* (see Fig. 4.11). With large amounts of RES-E traded on the wholesale markets (on windy and sunny days), wholesale prices are rather low. When high feed-in of RES-E corresponds to low demand on the consumption side (typically on Sundays), prices for electricity can even reach negative values. On these days, Germany sometimes exports electricity to foreign countries and has to remunerate these countries for absorbing the German electricity. There were negative spot market prices for almost 80 hours in 2013. Such negative prices occurred in ten of twelve months [52]. In conclusion, it can be said that the increasing share of RES leads to decreasing but much more volatile prices on the wholesale markets.

As wholesale market prices decrease, gas-fired power plants, which have high marginal costs, are dispatched less and less frequently making an economically viable operation difficult and deterring investors. However, with their flexibility and fast ramp times gas-fired power plants are considered a necessary part of a power system with a high share of variable RES. Due to these developments, discussions on a revision of the EEG and alternative support schemes and incentive mechanisms for investments in conventional power plants are currently taking place in Germany.

Electricity retail markets and prices Electricity retail markets are based on bilateral standardized contracts without any interactions on marketplaces. They are less complex than wholesale markets. In both Germany and China, households and industrial consumers pay different retail prices. In contrast to China, German households have to pay significantly more than industrial consumers. In 2012, the price amounted to roughly 0.13 €/kWh for industrial consumers, whereas the price for household consumers amounted to approximately 0.26 €/kWh [53]. These privileges for industrial consumers were introduced to increase the competitiveness of Germany's industry on world markets.

The retail price for electricity can be subdivided into three main categories:

- Taxes (electricity tax and value-added-tax) and fees (mainly concessional duties and the renewable energy surcharge) currently make up approximately 50 % of the electricity price.
- Costs of power generation and retail amount to approximately 30 % of the price. Between 1998 and 2000, these costs decreased from 0.1291 €/kWh to 0.0858 €/kWh as a result of the market liberalization of 1998, which created more market competition in all areas of the power sector supply chain. In the following years, the size of this price component increased slowly but steadily until 2009 and has remained rather stable since then [53].
- Governmentally regulated network charges compensating grid operators for electricity transmission and distribution. Network charges make up roughly 20 % of the retail price paid by household consumers [3]

Figure 4.12 illustrates the development of electricity prices for private households and its composition in Germany since 2006. The electricity retail price has increased due to rising costs of power generation and retail as well as rising taxes and surcharges (fees), which increased from 0.0714 €/kWh in 2006 to 0.1163 €/kWh by 2012 [53]. The increase of the renewable energy surcharge from 0.008 €/kWh in 2006 to 0.0528 €/kWh in 2013 contributed to this development. In the same timeframe, the network charges decreased slightly.

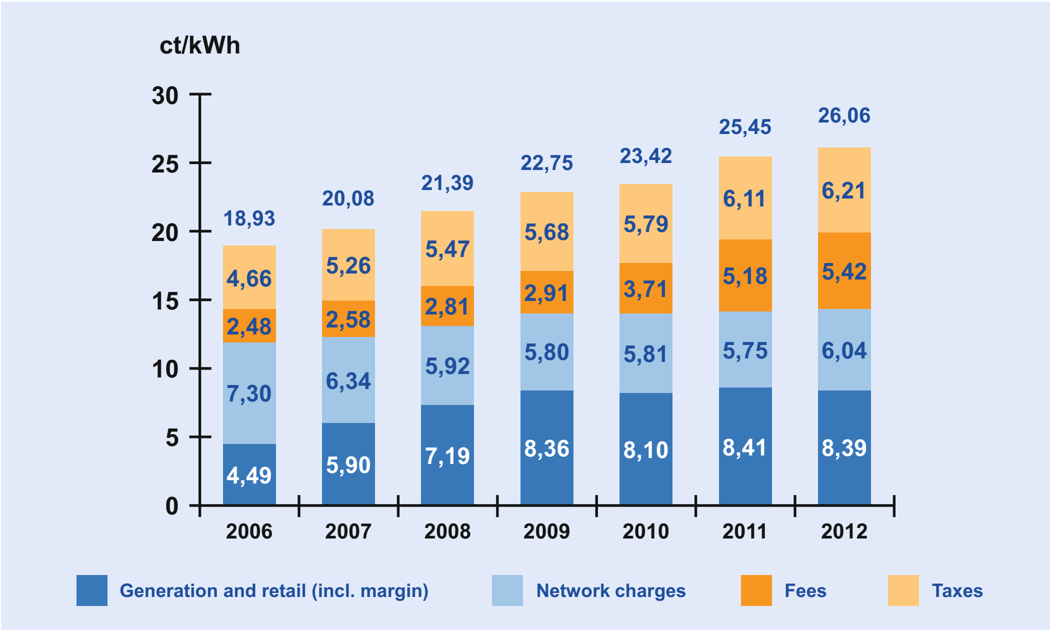

Fig. 4.12 Development of the electricity price for private households in Germany, adapted from [3]

4.4.4 Development of infrastructure and network regulation

Coordination of network expansion In Germany, many different stakeholders are involved in grid expansion planning. Even if planning activity is mainly in the hands of TSO and BNetzA, other established power sector companies, third parties and the public can also influence network expansion planning. From a legal point of view, the expansion of the electric power grid is mainly regulated by EnWG, by the *Energy Network Development Act* (EnLAG), and by NABEG:

- § 12 EnWG states that transmission grid operators are responsible for elaborating and issuing a coordinated network expansion plan each year. This plan is supposed to describe which upgrades of the transmission grids will be necessary during the following ten years. The process of network expansion planning is monitored by BNetzA. It allows for public participation and is open to comments from various stakeholders.
- EnLAG defines specific investment projects in single transmission lines with the intention of facilitating the integration of RES, improving the interconnection with neighboring countries, easing the connection of new power plants, and reducing network congestions.
- NABEG further specifies procedures relating to the network expansion plan. Its main motivation is to accelerate the planning and approval procedures of network expansion.

Cost pass-through regulation until 2009 The costs of investments in the grid infrastructure are shared by all electricity consumers via network charges. Until 2009, investment into the grid infrastructure was regulated using a so-called *cost pass-through regulation* which was also applied in many European countries and the United States. Cost pass-through regulation adjusts permissible revenues according to the grid operator's accounting and capital costs. The primary advantage of this system is that it lowers investment risks as practically all costs can be passed on to the end-user (via network charges), thus encouraging investment in the infrastructure. However, this regulation does not set incentives for efficient grid operation especially important in power systems with a limited need for grid expansion and upgrade.

Incentive-based regulation after 2009 Today, network charges in Germany are regulated using incentive-based regulation in the form of a so-called *revenue cap*. This solution relates to a model proposed by the former UK Treasury economist Stephen Littlechild in 1983. He criticized the lack of efficiency incentives of cost pass-through regulation and proposed the price-based regulation, which is known as *RPI-X* [54]. Apart from Germany, similar systems exist across Europe (e.g. the UK) and in some areas of the United States as well.

For Germany, the details of revenue cap regulation are defined in the *Incentive Regulation Ordinance* (ARegV). With price-based regulation, the future revenue cap is defined ex-ante for the coming regulation period (five years in Germany). Within the regulation period, the formula used to calculate the precise level of the revenue cap remains unchanged. Permissible revenues therefore follow a predetermined path during the regulation period. The revenue cap is mainly based on previous-year revenues minus the so-called *RPI-X Factor*. This factor consists of the *retail price index* (RPI) and an anticipated increase in productivity (the so-called *X-Factor*). The X-Factor is an important element of incentive-based regulation. It is determined individually for each grid operator. If a grid operator reaches a higher increase in productivity than anticipated by the regulator, additional cost savings need not be passed through to the consumer and thus remain as additional profit for the company. This mechanism therefore represents an incentive to improve efficiency. The disadvantage of incentive-based regulation is that cost-saving pressure may be at the expense of network investment. In Germany, with its large network investment requirements, a reform of the regulatory system to facilitate efficient investment is therefore currently being discussed.

Regulation of supply security Network regulation relates not only to network charges but also to monitoring supply security. EnWG contains several paragraphs on this aspect. § 13 and § 14 EnWG assign responsibility for stable grid operation to transmission grid operators and distribution grid operators respectively. In urgent situations with a national relevance (for example situations of network congestions), grid operators must contact BNetzA without any delays (§ 13, section 6, EnWG). With regard to less urgent and more local situations, grid operators are obliged to issue a yearly report listing all supply interruptions within their respective grid area (§ 52 EnWG). This report must be submitted to BNetzA every year by the end of April via an internet-based process (see [55]).

The description of each supply interruption must include the time, duration, scope, and cause of the interruption. Grid operators are also obliged to describe the preventive measures taken to avoid such interruptions in the future. A document entitled *Guidelines of BNetzA concerning reporting duties for supply interruptions in electric power grids according to § 52 EnWG* (see [56]) specifies the information to be transmitted to the regulator.

4.4.5 Coordination of generation and consumption

Long-term coordination vs. short-term balancing of generation and consumption Neither electricity generation nor electricity consumption has changed dramatically in Germany during the last two decades. Thus, policies focusing on facilitating the long-term coordination of electricity generation capacities with the development of electricity consumption are not a primary concern in Germany. However, due to the increasing intermittency of Germany's electricity generation caused by RES integration, policies aiming at balancing electricity generation and consumption in the short-term have become more and more important.

The role of TSO in balancing generation and consumption in the short-term Before the beginning of the unbundling process, decisions such as the dispatching of power plants were coordinated within the firms themselves. Today, these decisions are coordinated in the wholesale and retail markets described in ▶ Sect. 4.4.3. In some cases, however, the balancing of generation and consumption and respective dispatching of power plants as determined by the market cannot be realized due to physical restrictions with regard to power grid infrastructure capacities. In these cases, the TSO are responsible for balancing generation and consumption in order to secure system stability. Specifically, German TSO are allowed to take the following measures and make the following adjustments:

- So-called *balancing markets* are independent from EEX and OTC trading and allow generation and consumption to be adjusted in the very short term: according to § 12 EnWG, TSO can tender the required balancing power through a common internet platform.[9] Three different reserves are tendered: primary, secondary, and tertiary reserve. Primary reserve needs to be available within 30 seconds and is tendered on a monthly basis. Secondary reserve must be available within 5 minutes and is also tendered on a monthly basis. Tertiary reserve has to replace the secondary reserve after 15 minutes. Tertiary reserve is tendered on a daily basis.
- An *Ordinance on Disconnectable Loads* (AbLaV) was issued in 2013. It allows TSO to tender, on a monthly basis, loads of up to 3 GW that can be disconnected within 15 minutes if there is an urgent need to adjust consumption downwards. Like in the balancing markets, the loads are tendered on an internet platform.
- If generation and consumption cannot be balanced in balancing markets or by disconnecting loads according to AbLaV, TSO are entitled to overrule market outcomes by forcing power generators to adjust their generation. In that case, the affected generation companies have to be compensated for financial losses and BNetzA has to be informed immediately on such measures.

The role of electricity tariffs in balancing generation and consumption in the short term Traditionally, the main function of electricity prices was the coordination of electricity generation and consumption in the long-run by incentivizing investments in generation capacities, grid capacities, and end-use-devices. Currently, there is a trend towards tariff structures on retail markets being designed to take over the balancing of generation and consumption even in the short term. The widespread introduction of such time-of-use pricing critically depends on a successful rollout of smart meters. Currently, only few households in Germany are equipped with smart meters. According to a recent survey among German energy market experts, the widespread rollout of smart meters is not expected to be completed before 2029 [57].

As a consequence, the German tariff system currently has less time-of-use pricing elements than the Chinese tariff system. The following elements provide examples for time-of-use pricing elements included in the German tariff system:

- For more than 20 years, electricity prices for industrial consumers have been separated into a peak load price and a base load price. This offers users an incentive to keep peak demand as low as possible. Technically, energy management systems within factories supervise and control the processes within certain ranges to effectively reduce peak demand. In recent times, more differentiated time-of-use pricing has been introduced to take advantage of the flexibility within the industrial production process for load shifting.
- Since 2011, EnWG has obliged each power retail company to offer at least one electricity tariff for residential consumers with price levels differentiating at least between times of peak and base load. However, only few German households have chosen such a tariff because the potential financial savings it offers are rather low [58].

4.4.6 The role of information and communication

The role of government in promoting smart grid-related ICT In addition to guiding the German debate on smart grid developments and including third parties in the smart grid development process, the German government promotes the development of smart grid technologies by means of innovation policies. The smart grid innovation policies of the German government currently focus on the promotion of R&D and are embedded into the government's broader energy research policy.

- The first objective of Germany's energy research policy is to contribute to achieving the

9 Please refer to ▶ http://www.regelleistung.net for more information on this internet platform.

targets set by the government in relation to the energy sector and climate policy by supporting the early-stage development of new technologies, concepts and business models.
- The second target is to enhance the position of German companies in the field of modern energy technologies.
- The third objective is to secure and enhance technological options. This objective seeks to help improve the flexibility of Germany's energy supply and is consequently directly related to smart grid technologies.

In general, smart grid research projects are co-funded by the German government with a government grant amounting to 50 % of the total project costs being paid to industrial project members. Public research institutes and universities often get 100 % government funding. Mainly large consortia of industrial companies (utilities, manufacturers, telcos, innovative small and medium-sized enterprises, and energy service companies) and R&D institutions such as universities or independent institutes compete among each other for government funds. Their research proposals are evaluated by independent evaluators or government bodies and the best concepts are recommended for funding.

Some results from early R&D projects Germany's main funding program for smart grid and smart market policies so far was the so-called *E-Energy funding scheme* set up by BMWi and supported by BMUB. Extended demonstration projects were carried out in six German regions to validate the integration and balancing of renewables and the inclusion of third parties and smart markets such as regional energy marketplaces. The development of new ICT solutions for smart grids and smart markets was an additional key target. The overall volume of this program was roughly EUR 140 million [59].

The main motivations behind the E-Energy funding scheme were
- to establish a lead market in developing smart grid technologies,
- to integrate smart grid developments into the European context, and
- to guarantee the security of supply in the future power system.

The results of one of the E-Energy projects called *E-DeMa* show that in today's market conditions there are not enough incentives for residential consumers to apply DSM or *demand response* (DR) [60]. However, it is expected that the projected expansion of RES generation capacities will increase the demand and the corresponding business opportunity for DSM. Therefore, numerous German retailers have projects promoting consumers' commitment to shift electricity consumption to off-peak times and to use electricity more efficiently (e. g. by visualizing end users' electricity consumption). One important result in this context is that new market concepts are necessary to efficiently explore the load shifting potential of customers. An electronic marketplace developed in the framework of the E-Energy projects could, for example, serve as a communication and interaction platform for residential consumers.

Selected findings and lessons learned from E-Energy
- Household customers with detailed information on their load behavior are able to reduce electricity consumption by roughly 5 %.
- Saving potentials are higher for commercial and industrial enterprises. These consumers were able to save up to 20 % with detailed information on their electricity consumption.
- Electricity consumption needs to be made transparent with feedback instruments indicating current and historical consumption.
- An illustration of historical consumption provided with the monthly electricity bill can sometimes constitute sufficient feedback for household consumers. In general, more sophisticated feedback instruments are necessary, especially for companies.
- Transparent electricity consumption patterns are not sufficient to save on electric power. Consumers must also be empowered to assess the relevant information and decide on possible options. Advisory measures, efficiency indicators, and analytic tools are necessary in this context.

Source: B.A.U.M. Consult G.m.b.H. [59]

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In the wake of the E-Energy funding scheme, the call for project proposals for the *Future Proof Power Grids* research program took place in early 2013. The aim of the program is to improve cooperation between industry and academia throughout the value chain and facilitate international research cooperation. Another goal is to improve the environmental, economic, and resource efficiency of electricity networks as well as the security of electricity supply research under this program is supported with a total of EUR 150 million provided by three different ministries [61]. More than 400 companies and 300 academic and research institutions formed research consortia and submitted 171 project proposals. The large majority of project proposals deals with issues related to distribution grids, with proposed research on transmission grids also attracting a significant amount of proposals and wind power integration trailing behind [61]. The focus of most proposals is on the management of grid operations, followed by technical challenges of transmission and distribution grids as well as network planning.

The role of the ICT industry in promoting smart grids The ICT industry has developed a prominent view on Germany's smart grid issues. Representatives of the ICT industry contributed to the creation of the comprehensive German smart grid vision elaborated in FEG. Germany's ICT industry is focusing less on basic aspects of communications but more on general services to end consumers, e. g. value-added services at residential level, apps for energy efficiency, and big data aspects relating to power grid data exchange, data processing, and archiving. While smart grid funding and lobbying is strongly influenced by the ICT industry, aspects related to distribution grids are still dominated by companies from the energy sector.

The *Federation of German Industries* (BDI) and the *Federal Association for Information Technology, Telecommunications and New Media* (BITKOM), which focus on the ICT point of view, can be regarded as important players to address the view of the ICT industry in the smart grid debate: the former is a large general industrial association communicating the interests of German industry to those in positions of political responsibility. The latter is a large association dedicated to information technology, telecommunications, and new media industry. In addition to the promotion of the business development, these associations focus on the aspect of data privacy. Therefore, important legislation and regulatory topics covered by both associations are smart metering (private consumption data), smart home gateways (also private data and service interruptions), and certain aspects of controllable local systems and communication requirements of the German *Forum Network Technology/Network Operation in the VDE* (FNN).

Information security in Germany's smart grid environment

Besides system operation, information security in Germany strongly focuses on the aspect of user acceptance, e. g. in the domain of smart metering. In that context, data privacy is a very important issue. The standards discussed in the context of information security in Germany include the *IEC Technical Committee* (TC) 57 family, ISA 99 and the *North American Electric Reliability Corporation's* (NERC) *Critical Infrastructure Protection Committee* (CIPC). Furthermore, studies for the BMWi have been carried out to provide an overview of previous attacks in the energy domain, existing solutions and security standards, and also insights on security metrics and patterns [63].

Standardization in the information security sector seeks to unify the implementation of ICT security measures. The ultimate aim is to improve the common security level in the power system. An overview of common security standards in Germany is given by BITKOM and DIN, although it does not cover the energy domain directly [64]. An evaluation of security standards and guidelines for the energy domain was conducted in the European project *European Network for the Security of Control and Real Time Systems* (ESCoRTS). This topic is also addressed by the *Smart Grid Information Security* (SGIS) working group, which is partly responsible for carrying out the European *Mandate M/490* as well as the corresponding *DKE Group STD 1911.11* in Germany (see [65]).

The requirements stated in the white paper on *Requirements for Secure Control and Telecommunication Systems* [66] by the *German Association of Energy and Water Industries* (BDEW) aim to support the acquisition, development, and revision of control and telecommunications systems in the energy sector to minimize the consequences of threats.

Key findings

- Germany has a stable and nationwide integrated electric power system. The power sector is in an advanced state of unbundling, featuring widely used markets for power exchange. Retail prices are rather high in Germany due to taxes and levies imposed to finance the modernization of the power system.
- An important goal of the German government is to increase the sustainability of the electric power system. RES generation capacities have therefore been strongly built up in recent years and are likely to further increase in importance during the next decades. The increasing feed-in of intermittent RES generation puts more and more stress on grid operation in Germany. In this context, Germany has gathered significant experience on topics relating to grid integration and curtailment of RES.
- In Germany, smart grids are seen as a means to enhance the electric power grid so that it can cope with the increasing feed-in of RES and to avoid investments in the conventional (primary) grid infrastructure. New market concepts such as regional energy marketplaces, business services, and VPP also play an important role in the German smart grid concept. They are expected to increase business activities, integrate new market actors in the power sector, and facilitate the involvement of power consumers.
- Representatives from the electric power sector, manufacturing sector, ICT sector, and from the science and research community recently developed a comprehensive smart grid vision for Germany that uses a systematic and comprehensive top-down approach. This approach can serve as a best practice example of how to develop and formulate a smart grid vision.
- The government plays a strong role in Germany's energy sector regulation: it published credible long-term goals for the development of the power sector until 2050. There is also strong coordination between the different governmental institutions involved in energy policy. Finally, the regulatory authority is independent from the government and can be seen as a powerful player in Germany's power system. The government is very active in the smart grid development process as well: BNetzA has issued a widely acknowledged government position on smart grids and smart markets while BMWi aims at including new market actors in the smart grid development process.
- The unbundling process, the legally enforced trend towards more competition, as well as the migration towards smart grids and RES have contributed to the emergence of new market actors in Germany. Their growing importance can be considered as the most profound change in Germany's market structure during the last few years: new market actors introduced innovative products and services and contributed to the modernization of Germany's energy power sector. The ICT industry for example, has developed a prominent view on Germany's smart grid topics and places a special emphasis on services being provided to end consumers.

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Recommended approaches for smart grid development in China

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5.1 Define a long-term strategy for the electricity sector and establish an independent and powerful regulator

Chinese context

- China has formulated explicit targets for the short-term future of its electric power system in its *12th Five-Year Plan for Energy Development*. However, there are no official goals for the period after 2015. Also, there is as yet no comprehensive vision of China's smart grid, especially with regard to distribution grids and the period after 2020.
- The governance structure of China's energy system regulation comprises a broad variety of ministries and institutions. The multiplicity of these stakeholders as well as the frequent reorganizations that have been taking place lead to difficulties in coordination and increased overlap of competences between the various government institutions involved in the power system regulation.
- China's earlier regulatory authority, the *State Electricity Regulatory Commission* (SERC), was merged with the *National Energy Administration* (NEA) in 2013. The *National Development and Reform Commission* (NDRC) and NEA are currently the responsible regulatory institutions for the electricity sector. Both share regulatory responsibilities and are subject to political and industrial influence.

5.1.1 Background

Smart grids require strong government leadership Smart grids are not an objective in its own right, but a new approach to meet the challenges that will arise with future electricity systems, for instance with an increasing share of renewable energies. Specifically, smart grids aim at achieving economic efficiency by combining the strengths of conventional grids with the new capabilities of ICT. In Germany, ICT requirements in electricity grids are driven mainly by intermittent supply from RES. Without RES, the conventional grid infrastructure would be sufficient to maintain high reliability levels in Germany's electric power system.

The evolution towards smart grids necessitates strong vision and leadership on the part of the government, because smart grids are not a market-driven concept:

- A clearly defined long-term strategy for the electric power sector reduces uncertainty for smart grid investors and manufacturers. A lower level of uncertainty on future developments reduces the risks with respect to the investment's future cash flows. As such, smart grid investors and manufacturers are more willing to invest in smart grid technologies. A long-term strategy includes government targets with regard to the development of electricity generation capacities of different technologies (the so-called *generation mix*) and targets for energy efficiency.
- Clearly defined roles and responsibilities of government bodies are a fundamental requirement for the development of smart grids. Especially, a clear delineation between the competences of the ministries and the regulator, and possibly other supervisory bodies is associated with a high degree of credibility and assertiveness of government policy.
- An independent and powerful regulator functions as a coordinating institution between all market participants (incumbents and new market entrants). The coordination specifically focuses on the development of equal and non-discriminatory conditions of market entry where all market parties are treated equally and market power of single market actors is limited. The regulator should be sufficiently powerful to impose the measures necessary to manage the development of the electricity sector and the development of smart grids.

Characteristics of an independent regulator There are two aspects to a regulator's independence:

- independence from the regulated industry and
- independence from politics.

It is important for the regulator to be independent from the industry that is being regulated. If independence is not guaranteed, the danger of so-called *regulatory capture* (i. e. the regulator rather favors commercial and industrial interests instead of public interests) is high [1]. On the other hand, a regulator needs to cooperate closely with the industry. Therefore, a relation of mutual trust is important. In some cases, the regulatory office is actually financed by the regulated industry. Note that this is not necessarily a contradiction to the requirement of independence. Following the rules set by the government, the firms are actually obliged to finance the work of the regulator on the basis of a pre-defined payment plan which is not based on a firm's satisfaction with the regulator's work. The risk of regulatory capture is therefore small.

The independence of the regulator from the regulated industry can be ensured in several ways:

- The processes, decisions, and procedures of the regulator have to be transparent so that they can be controlled.
- The regulator should make use of public consultations in which not only the regulated industry but also other stakeholders or the general public can express their views. Again, this avoids opaque agreements between the regulator and regulated industries.
- The regulator should be monitored at regular intervals and should have to justify its work, for example, in an annual report.
- Personal financial interests between the regulator and the regulated industry must be avoided. Two rules are specifically important in this context: first, senior regulator management should not be allowed to have financial stakes in the regulated industry. Second, a moratorium period during which senior regulator management cannot accept a job in the regulated industry is very useful.

Why the regulator should be independent from politics or from the ministry is a less straightforward question. Ultimately, the regulator is a government institution that is governed by the ministry. The relevant concern is the precise legal delineation of authority: who decides on what? In the following, four main arguments for independence of the regulator are listed:

- Following the classical pattern of the *separation of powers*, the legislator, the body that sets the rules, needs to be separated from the regulator, who applies the rules, as a system of checks and balances.
- The state may be the owner of the regulated industry, which causes an obvious conflict of interest.
- Ministries are often very close to political decision-makers and base their decisions on criteria that are different from those of regulators. Politicians have to mediate and choose between various diverging preferences in their society. Regulators of a monopoly industry, in contrast, try to improve overall efficiency by applying legal and economic tools.
- Regulation requires a long-term perspective. Grid operators for example, are incentivized to continuously invest in the grid infrastructure only with a high predictability and stability of legal and regulatory decisions. Whereas politicians tend to be subject to so-called *short-termism* (i. e. they often ignore long-term issues), an independent regulator is less vulnerable to short-termism as he is not elected by the public.

How can independence of the regulator from politics be achieved?

- In the governance structure, the regulator can be an independent chamber of the ministry instead of an integrated department.
- The appointment and especially the dismissal of the chief regulator(s) should be a transparent and well-defined process.
- The regulatory office should have a budget that is largely independent from daily government business.
- The duties and powers of the regulator should be laid down in a law. Specifically, the delineation of competence between the regulator and the ministry should be clearly described. In many countries, a general energy law contains a description of the duties and powers of the regulator.

- There should be a system of checks and balances. Specifically, it has to be clear who is responsible for regulating and controlling the regulator. For example, this may be a judicial court system, or another regulatory authority with an equal level of substance (e. g. a competition commission). A system of checks and balances allows greater regulator independence.

It is important to note that the precise details of independence from politics or ministries depend strongly on the wider political and governmental structure in a country.

Characteristics of a powerful regulator The need for a powerful regulator is more obvious:

- The competences of the regulator need to be laid down in a law so that decisions can be enforced and challenged in court. In Europe, it has been extensively debated whether the liberalized parts of the energy sector could be regulated under a general competition law or whether sector-specific legislation is necessary to ensure the development of competition. The test of practical experience, for example in Germany, has shown convincingly that sector-specific regulation, executed by a sector-specific regulator, is necessary (e. g. [2]).
- The regulator needs to have an adequate budget. The stakes in industry are so high that it always pays off for the industry to hire consultants, lawyers, and lobbyists to argue their case; the regulator needs to address these claims. Moreover, good regulation is difficult and requires highly qualified staff; the regulator will have to compete with the industry for qualified employees.
- Electric power companies and other stakeholders should have the right to appeal the regulator's decisions before a court or other tribunals empowered to conduct judicial reviews. Such a system of checks and balances makes the regulator more powerful because knowing that another institution may check and correct the regulator allows him to take more risk.

5.1.2 International practice

Long-term strategies for the electric power sector Medium-term to long-term plans with concrete goals regarding electricity consumption, energy efficiency, and/or renewables have been published in many industrialized and emerging countries. These plans often cover a period of at least 25 years (see [3], [4], and [5] for examples from UK, India, and Brazil). In its *Federal Energy Concept,* Germany has defined binding political goals for renewables until 2050. The government has specified the future share of RES-E in gross electricity production with four goals for different time periods: by 2020 renewables are to have a share of at least 35 % in gross electricity consumption, a 50 % share by 2030, 65 % by 2040 and 80 % by 2050 [6]. Similar targets have been defined with respect to gross electricity consumption that is planned to decrease by 50 % until 2050.

Different studies commissioned by the German government analyze how to achieve the various government targets. At the same time, the scenarios for energy and power sector development put forward in these studies serve as a foundation for policy formulation and a point of reference for further studies on more particular topics such as smart grid development. A study entitled *Long-term scenarios and strategies for the expansion of renewable energies in Germany, taking account of developments in Europe and across the world* investigated potential scenarios with respect to the development of renewable energies in Germany [7]. The results of this study are used to define strategies for the development of smart grids in Germany (e. g. how to finance the large investment requirements for smart grids).

