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Research Article

Will Energy Infrastructure Systems in Germany Be More Decentralized in the Future? A Participatory Scenario Process

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Abstract Decentralized power generation is gaining significance in liberalized electricity markets. This paper explores the future development of the German energy infrastructure systems with regard to decentralization. Four scenarios have been developed using a participatory multiple-scenario approach. Stakeholders involved in production, consumption, and governance were involved. The results of the study show that the key factor driving the future decentralization of the energy infrastructure system is not technological development. In fact, the economic and political boundary conditions are decisive. It is shown that a scenario-based approach provides substantiated insights into the energy future. The methodology employed is presented, followed by a detailed description of each of the four scenarios. The developed scenarios differ in the share of decentralized energy supply and therefore both structurally and technologically. Based on the historic development, it is analysed whether the trends and developments of the four scenarios are already becoming apparent today.

Keywords scenario; energy; decentralization; participation

1 Introduction

Uncertainties about the long-term prospects of energy infrastructure systems are growing considerably. Network-bound infrastructure systems such as electricity, gas, water, and telecommunications are currently undergoing transformations in almost all industrialized and many developing countries (Al-Sunaidy and Green [2]; Garcia [16], Patlitzianas et al. [33]). These include changes of the regulatory framework (liberalization, deregulation, and privatization), the introduction of new technologies (especially decentralized generation technologies and cogeneration) and the widely recognized need to shift utility systems towards sustainability (climate protection, efficient resource use). The liberalization of the European energy markets has completely changed the way the energy sector functions. Since 1998 electricity systems have entered upon a process of accelerated structural change (European Commission [14]). Climatic changes, environmental issues, and finite resources are keywords in the current discussion about the future of the energy sector (Elliott [11]; Elzen et al. [12]; van Vliet [43,44]). A shift towards decentralized technology can be observed in many industrialized countries (Bohn [4]; International Energy Agency [19]; Lund [24]; Lund and Östergaard [25]). Distributed utility stands for a future network and utility architecture based on distributed generation, resources, and capacity. Different definitions regarding distributed generation are used in the literature and in practice. Decentralized generation can be defined as small-scale generation connected to the distribution network or on the customer side of the meter (Ackermann et al. [1]). In the USA the term "distributed utility" is used, which includes not only local generation but also local storage and local demand side management (Feinstein et al. [15]).

The development of utility systems is determined by the interaction of many heterogeneous factors such as technological innovations, political decisions, market strategies of companies, consumer attitudes, and public debates. The way in which the energy sector in Germany will develop in future remains uncertain. Traditionally, the electricity sector is characterized by a few producers of electricity exploiting large power plants in a country, a transportation company that operates a high-voltage long-distance electricity transmission network, regional companies exploiting a medium, and low-voltage distribution grid, and numerous industrial and residential end consumers. Since 1998 in Germany, the operators of large power plants have in many cases been identical with the operators of high- and medium-voltage networks and indeed, in part, of the low-voltage grids. The liberalization of the energy markets led to an unbundling of electricity producers and operators of electrical grids. In the case of more extensive decentralization, new players could emerge (e.g., wholesalers of electricity) as well as new services (e.g., home services, building management, demand-side management). Increasing demands on a vertical decentralization of the value-added chain of the electricity utilities could, for example, enable grid specialists to enter the market, who would operate grids in a horizontally integrated manner across various sectors. Together with market liberalization a new understanding of the user may be expected. Customer and service orientation may increase and gradually replace the former company logic, which was more strongly based on technological necessities than on user needs. Due to the complexity of possible changes in the energy sector, the future course must be set against a background of uncertainty and long-term strategies will have to be reconsidered (Weijnen and Bouwmans [46]).

This paper focuses on the impact of various internal and external forces on the energy sector in Germany. Due to increased uncertainty, the scenario technique is used to explore possible future developments in the energy sector. The starting point was the hypothesis that decentralization of the energy sector will increase both with respect to technologies (decentralized intelligent grids, distributed power generation in fuel cells, microturbines, cogeneration plants, renewable energies) and also to the supply market, and that the sector will be interlinked more closely with others sectors through the integration of infrastructures, such as the increased use of smart plants and device control ("virtual power plant") and "smart home". This will lead to a stronger focus on customers in the operation of the system. New services will be offered in the area of consumption management using measurement and control technology and customers will be more strongly involved in power generation ("IMS hypothesis": Integrated Microsystems for Supply).

The paper is organized as follows. Section 2 outlines the process used to develop the scenarios. Section 3 describes in detail the products of the scenario process. Section 4 compares the scenarios with current developments. Finally, we draw conclusions with respect to the method applied and the implications for the energy sector.

2 Research approach

The scenario method is an instrument for handling the uncertainties and the complexity of future developments and permits a joint reflection process on the driving forces and general framework of future developments in a structured manner (Chermack [8]; van der Heijden [40, 41]; Schoemaker [37]; Day and Schoemaker [9]). Schwartz [38] points out that the development of scenarios leads to an improvement in decision-making capabilities. In contrast to forecasts, alternative variants of the future are described (Ringland [34]). Scenario techniques have long been used as a method for exploring alternative futures of the energy sector. Energy scenarios have often been formulated with the aid of formal models. More than 400 quantitative energy scenarios are documented in the database developed by Morita and Lee [29]. During the past 30 years, a number of global studies have used those scenarios as a tool to assess future paths of energy system development (International Energy Agency [20]; Nakicenovic [30]). Formal models cannot capture all aspects of energy systems. Qualitative energy scenarios—as developed in the present study—integrate demographic, economic, societal, and technological knowledge (Ghanadan and Koomey [18]). There are different types of scenarios (Notten van et al. [42]). Ducot and Lubben [10], for example, distinguish explorative versus anticipatory scenarios and descriptive versus normative scenarios. Similarly, Börjeson et al. [5] differentiate between predictive, explorative, and normative scenarios. Whereas predictive scenarios concern themselves with the question of "what *will* happen?", explorative scenarios are defined by the fact that they respond to the question "what *can* happen?". The task in normative scenarios is to find out "how a specific target can be reached". In a comprehensive review of all the techniques for developing scenarios, Bishop et al. [3] identified eight general categories of scenario techniques with two or three variations for each type, resulting in more than two dozen techniques overall. Scenarios differ with respect to their starting point, their process, and also their product.