The role of an independent and powerful regulator The OECD points at the importance of a clear definition of roles and responsibilities with respect to regulation. Within the OECD's recommendations on regulation, the necessity of a common government policy defining clear goals for the regulation process is specified. According to OECD, strategies shall be set for the implementation of these goals to give regulation a clearly defined framework [8]. Furthermore, OECD emphasized the importance of an independent and powerful regulator for the efficient development of the electricity sector. The government has the task to clearly define the duties and the power of the regulator [8]. OECD also points out that independence of the regulator is essential since its decisions can have serious economic effects on the regulated parties. This is especially the case for smart grids, where the introduction of competition is directly related to economic effects for the incumbents.

The US American way: FERC

The *Federal Energy Regulatory Commission* (FERC) is the regulatory authority in the United States. It is an independent regulator responsible for the regulation of the interstate transmission of electricity, natural gas, and oil. In addition, FERC reviews proposals to build *liquefied natural gas* (LNG) terminals and interstate natural gas pipelines, and it licenses hydro power projects. Further responsibilities of FERC outlined in the Energy Policy Act of 2005 include, amongst others:

- review of mergers and acquisitions as well as corporate transactions by electricity companies,
- approval of siting and abandonment of interstate natural gas pipelines and storage facilities,
- licensing and inspection of hydro power projects,
- protection of the reliability of the high voltage interstate transmission system through mandatory reliability standards,
- monitoring and investigation of energy markets, and
- administration of accounting and financial reporting regulations and conduction of regulated companies [58].

The independence and power of FERC are specified in 42 USC section 7172 g – Jurisdiction of the Commission [59]:

"The decision of the Commission involving any function within its jurisdiction, other than action by it on a matter referred to it pursuant to section 7174 of this title, shall be final agency action within the meaning of section 704 of title 5 and shall not be subject to further review by the Secretary or any officer or employee of the Department."

The *European Commission* (EC) describes the characteristics of a powerful regulator in articles 37 et seq. of Directive *2009/72/EC* (see appendix E). It states, for instance, that a powerful regulator should fulfill the following tasks and requirements:

- issue decisions that are binding for electric power companies,
- impose effective, proportionate, and dissuasive penalties on electric power companies,
- ensure high standards of universal and public service,
- protect vulnerable customers,
- contribute to the effectiveness of consumer protection measures, and
- promote effective competition and the proper functioning of the electricity market.

Germany has established BNetzA, a regulator independent from the industry and the government. The powers and duties of BNetzA are recorded in EnWG. Neither the ministry nor the industry can overrule the decisions taken by BNetzA. The regulator's decisions can only be challenged before the court. The German regulator makes use of its power to supervise the network charges of the grid operators, to prevent or remove obstacles in access to energy supply networks for suppliers and consumers, to standardize processes for switching the power retail company, and to improve the conditions for connecting new generators to the grid. Driven by the growing share of renewables and the resulting need to expand the grid infrastructure in Germany, the regulator also has the task of supervising the network expansion process (see ► Sect. 4.4.1 for more detailed information on the German regulator).

5.1.3 Recommended approach for China

China has not yet formulated explicit targets for the long-term future of its electric power system. This situation risks creating uncertainty among smart grid investors and manufacturers which might consequently postpone smart grid investments. Their uncertainty could be reduced by means of a clearly defined and committed long-term strategy for the electric power sector. Such a strategy should include government targets with regard to future generation capacities, shares of different generation technologies (generation mix), and targets for energy efficiency. In Germany, the long-term energy strategy contains binding government goals for a period of roughly 40 years, whereas long-term energy strategies in countries with higher economic growth rates and accordingly more dynamic energy sectors (e. g. India and Brazil) cover periods of approximately 25 years.

The governance structure of China's energy system comprises a broad variety of ministries and institutions. The multiplicity of these stakeholders as well as the frequent reorganizations that have been taking place lead to a rather low degree of coordination and to a rather high degree of overlaps of competence between the various government actors involved in the power system regulation. Based on OECD recommendations and on the German experiences, clearly defined roles and responsibilities concerning the regulation of the electricity sector and the development of smart grids would accelerate and ease the smart grid development in China. The existence of an independent and powerful regulator is by far the most important regulatory issue in this context. China's earlier regulatory authority, SERC, was recently merged with NEA. NDRC and NEA are currently the most relevant regulatory institutions for the electricity sector. As they share regulatory competences and are subject to political and industrial influence, regulation in China is less powerful and independent than in countries such as Germany and the United States. Thus, specific attention should be paid to the development of an independent and powerful regulator in China.

The recommended approach at a glance

- A long-term strategy for the electric power system serves as a basis for more specific smart grid development strategies and objectives and is important for investors to gain investment security.
- It is beneficial to centralize responsibilities for the regulation of the electricity sector in the hands of a single independent and powerful institution (regulator) that supervises the efficient development of the electric power system in general and smart grids in particular.

5.2 Create level playing fields for access to power system infrastructure and information

Chinese context

- Chinese grid operators are still integrated as they own and operate the electric power grids, are responsible for power retail, and invest in RES generation capacities. Also, power system data management (i. e. data collection and provision on grid status as well as generation and consumption quantities) is their task. Both major grid operators are currently developing systems for data management in smart grids. However, these systems focus on information collection by the grid operator for their own operation management, but not on information provision to other market actors.
- New market actors are rarely participating in the development process of smart grids in China. Therefore, the innovation potential which could come from these new stakeholders, for instance from the ICT sector, currently remains untapped.
- The Chinese government plans to establish a modern energy market system to increase competition and affordability. In particular, the reform of state-owned enterprises and the introduction of more market-related elements are envisaged.

5.2.1 Background

Benefits of integrating new market actors Smart grids are a relatively new concept aiming at making grid operation more reliable and efficient and accelerating the emergence of new energy-related products and services. Due to the novelty of the smart grid approach, many technological advances and ideas are necessary for smart grids to be developed in an effective and efficient way. Experiences from other sectors and countries suggest that new market actors, i. e. new competitors in the electric power sector or companies from other sectors such as the ICT industry, are key drivers of innovations: on the one hand, they offer innovative products and services that were not supplied by established market actors before. In a smart grid context, non-incumbents create new business models and offer new products and services by making use of available power system information and infrastructure in an innovative way (see ► Sect. 4.4.2 for examples of new market actors in the German electricity sector). On the other hand, new market actors contribute to an increased level of competition which is usually considered to drive innovation, enable greater cost efficiency in production, lower retail price levels, and provide a higher variety of products and services (see ► Sect. 2.3).

A fair access to essential facilities is a prerequisite for new market actor integration New market actors can only enter the markets if equal and non-discriminatory access to essential facilities (i. e. a level playing field) is guaranteed [9] [10]. In smart grids, level playing fields should be secured in two respects:

- First, equal access to the physical grid infrastructure is important. Since connecting new power generation and consumption units to the power grid is laborious and often associated with high costs, grid operators might have a tendency to discriminate in favor of affiliated companies or against generators and consumers in remote regions. Regulation must prevent such a discriminatory behavior.
- Second, access to power system information and data is required. Power system information and data are getting increasingly important and are a prerequisite for new market actors to offer new and innovative products and services [11]. This does not mean that each established or new market actor has access to all power system information, or that information is even open to the public; instead it means that each eligible market actor has equal and fair access to the information relevant for his business model. This is the task of power system data management, which should be organized in a way that both established and new market actors can participate in the rule-making process and can trust on non-discriminatory access.

Concepts for a non-discriminatory access to power system information Two concepts should ensure a non-discriminatory access to power system information and data in smart grids:

- Technology neutrality is a regulatory concept for the telecommunications sector that was introduced by the European Commission in Directive 2002/21/EG. In this context, technology neutrality means that the regulator does not impose or discriminate in favor of a particular type of technology. This concept has been applied to several technological issues in Europe, for example with respect to the development of broadband internet, where the regulator left it open to the market to decide between the deployment of different technologies such as *digital subscriber line* (DSL), *power-line communications* (PLC), cable modem, or satellite. Technology neutrality is also important for smart grids, e. g. with respect to the question regarding which infrastructure should be used for the power system information exchange. This issue is currently being discussed under the headline of *advanced metering infrastructure* (AMI).[1] The development of AMI is in its early introduction phase. Therefore, what specific technology should be used for building up the necessary infrastructure has not yet been settled. Different technologies could be applied, e. g. PLC, wireless, or fiber technologies. In this context, regulation needs to ensure that the most efficient technology will be applied, independently of which company supplies the technology.
- Provider neutrality is another general regulatory concept that is also currently applied in the telecommunications sector in Europe. It basically states that the regulator should ensure that regulation does not discriminate

1 AMI is defined as *"systems [that] are comprised of state-of-the-art electronic/digital hardware and software, which combine interval data measurement with continuously available remote communications. These systems enable measurement of detailed, time-based information and frequent collection and transmittal of such information to various parties."* [60].

against particular service providers. Applied to smart grids, this means that the regulator should ensure that established and new market actors are treated equally and allowed to offer services on an equal footing in smart grids. On the one hand, services could be provided by established players (e. g. DSO), on the other hand new market actors could provide complementary services or even substitute services of established players for the costumer. Provider neutrality should consequently ensure that competitive advantages (e. g. best technologies or low costs/prices) and not the provider's market power affects consumer's choice.

Defining roles and responsibilities of all market actors eases new market actor integration Liberalized energy markets for energy resources, electricity, capacity, or ancillary services necessitate the exchange of large amounts of information and data between different market actors. A mounting number of market actors leads to a more intensive inter-company exchange of operational and business-related information and data. Against this background, it is of critical importance that all market actors get assigned their respective roles and responsibilities [12]: on the one hand, they have to know the stakes and information requirements of their business partners and other actors in the electric power sector to better understand their business opportunities and their own contribution towards smart grid development. On the other hand, specific rules and data standards for inter-company exchange of business-related information help to reduce the transaction costs among all market actors.

5.2.2 International practice

Ensuring technology neutrality For the development of smart grids, the concept of technology neutrality is particularly important with respect to the development of the ICT infrastructure. In principle, different communication technologies could be applied (PLC, 3G, etc.) and different data storages types could be used. Eurelectric, the association of the electricity industry in Europe, has defined basic requirements for the ICT infrastructures in smart grids. The German regulator has addressed this issue as well and specified that, currently, a medium-scale broadband connection should fulfill the necessary requirements to build up the AMI for smart grids. However, the German regulator stresses that with the use of real-time data the quality requirements concerning availability and latency cannot be fulfilled by all existing ICT solutions on the market [13].

Basic requirements for ICT infrastructures in smart grids

According to Eurelectric, the most important requirements for ICT in the context of smart grids are to:

- *"Ensure that telecoms infrastructure and links are absolutely reliable, robust, meet operational requirements in terms of speed, capacity and latency and will be available at all times, particularly at times of critical incidents (e. g. be resilient to power outages for several hours because they are needed to rebuild the grid.*
- *Provide well manageable and robust access control and user privileges mechanisms to the smart grid components and systems.*
- *Guarantee the confidentiality, integrity and authentication of all smart grid-related communication events.*
- *Guarantee a robust physical protection for the smart grid components as well as for the whole communication network.*
- *Ensure that mission-critical telecommunications services are still alive during and up to the end of a wide area 72 hours blackout.*
- *Implement strong monitoring systems to keep track of all the smart grid activity, implementing Security Information and Event Management (SIEM) systems for security related incidents analysis and maintain well trained security response teams to have a strong and quick response in the case of any security violation.*
- *Warrant a true real time transfer of information: for a part the smart grid can be seen as an extension of the current SCADA systems; fully available at any time and the guaranteeing the perfect transfer of commands and feedback confirmation of the system operations.*

- *Have an end-to-end security approach to guarantee a transversal security layer on the smart grid."*

Source: Wording from Eurelectric [61]

Ensuring provider neutrality Provider neutrality is a key requirement for third-party access in general and is currently being discussed within the evaluation of different governance models for power system information management in smart grids. In this context, the *European Commission* (EC) has been trying to define which actor should be responsible for the data handling in smart grids. The models under discussion are based on unbundled companies or new market actors. The discussion on the different governance models is ongoing and no decision has been taken yet. Three potential models are currently being discussed (for more details see [11]):

- ***DSO as market facilitator:*** This model allocates responsibility for power system data management, including collection of data and construction of the necessary information infrastructure to the DSO. The concentration of responsibilities within one institution has the advantage of centralized internal coordination and management of the ICT infrastructure. The main disadvantage of a DSO-centered solution addresses discrimination concerns. In principle, unbundling prescriptions require the neutrality of DSO in Europe. Yet, it is doubtful whether full neutrality can be guaranteed because of asymmetric information to the disadvantage of the regulator. This concept requires significant regulatory oversight. However, it is not new to the regulator, as the DSO are already regulated.
- ***Independent central data hub (CDH):*** The CDH would be responsible for power system data management in smart grids and for central data storage under the supervision of the regulator. A key advantage of this approach is the neutrality of the market facilitator and the non-discriminatory access to information for third parties. The key challenge for this concept is the need to establish coordination mechanisms between the parties involved, e. g. the network owners/system operators and the CDH. It should be noted that the regulator needs to ensure that the provider of the CDH does not discriminate against other parties or abuse its market power.
- ***Data access point manager (DAM):*** The DAM concept focuses on a competitive market for power system information management and proposes to establish independent and unregulated service providers that consumers can choose from. Each DAM offers to build up the necessary information infrastructure for the consumer. Importantly, the DAM does not store the data centrally. Storage remains decentralized with the users, giving consumers full control of their own data. The DAM only acts as an interface which allows each consumer to decide which commercial party gets access to its main data. Such a decentralized approach requires a high degree of standardization to ensure flawless system integration. The DSO would have to control the quality of services provided by the DAM and each regulator would need to define the basic principles of the DAM to integrate them into the national electricity system.

Defining roles and responsibilities of all market actors At the European level, the *Smart Grids Task Force* (SGTF) of the European Commission broadly defined roles and responsibilities of various market actors in smart grids [12]: in a first step, all relevant smart grid actors (including companies from all supply chain stages of the electric power sector, end-users as well as influencing actors such as regulators, legislation authorities and standardization bodies) have been defined (see appendix E for an overview of all smart grid actors defined). In a second step, current as well as future responsibilities related to the smart grid development have been described for all actors. The work of SGTF should be understood as a practical toolset and guideline for further developments and business models for use by grid operators and grid users [12].

Future responsibilities of grid operators in smart grids

"[…] it appears that it is the DSOs who will have to face the biggest challenges so that Smart Grids will become a reality. The reasons include;

- *Growing distributed generation, active management of demand, local storage and electric vehicles (EV) will impact the DSO infrastructure. Thus the DSO will have to be an active participant in all such projects along with the actors implementing these projects as these projects will fundamentally change today's relatively static distribution system to a much more dynamic distribution system.*
- *As more fluctuating distributed generation will feed into the distribution system, gathering and handling the data about the state of the distribution system will be one key issue for the DSO.*
- *Attention will need to be paid to ensure that all privacy and system security recommendations (in line with the provisions defined by EG2) will be adhered to. Ownership of the data, length of time data is stored etc. will all need to be addressed in an appropriate way.*
- *The data collected will enable the DSOs to fulfil their duty in relation to the overall grid stability and operational security, given that more and more distributed generation will be connected to the distribution grid.*

In order to resolve the above challenges, the DSOs will have to continue upgrading their grid infrastructure, control centres and educating their employees accordingly.

The TSOs will have to provide more support & communication of data to the DSOs, but will also require more specific information from the DSOs, especially with more distributed generation coming from the distribution grids. In order to achieve this, both TSOs and DSOs need to ensure that the standards they implement for communication and data exchange are compatible. It also follows that the TSOs will have to gradually redesign power system control as well as market information management relating to forecasting the overall system load in conjunction with the DSOs.

At the same time, the DSOs will have to strengthen their role in providing the required data relating to the distributed generation, local storage and electric vehicles within the distribution grid.

Both TSO and DSO should be able to execute their active role in Smart Grid management by ensuring more sophisticated legal provisions for system security management under increased uncertainty. Following the analysis about funding […], these mechanisms should include the ability to interfere with the planned market activities in case of disturbed or emergency operational conditions, without "automatic" socialization of the related costs to other grid users.

Finally, the role of grid communications will significantly increase as much more data will have to be gathered and exchanged frequently, which will be in turn used for different purposes by the grid operators and other service providers. As stated above, the standardization of communication protocols as well as clear rules for the handling and the security of this data will have to be developed and enforced. The security of the grid and supply systems as well as the privacy of customer data must remain the top priority."

Source: Wording from Smart Grids Task Force [11]

At the German level, roles and responsibilities of companies in the electric power sector are further specified in EnWG, with an emphasis on specific conditions in Germany. This definition of roles and responsibilities in Germany's most prominent energy law contributed to a high understanding on business opportunities and legal obligations among affected companies in Germany.

With respect to the inter-company exchange of business-related information, BNetzA issued the so-called *Business Processes for Delivery of Electricity to Customers* (GPKE) based on the *United Nations Electronic Data Interchange for Administration, Commerce and Transport* (UN/EDIFACT) in 2006 (see [14] for more information). GPKE standardize inter-company communication and data exchange in the case of typical business processes such as billing of customers or customers changing their power retail company. In reducing transaction costs of typical business processes, GPKE ease the emergence of new market actors.

5.2.3 Recommended approach for China

The main electricity sector reform of 2002 mandated the separation (or unbundling) of the state-owned vertically integrated utility responsible for all supply chain stages across China into five big power generation companies, two major grid operators handling transmission, distribution and retail as well as four power service corporations. China's power generation sector can be described as liberalized, as it potentially allows competition between the major five generation companies and the thousands of smaller local and regional generation companies. Chinese grid operators are not completely unbundled as they own and operate the electric power grids, are responsible for retail, and also invest into RES generation capacities. Recently a potential separation of grid operators into transmission and distribution companies or into smaller, regional businesses has been subject of debate [15]. With respect to smart grid developments, non-incumbents (e.g. from the ICT sector) are not yet actively participating in the development process. Therefore, the innovation potential which could come from these new stakeholders, for instance the ICT sector, currently remains untapped.

Experiences from Europe show that defining roles and responsibilities of established and new market actors (including specific rules and data standards for inter-company exchange of business-related information) leads to a better understanding of business opportunities and helps to reduce the transaction costs among all market actors. As such, the definition of roles and responsibilities contributed to the emergence of new market actors in the European electricity sector.

Currently, the management of power system data (e.g. grid status information or metering data on electricity generation and consumption) is in the hands of China's grid operators. The concepts of technology and provider neutrality are not applied. As soon as new market actors are to be integrated in the electric power system, power system data management will become more relevant on a broader scale.

The regulator should develop a governance system that will ensure provider and technology neutrality and a level playing field for all stakeholders. Non-discriminatory access to information in smart grids is of particular importance for third parties to be able to develop their business plans. Neutral information management is therefore a key issue. There are various models currently being discussed in Europe. However, there is not yet one preferred solution fitting all possible contexts. Therefore, recommending a best practice approach to China in this context is not yet advisable. A better approach would be to evaluate what governance model best suits China to ensure non-discriminatory access to information for third parties in the near future.

The recommended approach at a glance

- Defining roles and responsibilities of established and non-established market actors in the smart grid development facilitates the emergence of new market actors and helps to make the exchange of business-related information and data more efficient.
- It should be evaluated which framework for smart grid data management is able to ensure provider and technology neutrality in China. On this basis, a suitable framework needs to be established.

5.3 Introduce network regulation for efficient investment incentives for electricity grid expansion and upgrade

Chinese context

- China's main challenge in the electricity sector is how to handle the massive electricity grid expansion necessary to facilitate the country's rapid economic growth and to integrate the increasing number of RES. A network regulation system that focuses on facilitating investments is lacking.

- At present, there is no explicit price for power transmission and distribution (network charge) based on actual costs. The source of grid operators' income is the difference between the on-grid and the retail price for electricity, which are both fixed by the government.

5.3.1 Background

Network regulation for smart grids Smart grids require substantial investment and innovation, especially from the grid operators. In setting network charges (i. e. prices for power transmission and distribution), regulating institutions have an important influence on the investment behavior of grid operators. Which regulatory scheme (i. e. which specific method used for calculating network charges) is best suited to set incentives for efficient investment is far from settled: in general, regulation should facilitate necessary investment and avoid unnecessary investment at the same time.

In a smart grid context, incentivizing efficient investment into the infrastructure is becoming even more important because benefits of innovation and investment in smart grid technologies may not always accrue to the investor (more information on this issue is presented below). In these cases, additional incentive schemes are required to encourage grid operators to invest specifically in smart grid technologies.

The benefits of regulating only the monopolistic bottlenecks Even if it is far from settled which regulatory scheme is best suited to set incentives for efficient investment, it is generally accepted that network regulation should focus on the monopolistic bottlenecks (transmission and distribution grids), leaving the commercial businesses (generation, trade and retail) to competitive forces and monitoring by competition law [16], [17]. This approach is referred to as *disaggregated regulation*. Also with respect to the smart grid development, it has been emphasized that regulation should only focus on network charges and network planning while all other aspects should be subject to the market and competition law [13].

Disaggregated regulation has the following advantages:

- Regulation inevitably provides misdirected incentives: only competitive markets are able to provide incentives to hold prices down to marginal costs and to minimize long-run costs. Regulated markets can only do one or the other but not both [18]. In this light, a regulatory focus on the natural monopoly part of the supply chain avoids misdirected incentives at the competitive parts of the supply chain.
- Leaving a stage of the supply chain unregulated eases the market entry of new market actors [19] because requirements for licenses, permits and monitoring obligations in regulated markets raise the investment needed to enter a market.
- A focus on regulation of the natural monopoly may improve the quality of regulation because the regulator's most skilled employees can more easily focus their efforts on the natural monopoly part of the supply chain. It will then be easier for them to get a grip on the regulated firms' cost-developments and investment requirements.
- Different stages of the electric power system may require different types of regulation. In case the regulator decides to regulate the retail stage of the electricity value chain, it is important to set incentives for quality of service and cost efficiency of power retail companies and to allow differentiated tariffs for different consumer groups. Regulation for networks, in turn, needs to set incentives for efficient investment, as network expansion has become so urgent.

Network regulation and investment incentives Disaggregated regulation entails the necessity to apply a specific network regulation scheme. The challenge of network regulation is setting *efficient investment incentives* (i. e. allowing necessary investment while avoiding unnecessary investment) because the regulator is confronted with the following dilemma: the regulated companies know their own cost structures and market opportunities better than the regulator. As a consequence, regulation cannot provide full-powered incentives to incentivize necessary investment and to avoid unnecessary investment at the same time [18]. Regulators must always accept a trade-off between both goals.[2] The regulator's challenge is to achieve acceptable levels of both goals at the same time. In accordance with the trade-off described above, two polar cases are commonly distinguished in regulation theory:

- Rate-of-return (also known as cost-pass-through) regulation fixes the rate of return and requires revenues to adjust according to underlying costs. If costs go down, revenues should go down and if costs go up, revenues may go up as well. Therefore, the incentives to reduce costs are low. In fact, firms make profits by inflating the capital base as this is the basis for the rate of return. With cost-pass-through regulation, firms may actually have strong incentives to overinvest (i. e. they do not avoid unnecessary investment).
- Price-cap regulation, also called revenue-cap regulation or RPI-X regulation, tries to avoid these very incentives [20]. Price-cap regulation fixes the price or revenue path ex-ante for the next regulatory period, irrespective of the actual cost development during the regulatory period. If the firm succeeds in reducing its costs more than anticipated by the regulator, the firm can keep the additional profits; this is an incentive to minimize costs. Therefore, this type of regulation is often called *incentive regulation*.[3] A counterargument for price-cap regulation is a situation in which costs do not go down, but tend upwards. This typically happens if networks need to be expanded. Under the typical RPI-X regulation, firms then have an incentive to avoid necessary investments [21].

2 Note that the inevitability of this trade-off has been established repeatedly and with great rigor [18]. However, the extent of the regulator's dilemma can be reduced if the regulator has a fair amount of information on the cost structures and market opportunities of the regulated companies.

3 The term *incentive regulation* is unfortunately somewhat misleading. Regulation always sets incentives: the question is merely what incentives and whether they are good or bad.

The necessity of additional incentive schemes in a smart grid context An additional challenge is starting to emerge given the decentralization of decisions in the smart grid value chain. This challenge can be illustrated through the following example: suppose a new market actor, e. g. the operator of a wind farm, wants to invest in storage capacities close to a wind farm as the facility can store electricity from the wind farm at times of congestion in the grid. Imagine that this investment would be economically more efficient than expanding the distribution grid. From the perspective of the grid operator, only the costs associated with the investment in the grid infrastructure are usually taken into account for calculating the network charges. Thus, the grid operator has no incentive to support the investment in the economically more efficient storage facility. The regulatory framework needs to take account of the spill-over effects and allow cost- and revenue-sharing models to incentivize investment in smart grid solutions, like the storage facility in the example above.

5.3.2 International practice

Regulation of monopolistic bottlenecks and network regulation schemes In Europe and many other countries with liberalized electricity markets, regulation focuses on the natural monopoly part of the supply chain, i. e. power transmission and distribution grids. The other elements of the supply chain, i. e. generation and retail, are liberalized and governed by general competition law only. As such, European power sector regulators focus primarily on the regulation of network charges for transmission and distribution grids. In fact, most of them are not even authorized to intervene in the competitive parts of the electricity sector.

With respect to specific network regulation schemes, the cost-pass-through regulation was traditionally applied in many European countries and the United States. Since this regulation scheme does not set incentives for an efficient grid operation, which is especially important in power systems with a limited need for grid expansion and upgrade, most European countries and some parts of the United States abandoned cost-pass-through regulation in favor of different variants of price cap regulation.[4] Germany for example, applies an RPI-X regulation scheme since 2009 (see ▶ Sect. 4.4.4 for more details). Currently, only Belgium and most parts of the United States [22], [23] still apply cost-pass-through regulation. Owing to the large network investment requirements associated with the transition towards more RES and smart grids, a reform of the RPI-X system to facilitate efficient investment is currently being discussed in Germany and other parts of Europe. In the light of these developments, it can be seen that no single regulatory scheme is preferable in every situation. In the end, regulatory schemes have to take into account the current needs of each country under consideration.

Regulatory approaches setting incentives for efficient investments Network regulation should set incentives for network operators to develop a secure and stable network at the lowest cost. Also, network regulation should set incentives to invest in smart grid solutions, especially in solutions that defer costly investments in grid expansion. Three possible incentive instruments have been applied in countries such as Italy, the United States, and the United Kingdom. These instruments are described below. However, note that this list is not comprehensive:

- Explicit investment incentives could be applied. Such incentives could be so-called *rate-of-return adders*. The idea behind rate-of-return adders is that network operators can earn additional *return on equity* (ROE) for specific projects selected by the regulator. The rate-of-return adder (usually between 2 % and 3 %) increases the incentive for the network operator to build this specific line or to invest in the respective project. This concept has proven to be successful in Italy. Here, roughly 71 % of all investments made by the Italian TSO Terna in 2009 were priority projects with a rate-of-return adder. In Italy, this adder is provided for twelve years after the investment [24]. In Italy's case, it can be observed that overall investments, not only those with the rate-of-return adder, increased since the introduction of the adder. Similar effects were observed in the United States [24].
- Explicit profit-sharing mechanisms, or sliding scales, are currently applied in the UK [25]. They can contribute to strengthening the incentives for investment in smart grid technologies. The idea behind the profit-sharing mechanism is that the grid operator is allowed to keep a share of a cost reduction achieved through the application of a smart application (e. g. a storage facility) as a substitute for grid investments. If the costs for the smart application are lower than the investment in the grid infrastructure, but both measures result in a more stable grid, then the grid operator has an incentive to invest in the smart application. Note that the sliding scales have to be granted by the regulator and that calculating their size is a complex task.
- The innovation bonus is an additional instrument motivating the grid operator to invest in smart grid technologies. The innovation bonus is determined by the regulator and grants funds for R&D activities of the grid operators. The additional costs for the R&D activity are thereby at least partially refunded to the operator and do not reduce the operator's revenues. The innovation bonus is currently applied in the UK as well and has proved to be an efficient instrument [25]. Similar to rate-of-return adders, innovation bonuses can be designed and granted rather easily by the regulator.

5.3.3 Recommended approach for China

China does currently not apply disaggregated regulation, but electricity wholesale and retail prices are subject to regulation. A basic step in the regulatory environment would be to focus on the monopolistic networks alone. This would avoid misdirected incentives at the generation and retail sectors, ease the

4 Even if the general idea behind the price cap regulation scheme is identical in the different countries, specific formula and parameters (e. g. the length of the regulation period or the allowed return of grid operators) differ from country to country. A more specific and detailed overview of network regulation in Europe can be found in [22].

emergence of new market actors, and improve the quality of regulation. In applying a specific regulation scheme, the regulator should focus on setting efficient investment incentives. As there is no regulation scheme suitable to all countries in all contexts, the specific design of a regulation scheme for China has to be elaborated with great rigor. The considerable investment needs in China's electric power grid and the recent experiences with RPI-X regulation in Germany should be taken into account.

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China faces the primary challenge of having to increase security of supply. In addition, the potential that comes with smart grids can only be realized if there is an incentive for grid operators to invest into smart solutions (e.g. storage facilities or DSM). Thus, network regulation in China should specifically focus on incentives for security of supply and smart solutions. The application of rate-of-return adders for high priority projects for security of supply and for investment in smart solutions should be evaluated.

The recommended approach at a glance

- Regulating only the natural monopoly part of the electric power sector (transmission and distribution grids) improves the opportunities for market entry of new market actors, reduces misdirected incentives, and may increase quality of regulation.
- Network regulation should focus on setting efficient investment incentives balancing between network expansion and smart grid applications in an economically efficient way. Specifically, the application of rate-of-return adders for projects with a high priority for security of supply might be interesting for China. Furthermore, profit-sharing mechanisms or innovation bonuses could be applied to increase the diffusion of innovative technologies in China's electricity sector.

5.4 Coordinate network expansion planning for electricity grid expansion and upgrade

Chinese context

- From 2010 to 2015, generation and grid capacities are planned to increase by roughly 50 % in order to cope with the steadily growing demand. Their further expansion beyond that point in time is inevitable.
- RES generation capacities are expected to increase out of proportion – their share in the electricity mix will increase significantly.
- Electricity grid expansion planning is currently organized in a top-down process with low transparency and little involvement of actors other than government authorities and grid operators.

5.4.1 Background

Towards a more decentralized system So far, electric power grids have been designed to transport the electricity generated in central power stations (e.g. coal-fired power plants) to industrial or residential load centers. The subordinated distribution grids have only been used to redistribute the electricity towards end-consumers. Single distribution grids have been operated quite independently from those in other areas. In this setting, a coordination of the necessary grid expansion measures has been important mainly at the level of transmission grids.

The current developments towards more intermittent RES and actively involved end-consumers result in a more decentralized system with bidirectional flows of electricity and information. Massive investments in the power grid infrastructure have to be undertaken to cope with these developments, especially at the distribution grid level: in Germany for example, the investment needs in the distribution grid infrastructure are considerably higher than in the transmission grid infrastructure [21], [26] because roughly 97 % of RES in Germany are connected to the distribution grids [27]. A coordination of the necessary grid expansion measures is especially important at the level of distribution grids to facilitate an efficient allocation of investments and reduce economic inefficiencies as much as possible.

Fragmentation of interests Up to now, investments in generation capacities were made mainly by operators of large-scale centralized power plants, a situation that allows grid operators to collect information on where and when a new power plant is planned for construction rather easily. Network expansion planning was a task with a moderate complexity organized by grid operators, operators of large-scale centralized power plants, and coordinating government institutions.

Currently, the number and the heterogeneity of stakeholders with interests in network expansion planning increases:

- Investments into distributed RES are made by a larger number of more heterogeneous companies or even by private investors in many countries [28]. Therefore, advanced planning on how much new grid capacity need to be built in what area becomes more difficult for the network operators.
- The trend towards smart grids is associated with an increasing amount of new market actors with diverse interests. As the business models of new market actors often depend on available grid capacities, their interests are also relevant for long-term electricity network planning alongside the stakes of established market actors making the process of stakeholder consultation more complex. If the interests of stakeholders such as grid operators on different voltage levels, power plant operators, industrial consumers, representatives of small end-users, environmental groups, local governments and central government ministries are not coordinated effectively, network expansion risks being economically inefficient [29].

Against this background, it becomes of vital importance to develop a long-term centrally coordinated NDP that includes plans and interests of all relevant market actors and network users at an early stage.

5.4.2 International practice

Network expansion planning in Europe The EU requires each member state to develop a 10-year NDP currently focusing on transmission grid expansion but not distribution grid expansion [30]. Given the high investment and coordination needs on the distribution grid level, the non-coordination of distribution grid expansion unnecessarily inflates costs of network expansion. In Germany, a group of geographically adjacent DSO consequently started initiatives to coordinate distribution grid expansion planning [31].

The network development plans are based on several scenarios (three scenarios in the case of Germany) concerning the future development of RES and the corresponding electricity system in each member state. The national planning processes are accompanied by 10-year network development plans of the ENTSO-E. Starting in 2010, these plans are to be issued every two years. The main results of the version published in 2012 are:

- One third of investments planned in the first network development plan of 2010 are experiencing implementation delays owing to long approval processes.
- 52,300 km of extra high voltage transmission lines clustered in 100 projects have to be modernized or constructed, mainly due to bottlenecks related to RES integration.
- 20 megatons CO_2 can be saved in the period up to 2022 due to further market integration in Europe.
- Extending the grid by about 1.3 % enables the addition of 3 % more generation capacities [32].

Network expansion planning in Germany In Germany, the rules for developing the national NDP are defined in § 12 EnWG and the NABEG. Figure 5.1 illustrates the different steps towards the network development plan in Germany. These are [33]:

- The starting point in the network development process is the scenario framework. It is drafted by the four German TSO and includes forecasts relating to the development of electricity generation, the shares of different generation technologies, and power consumption for the

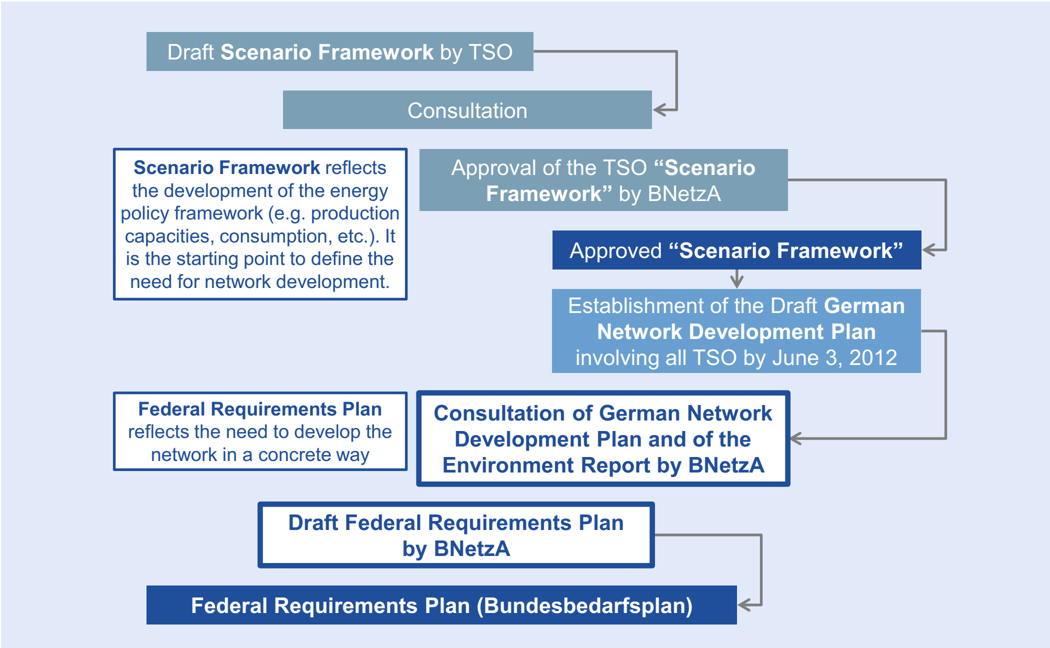

Fig. 5.1 Process for the network development plan in Germany, adapted from [34]

next ten years. To achieve a realistic forecast, three different scenarios based on different assumptions regarding the increase in generation capacities, RES expansion, and CO_2 abatement are considered. The scenarios are submitted to BNetzA, which approves them after a public consultation process. During this process, distribution grid operators and other interested parties have the opportunity to comment on the different scenarios.

- The four TSO subsequently employ the approved scenarios for calculating network expansion requirements. Selecting the necessary expansion measures and assigning a timeframe (two to ten years depending on the respective project) for their realization leads to a first draft of the respective network development plan. BNetzA again assesses this first draft within a public consultation process. During this process, the drafted network development plan is published on a public website and can be commented from various stakeholders and citizens. The network development plan is then revised by the TSO and once again assessed by BNetzA. Furthermore, BNetzA conducts the environmental impact assessment.
- Based on the final version of the network development plan and the environmental impact report published at the same time, BNetzA has the responsibility to draft the so-called *Federal Requirements Plan*, which is finally brought in the parliamentary legislative procedure.

While this process currently focuses on transmission grids only, it might serve as a best-practice example of how to organize the grid expansion planning on the distribution grid level as well.

The role of stakeholder platforms One of the main goals of BMWi with respect to grid development is to involve new market actors in the strategic smart grid planning process. One prominent example of the ministry's activities is the *Future-oriented Energy Grids Platform*, which was founded in 2010. In February 2011, the platform was transformed into a permanent dialogue forum [35]. The platform involves all relevant parties of the electricity sector:

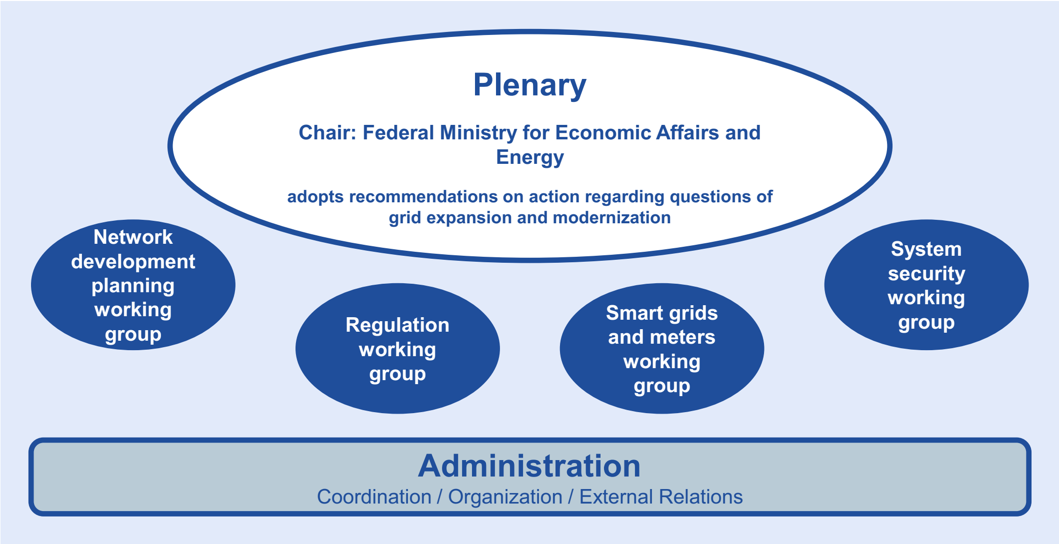

Fig. 5.2 Structure of the Future Oriented Energy Grids Platform, adapted from [35]

grid operators, ICT-companies, environmental and consumer associations, research institutions, and representatives of several ministries and governmental institutions. One of the platform's main tasks is to discuss the draft documents of the network development plan. The platform is therefore an important instrument for the regulator to get feedback on NDP. Besides this task, the grid platform serves as a discussion platform for planning and approval procedures, the regulatory framework for investments into networks, grid connection of offshore wind farms, funding and testing of new technologies, development of smart meters, system stability, and applications of storage systems for network stability.

Figure 5.2 shows the organizational structure of the platform. The plenary which adopts recommendations on actions is hosted by BMWi. The platform is subdivided in four different working groups, one of them directly responsible for smart grid issues. The different working groups provide consulting services for BMWi or other government institutions, make publicly available the results of their meetings, draft documents and recommendations, and support other publicly funded initiatives for smart grid development. The working group responsible for network development planning for example, proposed a joint grid connection process for offshore wind farms as well as an offshore master plan. In the meantime, both propositions have been included in NABEG [36].

5.4.3 Recommended approach for China

China faces a high need to expand the existing electricity network within the next few years. On both levels of the grid, transmission and distribution, this need is driven by growing consumer demand for electricity and the integration of RES. Supporting and guiding the formulation of a consistent and comprehensive concept regarding the set-up of China's future electric power grid is a key task for Chinese energy sector regulation. Government guidance is particularly important in the context of the build-up of RES generation capacities and smart grids both resulting in an increasing number of stakeholders involved in the electric power system.

Today, there are no formalized institutions that acknowledge stakeholder interests in grid expansion planning in China. Therefore, stakeholder involvement currently focuses mainly on the grid operators, the government, and the *China Electric Power Planning Institute*. Other stakeholders are not integrated into the process in a formal way.

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Three aspects are especially important with respect to the coordination of network expansion in China:

- First, the institution that has the responsibility to supervise the network planning process should be specified. Experience in Germany illustrates that a government institution such as the regulator should take this responsibility. This has the primary advantage that results from the planning process can be transferred directly into the government policy-making process.
- Second, an evaluation should be made of which stakeholders are relevant for network expansion planning. Specifically, formal coordination between grid operators and power generation companies seems to be of great importance to align grid and generation capacity expansion processes. A platform such as the *Future Oriented Energy Grids Platform* in Germany has been proven effective in integrating new stakeholders in the strategic network development process. The evaluation of which stakeholders are relevant for network expansion planning could also happen within such a stakeholder platform.
- Third, it is beneficial to specify procedures for the development of network plans. In this context, China could take advantage of German experience with the network development planning process. Making mandatory a NDP for both transmission and distribution grids, including smart grids, helps to make network expansion as efficient as possible. Clear scenarios about the development of RES, the general electricity mix, and electricity demand in China are needed as a basis for the definition of a network development plan in China. Such scenarios could then serve as a common basis for the network development process in China. Stakeholder involvement should be a key element of this procedure because the number of stakeholders is likely to increase in the near future due to the importance of non-incumbent market actors for smart grids. These new stakeholders should be integrated into the strategic network development process in a formal way.

The recommended approach at a glance

- A stakeholder platform on the topic of the future electricity network involving all relevant market actors of the electricity sector (e.g. similar to the *Future Oriented Energy Grids Platform* in Germany) could help to evaluate which stakeholders are relevant for network expansion planning, support the network planning process, enhance mutual understanding among different stakeholders and provide recommendations to the government.
- Make mandatory a network development plan (NDP) for transmission and distribution grids, including a procedure for consulting the NDP with third parties and the public. The NDP should reflect fundamental government policy, future energy policy goals, smart grid goals as well as reliability and security issues. The regulator should supervise and confirm the final NDP, which is then signed into law by the legislature.

5.5 Improve grid integration of RES

Chinese context

- Despite the fact that China has aggressively expanded solar and wind generation capacities since 2006, their shares in the electricity generation mix remain small. However, shares of both generation sources are planned to increase significantly according to government plans. Today, new market actors are only partly involved in the build-up of RES generation capacities.
- Within the existing regulatory framework a lack of sufficient incentives for grid integration of RES persists even though significant improvements have been made in recent years. A considerable number of wind farms is only connected to the electric power grid with delay.

- Often, wind farms can also not be connected due to the lack of a Low Voltage Ride Through Function. At the same time substantial quantities of wind power still have to be curtailed in order to increase grid stability.

5.5.1 Background

New market actors require a physical connection to the power grid In many countries, non-incumbent stakeholders have been investing in RES generation capacities and contributing to the increase of RES in the electricity mix: project developers, industrial and commercial companies, prosumers, and even venture capital and private equity companies [28]. These non-incumbent stakeholders need clearly defined conditions for the physical connection of RES installations to the power grid. Their RES plants need to be technically connected to the grid in such a manner that electricity generated from RES can be fed in. Without an equal and fair access, they abstain from investing in RES. As a result, a huge potential of capital resources for RES investment remains untapped.

The three elements of physical grid integration of RES Grid integration of RES, i.e. the issue of how effective, rapid, and fair the access of RES generation capacities to the electric power grid is organized, consists of three different aspects:

- Grid expansion, necessary due to the connection of RES, is a prerequisite for the large-scale integration of RES (compare ▶ Sects. 5.3 and 5.4).
- Grid connection of RES means technically interconnecting RES to the grid in such a manner that electricity generated from RES can be fed in.
- Specific grid operation issues with large amounts of RES implies assuring that the generated electricity has access to the grid so that it can be transported to end consumers [37].

Grid connection Important issues in many countries are so-called *long lead times* (e.g. delays). This subject groups all aspects associated with the time the investor of a renewable energy generation unit has to wait before connecting to the grid and feeding of electricity in the grid is allowed. Long lead times increase the financial risk for investors, creating less favorable credit conditions for them, and thus reducing the incentives for investments in RES.

The effectiveness of grid connection is also affected by how grid connection costs are distributed among the parties involved in the process. In this context, shallow or deep cost approaches can be applied:

- In a deep cost approach, the RES investors requesting connection not only cover the costs of grid connection but also further costs related to grid reinforcement and extension beyond the connection point (i.e. deeper into the network).
- In a shallow cost approach, the RES investor only pays for grid connection costs to the connection point, but not for reinforcement and extension costs. Generally, the deep cost approach creates higher costs and risks for the RES investor. It is therefore more often viewed as an obstacle to RES deployment [37].

Grid operation In countries with a low share of intermittent RES-E in the energy mix, grid operation is usually not adversely affected by RES installations. However, European countries like Germany or Denmark have made the experience that, with a share of approximately 10 % to 20 % of intermittent RES-E, grid operation becomes more and more difficult because regional feed-in often exceeds regional loads and the grids do not have sufficient capacities to absorb and transport the complete surplus of RES-E. One straight-forward remedy for these situations is to expand grid capacities. However, curtailing specific RES generators in times of peak production might be economically more interesting: a study suggests that curtailing only 2 % of the annual electricity production from RES (in times of peak production) could reduce infrastructure investments by 10 % between now and 2030 [26].

Grid curtailment is currently a critical issue in a number of European countries, especially due to the lack of specific curtailment rules and compensation issues [37]. Clear and well-defined grid codes for the interconnection of RES on all grid and voltage levels are a decisive factor to ease grid operation with RES [38]. These rules define the interaction of RES and the electric power grid in terms of grid operation. This also includes the handling of congestions and disturbances.

The ICT-integration of RES RES integration issues go beyond the physical connection of RES to the power grid. The basic idea of smart grids is to make all generators and consumers of electricity monitorable and in part remotely controllable by means of ICT. Only if RES plants are remotely controllable, RES generation can be coordinated with grid capacities at any time. In this light, the equipment of RES with communication interfaces is an essential part of smart grids. Also with respect to an economically efficient grid curtailment of RES, the capability of grid operators to monitor and control installations remotely is necessary.

Especially distributed RES (e.g. small rooftop PV installations or single wind turbines) are currently only rarely equipped with technology allowing the grid operator to remotely monitor or control the installations. Given that owners of RES, especially those of small-scale RES, have usually few incentives in investing in communication interfaces, the widespread deployment and usage of such interfaces depends on appropriate regulatory guidance.

5.5.2 International practice

The European perspective In its *Directive 2001/77/EC2* [39], the EU laid down a common regulatory basis for the promotion of electricity generated from RES and a framework for the integration of RES into the grid [40]. Paragraphs 1–3 of article 7 contain general references to grid connection and operation issues demanding that EU member states

» *take the necessary measures to ensure that transmission system operators and DSOs in their territory guarantee the transmission and distribution of electricity produced from renewable energy sources.*

Also, the directive proposes priority access to the grid for electricity from RES and favors a cost-sharing of grid expansion measures between grid operators and RES operators to pure deep cost and pure shallow costs approaches [39].

Published eight years later, *Directive 2009/28/EC3* further regulates grid connection and operation issues. In paragraphs 2–4 of article 16, the EU makes a clear case for priority access for electricity from RES. The Directive recommends that such electricity be fed in with priority, that grid curtailment measures for RES be minimized and justified by the regulator, and that grid expansion costs related to renewable energies be transparent and born in full or in part by the grid operators.

Since 2009, ENTSO-E has been working on a *network code* for grid connection requirements which aims at

» *setting out clear and objective requirements for generators for grid connection in order to contribute to non-discrimination, effective competition and the efficient functioning of the internal electricity market and to ensure system security* [41].

The network code

» *defines a common set of requirements for power generation facilities, including synchronous generation units, power park modules and offshore generation facilities, to be connected to the network and sets up a common framework for grid connection agreements between grid operators and the power generation facility operators* [41].

In defining these requirements, the network code clearly reduces conflicts between RES investors and grid operators and contributes to a better communication between them and to shorter lead times in RES connection as a result of more standardized procedures.

Grid connection of RES in Germany Part 2, chapters 1–3 of the EEG contain regulations that are of critical importance with respect to the effectiveness of grid connection in Germany:

- Chapter 1 section 5 emphasizes that grid operators must immediately and as a priority connect all RES to the grid even if this connection necessitates optimizing, boosting, or expanding the grid.

- Paragraph 1 contains a definition of the so-called *grid connection point*. It is the point in the electricity grid which is at the nearest linear distance from the location of the RES installation. The generation capacity of the RES unit to be connected determines the voltage level of the nearest grid connection point.
- The responsibility of building a connection between the RES installation and the grid connection point is assigned to the grid operator. However, the costs for building this direct connection are passed on to the RES investor as specified in chapter 3, section 13, and paragraph 1 of the EEG. Note that due to the rather close meshed electricity grids in Germany, the distances between the installations and the grid connection points are often rather short. Thus, connection costs to be paid by the RES investors are rather low in Germany.
- As specified in chapter 3, section 14, however, the share of the costs within the entire electric power grid that is related to optimizing, boosting, and expanding the grid system is allocated to the grid operator (shallow cost approach). This cost-sharing mechanism prevents the investors in RES projects from installing capacities at great distances from the existing power grid, as they are the ones who have to cover the costs for the direct line to the nearest connection point.
- Chapter 2, section 9 specifies further that the grid operator can only be forced to optimize or expand the electricity grid if this is not economically unreasonable.

EEG – Paragraphs 1–4 of Part 2, Chapter 1, Section 5

- *Grid system operators shall immediately and as a priority connect installations generating electricity from renewable energy sources and from mine gas to that point in their grid system (grid connection point) which is suitable in terms of the voltage and which is at the shortest linear distance from the location of the installation if no other grid system has a technically and economically more favorable grid connection point. […]*
- *Installation operators shall be entitled to choose another grid connection point in this grid system or in another grid system which is suitable with regard to the voltage.*
- *In derogation of subsections (1) and (2) above, the grid system operator shall be entitled to assign the installation a different grid connection point. This shall not apply where the purchase of electricity from the installation concerned would not be guaranteed in accordance with section 8(1).*
- *The obligation to connect the installation to the grid system shall also apply where the purchase of the electricity is only made possible by optimizing, boosting or expanding the grid system in accordance with section 9.*

Source: Wording from the BMUB [62]

The combination of a shallow cost approach and an obligation to connect RES with priority is one important factor with regard to grid connection in Germany. Another important element of the EEG (with regard to grid connection) is the definition of what happens if the grid operator fails to connect RES. Part 2, chapter 1, section 10 of the EEG is based on the notion that grid connection rules can be effective only if non-compliance of the grid operator leads to financial losses.

EEG – Paragraphs 1–2 of Part 2, Chapter 1, Section 10

- *In the event that the grid system operator violates his obligations under section 9(1), those interested in feeding in electricity may demand compensation for the damage incurred. The liability to pay compensation shall not apply if the grid system operator was not responsible for the violation of the obligation.*
- *Where there are facts to substantiate the assumption that the grid system operator did*

not fulfill his obligation under section 9(1), installation operators may require the grid system operator to submit information concerning whether and to what extent the grid system operator did not meet his obligation to optimize, boost and expand his grid system. This information may be withheld if it is not necessary in order to establish whether the entitlement in accordance with subsection (1) above exists.

Source: Wording from the BMUB [62]

Grid operation in the presence of RES at the German level In spite of the increasing share of electricity from wind and PV power, Germany's electric power grids are still among the most secure and reliable grids worldwide. Germany has made the experience that effective grid curtailment rules are necessary to sustain reliability and security of supply in times of rising feed-in from RES. To allow for an effective grid operation in spite of the presence of RES, the EEG distinguishes between normal and critical grid conditions:[5]

- In normal grid conditions, electricity produced in RES installations has to be fed in at any time – irrespective of electricity consumption. This is regulated in part 2, chapter 1, section 8 of the EEG, which states that *"[transmission] grid system operators shall immediately and as a priority purchase, transmit and distribute the entire available quantity of electricity from renewable energy sources"*.
- During critical grid conditions, however, grid operators are allowed to curtail electricity from RES by taking technical control over installations connected to their grid system. Part 2, chapter 2, section 6 of the EEG specifies that all RES plants have to be equipped with a communication interface allowing the grid operator to take over technical control over installations or to limit their effective capacity to 70 % of the installed capacity instead. Those RES with a capacity exceeding 100 kW have to be unconditionally enhanced with a communication interface allowing the grid operator to remotely monitor the electricity feed-in in real time and to remotely control installations. To prevent a misuse of grid curtailment, grid operators are obliged to immediately report such measures to the BNetzA. This grid curtailment of RES is not to the detriment of RES investors because they receive equivalent compensations to the extent that they incur no financial losses as a result of the grid curtailment (see appendix E for extracts from EEG, chapter 2, part 2, sections 11 and 12.).

EEG – Paragraphs 1–2 of Part 2, Chapter 1, Section 6

- *Installation operators and operators of CHP installations shall provide installations with an installed capacity exceeding 100 kilowatts with technical facilities with which the grid system operator can, at any time:*
  1. *reduce output by remote means in the event of grid overload; and*
  2. *call up the current electricity feed-in at any given point in time.*
- *Operators of installations generating electricity from solar radiation:*
  1. *with an installed capacity between 30 kilowatts and 100 kilowatts shall fulfil the obligation pursuant to subsection (1) no. 1 above;*
  2. *with a maximum installed capacity of 30 kilowatts shall:*
     a) *fulfil the obligation pursuant to subsection (1) no. 1 above; or*
     b) *limit the maximum effective capacity fed in at the grid connection point with the grid system to 70 percent of the installed capacity.*

Source: Wording from the BMUB [62]

Ensuring compliance with the EEG regulation Well specified laws alone might not be sufficient to ensure an effective grid integration of RES if there is no institution with a distinct judiciary function to monitor compliance with the rules

5 Critical conditions occur when operational limits, according to common technical guidelines, are violated.

and settle any dispute between grid operators and power plant owners. In this light, BMUB commissioned and funded the so-called *Clearingstelle EEG* in 2007. Since then the *Clearingstelle EEG* serves as a neutral and independent institution with the intention to settle any dispute between grid operators and power plant owners with regard to topics surrounding EEG. The staff of the *Clearingstelle EEG* consists of an interdisciplinary team of lawyers and engineers with expertise in the field of renewable energies [42].

The general idea is that ordinary courts settle potential disputes rather through costly and time consuming litigation while the *Clearingstelle EEG* can offer alternative dispute resolution options such as

- mediation,
- joint dispute resolution, and
- arbitration [42].

In addition, the *Clearingstelle EEG* reports the results of past legal disputes such that a high transparency on the jurisdiction exists among grid operators and plant owners. In sum, the *Clearingstelle EEG* clearly contributes to a high compliance with the EEG regulation in Germany.[6]

5.5.3 Recommended approach for China

The physical grid integration of RES in China currently lacks efficiency. This refers to both grid connection and grid operation. Specifically, a considerable part of wind power is currently being curtailed. There is also evidence that only a very small part of investments are being made by non-incumbent players in China: investments from venture capital and private equity companies for example, are quite low compared to many other countries [28]. For the government's ambitious RES expansion targets to be achieved and in order to incentivize new market actors to invest in RES, the physical grid integration of RES has to become more effective.

Transparency and a clear division of responsibilities between grid operators and RES investors would encourage the deployment of RES and incentivize new market actors to invest in RES. The following recommendations are made based on best practices from Europe and especially Germany:

- The grid operator is a monopolistic company with special responsibility. He has to define clear, transparent, and technically sound grid codes for the integration of generation units at all voltage levels. These codes have to be defined properly and made binding.
- For an efficient and fast connection, grid connection points have to be defined properly for all kinds of RES on all voltage levels of the grid. RES need to be assigned a grid connection point on request, so that the interconnection point can be installed without delay and according to well-defined technical standards.
- Grid operators have to bear liability for the grid connection of RES. This is very important, because liability puts a high priority on the establishment of the grid connection and avoids delays on the grid operator's side. In this context, definition of financial incentives (e.g. in form of penalties) is an effective measure to quicken the grid connection process and to reduce the risk for RES investors.