In the past, numerous energy-related scenarios were developed for different regions (regional, national, global) and different time horizons. Most quantitative projections were predictive or normative scenarios (Enquête-Kommission [13]; International Energy Agency [20]; Nakicenovic et al. [30]; Nakicenovic and Sward [31]; Nitsch and Wenzel [32]; Schlesinger et al. [36]; SRU [35]). In this context, most scenarios focus on technology and economic topics. Scenario generation has often been supported by partial or general equilibrium models calculating quantitative values of energy demand, emissions, and costs (van Vuuren et al. [45]). Uncertainties of data were analysed by sensitivity analysis, stochastic, or fuzzy approaches (Kanudia and Loulou [21]; Martinsen and Krey [26]; Messner et al. [27]). However, heterogeneous factors like consumer attitudes, public debates, or strategies of companies were not taken into account adequately. In this paper we try to include such factors. The energy scenarios presented here were developed with an explorative approach. The Battelle Scenario Inputs to Corporate Strategy (BASICS) method was used to generate scenarios of the likely determinants (Millett and Honton [28]). The time horizon of the projection is 20 years.

2.1 Participants

In the present study, 20 participants took part in each scenario workshop. The panel represented, on the one hand, a mix of knowledge and, on the other hand, a mix of views, positions, and scientific disciplines. The workshop involved experts with both theoretical knowledge and also practical know-how about the energy sector and cross-sector

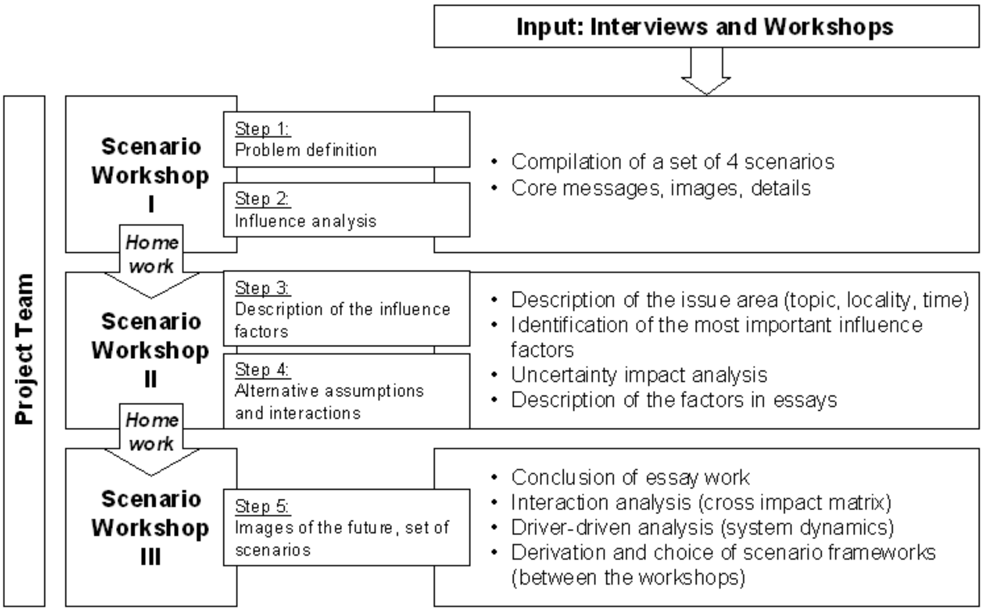

Figure 1: Course of the scenario process.

developments. Participants included providers of supply technologies, representatives of utilities, science, consumer and environmental associations, trade unions, and also politics and the regulatory authorities. Panel members were paid a fee. The amount paid represented a token of appreciation rather than a payment for services at normal professional consulting rates. The three workshops involved the same set of participants each time.

The three scenario workshops were accompanied by the project team. The team was composed of eight academics from various disciplines (i.e., scientists, engineers, economists, and social scientists). The task of the project team was to process the interim results and to make them available as a working paper for the next workshop.

Two independent consultants worked as facilitators of the scenario process.

2.2 Scenario process

In three two-day moderated scenario workshops with 20 participants from science and society at large, four energy scenarios were developed with a spatial focus on Germany and a time horizon of 2025.

The scenario process was guided by the following question: "How (de)centralized, integrated, and service-oriented is the future energy infrastructure system and on which sector-specific and cross-sector influence factors does it depend?" Figure 1 gives an overview of the scenario process.

In order to identify relevant factors influencing the future development of the energy infrastructure system, personal interviews structured by a guideline and workshops were implemented in Germany with more than 100 experts from different groups of actors. The participants included providers of supply technologies, representatives of utilities, science, trade unions, regulatory authorities, consumer and environmental associations. The results served as input for the scenario process. Forty of the most frequently mentioned factors that were regarded as particularly important in the interviews and workshops were included in the scenario process.