The same arguments which hold for the grid connection are equally valid for grid operation issues. To ensure grid stability, it is necessary to curtail RES in times of critical grid conditions. To provide transparent procedures to the RES operators, detailed processes for curtailment of RES (including documentation, transparency rules, timeframes, involved parties, etc.) have to be defined and the requirements for information exchange within these measures have to be specified. To ensure an economically efficient grid curtailment, the installation of communication interfaces at RES installations should be promoted by appropriate regulation (such as part 2, chapter 1, section 6 of EEG in Germany). Moreover, it is important that grid curtailment of RES only takes place if this is urgently needed to stabilize grid operation and that the compensation to the RES investor is calculated transparently.

6 Further information on the work of the Clearingstelle EEG can be found at ► https://www.clearingstelle-eeg.de/english.

The experiences from Germany further show that the establishment of an independent institution offering mediation, joint dispute resolution, and arbitration services contributes to a high compliance with the regulation.

5

The recommended approach at a glance

- Grid connection points and binding grid codes specifying respective responsibilities of grid operators and power generators have to be defined.
- Grid operators have to bear liability regarding the grid connection of RES.
- Binding procedures for curtailment of RES have to be defined. To ensure an economically efficient grid curtailment, the installation of communication interfaces at RES installations should be promoted by appropriate regulation.
- An institution offering mediation, joint dispute resolution, and arbitration services in the context of grid connection issues should be assigned.

5.6 Optimize the balancing of electricity generation and consumption

Chinese context

- Due to the high share of industrial load, China's overall electricity load curve is currently rather flat. In the future, China's electricity generation might become considerably more fluctuating owing to the further build-up of RES generation capacities planned by the government. In addition, shares of more intermittent residential and commercial electricity consumption are expected to increase. Both factors will lead to regionally higher load variability in China.
- Higher load variability necessitates a more effective coordination of electricity generation and consumption. Specifically, with growing shares of intermittent RES it will become indispensable that electricity consumption will be, at least partly, able to follow electricity generation. This necessitates the use of economic incentives as well as sophisticated technologies facilitating the coordination of electricity generation and consumption. All types of consumers, i.e. industrial, commercial, and residential, have to be involved in these activities.
- Time-of-use pricing (i.e. electricity prices depending on the time when electricity is provided) aims at incentivizing electricity consumers to shift their consumption according to generation and grid capacities. It has gradually been introduced in China to all categories of users except residential consumers and irrigational users. The Chinese government recently announced that it would introduce time-of-use pricing also for residential consumers by the end of 2015. While this is certainly a step in the right direction, it is still questionable whether the present tariff system offers sufficient price incentives for a pronounced intraday shifting of power demand.

5.6.1 Background

Peak shaving and residual peak load shaving The balancing of generation and consumption of electricity is of crucial importance for the stable operation of electric power systems. In a power system with 100 % generation from large central (bulk) power plants, electricity generation follows the load. Sometimes, peak loads may cause shortages on the generation side. *Peak shaving*, i.e. reducing the electrical power consumption during periods of maximum electricity demand, is then an important factor to stabilize system operation. In power systems with a high share of RES, however, the motivation for peak shaving changes somewhat: in such power systems, the residual load, i.e. the difference between load and renewable generation, is highly volatile due to the intermittent nature of renewable generation. In these cases, large central power plants, usually conventional fossil fuel-driven power plants, have to cover the residual load – also known as *residual peak load shaving* (or *residual load balancing*).

Balancing mechanisms and technologies like *demand side management* (DSM), *supply side management* (SSM), *microgrids*, *virtual power plants* (VPP), and *energy storage* can be employed to facilitate the coordination of electricity generation and consumption. All these mechanisms and technologies require an ICT infrastructure for measurement, control, and billing of various loads and/or generation units at local, regional, or distributed sites.

Demand side management DSM is an important mechanism for peak shaving and residual peak shaving for different types of loads. DSM means incentivizing electricity consumers to adapt their consumption to the availability of electricity generation. Principally, the loads can be influenced by means of two different mechanisms: on the one hand, end customers can react manually to suitable incentives such as price signals. On the other hand, automated load control is conceivable for devices where deferred use and a modulated operation mode entail no loss of comfort, economic consequences, or other restrictions in everyday household/business life (dispensable loads). With respect to the potential of DSM on low voltage level, the necessary IT infrastructure and the relation between DSM and AMI have been discussed widely [43].

Supply side management *Supply side management* (SSM) works similarly to DSM but refers to local or distributed generation facilities. SSM means incentivizing electricity producers to adapt their generation to the demand of electricity. The generation units are typically small-scale residential units like CHP plants or larger CHP units located at industrial facilities.

Virtual power plants *Virtual power plants* (VPP) aggregate power generation, storage, or consumption units into one balancing unit by means of ICT metering and control technologies. These units may be spread out over the grid and belong to separate owners. VPP are especially useful in the context of electricity markets: the VPP operator controls or manages the operation of the generation units to follow a joint schedule or to offer balancing power to the system operators.

Microgrids *Microgrids* are a specific solution to manage the intermittent character of RES on a regional level. They are grid areas in which generation from local RES or other distributed generation and consumption is balanced by local control mechanisms by means of information exchange between the devices through local ICT. As such, the higher-level distribution grid to which the microgrid is connected is not necessarily and immediately exposed to the intermittence of RES connected to the microgrid. Island grids without any connections to distribution grids are an extreme form of this approach. Note that microgrids are geographically connected grid regions, while VPP are virtually aggregated units which are distributed throughout larger grid areas.

Energy storage Requirements for power storage differ according to field of application. Some storage technologies are used to balance fluctuations within a very short timeframe (e.g. some milliseconds) and others are used for longer timeframes (e.g. days or weeks):

- Hydrogen generated by means of electrolysis can be used to store electric power for timeframes lasting up to several months.
- Pumped-storage and compressed air energy storage power stations are suitable for an intraday balancing of generation and consumption. On a global level, pumped-storage power plants are the most important technology to store electric power.
- Electrochemical storage mediums like batteries are employed to store electricity for timeframes ranging from one hour to several days.
- Centrifugal mass storage, super caps, and superconductive inductors can be charged and unloaded within an extremely short timeframe. They are used for grid stabilization services and voltage maintenance [44].

Barriers to the development of balancing mechanisms and technologies There are many different barriers to the development of balancing mechanisms and technologies as described above. The elimination of such barriers calls for suitable regulatory measures. In principal, these barriers can be classified into three different categories [45]:

- Technological barriers refer to the fact that the maturity of some technologies that might be important for the balancing of generation and consumption is still rather low [46]. Electrochemical storage mediums such as batteries, for example, are in many cases still too expensive to be used in a widespread manner [44].
- Economic barriers exist, because for many stakeholders in the electricity sector the costs of investing in balancing mechanisms and technologies are still higher than the benefits. For potential investors, especially for small-sized third parties, the administrative overhead and the necessary investments in ICT for controlling, balancing, and billing are relatively high. Many of them consequently refrain from investing in balancing technologies. Specifically, there are many open questions related to billing, balancing, and accounting, in the case that several market actors coordinate power generation and load for different business purposes.
- Institutional barriers may arise if new technologies have to adapt to practices and codes developed in a context in which these new technologies were not yet known. For example, microgrids require specific connection codes that are different from small conventional distribution grids. The costs of deploying such balancing mechanisms and technologies critically depend on connection codes, legal reporting obligations, and application processes [45].

5.6.2 International practice

Reducing technological barriers In order to promote the development of technologies and business models to balance electricity generation and consumption, government-supported R&D programs are of fundamental importance (Germany's R&D program *E-Energy* is presented in ► Sect. 4.4.6).

Many countries have established funding schemes to reduce existing technological barriers:

- The United States for example, claim to invest at least $3 billion into smart grid projects [47]. Specifically, they have funded two important R&D programs for microgrid and DSM demonstration projects run by the *United States Department of Defense* (USDOD) and the *United States Department of Energy* (USDOE). The USDOD provided $38.5 million for three different military base microgrid demonstrations, with a focus on reliability and energy security [45]. The USDOE spent over $50 million for nine projects having the concrete goal of achieving a 15 % peak load reduction in the local distribution feeder [45].
- In recent years, the EU has also invested significant amounts in smart grid-related R&D and devoted several major research efforts exclusively to DSM, SSM, VPP, microgrids, and energy storage. One promising example is the *Future Internet for Smart Energy* (FINSENY) project which was conducted as part of the private public partnership *Future Internet* from 2010 to 2013.[7]

In the United States and in Europe, the experience was made that two factors are especially important with respect to the success of R&D funding (cf. e. g. [45]):

- Clear targets on what should be achieved by means of the research program have to be defined in advance by the funding organization. Only if such targets exist can the success of the research project be measured and controlled during and after the project.
- The recipient of R&D subsidies often has to co-finance the research program with its own capital. Financial participation is an important additional incentive to ensure that the recipient of the subsidies will efficiently and effectively carry out the research project.

Reducing economic barriers All regulatory approaches aiming at decreasing investment costs in

7 See ► http://www.fi-ppp-finseny.eu for more information on this project.

balancing mechanisms or technologies or increasing profits related to their usage can be seen as an effective measure to promote their development:

- A possible solution aiming at reducing investment costs is to directly subsidize the usage of balancing mechanisms or technologies. To promote electricity storage, for example, the German government recently established a co-funding scheme for electric battery storages newly installed in private houses in combination with PV. The purpose of this measure is to promote local consumption of electricity generated by PV, thereby limiting the PV feed-in to the distribution grid.
- Time-of-use pricing is an important option to increase profits related to the usage of DSM, SSM, and energy storage. The higher the price differences between peak and base load prices, the higher the rate of return of DSM, SSM, and energy storage.
- The attractiveness of microgrids critically depends on the difference of electricity generation costs within the microgrid and general retail prices for electricity. If a microgrid is able to produce its own electricity, consumers within the microgrid are independent from general electricity retail prices. However, it is only if general retail prices for electricity are higher than electricity generation costs within the microgrid that investments in these technologies might be potentially amortized after some years. In this light, increasing electricity retail tariffs can be seen as an important driver for investments in microgrids. Depending on the regulatory environment, microgrid operators might also be able to export the electricity to the distribution grid. In this case, the question to be asked is whether the operators receive payments for the electricity they export and what rate these payments depend on: wholesale, retail, or potentially a feed-in tariff. Feed-in tariffs that are higher than the general retail price for electricity and higher than electricity generation costs inside the microgrid can be seen as an effective measure to promote the development of microgrids [48].

Reducing institutional barriers Standards for regulating the general grid connection of RES are common in most countries. Like Europe, the United States, for example, have a standard for grid connection: *IEEE 1547* was established in 2003. These standards often do not contain specific rules for VPP or microgrids. However, some countries have started to issue special regulation for VPP and/or microgrids:

- To ease the grid connection of microgrids, the United States issued *IEEE 1547.4: Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems.* This standard presents alternative approaches and good practices for the design and operation of microgrids and their integration with distribution grids. For instance, this includes the ability to separate from and reconnect to the distribution grid while providing power to the islanded microgrid. The IEEE 1547.4 standard is currently gaining approval on the international level.
- Another example of institutional barriers for microgrids being reduced is Germany, where microgrid operators have been relieved of several legal requirements that have applied to distribution grid operators in Germany since 2005. Special rules applying to so-called *site networks* have been introduced by EnWG for grids covering campuses and enterprises. Such site networks can be designed as microgrids. For example, operators of site networks are not subject to the general connection obligation (§ 18 EnWG): they are permitted to publish less reports on grid conditions (§ 14b EnWG), have less monitoring obligations (§ 35 EnWG), and less obligations to report service disruptions (§ 52 EnWG).

5.6.3 Recommended approach for China

The key driver for the usage of balancing mechanisms and technologies in China is peak shaving due to the high growth rate of power consumption. The balancing mechanisms and technologies described above, especially DSM and energy storage, will contribute to a more effective peak shaving and to an improved utilization rate of the grid infrastructure. In the long term, residual peak shaving – necessary due to the increasing expansion of RES generation capacities – will be an additional aspect in China. Balancing mechanisms and technologies like SSM, VPP, and microgrids will become more important in this context.

In 2011, more than 70 % of China's electricity was consumed by the industrial sector [49]. In general, the technical potential for peak shaving in this sector is comparatively high and can be realized with dedicated ICT solutions. Usually, the potential for peak shaving is smaller and more distributed in the commercial sector and especially in the residential sector. ICT requirements and costs of implementing balancing mechanisms and technologies in these sectors are therefore comparatively higher. In this light, balancing between generation and consumption in China should be optimized with a focus on industrial and commercial consumers in the short- to medium-term and on residential consumers in the long term.

With this general background in mind, several specific policies may foster the development and usage of specific balancing mechanisms and technologies:

- ***Time-of-use pricing to incentivize the usage of DSM and energy storage:*** Time-of-use pricing has gradually been introduced to all categories of users except residential consumers and irrigational users. With regard to commercial and industrial consumers, China already has a very high time-of-use adoption rate, with roughly two thirds of large-scale customers using time-based electricity tariffs [50]. Even if the difference between peak and off-peak prices has increased in recent times, it is still questionable whether the current tariff system offers sufficient incentives for a pronounced intraday shifting of power demand [51]. The Chinese government recently announced that it would also introduce time-of-use pricing for residential consumers by the end of 2015 [50]. In designing this new tariff system, sufficient differences between peak and off-peak prices have to be considered as a key success factor. The same key success factor applies to time-of-use pricing in non-residential sectors.
- ***Additional R&D funds for SSM, VPP, microgrid, and energy storage demonstration projects:*** To help abolish technological barriers, the Chinese government has decided to promote the development of different balancing mechanisms and technologies and it has already started to foster R&D in these areas. From an institutional point of view, the NEA has played the most active role in promoting balancing mechanisms [45]. Other institutions that are interested in the promotion of such technologies are the NDRC, the *Ministry of Housing and Urban Rural Development*, and the MOF [45]. However, the pertinent research has just started in China and consequently needs to be intensified in the future to catch up with international best practice technologies. Thus, additional R&D funds should be set up for SSM, VPP, microgrid, or energy storage demonstration projects. In this context, it is specifically important to set up concrete performance targets for funded demonstration projects and require a co-financing of the subsidies' recipients.
- ***Feed-in tariffs and interconnection standards for microgrids:*** compared to European countries and many other countries, retail prices for electricity are very low in China. As a consequence, prices for locally generated electricity (e. g. in microgrids) are often significantly higher than local retail prices for electricity. This has already led individual investors to abandon microgrids demonstration projects [46]. However, increasing electricity retail prices to promote the development of microgrids would directly contrast one of China's primary energy policy goals: affordable retail prices. Therefore, feed-in tariffs for local RES or microgrids could be an option to incentivize investments in microgrids. Also, interconnection standards for microgrids (such as IEEE 1547.4), currently not existing in China, should be issued and made legally binding.

The recommended approach at a glance

- Coordination between generation and consumption should be optimized with a focus on industrial and commercial consumers in the short- to medium-term and on residential consumers in the long term.
- Peak shaving is of crucial importance in the short to medium term. To promote peak shaving, it is specifically recommended to refine time-of-use pricing in China in order to set sufficient incentives (by means of high differences between peak and off-peak prices) for investments in DSM and energy storage for all categories of consumers.
- Residual peak shaving is relevant in the long term. Additional R&D funds for SSM, VPP, and microgrids as well as interconnection standards and feed-in tariffs specifically for microgrids can be employed to reduce technological, economic, and institutional barriers to the development of SSM, VPP, and microgrids.

5.7 Facilitate the development of a unified view of smart grids

Chinese context

- Due to the different strategies of China's grid operators with regard to smart grid development and the fact that the Chinese government has not yet publicly defined its view on smart grids, there is still no unanimously accepted vision on the technological and organizational design of smart grids in China. As a result, there is much uncertainty among potential smart grid investors regarding the future development.
- The diversity of stakeholders interested in standardization in China has increased in recent years: in addition to the central government, research institutes, universities, civilian and defense industries, and regional governments, all have their own interests with regard to standardization and are increasingly willing to contribute to the standardization process [63].

5.7.1 Background

Smart grids require a common understanding of all stakeholders Smart grids represent a concept aiming at the integration of information and communication among market actors from various sectors as well as a multitude of power system components. In a smart grid, data on the grid status is exchanged as well as data related to services, products, and reporting obligations. A key challenge of smart grids is to integrate its different components and ensure that they can communicate with the help of ICT. The definition of common standards for interfaces and communication protocols is therefore of utmost importance in order to ensure interoperability and a smooth exchange of information between the different elements of a smart grid. The costs of connecting smart grid technologies through ICT (integration costs) significantly affect the overall costs of deploying smart grid technologies and are thus one key success factor for smart grids. A prerequisite for reducing integration costs is a unified view on smart grid technologies, business processes, and procedures. Furthermore, smart grid-related technologies, products, and services can only be developed by the variety of stakeholders in a cost-efficient manner if requirements for smart grid solutions are accepted by all smart grid stakeholders.

Standardization as a means to create a common understanding Standardization can serve to create a common understanding between participating stakeholders, thus increasing interoperability, and reducing smart grid integration costs. According to the *German Institute for Standardization* (DIN), standardization usually has at least five major goals:

- securing the competiveness of domestic industries in the international context of a broad ensemble of diverging technologies and procedures,

- providing a strategic instrument to foster economic and social success,
- supporting and relieving government regulation,
- fostering technological convergence, and
- creating efficient processes and instruments [52].

These goals illustrate that the current scope of standardization goes well beyond the integration of two or more individual systems. The following aspects should be focused on in the context of smart grid-related standardization issues:

- How can the development of standards support the common understanding of future smart grids?
- How can the process of national and international standardization be optimized for faster time to markets of necessary standards?
- How can the heterogeneous requirements and viewpoints of different stakeholders with regard to smart grid architecture be expressed?

The government's role in promoting standardization In some cases, governments are quite actively involved in standardization processes. By issuing laws and regulations providing minimum standards for certain goods, services, or technologies, governments are even able to legally enforce standards. In many cases, however, standardization is mainly pushed forward by the private industry in cooperation with accredited *standards developing organizations* (SDO).[8] Note that, due to the involvement of many different stakeholders in SDO, a high level of coordination between the various stakeholders is necessary.

Even if standardization is left to the private sector, many governments acknowledge its importance in today's quickly developing technological environment. In 2009, for instance, the German government issued a *Standardization Policy Concept of the Federal Government* [53]. This policy paper presents the goals and expectations of the government with regard to standardization as well as specific measures of different ministries. In general, governments have many options to influence standardization, and consequently they play an important role in this context. To give just a few examples, possible governmental measures to promote standardization are:

- hosting conferences and symposia on standardization issues,
- strengthening the role and (financial) power of SDO,
- actively participating in the work of SDO, and
- considering standardization issues in the educational system [53].

5.7.2 International practice

European Mandate M/490 The EU specifically acknowledges the importance of standardization in smart grids: the European Commission issued the *European Mandate M/490* with the intention to promote the development of a unified and commonly accepted view on smart grids to increase interoperability and reduce integration costs. To execute Mandate M/490, the *Smart Grid Coordination Group* (SG-CG) was founded by the major European standardization organizations *European Committee for Standardization* (CEN), *European Committee for Electrotechnical Organization* (CENELEC), and *European Telecommunications Standards Institute* (ETSI). All of them are mirror-organizations of the main international standardization organizations *International Organization* for *Standardization* (ISO), *International Electrotechnical Commission* (IEC), and *International Telecommunication Union* (ITU).

Scope and objective of Mandate M/490

"The challenge of Smart Grids deployment will require changes to existing standards, industry rules and processes.
This mandate is to address such a challenge in the field of standardization. The expected long term duration of Smart Grid deployment suggests the need for a framework that is:

- *Comprehensive and integrated enough to embrace the whole variety of Smart Grid actors and ensure communications between them*

8 Especially in those areas where potential harm to citizens resulting from non-compliance with the standard is low, standardization is mainly left to private industry [64].

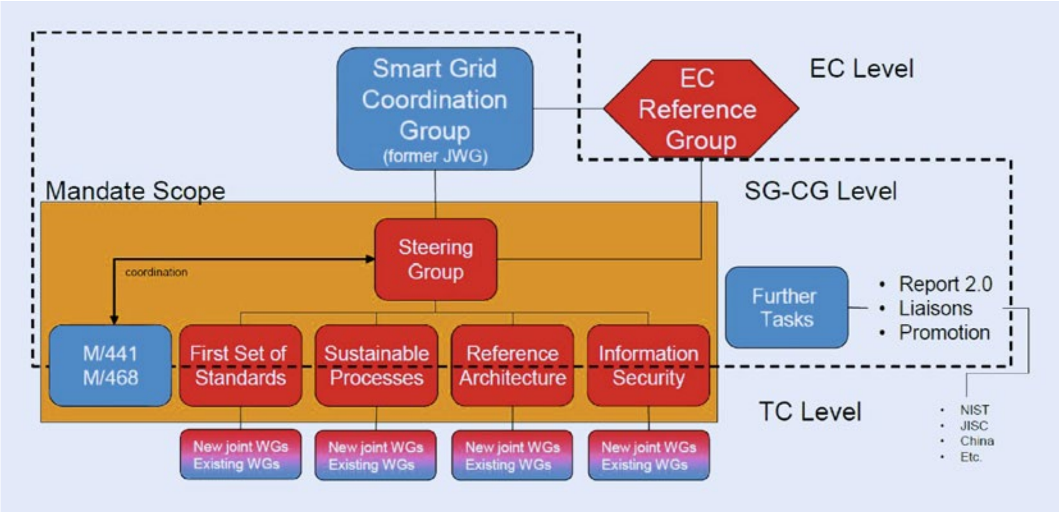

Fig. 5.3 Organizational structure of M/490 SG-CG, taken from [55]

- *In-depth enough to guarantee interoperability of Smart Grids from basic connectivity to complex distributed business applications, including a unified set of definitions so that all Members States have a common understanding of the various components of the Smart Grid.*
- *Flexible and fast enough to take advantage of the existing telecommunications infrastructure and services as well as the emergence of new technologies while enhancing competitiveness of the markets.*
- *Flexible enough to accommodate some differences between EU Member States approaches to Smart Grids deployment […].*

The expected framework will consist of the following deliverables:

- *A technical reference architecture, which will represent the functional information data flows between the main domains and integrate many systems and subsystems architectures.*
- *A set of consistent standards, which will support the information exchange (communication protocols and data models) and the integration of all users into the electric system operation.*
- *Sustainable standardization processes and collaborative tools to enable stakeholder interactions, to improve the two above and adapt them to new requirements based on gap analysis, while ensuring the fit to high level system constraints such as interoperability, security, and privacy, etc."*

Source: Wording from the European Commission [65]

Organizational aspects of Mandate M/490 The SG-CG consists of four working groups that are synchronized with those of mandates M/441 (smart metering) and M/468 (electric mobility). The following four working groups are organized under a joint steering committee (see Fig. 5.3):

- ***First Set of Standards (WG FSS):*** Responsible for compiling a consistent set of smart grid standards based on existing standards by applying the concepts and processes from the other working groups.
- ***Reference Architecture (WG RA):*** Responsible for the design of a technical reference architecture to be used in the other groups in order to consistently and comprehensively describe smart grids. The technical reference architecture can be thought of as a map showing the

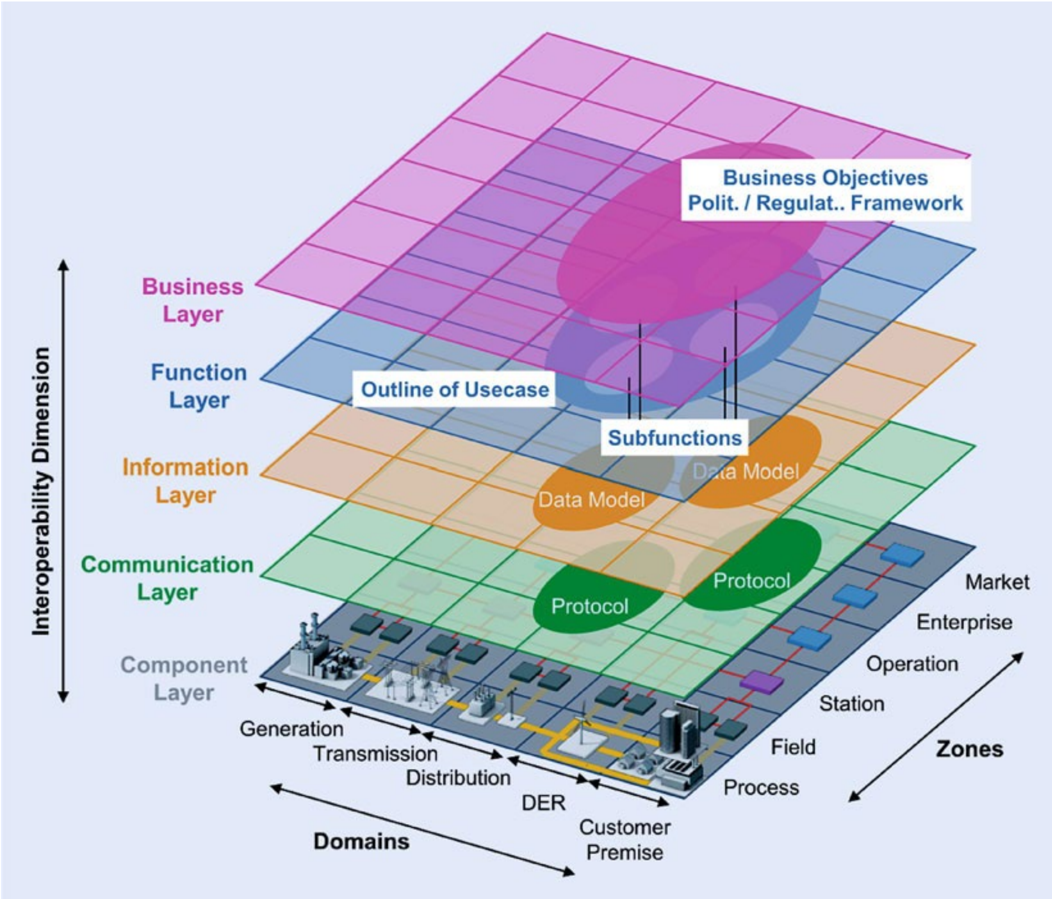

Fig. 5.4 SGAM – The Smart Grid Architecture Model, taken from [56]

boundaries as well as different areas of smart grids. It can be used to increase the understanding of who does what with whom in which manner in smart grids.

- ***Sustainable Processes (WG SP):*** Responsible for the design of processes for the identification and application of smart grid use cases. In the smart grid context, use cases describe specific smart grid applications and define the important actors, systems and technologies and their requirements and functions contributing to the development of a common understanding of smart grids [54]. Use cases are neutral with regard to specific projects, products, and vendors and can also be applied within a gap analysis revealing the need for future smart grid standardization.
- ***Smart Grid Information Security (WG SGIS):*** Responsible for identifying the guidelines to achieve information security and privacy in the context of the application of current smart grid standards.

Main results of European Mandate M/490 As it provides the structure referenced in the results of the other SG-CG working groups, the so-called *Smart Grid Architecture Model* (SGAM), a technical reference architecture developed within WG RA, can be described as the first deliverable of the Mandate M/490. SGAM (see Fig. 5.4) is a three-dimensional model of the European smart grid environment. It distinguishes between physical domains (generation, transmission, distribution, distributed energy resources, and customer premises), management zones (process, field, station, operation, enterprise, and market) and interoperability dimensions (component, communication, information, function, business).

The different interoperability dimensions are based on the *GridWise Architecture Council's* (GWAC) *Inter-operability Context-Setting Framework* [57]: the component layer represents the physical/technical aspect of the system and is therefore used to model physical equipment and infrastructure. The communication layer further specifies protocols and procedures of data exchanges between the components, while the information layer outlines the information models used in the context of the components and information exchange. Above these solution-oriented dimensions, the function layer specifies the logical and thus technology-independent viewpoint in terms of the functions and services realized by the implementation, while the business layer finally represents the objectives as well as regulatory and legal requirements connected to these functions.

WG SP applied the SGAM to identify smart grid use cases. The use case methodology is widely based on the *Publicly Available Specification* (PAS) IEC 62559 and includes a template for the unified description of use cases as well as a process to identify and manage use cases (subject to standardization as IEC 62559). WG FSS compiled a smart grid standards list based on SGAM and the smart grid use cases. The list structures the multitude of standards within a common framework reducing the complexity of the standardization landscape. Users of the list may search for appropriate smart grid standards based on their classification by domains, zones and layers (see appendix F for further information on the work of WG SP and WG SGIS as well as the next steps of Mandate M/490).

5.7.3 Recommended approach for China

The diversity of stakeholders interested in standardization issues in China has generally increased in recent years. The trend towards RES and more actively involved end consumers of electric power additionally tends to increase the number of stakeholders engaged in smart grid standardization. In particular, new market actors such as the ICT industry are expected to participate actively in order to unfold their innovative potential.