In the first scenario workshop, these 40 factors were discussed by the participants. Factors that were not considered to be important were eliminated, others were added, identical and similar factors were combined. The result was a list of 37 factors which, from the perspective of the participants, represent the driving forces in the future development of the supply systems (Table 1).

Each factor was evaluated with respect to importance and uncertainty in the uncertainty impact analysis. The resulting 25 factors with both high influence and high uncertainty (shaded in grey in Figure 2) formed the basis for formulating the scenarios. To this end, each of the factors was described in detail in order to obtain a common understanding of the definition of the factor and the possible directions of the developments. These factor essays comprised:

- Title of the factor.
- Description of the factor.
- Core statement on the current situation.
- Alternative projections of the future.
- Description of the projections of the future.

No.	Factor	No.	Factor	No.	Factor	No.	Factor
1	Interaction of the standard setting within the sectors	11	Macroeconomic development (gross domestic product)	21	Geographical change in consumer structures	31	Price trend (incl. taxes and emission charges)
2	Interaction of cross-sector standard setting	12	Funding environment for investments and innovations	22	Convenience-related acceptance behavior of consumers (users)	32	Level of demand
3	Demands on technical security of supply	13	Development of funding instruments	23	Societal acceptance of new services and technologies	33	Service orientation
4	Development of technologies for increasing efficiency (producer side)	14	Type of control	24	Development of private consumer behavior	34	Size and structure of power plant stock
5	Development of technologies for increasing efficiency (demand side)	15	Shift of decisions to European level	25	Significance and extent of ecological building construction and living	35	Significance of long-term infrastructure investments
6	Development of decentralized technologies and processes	16	Political demands on security of supply	26	Energy mix	36	Market development for smart building technology
7	Development of grid technologies	17	Pressure to deregulate	27	Availability of primary energy carriers	37	Demand side management
8	Development of storage technologies	18	Policy mix of energy and environmental policy	28	(Infra)structural convergence		
9	Development of supply and processing technologies	19	National environmental goals	29	Company and market concentration		
10	Demand for investment in sewage sector	20	Demographic developments	30	Pricing (structures)		

Table 1: Scenario factors.

In the second workshop, a cross-impact evaluation was performed. The aim was to identify interactions between the factors. To this end, the influence of the impact of one factor on the impact of all the other factors was investigated with the aid of a cross-impact matrix. An evaluation was made of both whether a significant influence existed as well as the extent to which this was a strong or weak influence on a scale from 3 to -3. The overall matrix was divided up. The submatrices were each dealt with in small groups. At the end of the work in groups, a cross-check was made of the matrix results. For this purpose, some members of each group moved to another group. This meant that, on the one hand, the scaling of the evaluation was performed in a uniform manner and also that a common approach was taken by all participants, especially in the case of contentious points.

The results of the second workshop were evaluated and processed on the basis of software-assisted analyses. A proven process for developing explorative scenarios was applied, based on the BASICS methodology from Batelles (Börjeson et al. [5]). The input was the cross-impact matrix described above. A total of 75 model runs yielded 36 scenarios, which in part formed clusters. The results were represented in so-called “scenario frameworks”, that is, each factor in a scenario is assigned an impact which then enters into the corresponding scenario.

In the third workshop, four scenarios were chosen from the total and these four were then developed in detail. The scenario frameworks do not provide much detail since the causal relations and interpretations remain unclear. The scenarios are therefore described in detailed, conceivable and plausible, concepts of the future. This comprises the characterization of the scenario with an informative title, identifying the essential core statements and defining the content of the scenario on the basis of the factor essays.

3 Results

3.1 Driving forces and projections

Influence factors covered processes in the provision of the utility such as the size and type of power plant, consumption factors such as geographical changes of consumption structure and regulatory factors such as environmental and energy policy (Table 1).

These factors were evaluated with respect to their uncertainty and their influence on the future of supply. The results of this evaluation are shown in Figure 2. In both categories, each factor (identified by number in the diagram) can be given a number of points ranging from 0 to 4 by a total of six expert groups, that is to say, each factor can receive a maximum of 24 points. The diagram has four quadrants. The 1st-order scenario factors, that is, the very important and highly uncertain factors, provide the main framework of the scenarios.

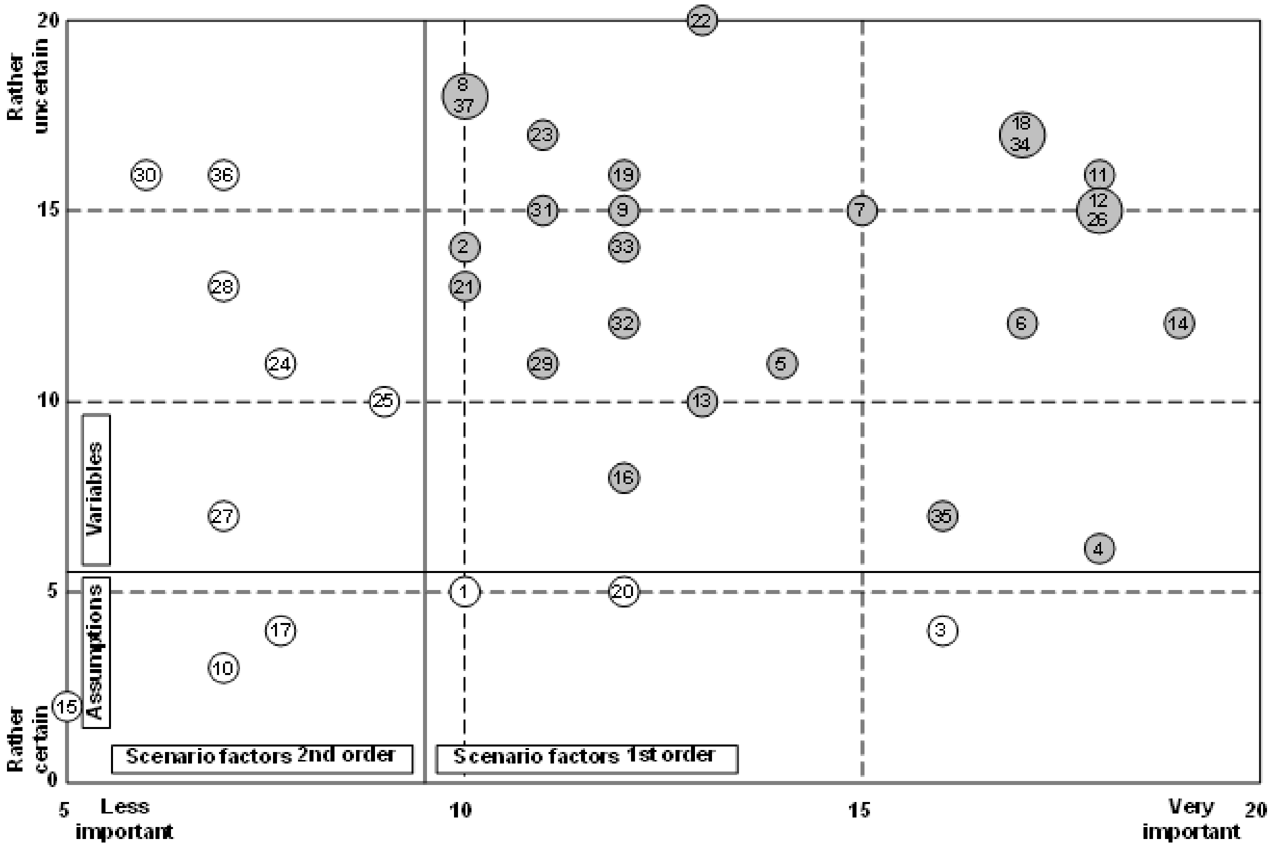

Figure 2: Results of the evaluation of the scenario factors with respect to importance and uncertainty.

The factors regarded as particularly important by the workshop participants are the following.

Technological development:
(4) Development of technologies for increasing efficiency (producer side): the amount of primary energy required for providing a certain amount of electricity and heat can be reduced on the producer side by applying modern highly efficient plants. The measure for this factor is percentage savings of primary energy (relative to the entire stock of power plants). Projections: (a) 20% savings; (b) 10% savings; (c) 5% savings.

(6) Development of decentralized technologies and processes: decentralized technologies are taken to mean plants that provide supply services in a decentralized manner, that is, with little or no recourse to centralized structures. In the energy sector these are decentralized generation of energy with small combined heat and power technologies and decentralized use of renewable energies (such as photovoltaics, solar thermal power, or biomass plants). The measure for this factor is market share. Projections: (a) stagnation at the present level; (b) expansion of the market share to 20–35%; (c) expansion of the market share to 35–50%.

Economic factors:
(11) Macroeconomic development: the measure for this factor is gross domestic product. Projections: (a) no or only weak growth (0–1% p. a.); (b) moderate growth (1–2% p. a.); (c) strong growth (2% p. a.)

(12) Funding environment for investments and innovations: the measure for this factor is the interest rate for long-term loans for utilities. Projections: (a) favorable conditions at approx. 6% p. a.; (b) unfavorable at $> 7\%$ p. a.; (c) unfavorable at $> 9\%$ p. a.

Political requirements:
(14) Type of control: the type of control (economic, ecological, technological) and intensity of regulation has a decisive influence on the development potential and the readiness to innovate on the part of public utilities. The intensity is expressed in the type and extent of the intervention of government regulatory authorities in market events with the aim of, for example, creating competition on the service or grid level. Instruments of regulation are, for instance, controls on market entry (licences), price regulation, obligations to interconnect supply or management of scarce resources. Projections: (a) hardly any regulation, free market; (b) balanced regulation (with proven

Energy mix	Projection 1	Projection 2	Projection 3
Share of nuclear energy	5%	25%	5%
Share of natural gas	40%	9%	9%
Share of oil	1%	1%	1%
Share of coal	24%	60%	60%
Share of renewables	30%	5%	25%

Table 2: Projections of the energy mix.

and well-functioning regulatory mechanisms and authorities complementary to the market); (c) overregulation (measures and specifications are poorly harmonized and consequently inconsistent, inadequate cost optimization).

(18) Policy mix of energy and environmental policy: this involves instruments which can be used to promote energy and environmental goals. On the one hand, there are regulatory instruments such as standards and limits, and on the other hand, market instruments like taxes and certificates. Projections: (a) regulatory instruments are dominant; (b) market instruments are dominant; (c) no or hardly any restrictions (laissez-faire).

Technical implementation:
(3) Demands on technical security of supply: availability of supply is used as a measure of the technical security of supply. Availability is dependent on the availability of capacity reserves and the extent of preventive maintenance. Projections: (a) high reliability due to high expenditure for preventive maintenance, servicing and investments as well as considerable reserves of capacity; (b) moderate reliability due to condition-related control and maintenance as well as moderate capacity reserves; (c) minimal demands on reliability, expenditure for maintenance and servicing and investments minimized as far as possible, low capacity reserves, sensitive customers are increasingly dependent on their own measures for security of supply. Demands on technical security of supply are, however, regarded as fairly certain and a significant deterioration in comparison to the present standard is regarded as fairly unlikely.