Examples for current standardization activities in China and possible connections to the European Mandate M/490

The *SGCC Framework and Roadmap for Strong & Smart Grid Standards* [66] stresses the importance of standardization for the smart grid development. Analyzing this document reveals the intention to identify gaps and thereby support the planning and implementation process. The mechanisms and concepts proposed in the context of the Mandate M/490 are appropriate to be taken into consideration for the standardization in China and the coordination and harmonization of activities on the international level.

The issues and aims discussed in the context of the standardization process in China may benefit from coordination with similar activities in the international context. Within the organizational structure of the M/490 SG-CG, possible liaisons with standardization activities in other countries including China are mentioned as future tasks within the scope of Mandate M/490. Therefore a joint discussion on the issues of smart grid standardization may support the design of the smart grid architecture based on a unified planning process and a set of consistent standards.

As the goal of a consistent standardization framework is expressed in context of the SGCC Framework and Roadmap for Strong & Smart Grid Standards, its structure regarding the standardization system in China may represent a suitable starting point to integrate the European and Chinese viewpoints in context of a common framework. Furthermore, the national smart grid standardization task force established by the Standardization Administration of China (SAC) and NEA about two years ago may also be considered as an organizational platform to address these issues.

The further promotion of smart grid standardization activities would accelerate the development of an unanimously accepted vision on the technological and organizational design of smart grids in China. Specifically, the integration of new market actors in the standardization process would increase the innovation potential in the smart grid development. Based on the activities of the European Commission, the following policies are worth considering:

- ***The establishment of an organizational arrangement for smart grid standardization:*** the Chinese government, for example via MOST, could promote the foundation of an organizational arrangement such as SG-CG to coordinate standardization issues and integrate new market actors in the standardization process. Within this organizational arrangement, clear structures and processes to foster the understanding of the smart grid concept and to provide the means to model and implement smart grid solutions should be defined and implemented. The requirements of smart grids should be analyzed and current and future stakeholders identified.
- ***The commissioning of a reference architecture framework:*** the government could engage this organizational arrangement to develop architectural concepts such as a technical reference architecture (i.e. a Chinese Smart Grid Architecture Model). The models applied in this context should be able to describe interoperability aspects of the systems, ranging from business objectives to technical connectivity of the components involved in a solution.
- ***The commissioning of smart grid use cases and standards:*** use case descriptions and a thorough process to address governance and quality aspects are beneficial to develop a set of consistent and complimentary smart grid standards. The work of the SG-CG may be regarded as a reference in this area. Moreover, adapting the results of SG-CG to the Chinese context or creating a compatible (mirror-like) approach could serve as the basis to initiate a joint discussion on the issues of smart grid standardization.

Following these recommendations, the key quality requirements of interoperability, data management, and cyber security can then be thoroughly analyzed and managed to create appropriate architecture models and identify supporting smart grid standards. This way, Chinese standardization processes could be synchronized more with international standardization. For example, Chinese standards could be promoted to the international level. Currently, the joint work in standardizing information exchange for demand response and in connecting demand side equipment and/or systems into the smart grid (in IEC PC 118) is a good example for the benefits of such cooperation.

The recommended approach at a glance

- Promote the establishment of an organizational arrangement (e.g. similar to SG-CG) to coordinate smart grid standardization.
- Initiate the development of a reference architecture framework taking into account technical and organizational aspects which are unique to China (i.e. a Chinese Smart Grid Architecture Model).
- Ensure that effective and efficient standardization processes exist and promote the development of smart grid use cases and standards.

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6

Regulatory pathways for smart grid development in China

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Chapter at a glance

– There are inherent conflicts between the fundamental energy policy goals of reliability, affordability, and sustainability. Government priorities on the energy policy goals are often reflected in energy sector regulation.
– Seven recommendations have been presented in support of smart grid development in China. In principle, each recommendation is intended as support for the fundamental energy policy goals. Nevertheless, the implementation sequence of the recommendations is not arbitrary with respect to the energy policy goals.
– In order to give policy makers an impression of how policy goal prioritization influences the timeline in which the recommendations should be implemented, the present chapter will outline three possible regulatory pathways. Each of these pathways prioritizes one specific goal of the energy policy triangle and develops a suitable implementation roadmap. These roadmaps are intended to serve as blueprints for policy makers, who have to decide about proper regulation based on the individual Chinese prioritization of energy policy goals.

6.1 Government targets for China's future electric power system

The following chapter will present the main targets of China's government for each stage of the electric power system. These targets are the basis for a comprehensive description of the scenarios underlying the regulatory pathways. The targets are based on the following documents:

- *12th Five-Year Plan for Energy Development*, issued by China's State Council in 2013 [1],
- *Opinions on Accelerating the Development of Environmental Industry*, issued by China's State Council in 2013 [2],
- *Key Information at a glance – China's 12th Five-Year Plan for Renewable Energy Development*, issued by NEA in 2012 [3],
- *China's 2012 Energy Policy*, issued by the Information Office of the State Council in 2012 [4].
- *Understanding China's 12th Five-Year Energy Plan*, issued by IEA in 2013 [5].

Targets for the power generation sector In order to cope with rapidly increasing power consumption and to ensure power system reliability, China's government plans to increase total electricity generation capacities during the next years from 970 GW in 2010 to 1490 GW in 2015. It is projected that generation capacities will increase further to 1935 GW in 2020 [6].

More specifically, China's government aims at vigorously developing distributed and renewable energy sources. From 880 TWh in 2011, electricity generated solely from renewable sources is projected to increase to more than 1,200 TWh in 2015. The projected increases in generation capacities for solar power, wind power, and biomass power are impressive. If these expansion targets are to be achieved, RES must be integrated in the grid more effectively than today. The Chinese government additionally aims at stopping the deterioration of air quality as well as the increase of CO_2 emissions. The target is therefore for the total amount of discharge of SO_2 and NO_x to remain constant between 2015 and 2020. Also, the increase in CO_2 emissions will be slowed in spite of the planned coal power generation growth.

Government targets for the power generation sector at a glance

- Roughly double generation capacities from 2010 to 2020
- Vigorously develop RES
- Stop the deterioration of air quality.
- Reduce the growth of CO_2 emissions

Targets for the power logistics sector China's government plans to significantly expand transmission and distribution grids. The capacity of China's transmission grids is planned to double by 2020 (compared to 2010), creating a national backbone grid, interconnecting different Chinese regions and improving electricity transmission from the energy bases to the load centers. The plan also include upgrading urban and rural distribution grids, promoting distribution intelligence, and improving the capacity and reliability of the overall power supply. This enhancement of distribution grids primarily aims at reducing blackout times by roughly 40 % from 2012 to 2020. The government also aims at improving asset utilization of the grid infrastructure by peak shaving and by reducing the line loss rate from 6.5 % in 2010 to 6.3 % in 2015.

With the goal of facilitating the integration of large-scale and intermittent RES, the Chinese government aims at promoting energy storage technologies by funding R&D on energy storage, energy conversion and related key technologies.

Government targets for the power logistics sector at a glance

- Build up a backbone network and roughly double grid capacities from 2010 to 2020
- Upgrade distribution grids and reduce blackout times significantly
- Improve asset utilization of grid infrastructure
- Promote energy storage

Targets for the power trade and retail sector The Chinese government plans to establish a more market-oriented energy system to increase competition and affordability. Administrative reforms of SOE are planned to take place: transmission and distribution will be separated in a number of pilot projects and independent power trading institutions will be established. Electricity markets and price-based coordination mechanisms are planned to be introduced: the government strives to form a pricing mechanism where markets set on-grid and off-grid prices and the government only sets the price for electricity transmission and distribution (network charge), the economic dispatch for power generation will be increased, and time-of-use prices, seasonal tariffs and interruptible load electricity tariffs are planned for more widespread introduction.

Government targets for the power trade and retail sector at a glance

- Establish a modern energy market system
- Promote reforms in key energy sectors
- Improve energy pricing mechanisms

Targets for the power consumption sector One of the government's major targets is to increase the efficiency of power use in order to reduce growth in total electricity consumption. Specifically, the government intends to reduce energy consumption per unit of GDP by roughly 16 % from 2010 to 2015. Given that some of China's most remote regions are still not connected to the electric power grid, China's government also wants to provide universal access to electric power even in most remote regions of China by 2015.

Government targets for the power consumption sector at a glance

- Increase efficiency of power use
- Provide universal access to electric power even in most remote regions of China by 2015

Cross-sector targets With regard to power system governance, the government aims at improving the planning and implementation of power sector development: targets and responsibilities of different governmental institutions will be clarified and coordinated; local governments and the pertinent departments of the State Council will be made responsible for binding indicators such as the share of non-fossil fuels in energy consumption or the intensity of energy consumption.

Simultaneously the government is moving forward to strengthen energy industry management by accelerating the introduction of an *Energy Law* and by enacting amendments to the *Coal Law* and the *Electric Power Law*. Also, technology and equipment in the energy sector will be further standardized and capacities of statistics, monitoring, prediction, and warning will be built up.

The Chinese government envisages rationalizing energy investment and the management system of SOE. The government wants to explicitly adhere to the dominance of its state-owned economy in key energy sectors related to national security and economy but, at the same time, it wants to improve the management and assessment mechanisms of SOE.

Regardless of the adherence to the dominant position of SOE in China's power system, the government also has the objective of diversifying investments in the energy sector. Approval for energy infrastructure investments is intended to become less restrictive so that the participation of private and foreign capital is encouraged. Single energy markets, like the oil market, will be opened up to competition. The government wants to strengthen the innovation potential of China's environmental industry in order to enable the industry to increase the supply of green products, expand market demand, and enhance export prospects.

Another goal is to accelerate the development of the environmental industry in order to promote the development of technologies and equipment that save energy, protect the environment, and encourage reuse of resources.

Governmental cross-sector targets at a glance

- Improve planning and implementation
- Strengthen the management of the energy industry
- Rationalize energy investment and the management system of SOE
- Diversify energy investment
- Accelerate the development of the environmental industry

6.2 Underlying scenarios

In the following chapter, three smart grid development scenarios will be presented, based on different energy policy goals. For each scenario, the recommendations made in ► Chap. 5 will be prioritized and their interdependencies analyzed. The results of this analysis are scenario-based propositions for the implementation sequences of the recommendations. They will be presented in the form of a roadmap. Each roadmap is intended to support China's smart grid development with a focus on one particular scenario. The smart grid scenarios presented in the chapter are:

- ***Reliability/Security of Supply:*** In this scenario, the goal is to maximize electricity availability and to minimize outages and disruptions of the electricity supply.
- ***Ecological Sustainability:*** The second scenario focuses on improving air quality as well as on decreasing and potentially stopping the growth of CO_2 emissions in order to contribute to climate protection. Amongst others, this is achieved by an accelerated installation of RES capacities.
- ***Affordability/Competition:*** Competition is a key factor for innovation and affordability. This scenario will consequently focus on the creation of level playing fields and of incentives for market participation of new market actors through appropriate market design.

The government targets presented in ► Sect. 6.1 are associated to the three scenarios (see ◘ Fig. 6.1). In some cases, a specific target contributes to more than one energy policy goal. Yet, in these cases, in an effort to increase clarity, only the most obvious association to one specific policy goal will be presented. Two targets are general smart grid development targets as recorded in the *12th Five-Year Plan for Energy Development*. They are placed in the center of the triangle, as smart grids are seen as a means to contribute to all energy policy goals.

6.3 Drawing the roadmaps

For migrating from today's electric power system towards smart grids based on one of the given scenarios, it is favorable to implement the recommendations in a specific timeline. For deriving the implementation sequences, the recommendations were sorted by priority in a first step. In a second step, main aspects of the recommendations in each scenario were collected and allocated to the timeframes *short term* (2015–2016), *medium term* (2017–2020) and *long term* (2021–2030). Interdependencies between main aspects were explored additionally. Afterwards the recommendations were arranged chronologically.

The following three sections show recommended priorities, their main aspects, interdependencies, and the sequences worked out for the implementation for each scenario. Recommendations and dependencies are highlighted within the order of their respective importance for the scenario. In

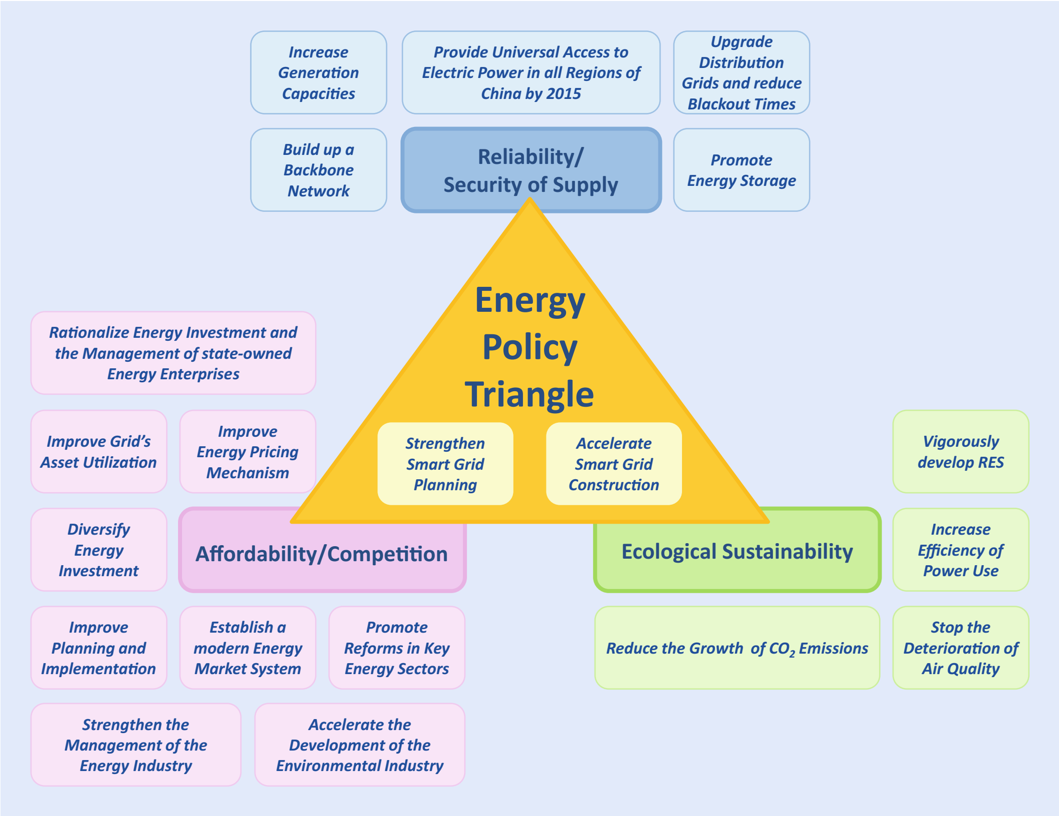

Fig. 6.1 Scenarios and their associations with energy policy goals

addition, a visualization pertaining to the scenario and summarizing the timeframes of the respective measures of each recommendation is also presented. Furthermore, a possible sequence of starting points for work on the recommendations has been worked out. The justifications for the prioritization of the recommendations are discussed together with each chart. Moreover, the specific measures to be executed for each recommendation, their respective interdependencies, and their timeframes are explained.

6.3.1 Reliability/Security of Supply scenario

Looking at the overall prioritization with respect to the Reliability/Security of Supply scenario, it can be seen that the recommendations to *Define a long-term strategy for the electricity sector and establish an independent and powerful regulator*, *Coordinate network expansion planning for electricity grid expansion and upgrade*, and to *Improve grid integration of RES* have a high priority (Fig. 6.2). Remember that these priorities do not necessarily correspond to the proposed implementation sequence, because interdependencies within the given scenario have to be analyzed before recommendations are implemented.

Define a long-term strategy for the electricity sector and establish an independent and powerful regulator Effective government work is a precondition for the efficient development of smart grids. Therefore, roles and responsibilities for government administration and regulation have to be set from the start. As a consequence, it is important to implement in the short term all the measures proposed in the recommendation to *Define a long-term strategy for the electricity sector and establish an independent and powerful regulator*:

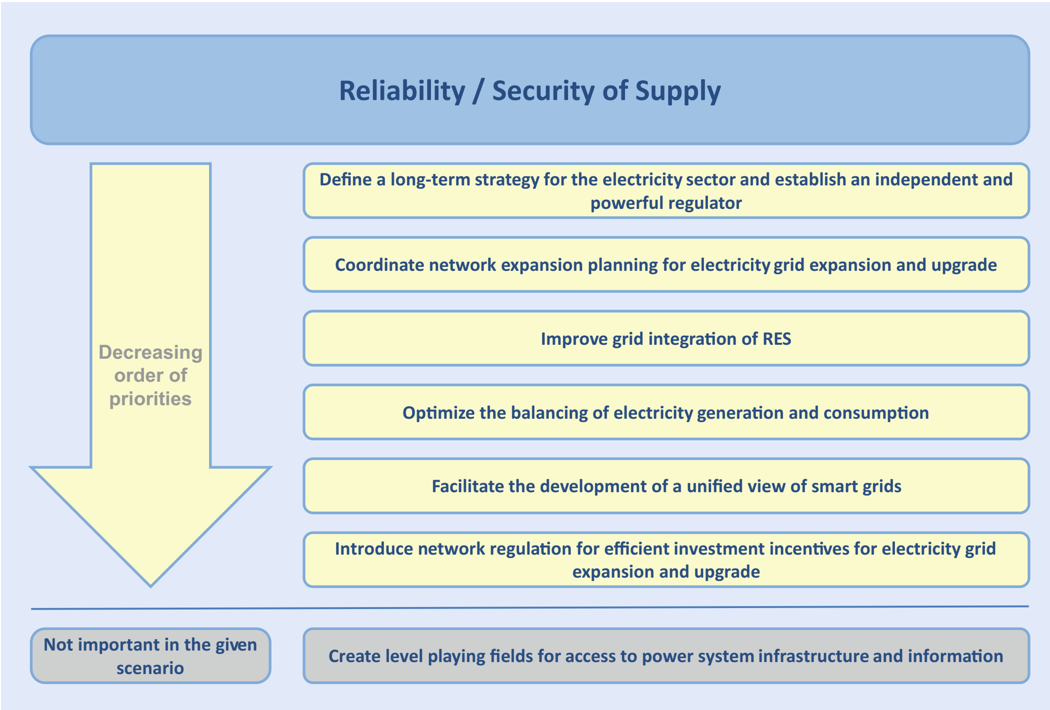

Fig. 6.2 Priority of recommendations in the Reliability/Security of Supply scenario

- A clearly defined long-term strategy for electricity system development has to be specified by the government. The strategy should include long-term government targets with regard to the development of generation capacities of different generation technologies, and targets for energy efficiency. Such a strategy is a prerequisite for coordinated expansion of the electric power system as well as smart grid development. It might also serve as a point of reference for related government policies.
- The centralization of all regulatory aspects in one independent and powerful regulatory institution is of critical importance to increase the effectiveness of regulation. The main tasks of the regulator are coordination of network expansion planning and network regulation. In the Reliability/Security of Supply scenario, the regulator should specifically monitor power disruptions and outage times on national and local levels to provide an overview of the quality of electricity supply. Much like in Germany, grid operators should be obliged to regularly report data on power disruptions and outage times to the regulator (see ► Sect. 4.4.4 for related regulation in Germany). Pertinent laws (for example, a general energy law) should empower the Chinese regulator to effectively monitor power disruptions and outage times.

Coordinate network expansion planning for electricity grid expansion and upgrade Network expansion planning has a high priority in this scenario because the electric power grid is the backbone of the power system. Coordinated and efficient network expansion is the basis of a power infrastructure that can be adapted to consumer needs in a timely manner. This maximizes energy availability as the reliability of the future energy system essentially depends on the grid and generation capacities being matched to the consumption side.

Within this scenario, the main measures of the recommendation to *Coordinate network expansion planning for electricity grid expansion and upgrade* are:

- In the short term, the main task to be accomplished for successful network expansion planning is to improve coordination between power system stakeholders and to define a common procedure for network expansion planning. Specifically, it is beneficial to coordinate network expansion planning and the construction of new generation capacities. The *Future-oriented Energy Grids Platform* can serve as a role model to encourage the establishment of a similar grid platform in China.
- In the medium term, stakeholders involved in the grid planning process have to elaborate a network development plan that will be mandatory for TSO and DSO under supervision of the regulator.

The measures to be implemented within the recommendation to *Define a long-term strategy for the electricity sector and establish an independent and powerful regulator* should precede the measures within the recommendation to *Coordinate network expansion planning for electricity grid expansion and upgrade*: a government strategy for the electric power system including long-term targets for generation capacities is a prerequisite for the network development process. An independent and powerful regulatory institution is supposed to supervise the network development process.

Improve grid integration of RES Increasing RES capacities contribute to supply the quickly increasing demand for electric power. Therefore, they support reliability and security of supply if the technical integration of RES is clearly defined. However, RES that have not been properly integrated may even endanger security of supply and stability.

Within this scenario, the main measures of the recommendation to *Improve grid integration of RES* are:

- In the short term, grid connection points must be defined for all kinds of RES at all grid levels.
- Defining a binding network code for grid connection that specifies responsibilities of grid operators as well as power generators is also a task in short term.
- RES generation capacities are needed in order to maximize available electricity and thereby reduce load curtailments. However, for grid stability and security of supply to be ensured, RES generation has to be curtailed under specific conditions. Therefore, procedures and documentation for curtailment of RES and the requirements in terms of IT support must be specified in the medium term.

Even if the recommendation to *Improve grid integration of RES* has high priority, measures to be implemented within several other recommendations serve as an input and should be implemented early: along with the need for an independent and powerful regulator to supervise curtailment procedures and define network codes, the clear specification of targeted RES generation capacities and well-defined network development procedures for network enhancement are preconditions for more effective RES integration. Also, a unified view of smart grids and technical standards contribute to a more effective integration of RES [7].

Optimize the balancing of electricity generation and consumption When electricity consumption increases so quickly that the growth of generation capacities can hardly follow, balancing and especially peak shaving are measures that support security of supply. Grid operation with higher safety margins eases grid control. Therefore, reduced peak loads resulting from peak shaving help to avoid system instabilities. Coordination of electricity generation and consumption is therefore of considerable priority in the scenario of reliability and security of supply. This includes load management, time-of-use pricing, and smart meter rollout.

Within this scenario, the main measures of the recommendation to *Optimize the balancing of electricity generation and consumption* are:

- In the short term, the main aspect is the further refinement of peak shaving mechanisms and technologies for system stabilization with focus on industrial and commercial consumers. One interesting option in this context is to tender the disconnectable loads on an internet platform (see ▶ Sect. 4.4.5 for related regulation in Germany).
- As already planned by the Chinese government, the time-of-use pricing system has to be

refined (sufficient price differences between peak and off- peak prices for all categories of consumers) in the short term as well. A more sophisticated time-of-use pricing would incentivize investments in balancing mechanisms and technologies – for instance DSM, SSM, and energy storage.

An additional interesting measure originally not included in the recommendation to *Optimize the balancing of electricity generation and consumption* is locational pricing that can be used to signal network congestion. Locational pricing refers to power prices which are calculated for a number of locations – called nodes – on the transmission grid. Each node represents a physical location where power is injected by generators or withdrawn by loads [8]. Locational pricing reduces network congestion and may also set incentives for network expansion in regions with many network congestions [9]. It is an option for the long term and might become necessary in future in order to efficiently integrate the projected RES generation capacities. The regulator is supposed to supervise such locational pricing by regulating network charges with a clear scheme for the interaction between network operators and market players.

The discussion reveals that measures implemented within the recommendations to *Define a long-term strategy for the electricity sector and establish an independent and powerful regulator* and to *Improve grid integration of RES* serve as an input for the recommendation to *Optimize the balancing of electricity generation and consumption*.

Facilitate the development of a unified view of smart grids A technical reference architecture helps better understand smart grids and allows holistic analyses of security aspects relating to their implementation. Interoperability minimizes individual integration efforts and reduces the probability of interface failures. Such a reference architecture will therefore increase reliability and security of supply.

Within this scenario, the main measures of the recommendation to *Facilitate the development of a unified view of smart grids* are:

- In the short term, the main aspect is the creation and adoption of an organizational arrangement to model smart grid reference architectures and to coordinate smart grid standardization.
- Defining effective and efficient standardization processes (e. g. based on smart grid use cases) as well as coordinating the work of SDO to establish effective and efficient standardization processes are two further important aspects that should take place in the same time frame.
- In the medium term, a set of consistent smart grid standards should be created using the technical reference architecture.

Introduce network regulation for efficient investment incentives for electricity grid expansion and upgrade In the scenario focusing on reliability and security of supply, network regulation is somewhat less important but not irrelevant. It contributes indirectly to this scenario, as it sets economic incentives for the build-up and maintenance of the grid infrastructure. Incentives for efficient network investments and investments in R&D and innovation are important in the context of the measures within this recommendation. These incentives, by contributing to the introduction of smart grid technologies, will directly ensure security of supply and reduce costs.

Within this scenario, the main measures of the recommendation to *Introduce network regulation for efficient investment incentives for electricity grid expansion and upgrade* are:

- In the short term, the use of incentive instruments like rate-of-return adder or innovation bonus should be assessed for application in China.
- A decision about the use of disaggregated regulation (i. e. regulating only the monopolistic bottlenecks) should be made in the short to medium term. If applicable, disaggregated regulation should be implemented in the medium term.
- Also in the medium term, incentives should be defined for investment in innovation and smart applications. In this context, the network development plan should be aligned and critical network connections for system stability which necessitate stronger investment incentives should be identified. At this point in time, a rate-of-return adder can be especially beneficial.

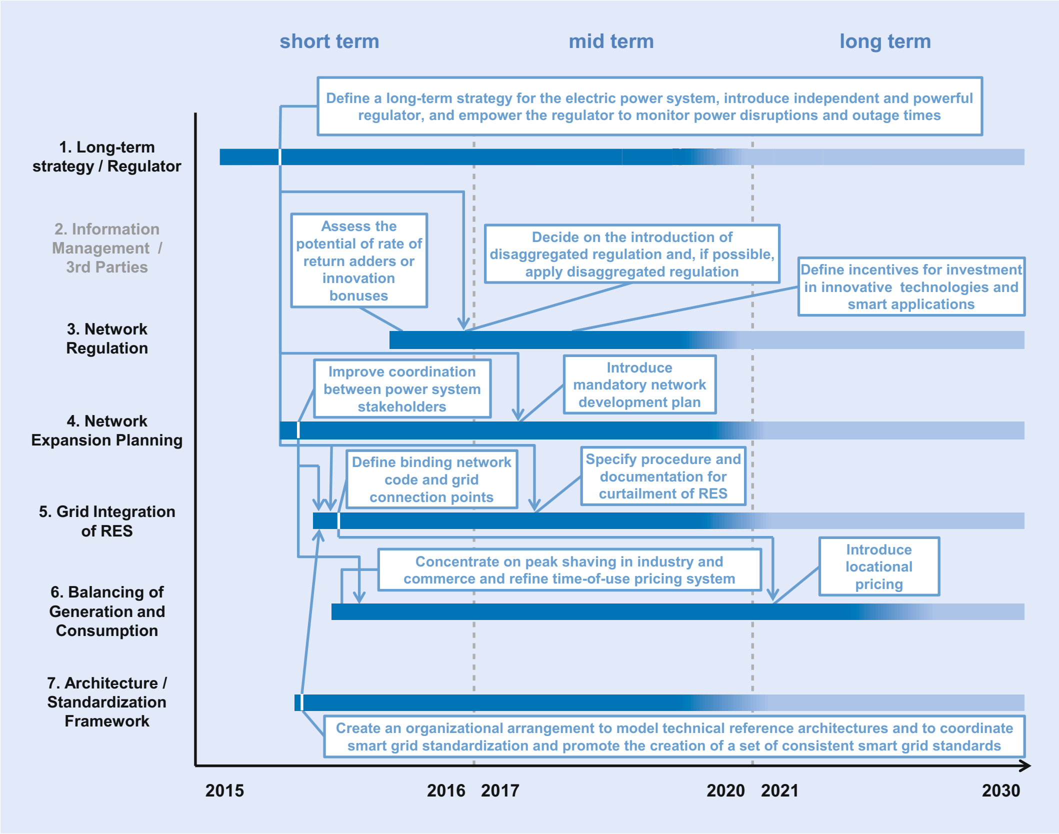

Fig. 6.3 Starting points, timeslots of main activities, and dependencies between main aspects of recommendations in the scenario focusing on reliability and security of supply

As an independent and powerful regulator is a prerequisite for network regulation, the recommendation to *Define a long-term strategy for the electricity sector and establish an independent and powerful regulator* should be realized before network regulation is focused upon.