(26) Energy mix: “energy mix” is taken to mean the proportion of the individual energy carriers in overall electricity generation (Table 2).

(34) Size and structure of total power plant stock: in 2002, approx. 66% of the installed power generation capacity consisted of medium-sized to large power plants ($>$ 300 MW). Approx. 50% of the installed capacity consisted of power plants that were more than 25 years old and would have to be replaced in the period under consideration. The factor described here indicates the power plant sizes that could cover replacement needs. Projections: (a) 90% of the replacement needs is covered by power plants $<$ 300 MW; (b) 90% of the replacement needs is covered by power plants $>$ 300 MW.

(35) Significance of long-term infrastructure investments: the infrastructure of the supply sectors is composed of long-term capital goods of high value, which can therefore only be gradually replaced by new technologies. This factor describes future changes in the lifetime (turnaround time) of the infrastructure elements. Projections: (a) turnaround times decrease; (b) turnaround times do not change.

The results show that the participants in the scenario workshops attach great importance for the future of the energy supply above all to general social conditions such as economic development, political orientation and its instruments, and also to social values and attitudes. They also consider that these aspects are difficult to predict. In contrast, technological factors, such as the development of technologies for increasing efficiency on the producer side or the development of grid technologies, are also regarded as significant but are much more predictable.

3.2 The scenarios

The participants compiled four scenarios for future energy infrastructure systems:

Scenario A: Decentralization based on consensus

Scenario B: Conservative ecological development path

Scenario C: Wide range of technologies due to strong competitors

Scenario D: No displacement of established structures

In Scenario A, the changes in comparison to the present situation are brought about by a consensus throughout society. Agreement has been reached on the primacy of climate and the environment. However, the defined environmental and health goals remain modest. The main instrument of political control is emissions trading. This leads to the emergence of a reliable basis for innovations, which moreover also profit from moderate economic growth of 2% p. a. and good financial boundary conditions. The government budget for innovation funding remains almost unchanged.

In the course of changes, numerous small companies appear on the supply markets in addition to the well-established utilities, whose share of the market drops to 50%. Rigorous unbundling of the value-added stages prevents cross-subsidies within large concerns and permits fair competition.

Services such as smart home or fully comprehensive packages are not only used to satisfy demands for convenience but also for reasons of efficiency. Smart building applications will gain broad acceptance (30% market penetration). With respect to demand-side management (market penetration 20%) a possibility is perceived of increasing the economic and ecological efficiency of the supply systems and at the same time of opening up export markets for intelligent control technologies. The deliberate exploitation of efficiency potential on the supply and demand side as well as great efforts at further savings on the part of the public will lead to a perceptible decrease in the consumption of electricity by more than 5% in the period under consideration from 2002 to 2025.

Other significant changes concern the energy carriers and generation facilities. Nuclear energy will no longer be used in 2025, the proportion of coal in electricity generation will be halved to 24% while the use of natural gas will increase by a factor of 4 to 45%. About one third of the electricity originates from renewable energies. Decentralized technologies and processes will be greatly expanded. Nearly 23% of the electricity will be generated in decentralized facilities. Cross-sector integration is shown by an appreciable proportion of “virtual power plants” and comprehensive cross-sector standards.

In Scenario B, due to an obvious deterioration in environmental conditions, the government actively implements environmental and climate protection measures. However, the defined environmental and health goals remain modest. The political goal is to speed up technological developments in order to achieve a more efficient provision of energy and a reduction in consumption. To this end, the government innovation budget will be increased by 50% in the energy and supply sector. This will be accompanied by a mixture of regulatory instruments and measures concerning competition and the market; primarily in order to strengthen energy offensives on the part of companies. In spite of merely average economic growth (1.5% p. a.), sufficient capital is available since innovative technologies promise growth.

Severe regulation leads to a deconcentration of the market. Large enterprises encounter competition from foreign companies and from medium-sized enterprises at home. Strong service orientation will become a competitive factor, but new services such as fully comprehensive packages or smart buildings will not be in much demand (market penetration 10% each). The electricity demand will remain at roughly the present level since increases in efficiency will be compensated by demands for greater convenience.

In the energy supply sector, funding and control measures benefit, in particular, from increasing efficiency with centralized technologies. As in Scenario A, gas will become the central pillar of the electricity production with a share of 45%, at the expense of coal (24%). Due to the establishment of large-scale facilities (wind farms, photovoltaic parks), the share of renewable energies rises to 30%. The decentralized and integrated variants of the technologies will be able to moderately expand their share of the market (for electricity 14%) since they cannot be economically exploited to a greater extent. Moreover, the innovative telecommunications services that are a prerequisite for these types of technologies are only found in urban centers.

In Scenario C, the government supports the success of German companies by a massive innovation and technology policy measures with an increased innovation budget. Health and the environment are of minor significance and public awareness of health is also little developed. The aim of the policy is an energy mix mainly driven by economic motivation. Due to attractive returns in other sectors, funding conditions for investments in the supply sector are difficult in spite of high economic growth (2% p. a.).

The structure of the markets in all sectors is characterized by strict price regulation and fierce competition. There is a high level of centralization; four or five large companies dominate the German electricity sector.

The utilities increasingly include the telecommunications sector in their activities in order to accommodate the customers’ rising demands for convenience such as smart buildings (market penetration 30%) and fully comprehensive packages (20%). The introduction of distinct demand-side management (15%) has a cost-cutting effect. Consumer demand for gas and electricity increases slightly. Increase of efficiency is not sufficient to compensate growing demands for more convenience.