Create level playing fields for access to power system infrastructure and information As new market actors are necessary more for innovation than for stability of the energy supply, the measures proposed in the recommendation to *Create level playing fields for access to power system infrastructure and information* are not considered as important in this scenario with a focus on reliability and security of supply.

Sequence of implementation In the light of the interdependencies described above, the following implementation sequence is proposed in the scenario focusing on reliability/security of supply:

- Define a long-term strategy for the electricity sector and establish an independent and powerful regulator.
- Coordinate network expansion planning for electricity grid expansion and upgrade.
- Facilitate the development of a unified view of smart grids.
- Improve grid integration of RES.
- Optimize coordination of electricity generation and consumption.
- Introduce network regulation for efficient investment incentives for electricity grid expansion and upgrade.

Figure 6.3 depicts the points in time for undertaking the main activities and shows dependencies

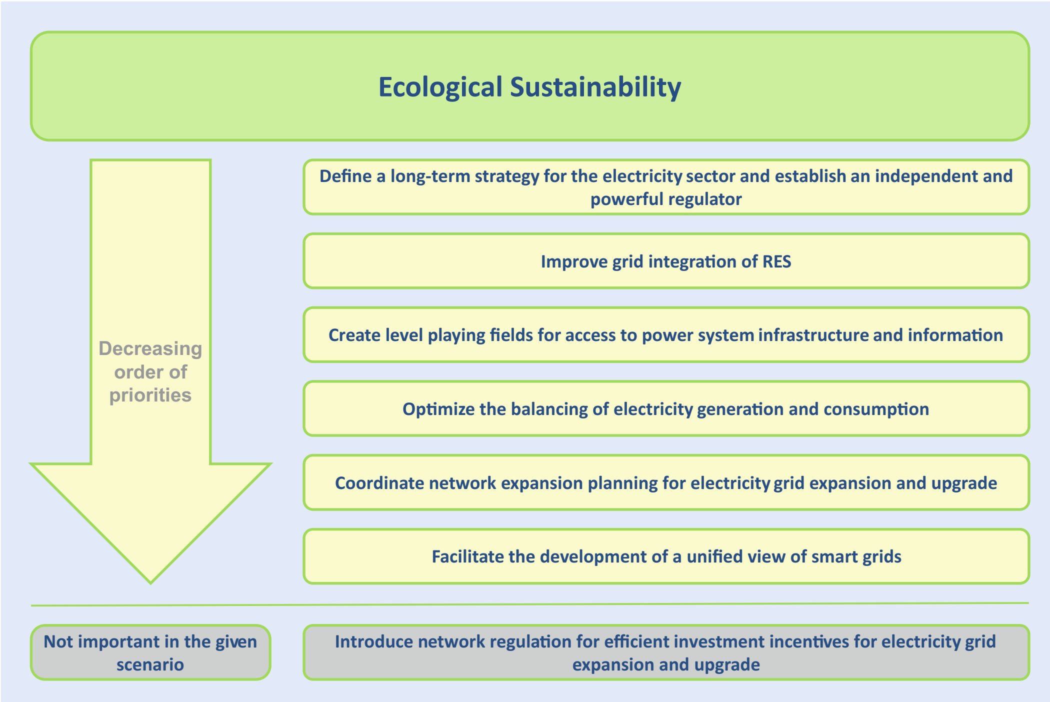

Fig. 6.4 Priority of recommendations in the Ecological Sustainability scenario

between the key aspects of recommendations for the scenario focusing on reliability and security of supply. Each recommendation is represented by a bar partitioned into timeframes from left to right. The starting point of each bar depicts the proposed beginning of work on each recommendation. Recommendations that are unimportant to the scenario are shown in gray. Proposed time points for the main measures are represented by the opaque blue regions on each bar. At the end of each bar, color gradients have been used to show that work on the recommendations continues even after the main aspects have been taken care of. The main measures are shown as boxes. The proposed starting time of each measure is shown by a diagonal line connecting the box to the bar. Dependencies between measures are shown by arrows while preconditions are marked with a white line crossing a bar at the beginning of the arrow. The end of the arrow points to the dependent measure.

6.3.2 Ecological Sustainability scenario

An introductory overview of the overall prioritization with respect to this scenario is presented in Fig. 6.4. It can be seen that the recommendations *Define a long-term strategy for the electricity sector and establish an independent and powerful regulator*, *Improve grid integration of RES*, and *Create level playing fields for access to power system infrastructure and information* have a high priority in the Ecological Sustainability scenario. Again, remember that these priorities do not necessarily correspond to the proposed implementation sequence because the interdependencies within the given scenario have to be analyzed before.

Define a long-term strategy for the electricity sector and establish an independent and powerful regulator As in the previous scenario, the commitment to a long-term strategy and the creation of an independent and powerful regulator has the highest priority in the scenario for ecological sustainability because a government-defined long-term strategy for the future electricity sector including specific RES expansion targets is a prerequisite for effective and efficient expansion of RES generation capacities.

Within this scenario, the main measures of the recommendation to *Define a long-term strategy for the electricity sector and establish an independent and powerful regulator* are:

- Effective regulation is required to ensure RES integration. Thus, the centralization of regulatory aspects in one independent and powerful regulatory institution should be addressed in the short term. Responsibilities for grid integration of RES and for power system information management should be assigned in this context.
- Official government targets for RES expansion are currently defined only until 2015. Within the forthcoming Five-Year Plan, the planning period will be extended to 2020. Defining a long-term government strategy concerning energy mix (including RES share), and energy efficiency indicators beyond 2020 is consequently a task for the medium term.

Improve grid integration of RES Timely connection and low curtailment of RES will speed up the reduction of greenhouse gas emissions as well as emissions of local and regional air pollutants. RES therefore need to be integrated into the grid with a very high priority and all of the following tasks need to be implemented in the short term:

- Proper definitions of grid connection points are necessary for all kinds of RES on all grid levels.
- A binding network code specifying responsibilities of both grid operators and power generators needs to be defined, as investors in RES need clear time limits for grid connection of RES in order to deliver generated electricity to the market at the right time. Grid operators should have to bear liability for grid connection of RES – resulting in a shallow cost approach for interconnection, whereby grid operators have both the responsibility and the opportunity for efficient overall grid development.
- Detailed procedures and documentation for curtailment of RES must be specified, and the requirements for IT support of these procedures must be clear. The implementation of this measure can be seen as a technical and economic framework to encourage investments into RES.

Measures related to the recommendation to *Define a long-term strategy for the electricity sector and establish an independent and powerful regulator* positively impact the effectiveness of the recommendation to *Improve grid integration of RES*: credible long-term government targets for RES generation capacities reduce risks related to investments in RES units. Another prerequisite is a powerful and independent regulator to supervise curtailment procedures and to define network codes.

Create level playing fields for access to power system infrastructure and information In principle, new market actors in China can already invest in RES. However, they need to be integrated into electricity sector governance more effectively in order to ensure efficient integration of RES. Non-incumbent market actors will invest in RES generation capacities only if the necessary information for competition and market access is available to them. Methods for the integration of the innovation potential of third parties have to be institutionalized and non-discriminatory information sharing has to be guaranteed.

Within this scenario, the main measures of the recommendation to *Create level playing fields for access to power system infrastructure and information* are:

- In the short term, the main measure of this recommendation is the definition of minimum necessary requirements for power system information management. Note that this task is related to the recommendation to *Define a long-term strategy for the electricity sector and establish an independent and powerful regulator* in Fig. 6.5 due to the pivotal role of the government in this context.
- In the medium term, the role of new market actors in smart grids should be defined and how these actors can be integrated should be clarified.

- An institution for power system information management should be specified, and this institution should set up a platform. It should then organize access to and exchange of information between all eligible parties.

Before the role of new market actors in smart grids can be defined, a long-term strategy for the electric power sector should be developed. Therefore, the recommendation to *Define a long-term strategy for the electricity sector and establish an independent and powerful regulator* should precede the recommendation to *Create level playing fields for access to power system infrastructure and information*. An architecture and standardization framework encourages the development of a unified smart grid model containing an overview of relevant use cases and business processes. Such a model, representing a form of Chinese SGAM, significantly eases the organization of power system information management. The platform for information management should therefore be implemented after the measures relating to the recommendation to *Facilitate the development of a unified view of smart grids* have been applied.

Optimize the balancing of electricity generation and consumption When consumption is not coordinated with generation, significant curtailments of RES generation are necessary to ensure grid stability. This reduces the attractiveness of investments in RES generation capacities. The usage of VPP, microgrids, or energy storage units facilitates the integration of distributed RES.

Within the scenario, the main measures of the recommendation to *Optimize the balancing of electricity generation and consumption* are:

- The first task in coordinating electricity generation and consumption is to promote VPP, microgrids, and energy storage technology for local integration in the short term by increasing R&D funding in this area.
- The time-of-use pricing system, which depends on a successful smart meter rollout, also has to be refined (sufficient price differences between peak and off peak prices for all categories of consumers) in the short term. This measure is already planned by the Chinese government. The first focus should be set on industrial and commercial consumers and then on residential consumers.
- Another interesting measure, originally not included in the recommendation to *Optimize the balancing of electricity generation and consumption*, is locational pricing. It might be interesting in the long term and contribute to RES integration (see ▶ Sect. 6.3.1 for a brief description of locational pricing).

Coordinate network expansion planning for electricity grid expansion and upgrade Network development is necessary to connect new consumers and generators to the network, including generation units belonging to third parties. The network development plan allows planning of RES installation and thereby increases investments in RES. As a consequence, network expansion planning is relevant in this scenario. The main measures of the recommendation to *Coordinate network expansion planning for electricity grid expansion and upgrade* should be taken in the short term:

- Increased coordination between established stakeholders and new market actors should be promoted by the government.
- A coordinated and mandatory network development plan including the aspect of RES integration should be established.

Based on experiences in Germany, an independent and powerful regulator is the best-suited organization for organizing and implementing these measures. Therefore, the recommendation to *Define a long-term strategy for the electricity sector and establish an independent and powerful regulator* should be implemented before the recommendation to *Coordinate network expansion planning for electricity grid expansion and upgrade*.

Facilitate the development of a unified view of smart grids As mentioned above, distributed energy resources are important and in this scenario their number is expected to rise. This implies an increase in system scale and complexity and calls for a smart grid architecture and standardization framework (i.e. an organizational arrangement to coordinate and promote smart grid standardization

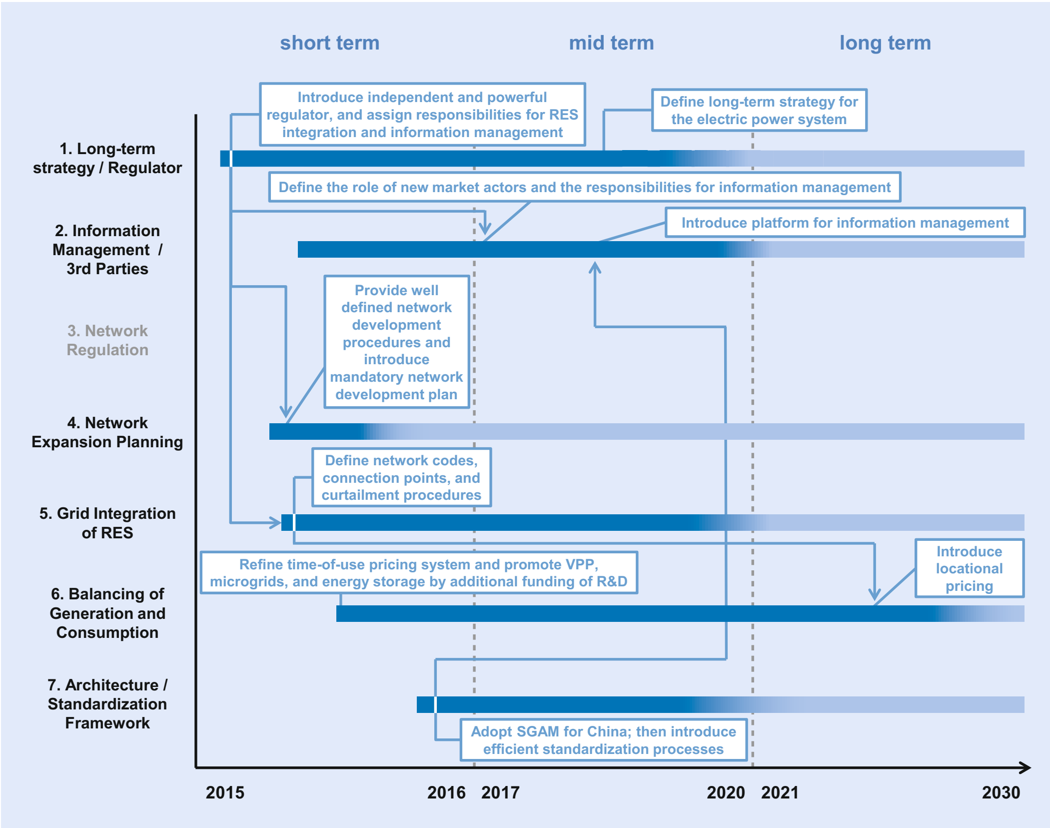

Fig. 6.5 Starting points, timeslots of main activities, and dependencies between main aspects of recommendations in the scenario focusing on ecological sustainability

and the development of a reference architecture). A unified view of smart grids should exist to elicit the resulting requirements and to compare different architectural solutions. The smart grid architecture and standardization framework should focus on interoperability between actors and systems, which is a key aspect in the context of decentralized system architectures. The high number of interfaces between systems implies the need for security analyses, which in turn requires solid models of systems architectures [7]. Clear structures and processes should be defined in order to coordinate the work of SDO.

Within this scenario, the main measures of the recommendation to *Facilitate the development of a unified view of smart grids* are:

- In the short term, an organizational arrangement to coordinate and promote smart grid standardization should be created and the development of a technical reference architecture framework should be assigned.
- In the medium term, effective and efficient standardization processes (e. g. based on a collection of smart grid use cases) should be established.

Introduce network regulation for efficient investment incentives for electricity grid expansion and upgrade For ecological sustainability, an electric power grid does not necessarily have to be developed at lowest costs. As network regulation focuses on efficient network investments, it is not an important regulation measure for this scenario.

Sequence of implementation Figure 6.5 shows the timeframes of the main activities and interde-

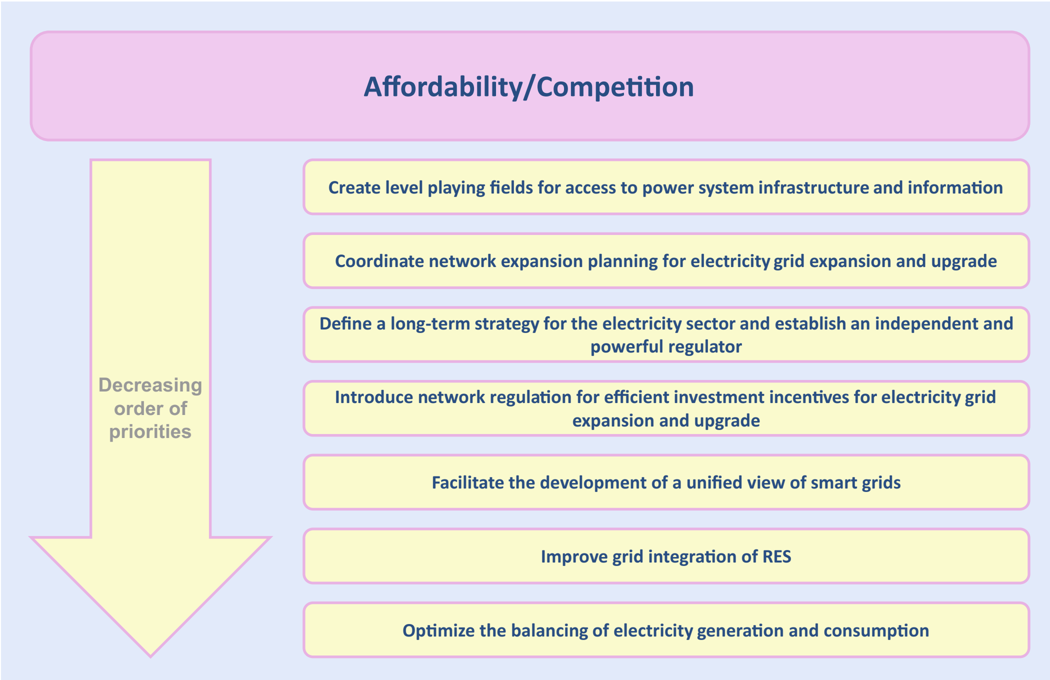

Fig. 6.6 Priority of recommendations in the Affordability/Competition scenario

pendencies involved in this scenario. For a detailed description of the layout of the visualization, please check back to the previous section. In the light of interdependencies described above, the following implementation sequence is proposed in the scenario focusing on ecological sustainability:

- Define a long-term strategy for the electricity sector and establish an independent and powerful regulator.
- Improve grid integration of RES.
- Coordinate network expansion planning for electricity grid expansion and upgrade.
- Create level playing fields for access to power system infrastructure and information.
- Optimize the balancing of electricity generation and consumption.
- Facilitate the development of a unified view of smart grids.

6.3.3 Affordability/Competition scenario

An introductory overview of the overall prioritization with respect to this scenario is presented in Fig. 6.6. It can be seen that the recommendations *Create level playing fields for access to power system infrastructure and information*, *Coordinate network expansion planning*, and *Define a long-term strategy for the electricity sector and establish an independent and powerful regulator* have a high priority in the Affordability/Competition scenario.

Create level playing fields for access to power system infrastructure and information In the scenario focusing on competition and innovation, two very important aspects are power system information management and the inclusion of new market actors. As non-incumbent market actors are main drivers for competition and innovation, non-discriminatory access to relevant information is crucial for them to encourage investments in the electric power system. China's smart grid development is dominated by SGCC and

CSG, whereas the ICT industry hardly participates in strategic smart grid developments. It would be highly beneficial to change this situation with regard to the non-involvement of the ICT sector and to create business opportunities for new market actors.

Within this scenario, the main measures of the recommendation to *Create level playing fields for access to power system infrastructure and information* are:

- In the short term, the definition of the role of new market actors in smart grids and how these actors can be integrated is one of the main aspects.
- Defining minimum requirements for a data platform to organize access to and exchange of power system information between all eligible parties has to be accomplished in the short term.
- Also, the establishment of such a data platform is another task to be accomplished in this timeframe.

A common understanding of the structural aspects of smart grids would encourage the identification and description of the roles of new market actors as well as their need for information and interfaces both on the business and technical level. An institutionalized smart grid architecture and standardization framework might therefore serve as an intercompany interaction mechanism to strengthen the role of third parties even beyond standardization.

Coordinate network expansion planning for electricity grid expansion and upgrade The recommendation to *Coordinate network expansion planning for electricity grid expansion and upgrade* proposes that a stakeholder platform for network development should be established. This platform would mean more involvement of all market actors. All measures associated to this recommendation should be implemented in the short term:

- Coordination between established power system stakeholders and new market actors has to be strengthened. For this purpose, a stakeholder platform similar to the *Future-oriented Energy Grids Platform* in Germany could be established and managed by a government institution.
- Common procedures for network expansion planning should be defined. A network development plan should be elaborated within a coordinated process and shared responsibilities and made mandatory afterwards.
- Responsibilities for network planning should be identified, thereby clarifying which new market actors should participate in this process. This task shall be accomplished by a government organization, but it can be supported by grid operators.

Before the start of network expansion planning including new market actors, the role of new market actors in China's electric power system must be defined. Therefore, the recommendation to *Create level playing fields for access to power system infrastructure and information* should precede the recommendation to *Coordinate network expansion planning for electricity grid expansion and upgrade*.

Define a long-term strategy for the electricity sector and establish an independent and powerful regulator As government agencies have to supervise and guide grid operation, an effective definition of the government's roles and responsibilities is important. This ensures favorable conditions for the development and rollout of innovations.

Within this scenario, the main measures of the recommendation to *Define a long-term strategy for the electricity sector and establish an independent and powerful regulator* are:

- If the responsibilities for network planning have not already been defined within the previous recommendation, the government has to define these responsibilities in the short term.
- An independent and powerful regulator should be established in the medium term.
- A long-term strategy for the future electric power sector beyond 2020 must be defined in the same time frame.

Introduce network regulation for efficient investment incentives for electricity grid expansion and upgrade In the scenario focusing on affordability and competition, disaggregated regulation should ensure that only monopolistic bottlenecks (transmission and distribution grids) are regulated. Consequently, competition can evolve in all other stages of the supply chain and incentives are created for a cost-efficient build-up of the grid and for technical innovations.

Within this scenario, the main measures of the recommendation to *Introduce network regulation for efficient investment incentives for electricity grid expansion and upgrade* within this scenario are:

- Network charges offering efficient investment incentives in smart grids have to be introduced in the medium term.
- After network charges have been fixed, disaggregated regulation can be introduced. Due to the high impact of disaggregated regulation on competition in the retail sector, this measure should also be implemented in the medium term.

Before network regulation can be established, the responsibility for network regulation has to be defined and an independent and powerful regulator is necessary.

Facilitate the development of a unified view of smart grids As mentioned above, a smart grid architecture and standardization framework (i. e. an organizational arrangement to coordinate smart grid standardization and the development of a reference architecture) can be institutionalized as an inter-company interaction mechanism to strengthen the role of new market actors. In addition, it ensures interoperability between solutions coming from different vendors, prevents vendor lock-in and makes Chinese smart grid technologies applicable in international markets as well as vice versa [10], [11]. Furthermore, the framework supports the standardization and engineering process and thereby the diffusion of knowledge.

Within this scenario the main measures of the recommendation to *Facilitate the development of a unified view of smart grids* are:

- In the short term, the smart grid architecture and standardization framework has to be created or adopted to enable modeling of smart grid solution architectures.
- Coordinating the work of organizations involved in the development of standards needs clear structures and incentives for new market actors to participate in the process. The definition of these structures and incentives is also a short-term task.
- In addition, standardization processes need to be coordinated with international standardization in the short term in order to establish effective and efficient standardization processes (e. g. based on a collection of smart grid use cases) in the medium term.

Improve grid integration of RES Grid integration of RES is important in this scenario. The stricter the conditions for grid connection of RES are formulated, the less smaller power generation companies are dependent on the grid operators. Rules favorable for the integration of RES attract new investors, i. e. third parties that need both stable investment and technical conditions. The following measures should therefore be implemented in the short term in order to allow competition in the field of RES generation:

- Grid connection points need proper definition for all kinds of RES on all grid levels.
- A binding network code for grid connection specifying the respective responsibilities of grid operators and power generators needs to be specified. In this context, grid operators should bear liability for grid connection of RES.
- A detailed procedure and documentation for curtailment of RES including, for example, document exchange and transparency rules must be defined. Additionally, the requirements for IT support for these procedures need to be specified.

Well-defined network development procedures for network enhancement involving RES will positively impact the effectiveness of these measures. The recommendation to *Coordinate network expansion planning for electricity grid expansion and upgrade* should therefore start before the recommendation to *Improve grid integration of RES*.

Optimize the balancing of electricity generation and consumption The recommendation with the lowest priority in this scenario is the balancing of electricity generation and consumption, which is relevant for integrating prosumers in the electric power system. Balancing of electricity generation and consumption includes load management, time-

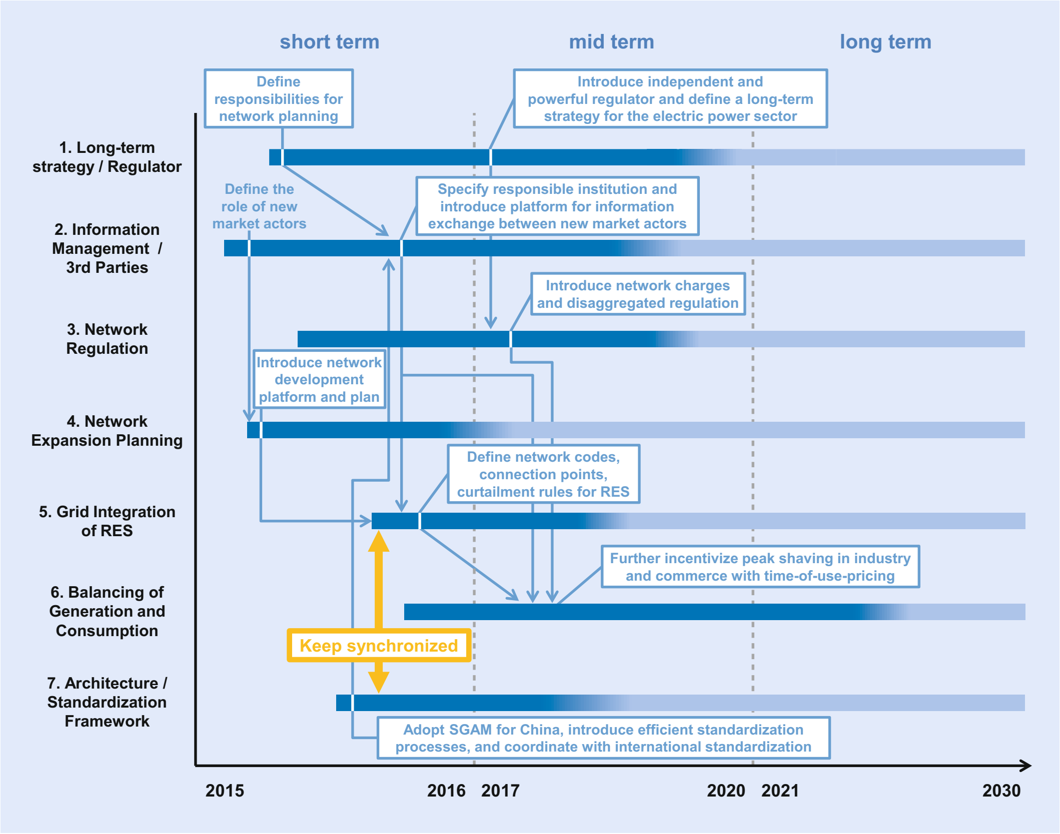

Fig. 6.7 Starting points, timeslots of main activities, and dependencies between main aspects of recommendations in the scenario focusing on competition and innovation

of-use pricing, smart meter rollout, and the promotion of VPP, microgrids, and energy storage by reducing barriers to their implementation.
Within this scenario, the main measures of the recommendation to *Optimize the balancing of electricity generation and consumption* are:

- In the medium term, coordination between electricity generation and consumption can be optimized by peak shaving and a further refinement of time-of-use pricing. Such a time-of-use based framework for pricing with sufficient price differences will incentivize the usage of balancing mechanisms and technologies such as DSM, SSM, and energy storage.

Balancing of electricity generation and consumption potentially depends on the grid integration of RES. However, power system information management with smart meter infrastructure and information interchange between all parties as well as an independent and powerful regulator for regulation of network charges are also necessary.

Sequence of Implementation Figure 6.7 shows the timeframes of main activities and interdependencies. In the light of the interdependencies described above, the following implementation sequence is proposed in the scenario focusing on ecological sustainability:

- Create level playing fields for access to power system infrastructure and information.
- Coordinate network expansion planning for electricity grid expansion and upgrade.
- Define a long-term strategy for the electricity sector and establish an independent and powerful regulator.

- Introduce network regulation for efficient investment incentives for electricity grid expansion and upgrade.
- Facilitate the development of a unified view of smart grids.
- Improve grid integration of RES.
- Optimize coordination of electricity generation and consumption.

6.4 Discussion of the three roadmaps

In addition to the specific timeline of each scenario, the three different roadmaps presented above give policy makers the following general hints:

- The priority and relevance of each recommendation can be assessed on the basis of the underlying scenario. For example, it can be seen that the measures of the recommendation to *Create level playing fields for access to power system infrastructure and information* have the highest priority if the government focuses on fostering competition and innovation but are virtually irrelevant if the government focuses only on reliability issues.
- Comparing the proposed implementation sequences in all three scenarios shows which recommendations have high priorities in all three scenarios. Such recommendations can be considered as political imperatives and should be implemented irrespective of the underlying policy goals of the Chinese government.

Figure 6.8 summarizes the proposed implementation sequences for all three scenarios. Those recommendations to be implemented in the beginning are presented in the left. For example, the *Ecological Sustainability* scenario starts with *Define a long-term strategy for the electricity sector and establish an independent and powerful regulator,* followed by *Improve grid integration of RES* and then by the remaining recommendations.

Comparing the implementation sequences in all three scenarios reveals that there are two recommended approaches with the highest overall priority. The measures subsumed within these recommendations shall be implemented independently of the underlying scenario:

- *Define a long-term strategy for the electricity sector and establish an independent and powerful regulator,* and
- *Coordinate network expansion planning for electricity grid expansion and upgrade.*

Three of the remaining five recommendations are relevant in each scenario, though with a lower priority:

- The *Improvement of the grid integration of RES* has a very high priority under the *Ecological Sustainability* scenario and is also important for the *Reliability/Security of Supply* scenario. It is somewhat less important in the *Affordability/Competition* scenario.
- The *Facilitation of the development of a unified view of smart grids* is especially important with respect to the *Reliability/Security of Supply* scenario. It is somewhat less important with regard to the *Affordability/Competition* and *Ecological Sustainability* scenarios.
- The *Optimization of the balancing of electricity generation and consumption* is particularly relevant for the *Reliability/Security of Supply* scenario. The recommendation has a lower relevance in the *Ecological Sustainability* scenario and is ranked last in the *Affordability/Competition* scenario.

The two remaining recommendations are not relevant in every scenario. Rather, they contribute to single energy policy goals. In particular, both of these recommendations are essential for migrating towards smart grids focusing on affordability and competition:

- The *Creation of level playing fields for access to power system infrastructure and information* is the first recommendation that should be implemented if the government strives to develop smart grids focusing on affordability and competition. It is also important if the government chooses to focus on ecological sustainability.
- The *Introduction of network regulation for electricity grid expansion and upgrade* is at position four in the implementation sequence

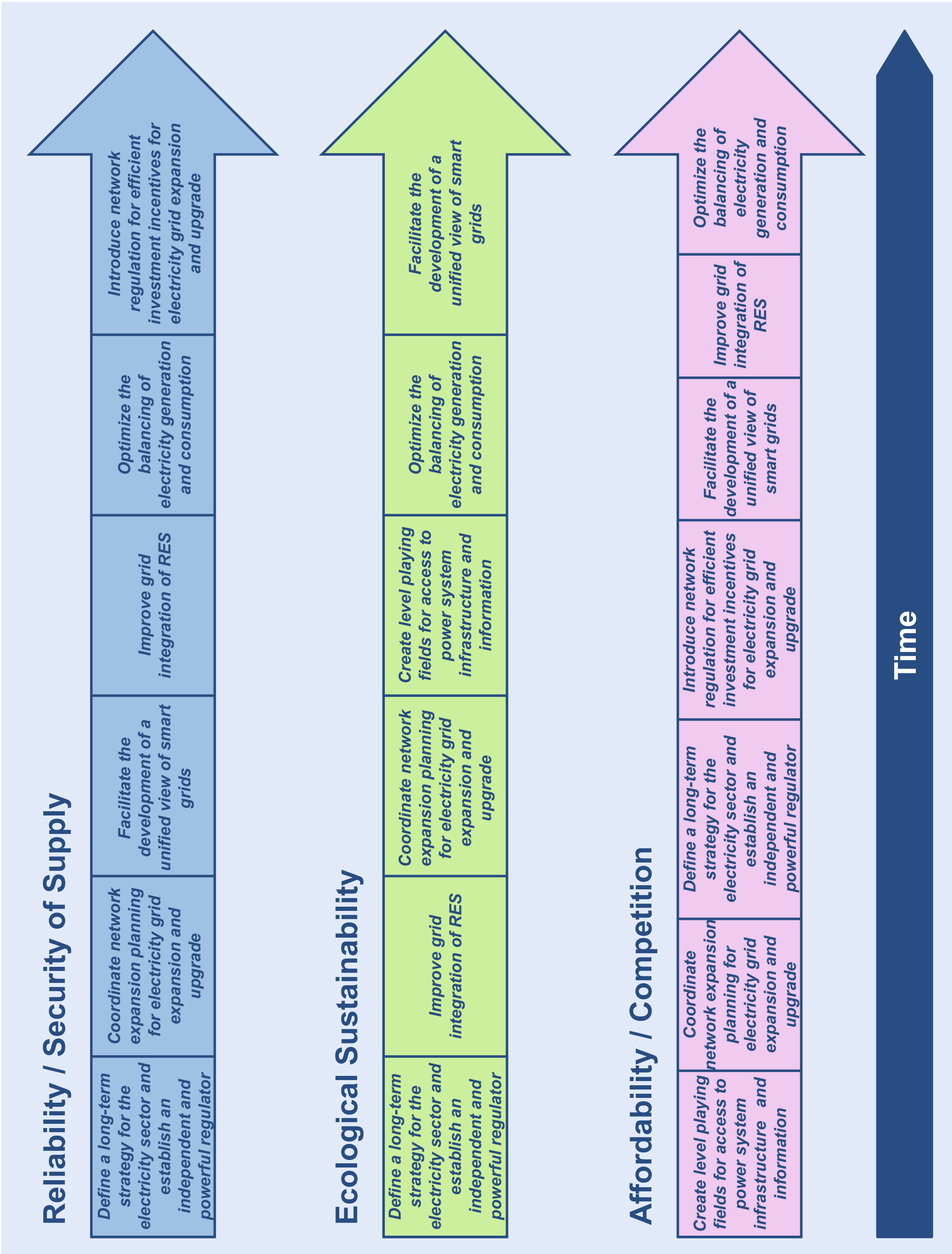

Fig. 6.8 Overview of proposed implementation sequences for all three scenarios

of the *Affordability/Competition* scenario. It is also relevant, though at a later stage, in the *Reliability/Security of Supply* scenario.

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Backmatter

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Appendix A – Tables and Figures

Table A.1 Electricity consumption in China in 2011, data from [1]

Consumer	Electricity Consumption in TWh in 2011	in % of Total
Industry	3,469	73.8
Residential Sector	562	12.0
Wholesale, Retail, Trade, and Hotels/Restaurants	150	3.1
Agriculture, Forestry, Animal Husbandry, Fishery, and Water Conservancy	101	2.2
Transport, Storage, and Postal Service	85	1.8
Construction	57	1.2
Others	275	5.9

Table A.2 Circuit length of transmission lines with 35-kV and above and installed capacity of transformers by the end of 2010

Voltage level	Circuit length of transmission line/km	Capacity of transformers/ 10,000-kVA
Total 35-kV and above	1,336,772	361,742
1000-kV AC	1,006	600
+/– 800-kV DC	3,334	593
750-kV AC	6,685	3,870
+/– 660-kV DC	1,095	
500-kV AC	135,180	69,843
+/– 500-kV DC	8,081	4,031
330-kV	20,338	6,457
220-kV	277,988	118,247
66-/110-kV	458,477	125,224
35-kV	432,668	37,501

Table A.3 Reliability rate of power supply for users in cities at the level of 1000-KV during the 11th Five-Year Plan (2006–2010)

Year	Reliability ratio of power supply/%	Average blackout time/hours/household
2010	99.923	6.722
2009	99.896	9.111
2008	98.863	12.071
2007	99.882	10.360
2006	99.849	13.191

Table A.4 Administrative regime of the power sector in China

Organization	Description
Power sector regime reform working group	– Theoretically enjoying top decision-making rights regarding the power regime reform
National Development and Reform Commission (NDRC)	– Responsible for long-term planning and for the issuance of energy-related Five-Year Plans – Approving important investment projects – Regulating energy and electricity prices – Proposing energy conservation and new energy development policies
National Energy Administration (NEA)	– Proposing the energy development strategy – Drafting energy development plans and industrial policies and organizing their implementation – Drafting all energy-related provision and rules – Advancing energy regime reforms – Coordinating key issues emerging in the process of energy development and reforms – Exercising regulations on power system construction, power safety, power supply and service, as well tariff and information disclosure
Ministry of Finance (MOF)	– Responsible for final decisions on some matters concerning the financial code and financial costs standards
Provincial Economic and Trade Commission (PETC)	– Acting as the regulator at local level and serving as coordinators; in practice, they also perform the functions of local regulation institutions
State-owned Assets Supervision and Administration Commission of the State Council (SASAC)	– Supervising the performance of SOE – Appointing and dismissing SOE executives – Formulating auditing requests and approving key decisions
Ministry of Environmental Protection (MEP)	– Responsible for tasks related to overall environmental protection – Cooperating with NEA in the performance of its duties
State Administration of Work Safety (SAWS)	– Giving guidance to safety inspection and being responsible for industrial safety regulation

Table A.5 Regional and provincial grid operators in China

SGCC		
Regional subsidiaries	**Provincial subsidiaries**	**Province**
North China Grid Ltd.	Beijing Electric Power Corporation	Beijing
	Tianjin Electric Power Corporation	Tianjin
	Hebei Electric Power Corporation	Hebei
	Shanxi Electric Power Corporation	Shanxi
	Inner Mongolia Autonomous Region Electric Power (Group) Co. Ltd.	Inner Mongolia
	Shangdong Electric Power Corporation	Shangdong
Northeast China Grid Company Ltd.	Liaoning Electric Power Corporation	Liaoning
	Jilin Electric Power Corporation	Jilin
	Heilongjiang Electric Power Corporation	Heilongjiang
East China Grid Company Ltd.	Shanghai Electric Power Corporation	Shanghai
	Jiangsu Electric Power Corporation	Jiangsu
	Zhejiang Electric Power Corporation	Zhejiang
	Anhui Electric Power Corporation	Anhui
	Fujian Electric Power Corporation	Fujian
Central China Grid Company Ltd.	Henan Electric Power Corporation	Henan
	Hubei Electric Power Corporation	Hubei
	Hunan Electric Power Corporation	Hunan
	Jiangxi Electric Power Corporation	Jiangxi
	Sichuan Electric Power Corporation	Sichuan
	Chongqing Electric Power Corporation	Chongqing
Northwest China Grid Company Ltd.	Shaanxi Electric Power Corporation	Shaanxi
	Gansu Electric Power Corporation	Gansu
	Qinghai Electric Power Corporation	Qinghai
	Ningxia Electric Power Corporation	Ningxia
	Xinjiang Electric Power Corporation	Xinjiang
CSG		
	Provincial subsidiaries	**Province**
–	Guangdong Power Grid Corporation	Guangdong
	Guangxi Power Grid Corporation	Guangxi
	Yunnan Power Grid Corporation	Yunnan
	Guizhou Power Grid Corporation	Guizhou
	Hainan Power Grid Corporation	Hainan

Table A.5 (*continued*) Regional and provincial grid operators in China

Grid operators non-affiliated to SGCC or CSG		
–	East Inner Mongolia Electric Power Company Ltd.	Inner Mongolia
	Tibet Electric Power Company Ltd.	Tibet
	CLP Holdings Ltd.	Hongkong

Table A.6 Share of current application of ICT and challenges structured by voltage levels, adapted from [2]

Voltage Level	ICT in use	Character	Requirement	Control Functions	Challenges	
Extra-high-voltage/High-voltage 380-kV/ 220-kV	Control systems Further development	Quasi-real-time	Data security Availability (24/365) Active data management	f (Hz)	Wind Trade	The grids are increasingly being operated at the limit of their capacity
High-voltage 110-kV	Control systems Telecontrol systems	Quasi-real-time	Data security Availability (24/365) Active data management	Voltage	Wind, large PV plants Bidirectional load flow Demand response	
Medium voltage 10-kV/20-kV	Tele-control systems Consumption metering	Not time-critical	Data collection and processing	In part voltage	Wind, PV Rural areas Over 800 system operators Bidirectional load flow Demand response Reactive power provision	
Low voltage 0.4-kV	–	–	–	–	Distributed feed-in especially PV Rural areas Active customers (prosumers) Virtual power plant Consumption follows generation Electric mobility	

Fig. A.1 Germany's power grids in 2012 (© VDE e.V. [3])

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Appendix B – Bottom-up view on China's technological smart grid vision

The following descriptions and lists present a full picture of the modern grid technologies that are being deployed and tested in demonstration projects, individual cities, or individual provinces. These descriptions and lists have been provided by the Chinese expert team, and they represent the state-of-the-art of China's smart grid technologies.

Transmission grids

- ***Control systems:*** SGCC has successfully developed a smart grid dispatching support system. In order to improve safe and stable operation, CSG carried out a series of advanced projects to improve the dispatching automation. An automatic dispatching system covering all dispatching areas has recently been completed; it is still based on a manual dispatcher but supplemented by automatic decisions. An integrated dispatching system is under construction; it will include strong simulation capability, off-line analysis, and decision-making capacity. Furthermore, research and pre-testing of intelligent system integration is in process.
- ***Power lines:*** Several UHV transmission lines constructed by SGCC and CSG have gone into normal operation in recent years. This technology is perceived as an important component of the Chinese smart grid vision.
- ***Transformers:*** At the end of December 2008, the 1,000-kV transformers manufactured by Baoding Tianwei Baobian Electrical Co., Ltd and TBEA Shenyang Transformer Co., Ltd all passed the pre-delivery test and on-site delivery test. On January 6th 2009, they passed the 168-h assessment. The UHV transformer with single-unit capacity of 1,000 MVA and single-column capacity of 334 MVA is the largest in the world. Moreover, three of the largest transformer manufacturers in China have enjoyed enormous development in ± 500-kV converter transformer by absorbing foreign technologies. Xian XD Transformer Co., Ltd has mastered the core technology for manufacturing ± 500-kV DC power transmission devices with the capabilities of independent design and manufacturing. Now it has set up annual production of 18–50 ± 500-kV converter transformers and smoothing reactors. Shenyang Transformer and Baobian Transformer have all introduced Siemens technologies. They have developed ± 500-kV converter transformers jointly with Siemens and mastered the basic technology for designing and manufacturing converter transformers.
- ***Fixed series compensation:*** This technology is seen as one of the most important technologies for improving transmission and distribution grid capacities. Since 2000, China has witnessed rapid development and satisfactory results in the 500-kV fixed serial compensation technology. One of the important technical issues in the promotion of fixed series compensation technology is the stability of sub-synchronous resonance induced by the interaction between fixed series compensation and large-scale turbo-generators. Recently, domestic companies have achieved technical breakthroughs in this area. For example, Inner Mongolia Shangdu Power Plant has successfully resolved the problem of sub-synchronous resonance by using supplementary excitation damping control and shaft torsion. Their achievements have created a basis for further promotion of the technical application of fixed series compensation.
- ***Wires:*** CSG launched a pilot application of high-strength heat-resistant wires, carbon fiber wires, compact lines, and a helicopter patrolling line.
- ***Substations:*** SGCC has developed intelligent components of *high-voltage* (HV) switchgears, intelligent transformer components, modular intelligent HV vacuum circuit breakers with

phase selection function, integrated monitoring systems based on a unified information platform, a time synchronization system, grid security and grid status monitoring equipment, data and event logging equipment, polymorphic remote viewing inspection and firefighting system, secondary equipment for online automatic calibration and early warning systems as well as other critical equipment and systems. Turning to CSG, they launched the promotion and application of digital substations. One 220-kV and seven 110-kV digital substations have been built. Furthermore, online equipment monitoring technology has been applied. Equipment condition monitoring centers and technical supervision centers are under construction. These centers will provide monitoring and early warning capability, fault diagnosis, status evaluation, risk assessment, maintenance strategies as well as asset management and maintenance decision support. In 2009, the company completed the formulation of the relevant technical specifications and acceptance codes, and in 2010 it built the provincial host station system.

- ***Gas insulated substations:*** Gas insulated substations have entered the application stage. Online ice monitoring and lightning detection monitoring tools have been gradually applied.

Distribution grids

- ***Distribution grids with ring structures:*** SGCC has developed an intelligent environmentally friendly ring main unit, and an automatic distribution system. CSG has continued to expand the distribution grid structure of urban and rural distribution grids. The current distribution grid is still weak and most of the loads have single-supply access with T connections without ring structures.
- ***Troubleshooting and diagnosis:*** Currently, the troubleshooting and diagnostic work needs to be done manually. Distribution automation pilot installations exist only in large and medium-sized cities and mainly cover the telemetry data acquisition and monitoring, fault signal sending, problem solving and alarm, fault location and troubleshooting functions.

The systems have information distribution and partition management functions via an integrated bus, in accordance with IEC61970 and IEC61968 public information model standards and distribution grid management system interface standard. They provide real-time information exchange and synchronization of data and models among distribution automation system and related automation systems.

Power consumption

- ***Smart home and consumption systems:*** SGCC exploits smart technologies such as a chip dedicated to information collection, smart meters, smart appliances, smart sockets, smart interactive terminals, smart energy storage systems, power grid management terminals and systems, smart energy-using service systems, electric vehicle charging equipment, self-service electricity service terminals, information collection systems, and smart interactive terminal detection devices. CSG has built a market automation system, standardized market businesses, carried out research on the power supply customer service standardization system, and strengthened demand side management activities of large consumers.
- ***Market management systems:*** Through the construction of market and management systems in accordance with uniform technical specifications, Yunnan Power Grid Company and Hainan Power Grid Corporation have realized centralized provincial deployment systems, while other branch and subsidiary companies have deployed such systems at city level. In an effort to meet the actual needs of the power market, measurement automation systems have mainly encouraged off-peak power consumption and introduced electricity metering and monitoring, remote meter reading, and other functions.
- ***Electric vehicle charging:*** Various Chinese companies have started research on the key technology for electric vehicle charging. Electricity charging stations and poles for electric vehicles have been constructed as trial points in Shenzhen, and exchange electricity Experience Centers in Guangzhou.

Information and communication technology (ICT)

- ***ICT systems:*** SGCC has developed an optical phase conductor and the pertinent supporting equipment, information security technology inspection tools, and analysis platforms. It has also developed smart grid key equipment including intelligent switch combinations and electrical and optical fiber composite low-voltage cables, which have successfully been put into operation. Smart grid dispatching technology support systems, intelligent primary equipment and facilities for electric vehicle charging have achieved a major technological breakthrough. CSG has developed a common information model, enterprise data resource planning, SOA technical specifications as well as a series of technical standards. It has also undertaken the construction of a unified data center, an integrated distribution system, an enterprise cockpit, and a massive real-time data platform. In 2006–2010, the company launched the "CSG 123 Plan", which promotes unified business standards for the entire grid and unified information standards by building an integration system that includes IT infrastructure, technology architecture, and IT services to realize digitized grid support, informational business management as well as intelligent analysis and decision. As a result of this plan, the company has made remarkable achievements in terms of information technology, and information levels have been improved significantly: optical fiber communications now basically cover substations and generation stations for 110-kV and above. Emergency communication grids have been built. Distribution grid communication gives priority to optical fiber communication, public grid wireless communication, and medium voltage power line carrier communication. From an information security aspect, a series of technical standards and specifications involving information security protection technology have been worked out. System-level protection measures are being implemented in order to achieve information resource partition and hierarchical security protection. Information security technology and management systems have been developed, combining a variety of technical means including firewalls, intrusion detection systems, antivirus systems, public key infrastructure, risk assessment, and other features.

Energy storage

- ***Pumped-storage power:*** Energy storage is of great significance for the development of smart grids. It can be applied in the case of peak shaving in electrical systems to solve the power utilization problem or to improve power supply quality and grid reliability. Meanwhile, it can also be used to control the fluctuation of the electricity system in order to enhance the safety of the grid and to foster optimal utilization of renewable energy and promote further developments in this area. By 2011, 11 pumped storage power stations had already been constructed with total installed capacity accounting for 1.8 % of overall installed power. With the construction of pumped storage power stations during the 11th Five-Year Period, the dispatchable hydro power including that of pumped storage power stations in the whole country except for Hubei and Lasha will be 3–7 % of China's total installed capacity once they have been put into normal operation.
- ***New energy storage technologies:*** Significant progress has been made in research into new types of energy storage. In the past decades, organizations such as the Electrical Engineering Institute of the Chinese Academy of Sciences, the Beijing Feilun Energy Storage Flexible Research as well as some academic institutions have all been engaged in studying fly wheel energy storage. At present, important breakthroughs have been obtained in key technical fields such as superconductive magnetic levitation, high-speed motors, and power conversion. A research group at the Advanced Material Lab and Macromolecular Science Department of Fudan University has successfully developed a new kind of type of energy element-oriented carbon nano fiber. Based on this technology, a new type of solar fiber battery with a diameter of only 60–100 microm-

eters can be manufactured, allowing PV conversion and energy storage in the same piece of fiber. In addition, China has also achieved lasting breakthroughs in research into energy storage using storage batteries. Since the research into battery supported energy storage with vanadium redox flow in 1995, China has developed a 10-kW-battery energy storage system and established battery energy storage lab modules. In 2008, China Electric Power Research Institute developed a 100-kW battery energy storage system applicable to wind power plants. In January 2011, China achieved an important breakthrough in the construction of large-capacity battery energy storage technology through the synchronization of a megawatt battery energy storage station of Southern Grid, a development representing material progress in the integrated application technology of Chinese large-capacity battery energy storage. The final construction scale of Southern Grid's 10-MW battery energy storage station is 10 MW for four hours with initial project construction of 5 MW for four hours. Currently, a 1-MW four-hour battery energy storage system has been successfully synchronized and put into normal operation.

Appendix C – Integration levels of China's power system components in 2012 and 2020

The system integration of China's power system components in 2012 and 2020 was discussed among the experts involved in the study generation process in the course of workshops carried out in Beijing in June 2013. In addition, the prevalence of market elements in 2012 and the targeted prevalence of market elements in 2020 were also discussed. In a first step, the experts agreed on the power system components and market elements that are relevant in China's current electric power system as well as on the corresponding components and elements in 2020 (see Fig. C.1 for a definition of the power system components and market elements).

In a second step, the experts developed a common understanding of the extent to which each single power system component is currently integrated in China's electric power grid. In other words, they examined whether the components are physically connected to the grid, remotely monitorable, remotely controllable, or autonomously controllable/self-healing (see Table C.1 for a definition of integration levels). The targeted integration levels of the power systems components for 2020 were also discussed.

After the Beijing workshops, an evaluation was made of the extent to which the market elements are currently used and will be used in 2020, ranging from demonstrational level to national level (see Table C.2 for a definition of these values). Figure C.2 shows China's current power grid integration as of 2012. The main findings are:

- In the area of power generation, it can be seen that monitoring and control technologies are common in conventional power plants but are rather seldom used with RES. More particularly, currently installed rooftop PV installations and biomass power plants are only physically connected to the grid, without the possibility of remote monitoring or any control functionalities.
- In the area of power logistics, China's transmission grids, the associated transformer substations, and the pumped storage power plants are currently already remotely controllable by the grid operator. On the distribution grid level, however, the various components' system integration levels are significantly lower – most of the components are not equipped with monitoring and control technologies.
- China's end consumers of electricity are for the most part physically connected to the power grid. Early examples of remote monitoring technologies are used only at industrial and commercial levels and for large-scale urban buildings.
- With respect to the prevalence of market elements, it can be stated that only few of these elements are currently used in China's power system: early demonstration projects for spot markets have been implemented by the grid operators and time-of-use pricing for residential consumers is being tested in the provinces. For the most part, China's electricity is still being traded at governmentally fixed prices. Elements such as futures markets, balancing markets, or capacity markets used in other countries have not yet been implemented in China.

The following advances are planned until 2020 (see Fig. C.3):

- In the power generation area, various energy sources are projected to have a place in the Chinese power system of 2020. All of them will be fully integrated in the power grid and most of them will reach the highest integration level so that they can autonomously react to grid and/or market conditions. A comparison with the present situation reveals that especially RES are likely to make a big leap forward. While a considerable part of RES is currently not connected to the grid, grid ac-

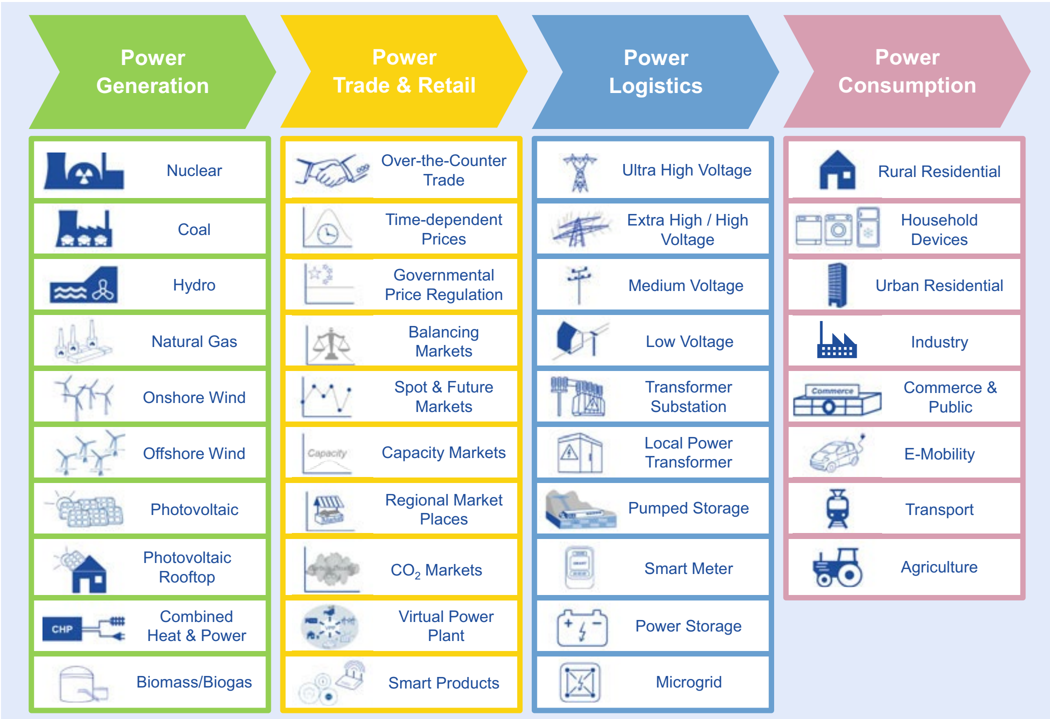

Fig. C.1 Power system components and market elements in the Chinese power system model

Table C.1 Definition of system integration levels of power system components

	System integration levels of power system components
0 – untapped	This power system component is principally ready for operation. However, it is not yet physically connected to the power grid. Therefore, it is not able to feed in, transport, distribute, store, or consume electricity.
1 – physically connected	This power system component is principally ready for operation and physically connected to the power grid. It is therefore able to feed in, transport, distribute, store, or consume electricity.
2 – remotely monitorable	In addition to being physically connected to the grid, this power system component is remotely monitorable by grid operators or other actors within the power system. Authorized actors are able to supervise the current status of power flows, power frequencies, outages, etc.
3 – remotely controllable	In addition to being remotely monitorable, this power system component can be controlled remotely. In other words, grid operators or other authorized actors of the power system are able to remotely control specific functions of the component allowing very quick reactions to critical grid conditions.
4 – autonomous/self-healing	In addition to being remotely controllable, this power system component can autonomously react to specific grid and market conditions via incorporated ICT agent functionality.

Table C.2 Definition of the prevalence of market elements

	Prevalence of market elements
A – Demonstrational level	This market element is being tested in (small) demonstration projects.
B – City/district level	This market element is being used in one or in some individual cities or districts. However, it is not used extensively in one entire province.
C – Provincial level	This market element is used in one or in more provinces. However, it is not used nationwide in all Chinese provinces.
D – National level	This market element is principally used nationwide. This means that with the eventual exemption of some special economic zones or single provinces, the organizational component is applied in all Chinese provinces.

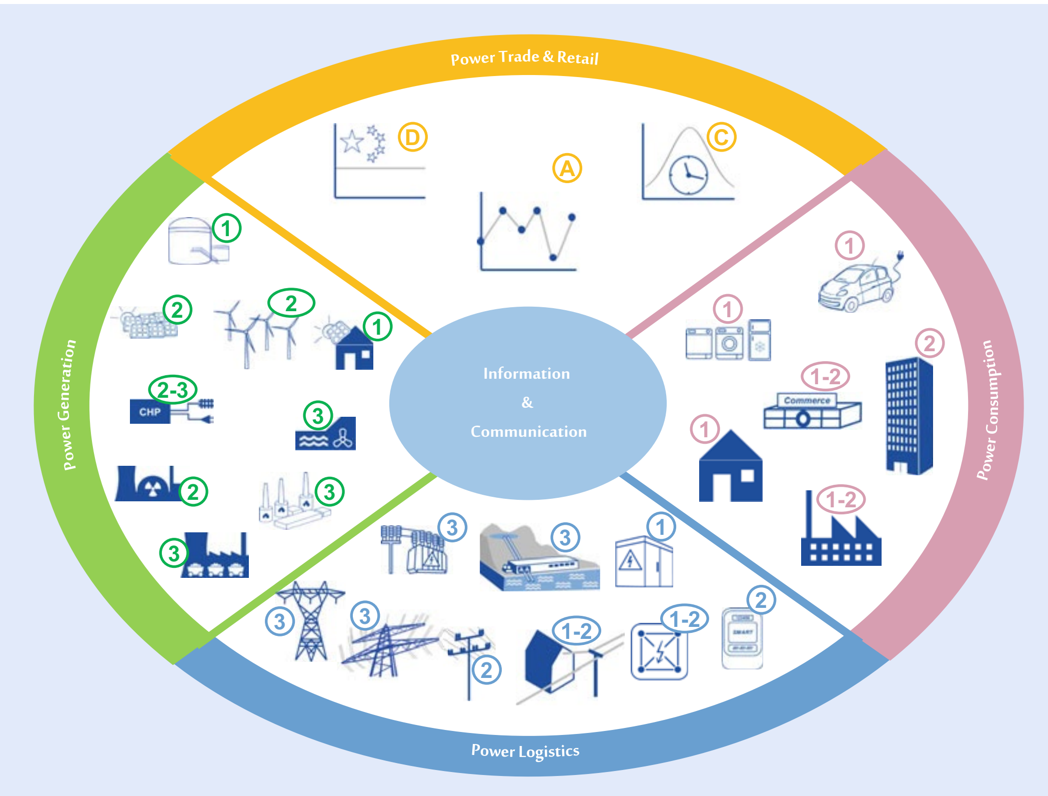

Fig. C.2 System integration levels in China in 2012

cess of RES will have become plug-and-play by 2020.