The emphasis both in the industrial and private sector is placed on cost effectiveness. This leads to an expanded technology portfolio which focuses on fossil and nuclear energy. The major proportion of electricity is generated from coal (52%) and nuclear energy (20%). Whereas the proportion of renewable energies stagnates (at 10%), the proportion of gas increases to 17%. Decentralized technologies only represent a small share (8.5% for electricity). The electricity grids are optimized while retaining their structure and virtual power plants remain the exception.

In Scenario D, the national economy only experiences weak growth (1% p. a.). Both industry and the government give priority to economic goals. Due to tight public funds, the innovation budget drops by 50%. Competition in the supply sectors is only weakly regulated so that oligopolistic market structures are established. The government only applies market economy regulation instruments such as taxes, charges, and targeted investments. Environmental and health goals remain modest. There is little public interest in environmental and climate policy.

Due to the macroeconomic conditions, a two-class society emerges with a small moneyed upper class whose private consumption is geared to convenience and leisure. Consumer demand for electricity, gas, and water remains constant on the whole since increased demand for more convenience on the part of the “upper class” can be compensated by efficient devices and by the need to save on the part of the broad mass of the population.

There is little change in the supply structure. Centralized supply structures are consolidated. There is little investment due to the weak economy. Although there is a high level of service orientation, the large companies that dominate the market are primarily concerned with their shareholder value and only consider consumer requirements if their turnover is satisfactory. Smart buildings and fully comprehensive packages are available for office buildings and for the moneyed upper class (market penetration 10% each). Demand-side management will become established as a service to a limited extent (10%).

The focus is also on cost efficiency with respect to the whole range of power plants. As in Scenario C, coal is dominant (52%) followed by nuclear energy (20%) and gas (17%). The fraction of renewable energies stagnates (at 10%). Decentralized technologies have only a small share (7.5% of electricity production) because consumers prefer conservative solutions.

Table 3 shows in detail the projections of the important factors in the four scenarios.

4 Comparison of the scenarios with current developments in Germany

The scenarios presented above were developed in 2003. The year 2000 was used as a baseline. Some of the most important influencing factors were quantitatively estimated by the parties involved. These data allow a framework of data to be constructed for the four scenarios for 2025. From the point of view of today, 7 years after they were designed, the question arises whether any of the defined scenarios is now set to become reality. In an initial step, the available energy statistics for 2008 are taken as a basis and a comparable framework of data is created. Current energy statistics do not make a distinction between centralized and decentralized energy supply. Based on a variety of energy statistics, we attempted to distinguish between centralized and decentralized energy supply of the electricity sector between 2000 and 2008. We followed the definitions of centralized and decentralized supply used earlier. In Table 4, the results are compared with the four scenario evaluations for 2025.

It is striking that power generation increased by 14% between 2000 and 2008. This development contradicts the trends in the four scenarios, all of which assume a more or less strong decrease in power generation. The strong increase is, one the one hand, due to the rise in consumption in all sectors. On the other hand, Germany has become a net electricity exporter since the beginning of liberalization. Both developments were either misjudged by the actors or were not even taken into consideration. The rise in electricity from renewable energy sources is particularly significant. This is mainly due to the Renewable Energies Act (Figure 2, Factors 12, 18). The current share of renewables in total power production is approx. 16% (97 TWh). If this is interpreted as a trend, it is in accordance with Scenarios A and B. Table 4 is subdivided into centralized and decentralized supply. An increase in the contribution of decentralized generation is present from 2000. Its share in net power generation rose from 4.6% in 2000 to 17.4% in 2008. This is mainly due to the increase in onshore wind production. No significant increase in decentralized generation from nonrenewable sources (e.g., micro cogeneration), as predicted in Scenarios A and B, has been observed since 2000, even though subsidies are available. The reason is that the necessary technologies are not yet commercially available, which underpins the correct assessment made by the actors in the scenario process (see Figure 2, Factor 6).

5 Insights from the energy scenarios

The findings presented here show that the participants in the scenario process for 2025 only expect a significant decentralization of the energy sector in Germany of a maximum of 22.5% in the sense of the integrated microsystems hypothesis if there is a general consensus in society about the primacy of climate and the environment as assumed in Scenario A. This must be accompanied by relatively high economic growth of on average 2% p. a. throughout the entire period. In real terms, a general societal and user-related acceptance of decentralized technologies can be achieved, which would lead to their widespread application. Application-oriented government funding does indeed improve the climate for investments, but is not in itself sufficient without goodwill on the part of society and the prosperity of wide sections of the population. This is particularly important if high energy savings are also to be achieved as expected in Scenario A.

The current development shows that the framework of governmental control using regulatory measures is necessary for the trend towards decentralization and that the participants of the scenario process rated the importance of this prerequisite correctly but underrated its impact. Subsidies (e.g., German Renewable Energy Act (EEG) and Cogeneration Act (KWKG)) facilitated the expansion of power generation by onshore wind turbines between 2002 and 2008. This explains the high percentage of decentralized units using renewable energies today.