- In the area of power logistics, all voltage levels above 35-kV will have reached the highest level of system integration by 2020. Power grids and transformer substations at these voltage levels are projected to be enhanced with a large amount of control and monitoring devices so that they can react almost autonomously to unforeseen events. The distribution grids (voltage levels below 35-kV) and their associated local substations are projected to be either remotely monitorable or remotely controllable (depending on their location). This

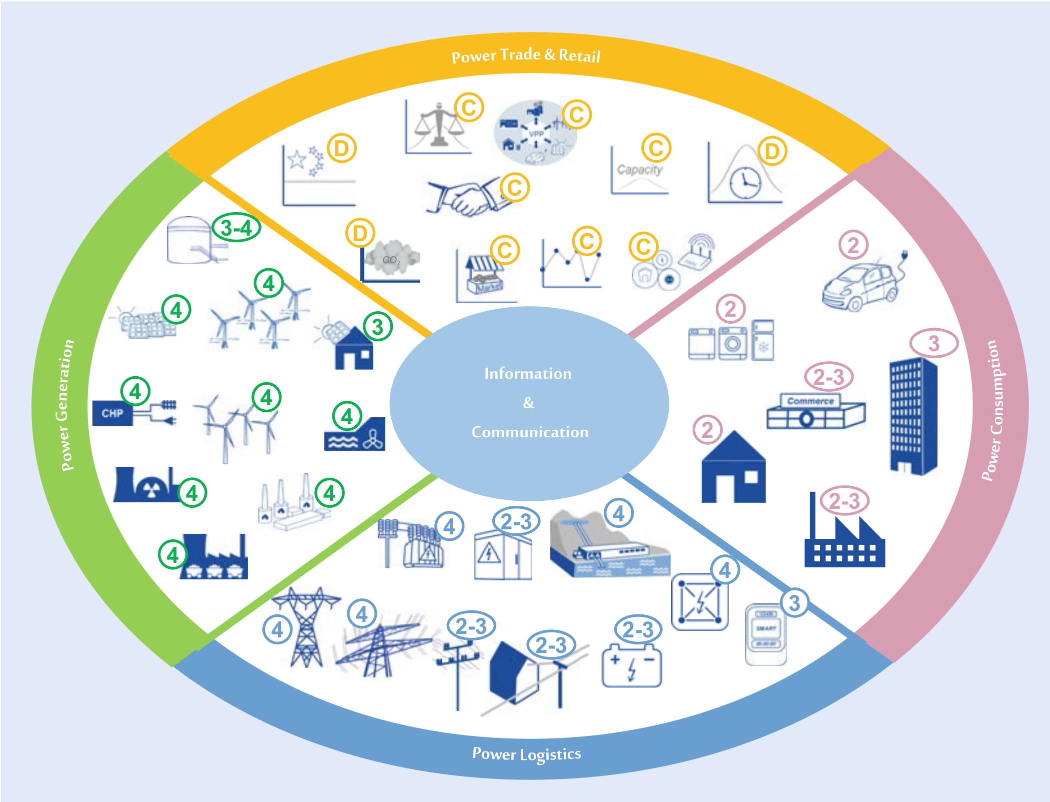

Fig. C.3 System integration levels in China 2020

implies a significant improvement compared to their current system integration.

- With regard to power storage, hydro-pumped storage plants will be autonomously controllable and, compared to the situation of today, new power storage technologies will be developed and integrated in the grid. Smart meters will be widely used and reach higher integration values than today.
- In the power consumption area, industrial and commercial users – China's major power consumers – will be either remotely monitorable or remotely controllable in 2020. This means that grid operators and other players will be well informed with regard to their power consumption and have the opportunity to directly control some customers' loads. City dwellers residing in large buildings are expected to be fully integrated into the power grid with remote control activities by the grid operator. However, remote control activities are not planned for smaller, rural households. But even these customers will be remotely monitorable by means of smart meters. Advances are also projected to be made with regard to smart home technologies such as intelligent household devices and electric mobility being monitorable for grid operators.
- In the power trade and retail area many new types of markets are envisaged for 2020. Whereas today governmental price regulation leads to low penetration with market elements, spot markets (including futures markets), OTC, and balancing markets prominent in other countries will be used in China's power system of 2020. Also, carbon markets, capacity markets, and market-related elements such as virtual power plants (VPP), time-of-use tariffs, and smart products are expected to be part of China's power grid in 2020.

Appendix D – Germany's smart grid vision according to the study *Future Energy Grid*

Using the three system layers presented in Fig. 4.3 and eight different domains of the power sector representing particular sub-fields of the power sector supply chain, nineteen relevant smart grid technology areas were identified [1], [2]. The set of these technology areas, their individual maturity levels, and development stages describe Germany's smart grid vision. The respective maturity levels help to assess the speed of development of different smart grid technologies in Germany. The different technology areas are shown in Fig. 4.4 and are described in more detail in the remainder of this section.

Smart grid technologies of the closed system layer The closed system layer requires a high level of security as well as the capability of real-time communication since it is supposed to ensure the stability of the power system. Only few actors are granted with controlling access of this system layer. ICT components used within this system layer address the operation of the grid infrastructure and large-scale power stations. These components are classified into the following technology areas:

- ***Asset management systems (AMS)*** for grid components are employed to plan the usage of electrical equipment following technical and commercial constraints. Their focus is on grid infrastructure components and components of large conventional power stations. Today, AMS are mostly used for central assets managing static data. Automation of this process is only done for core components.
- ***Grid control systems*** are used for monitoring and controlling electrical transmission and distribution grids, or bulk generation units. Grid control systems are mainly deployed in transmission grids and distribution grids of 20-kV or 10-kV but rather seldom below.
- ***Wide area monitoring systems (WAMS)*** subsume technologies to measure, transfer, store, and visualize time-synchronized values with high temporal resolution. WAMS are currently used in some selected areas of transmission grids. The application within the distribution grids is evaluated in single pilot projects.
- ***Grid automation*** refers to ICT components at the substation or field level processing data from grid components, measuring transducers, and giving control signals. Germany's high voltage segment is currently already automated. In medium and low voltage grids, automation solutions are subject to evaluation in a variety of field tests.
- ***Flexible control and AC transmission systems (FACTS)*** represent power electronic control systems which are used to affect the power flows or voltage levels in the electricity grids. Currently, FACTS are occasionally used only in the transmission grids.

Smart grid technologies of the ICT infrastructure layer The ICT infrastructure layer accounts for the communication between the closed and the networked system layer. The technology area associated with this layer therefore deals with the interface functionality required for the realization of smart grids:

- ***ICT connectivity*** refers to the prerequisites regarding the communication infrastructure and the amount and scope of the information exchange used in the power system. Thereby, the ICT connectivity accounts for the quality-of-service level regarding the discovery and accessibility of services. The transmission grids are currently equipped with ICT infrastructures using point-to-point connections and proprietary interfaces. In contrast to that, the distribution grid is normally not yet equipped with ICT infrastructures.

Smart grid technologies of the networked system layer The networked system layer is distinct regarding the high amount of heterogeneous stakeholders and power system components it is supposed to connect. It is expected that this system layer will gain more and more importance in the future, especially with respect to the rising amount of renewable generation. Therefore, this layer is expected to become system-critical in the process of developing robust smart grids and smart markets. The layer subsumes the following technology areas:

- ***Asset management for distributed energy resources*** refers to the processing of operational and commercial data regarding power system assets. Distributed energy resources are referred separately because currently no end-to-end asset management systems exist for medium and small generation units which are expected to be of high importance for the development of smart grids in Germany.
- ***Regional energy marketplaces*** are established to enable market participation for industrial, commercial and domestic customers, thereby taking requirements regarding grid operation, especially for the distribution grids, into account. First demonstrators of regional energy market places were evaluated in pilot projects, e.g. the E-Energy model regions.
- ***Trade control systems*** support the analysis of relevant data and the subsequent planning and execution of energy trading activities. Current systems support trading on the spot and day-ahead markets, as well as energy portfolio management.
- ***Forecasting systems*** compute state estimations of various measurement parameters. Examples for this are forecasts regarding electricity generation subject to weather conditions or the price elasticity of electricity demand.
- ***Business services*** comprise technologies concerning the efficient use of resources, low costs, high availability and reliability in the context of important business processes of the energy sector. Main challenges in this area address the extension of service offerings for customers, handling of big data, cloud computing and the optimization of the supply chain across enterprise boundaries. Currently, processes prescribed by laws and regulations are fully supported. Additional services address basic customer management functions and the billing of electricity consumption.
- ***Virtual power plant (VPP) systems*** aggregate power generation, storage and consumption units. This way the provision of effective and balancing power as well as system services is optimized. Today, VPP are used to provide balancing power. The installations are heterogeneous.
- ***Plant communication and control modules*** refer to embedded systems, similar to grid automation components, providing access to distributed generation, storage or consumption units for data reading and control signal processing. Today, the communication interfaces of distributed energy resources are mostly proprietary. Their main function is disconnection from the grid.
- ***The advanced metering infrastructure (AMI)*** provides remote access to energy consumption data. In later development stages, this shall lead to advanced smart meter processes, e.g. for calculation of grid conditions. Standardization, security, and mass data processing are key capabilities in this area. Today, there are no large-scale installations in Germany due to missing regulatory action. Functionalities and interfaces are proprietary.
- ***Smart appliances*** refer to equipment in households, buildings or small enterprises possessing communication and control capabilities. The provision of a standardized infrastructure is currently one of the main challenges within this area. While smart appliances may not be essential regarding the technical smart grid infrastructure itself, they are expected to have a high market potential in the future. Currently, energy management systems (e.g. in the areas of lighting and heating) operate independently from the grid. Energy-related apps (e.g. for usage on smart phones or tablet computers) are developed and offered in the context of pilot projects.
- ***Industrial demand side management/demand response*** subsumes the integration between the requirements of the electrical infrastructure with those of industrial processes. This includes the possibility to take influence on industrial assets from outside the enterprises. DSM is motivated by pricing of electrical

energy: the industrial enterprise tries to match its operations to the development of market prices. The enterprise may also agree to manually reduce their load on request of the grid operator. Automatic load shedding possibilities are partially realized in the context of industrial operations.

Cross-cutting technologies Beyond the sixteen functional technology areas introduced above, there are three key issues regarding quality aspects of the future smart grid vision in Germany. They are regarded as cross-cutting issues which have to be separately considered in context of each functional area.

- ***Integration technologies*** address the aspect of interoperability being of critical importance for smart grids as ICT-based systems.
- ***Management of data*** refers to procedures regarding structuring, aggregation, analysis, processing, and storage of high amounts of distributed and heterogeneous data.
- ***Security,*** in terms of information security, provides procedures to protect the stakeholders of the power systems as well as the infrastructure. Key requirements refer to the aspects of availability, confidentiality, and integrity.

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Appendix E – Extracts from specific laws

Directive 2009/72/EC, Article 37

"Energy regulators should have the power to issue binding decisions in relation to electricity undertakings and to impose effective, proportionate and dissuasive penalties on electricity undertakings which fail to comply with their obligations or to propose that a competent court impose such penalties on them. Energy regulators should also be granted the power to decide, irrespective of the application of competition rules, on appropriate measures ensuring customer benefits through the promotion of effective competition necessary for the proper functioning of the internal market in electricity. […]

Energy regulators should also be granted the power to contribute to ensuring high standards of universal and public service in compliance with market opening, to the protection of vulnerable customers, and to the full effectiveness of consumer protection measures. Those provisions should be without prejudice to both the Commission's powers concerning the application of competition rules including the examination of mergers with a Community dimension, and the rules on the internal market such as the free movement of capital. The independent body to which a party affected by the decision of a national regulator has a right to appeal could be a court or other tribunal empowered to conduct a judicial review."

Source: Wording from The European Parliament and the Council of the European Union [1]

Roles and Responsibilities of smart grid actors according to SGTF

- "***Transmission System Operator (TSO):*** *according to the Article 2.4 of the Electricity Directive 2009/72/EC (Directive): "a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity". Moreover, the TSO is responsible for connection of all grid users at the transmission level and connection of the DSOs within the TSO control area.*
- ***Distribution System Operator (DSO):*** *according to the Article 2.6 of the Directive: "a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity". Moreover, the DSO is responsible for regional grid access and grid stability, integration of renewables at the distribution level and regional load balancing.*
- ***Generator:*** *Generating electricity, contributing actively to voltage and reactive power control, required to provide the relevant data (information on outages, forecast, actual production) to the energy marketplace (see also the Articles 2.1 and 2.2 of the Directive).*
- ***Electricity Installer/Contractor:*** *Electrical contractors design, install and maintain intelligent systems for all kinds of industrial, commercial and domestic purposes. Alongside the power and lighting applications, they equally install ICT and telecommunications, public street lighting, high medium and low voltage lines, control and energy management systems, access, fire and security control equipment, lightning protection systems, advertising and identification signs, emergency power generating systems and renewable energy systems.*
- ***Industrial customer:*** *A large consumer of electricity in an industrial/manufacturing industry. May be involved in contract based Demand/Response.*

- ***Transportation customer:*** *A consumer of electricity providing transport systems. May be involved in contract based Demand/Response.*
- ***Buildings:*** *A consumer of electricity which is a private or business building, may also be involved in contract-based Demand/Response.*
- ***Home customer:*** *A residential consumer of electricity (including also agriculture users) may also be involved in contract-based Demand/Response.*
- ***Supplier* [in the area of grid users]*:*** *A grid user who has a grid connection and access contract with the TSO or DSO. Moreover, suppliers are those actors which will provide new services, real-time information, energy efficiency services and dynamic energy pricing concepts with Time-of-Use (ToU). The suppliers also provide local aggregation of demand and supply, in order to increase the effectiveness and efficiency of the electricity supply at all voltage levels (including low/medium voltage levels).*
- ***Retailer:*** *Entity selling electrical energy to consumers – could also be a grid user who has a grid connection and access contract with the TSO or DSO.*
- **Power Exchange:** Provides a market place for trading physical and financial (capacity/energy and derivates) contracts for capacity allocation by implicit auctions within the defined country, region or cross border.
- **Balance Responsible Party:** Ensures that the supply of electricity corresponds to the anticipated consumption of electricity during a given time period and financially regulates for any imbalance that arises.
- **Clearing & Settlement Agent:** Assumes liability for clearing and/or settlement of contracts and provides contractual counterparty within a Power Exchange and for over-the-counter (OTC) contracts.
- **Trader:** A person or entity that buys and sells energy goods and services in an organized electricity market (Power Exchange) or over-the-counter.
- **Supplier [in the areas of energy market places]:** Has a contractual agreement with end customer relating to the supply of electricity.
- **Aggregator:** offers services to aggregate energy production from different sources (generators) and acts towards the grid as one entity, including local aggregation of demand (Demand Response management) and supply (generation management). In cases where the aggregator is not a supplier, it maintains a contract with the supplier.
- **Electric Power Grid Equipment vendors**
- **Ancillary Services providers**
- **Metering operator:** the entity which offers services to provide, install and maintain metering equipment related to a supply. In most EU Member States the DSO is also metering operator. In case of a specific contractual basis, the contract is mostly with the network operator, or may be with the customer or the supplier. The meter may be rented to, or exceptionally owned by, the customer.
- **Information & Communication Technology (ICT) service providers**
- **Grid communications network providers** Plan, build and maintain the communications systems that enable the data communication required to maintain grid stability, load balancing and fault protection systems by a TSO or DSO. This function is mostly executed by the TSO or the DSO, or may be performed by an independent actor but the overall responsibility and ownership of information remains with TSO and DSO. Grid communications network provider ensures compliance with the agreed service levels (Service Level Agreements including quality of service, data security and privacy) and compliance with any national and/or international regulations as necessary.
- **Home Appliances vendors**
- **Building Energy Management Systems (BEMS) providers**, delivering the systems

which facilitate management and control of building facilities, realizing energy saving and increasing comfortability of users of buildings and making full use of the state-of-the-art Information Technology.

- ***Electric Transportation/Vehicle Solutions providers***
- **Grid User/Customer/Consumer:** Entity or person being delivered electricity. How a customer perceives the value received from other actors in the electricity supply chain has a substantial influence on the economic viability of the grid in general and on the overall acceptance of how the electricity supply chain performs.
- **Regulator:** Independent body responsible for the definition of framework (market rules), for setting up of system charges (tariffs), monitoring of the functioning and performance of energy markets and undertaking any necessary measures to ensure effective and efficient market, non-discriminative treatment of all actors and transparency and involvement of all affected stakeholders.
- **Standardization bodies:** Responsible for standardization of all relevant elements and components within the electricity supply chain, which in turn leads to harmonization of relevant services, support towards removing barriers to trade, creating new market opportunities and reducing manufacturing costs.
- **EU and national legislation authorities:** Entities are in charge of defining legislation and metrics for areas such as environmental policy, social policy, energy policy and economic policy. They are also responsible for the authorization needed to develop the electricity grid infrastructure.
- **Financial Sector undertakings:** Provide capital to other actors or invest themselves into the projects within the electricity supply chain (grid, generation, etc.)."

Source: Wording from the EU Commission Task Force for Smart Grids, Expert Group 3 [2]

EEG – paragraphs 1–3 of part 2, chapter 2, section 11

1) *Notwithstanding their obligation in accordance with section 9, grid system operators shall be entitled, by way of exception, to take technical control over installations connected to their grid system with a capacity of over 100 kilowatts for the generation of electricity from renewable energy sources, combined heat and power generation or mine gas, if*
   a) *the grid capacity in the respective grid system area would otherwise be overloaded on account of that electricity,*
   b) *they have ensured that the largest possible quantity of electricity from renewable energy sources and from combined heat and power generation is being purchased, and*
   c) *they have called up the data on the current feed-in situation in the relevant region of the grid system.*

Taking technical control over installations in accordance with the first sentence above shall only be permitted for a transitional period until measures referred to in section 9 are concluded.

2) *The rights under section 13(1) and section 14(1) of the Energy Industry Act of 7 July 2005 shall continue to apply vis-à-vis the operators of installations for the generation of electricity from renewable energy sources, combined heat and power generation or from mine gas where the measures in accordance with subsection (1)*
3) *Grid system operators shall, upon the request of those installation operators whose installations were affected by measures referred to in subsection (1) above, provide verification, within four weeks, for the need for the measure. The verification must enable a qualified third party to fully understand the need for the measures without any additional information; particularly the data ascertained in accordance with subsection (1) first sentence no. 3 above shall serve that purpose.*

Source: Wording from the BMUB [3]

EEG – paragraphs 1–3 of part 2, chapter 2, section 12

1) *The grid system operator whose grid system gives rise to the need for the assumption of technical control under section 11(1) shall compensate those installation operators who, on account of the measures under section 11(1), were not able to feed-in electricity to the extent agreed upon. Where no agreement has been reached, the lost tariffs and revenues from the use of heat less the expenses saved shall be paid.*
2) *The grid system operator may, when determining the charges for use of the grid system, add any charges arising on account of subsection (1) above if the measure was necessary and he bears no responsibility for it. The grid system operator shall, in particular, bear responsibility if he did not exhaust all the options for optimizing, boosting and expanding the grid system.*
3) *Claims for compensation made by installation operators against the grid system operator shall remain unaffected.*

Source: Wording from the BMUB [3]

References

[1] The European Parliament and the Council of the European Union, “Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 Concerning Common Rules for the Internal Market in Electricity and Repealing Directive 2003/54/EC,” Official Journal of the European Union, Brussels, 2009.

[2] EU Commission Task Force for Smart Grids, Expert Group 3, “Roles and Responsibilities of Actors involved in the Smart Grids Deployment,” 04 04 2011. [Online]. Available: http://ec.europa.eu/energy/gas_electricity/smartgrids/doc/expert_group3.pdf. [Accessed 13 05 2014].

[3] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), “Act on Granting Priority to Renewable Energy Sources,” 2013. [Online]. Available: http://www.erneuerbare-energien.de/fileadmin/Daten_EE/Dokumente__PDFs_/eeg_2013_bf.pdf. [Accessed February 20, 2014].

Appendix F – Further results from the European Mandate M/490

Figure F.1 outlines the application process of these use cases with reference to the SGAM (WG RA), the results of the WG SGIS and the set of standards compiled by the WG FSS.

The objective of WG SGIS was to support the analyses regarding information security for smart grids (see [1]). The group identified pertinent standards and assigned them to the needs of the stakeholders. Confidentiality, integrity, and availability were considered as the key requirements regarding information security in this context. The SGIS methodology supports the assignment of weights regarding these aspects.

Structural elements of the approach were used in form of a security view assigned to the SGAM, the SGIS security levels as well as the smart grid data protection classes. Starting with the collection of use cases, the assessment process (referenced as the SGIS toolbox shown in Fig. F.2) includes the assessment of risk impact levels (1–5) for the assets in context of scenarios addressing the key requirements of confidentiality, integrity, and availability. The combination of these impact levels with their likelihood leads to the assignment of an overall security level. Appropriate standards are afterwards assigned as countermeasures appropriate to the individual security level.

The first iteration of Mandate M/490 was completed in November 2012. A second iteration for 2013 to 2014 is currently ongoing, its main focus being the implementation and further refinement of the methodologies of the first iteration and development of a second set of standards as well as system interoperability testing methods and a conformance testing map.

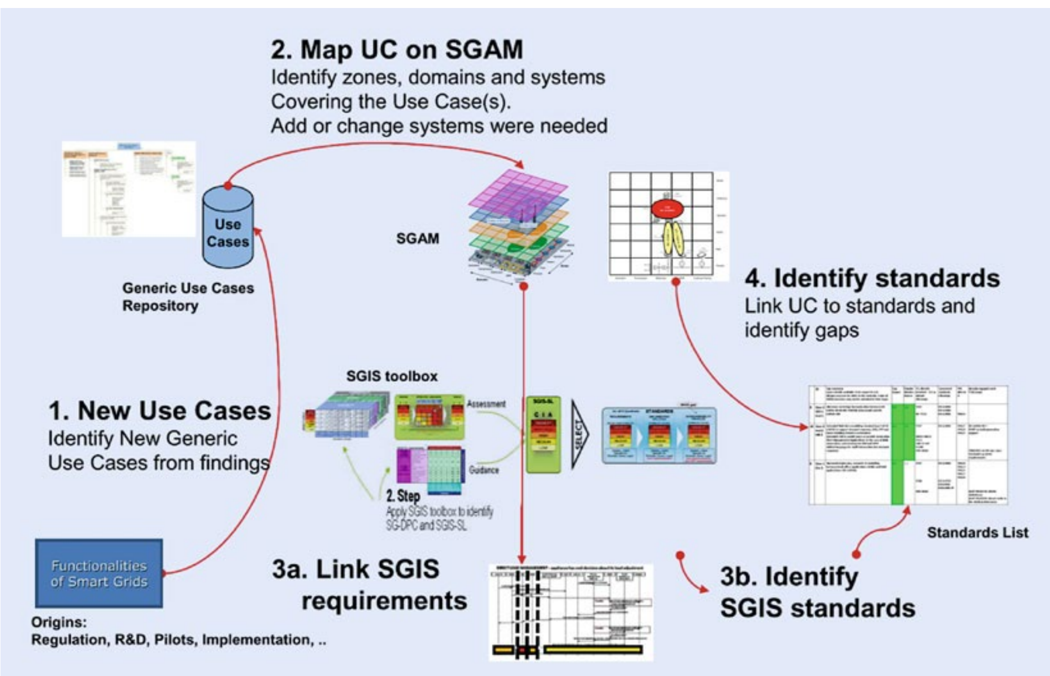
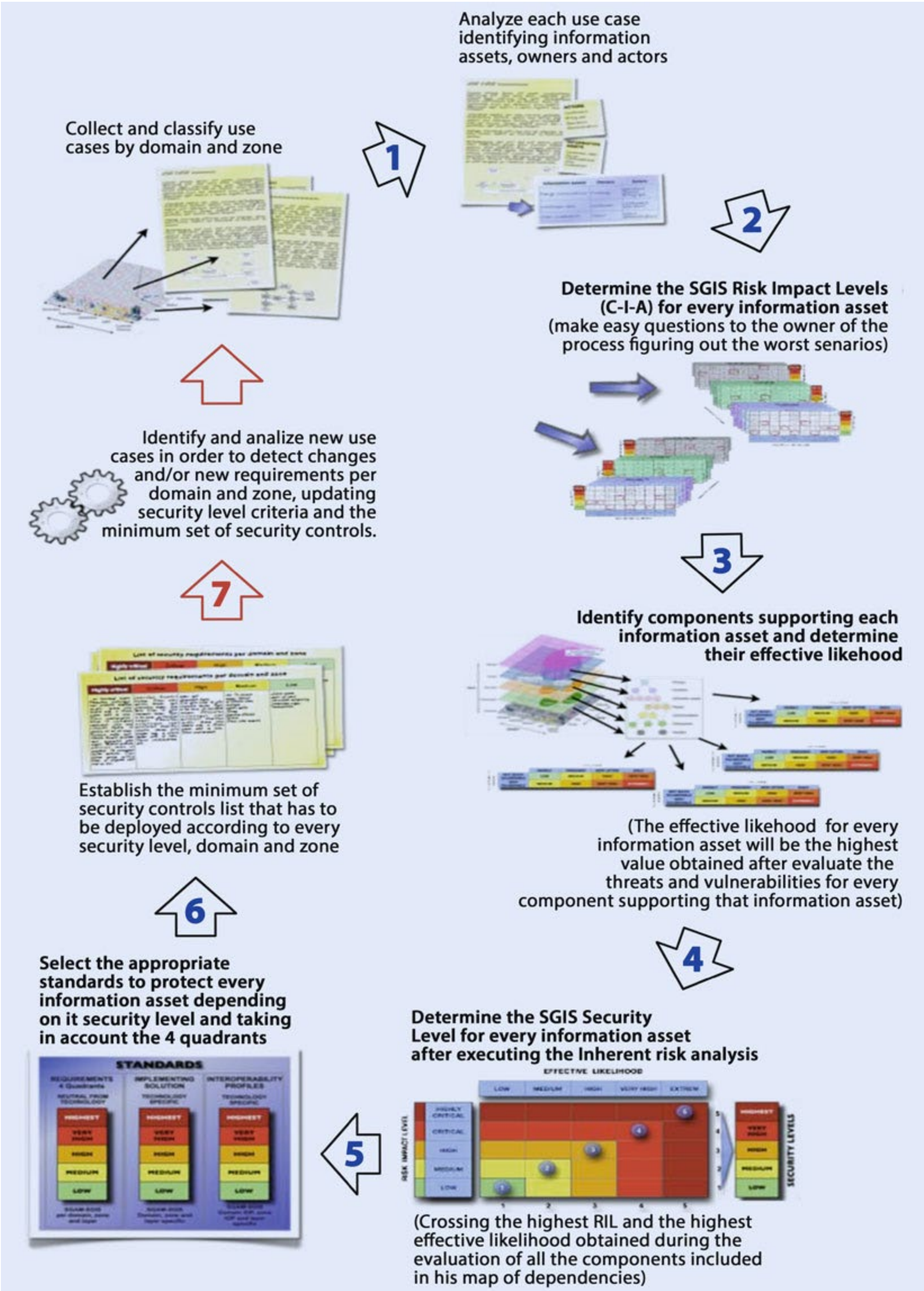


Fig. F.1 Process to apply use cases as the basis for a standardization gap analysis under consideration of functional and security-related requirements, taken from [2]



■ **Fig. F.2** Overview on the smart grid security assessment proposed by WG SGIS, taken from [1]

References

[1] CEN-CENELEC-ETSI Smart Grid Coordination Group, "Smart Grid Information Security," European Committee for Standardization, Brussels, 2012.
[2] CEN-CENELEC-ETSI Smart Grid Coordination Group, "Sustainable Processes," European Committee for Standardization, Brussels, 2012.