However, this is not (yet) connected with the idea of an integrated, service-oriented, decentralized supply as assumed in Scenario A. In Scenario A, an important role is played by innovations such as the integration of decentralized generation (e.g., micro-cogeneration) in "virtual power plants" or in the area of decentralized "mini-cogeneration plants" using high-efficient fuel cells. This was based on the assumption that primarily fuel cell technologies such as SOFC, MCFC, and PEM would be used, in particular, in trade and industry, public institutions, or entire residential areas. These are primarily supplied with natural gas, but also—and more so than in the other scenarios—with biogas, local sewage gas, or gases from waste treatment. The use of such decentralized options

	Decentralization on the basis of consensus	Conservative ecological development path	Wide range of technologies due to strong competition	No displacement of established structures
	Scenario A	Scenario B	Scenario C	Scenario D
Factor description				
Technologies for increasing efficiency (producer side)	Reduction potential 20%	Reduction potential 20%	Reduction potential 10%	Reduction potential 10%
Technologies for increasing efficiency (demand side)	Reduction potential for electricity and heat 25%, in the water sector 20%	Reduction potential for electricity and heat 25%, in the water sector 20%	Reduction potential for electricity and heat 15%, in the water sector 10%	Reduction potential for electricity and heat 5%, in the water sector 5–10%
Proportion of decentralized electricity generation	22.5%	14%	8.5%	7.5%
Development of grid technologies	Electricity: Conversion from transmission to distribution TC*: Expansion of software and net services for “active” grids	Electricity: No essential change TC*: Some expansion of software and net services for “active” grids	Electricity: Optimization of existing structure TC*: Expansion of software and net services only in pilot projects	Electricity: No essential change TC*: Expansion of software and net services only in pilot projects
Storage technologies: Proportion of electricity storage	5%	2%	< 1%	< 1%
Overall economic development	Economic growth 2% p. a.	Economic growth 1.5% p. a.	Economic growth 2% p. a.	Economic growth 1% p. a.
Funding environment for investments and innovations	Favorable interest rate 6%/a	Favorable interest rate 6%/a	Unfavorable interest rate 9%/a	Favorable interest rate 6%/a
Development of funding instruments	Govt. investment budget remains constant	Govt. investment budget increased by 50%	Govt. investment budget increased by 50%	Govt. investment budget reduced by 50%
Type of regulation	Moderate market regulation aims to strengthen competition	Dominant competition-oriented market regulation	Weak market regulation	Moderate market regulation
Political demands on security of supply	Continuation of the present approach of a strategy of diversification of the energy carrier structure and of supply sources as well as utilization of rationalization potential			
Policy mix of energy and environmental policy	Dominance of market economy instruments	Mixture of regulatory and market economy instruments	Dominance of market economy instruments	Dismantling of existing regulatory and market economy instruments
National environmental goals	Social consensus on primacy of environment/climate	Government actively involved in protecting climate/environment	Primacy of cost efficiency	Government disengagement
Geographical change in consumer structures	Migration to rural areas	Preference given to outskirts of urban areas	Preference given to outskirts of urban areas	Concentration in urban areas
Acceptance behavior Health awareness Significance of transparency	Very high Consumer interest in environment and price labeling	High Government-regulated environmental and price labeling	Minor significance Consumer interest in price labeling	Present but not implemented No consumer interest in labeling
Societal acceptance of new services and technologies	Widespread acceptance			
Energy mix: Proportions of natural gas coal renewable energies nuclear power	45% 24% 30% 0%	45% 24% 30% 0%	17% 52% 10% 20%	17% 52% 10% 2%
Company and market concentration	Deconcentration	Deconcentration	Oligopolies	Oligopolies
Price rise (incl. taxes and emission charges)	Electricity & gas 1%/a	Electricity & gas 1.5%/a	Electricity & gas 2%/a	Electricity & gas 2.5%/a

Table 3: Continued.

Level of demand	Decrease by more than 5% for electricity and gas	Constant for electricity and gas	Increase of 2% for electricity and gas	Constant for electricity and gas
Service orientation: Proportions of	Plant contracting 30% fully comprehensive packages 15%	Plant contracting 5% fully comprehensive packages 5%	Plant contracting 30% fully comprehensive packages 20%	Plant contracting 10% fully comprehensive packages 10%
Coverage of replacement needs (power plant stock) by small & medium-sized power plants	50%	30%	30%	30%
Significance of long-term infrastructure investments	Turnaround times decrease	Turnaround times constant	Turnaround times decrease	Turnaround times constant
Proportions of demand-side management	20%	10%	15%	10%

Table 3: Overview of the features of the four scenarios.

		2000	2008	2025			
				Scenario A	Scenario B	Scenario C	Scenario D
Savings compared to 2000	%	—	−14	5	0	−2	0
Net electricity production	TWh	527	599	501	527	538	527
Nuclear	%	30	23.5	0	0	20	20
Lignite	%	26.3	23.1	10	8	22	30
Hard coal	%	25.3	19.1	14	16	30	22
Natural gas	%	10.9	13.9	45	45	17	17
Oil	%	0.6	1.5	1	1	1	1
Renewables	%	6.9	16.1	30	30	10	10
Others	%	0	2.8	0	0	0	0
Total	%	100	100	100	100	100	100
Centralized	%	**95.4**	**82.6**	**79.7**	**87.4**	**90.8**	**92.3**
Renewables	%	4.8	4.3	17.2	21.4	4.3	4.3
Non-renewables	%	90.6	78.3	62.5	66.0	86.5	88.0
Decentralized	%	**4.6**	**17.4**	**20.4**	**12.6**	**9.2**	**7.7**
Renewables	%	2.1	14.6	12.9	8.6	5.7	5.7
Non-renewables	%	2.5	2.8	7.5	4.0	3.5	2.0

Table 4: German net electricity production subdivided by centralized and decentralized categories and energy sources (Bundesnetzagentur [7]; Lochte et al. [23], BMU [6]; own calculations).

for generation has failed so far because they are not (yet) commercially available. This underlines the assessment of those involved in the scenario process, who regard the technological development of decentralized generation techniques as particularly important and consider forecasts very unreliable.

However, the hypothesis of integrated microsystems encompasses not only the technological side, but also structural changes of the energy sector. The supply market in Scenario A is characterized by a combination of public utilities, new service providers (such as service brokers, integrated facility management companies), small-scale enterprises (e.g., for the inspection and service of on-site fuel cells), providers from abroad and large utility companies. The dominance of 3 to 4 large companies on the supply market will be reduced to a market share of 50% by the year 2025.

Smaller companies such as municipal utilities, which specialize in customer groups and individual services, or companies outside the business sector, for example, facility management companies, will compete with the large utility providers. In addition to the core product, electricity, they may also offer other services such as contracting, in particular for industrial customers, control technology, and other devices or facilities for energy and resource management as well as communication and information services. The market penetration of facility contracting in 2025 is estimated at 30% for Scenario A.

Looking at the developments since the year 2000 (Table 4), it becomes clear that power consumption has risen and that there is no trend toward savings as predicted in all scenarios.

The assumption behind Scenario A, but also behind Scenario B, was that the state promotes environmental protection and that there is a societal consensus supporting the primacy of environmental protection. Research funding and so on is to ensure that innovations such as fuel cells are developed further while subventions are to facilitate the implementation of decentralized facilities are implemented and the acceptance of renewable energies. Today, new decentralized technologies such as fuel cells are not yet mature. The same is true for micro-cogeneration technologies and virtual power plants. All topics, including demand-side management, smart buildings, and so on, play an important role in the current discussion on energy and are the subject of numerous current research and development activities. At the moment, no large markets are expected to be opened up, with a few exceptions such as smart metering. It is now becoming obvious that new decentralized providers, who are increasingly characterizing the market, do not necessarily mean technological decentralization. Instead, there is an increased interest on the part of today's central providers in decentralized technologies (e.g., smart metering, virtual power plants), which the actors tended to underestimate.

The considerable decentralization that has already been achieved in comparison to 2000 is not associated with a fundamental change in grid-based supply. In addition, it does not (yet) lead the way by promoting the use of renewable energies to the extent expected. This is mainly due to the conflicting interests of the market players (e.g., producers, grid operators).

At the moment, there is a strong trend towards decentralization of the energy supply based on technology. However, there is currently no development towards a decentralized, integrated, service-oriented grid supply. The quantitative expansion does not necessarily represent the simultaneous qualitative change assumed in Scenario A.

The study reveals how important government activities are for increasing the decentralization of the energy sector—especially under unfavorable economic conditions. One of the most important future challenges seems to be in applying suitable government measures to remove obstacles standing in the way of implementing decentralized, integrated, and service-oriented systems. In parallel, suitable public R&D programmes must promote the required technological innovations (e.g., micro-cogeneration, grids, storage technologies), because they are a necessary prerequisite for a decentralized supply.

6 Conclusions

The aim of this study was to obtain some idea of whether in future, greater decentralization, integration, and service orientation of the energy sector is to be expected in Germany. The results of the current study are based on a participatory scenario process. We especially focused on the scenario method, the participatory process and its value for understanding the energy futures exemplary pointed out for Germany.

In technology foresight exercises, expert panels have tended to be the norm, although there is now a shift towards incorporating more stakeholder-type panels. Technology foresight is, by definition, a participative, discursive activity that should be based upon the best available evidence and judgement where "academic" knowledge and "practical" know-how can complement each other (Georghiou and Keenan [17]).

The present study shows that as a participatory tool, the scenario method is suitable for fostering societal involvement in the debate about possible futures. The scenario method employs highly structured and systematic processes. This is a special advantage of the method so that it can provide well-founded results even for controversial topics. The participants were in agreement that the results would be relevant in the context of their own work and helpful for strategic planning in the energy sector.

Three factors proved essential for the success of such a complex process. (1) A strong commitment to the process by the participants is indispensable since it requires a good deal of time, attentive capacity, and willingness to engage. (2) Implementation of the process requires independent facilitators, who not only contribute their experience in methodology and moderation, but also a basic understanding of the topic, in this case energy. (3) A participatory scenario process requires clear rules on how to deal with controversial positions, as shown, for example, in weighting the driving forces or evaluating interactions in the cross-impact matrix. It is recommended that agreement on the approach to be taken be reached right at the beginning of the process.

One of the most difficult steps in the scenario process is compiling the cross-impact matrix (Weimer-Jehle [47]; Stover and Gordon [39]). The main issue arising here is, on the one hand, how the quality of the evaluation can be ensured and, on the other hand, how the time required for processing can be reduced. The process applied in the study of cross-checking the matrix results for quality assurance has proved its worth.

The time required for scenario processes is a critical factor. In the present study, the project team undertook a number of tasks such as composing the text of the factor essays on the basis of core statements made at the workshop. Since the participants had the opportunity to modify the input, they experienced a high level of identification with the results. However, further research is required to evaluate the extent to which the establishment of transparency in the process with respect to the "participation" of the project team ruled out any distortion of the results. For future projections the presented scenario approach should be complemented by traditional quantitative energy scenario approaches. The advantages of such a framework should be used as an instrument for early detection. In combination with an assessment of the scenarios with regard to sustainable development, it could supplement the decision process of policy makers (Karger and Hennings [22]).

The historical development since 2000 shows that the framework of governmental control using regulatory measures plays an important role to push the development towards decentralization and technology development. The participants of the scenario process rated the importance of this prerequisite correctly but underrated its impact. Adjusting of the scenarios from time to time seems to be a suitable way. A comparison of scenarios with the actual development (e.g., after five years) makes it possible to modify action strategies accordingly and to redetermine them in an incremental scenario process.

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