Qualitative Infrastrukturszenarien für die deutsche Energiewende: Integration von Akteuren und Institutionen in langfristige Technologiezukünfte

8 - Energie, Wirtschaft und Gesellschaft

Who puts the German Energiewende into action? Characterizing arenas of change and implications for electricity infrastructure

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Abstract

Germany's energy system is in a state of transition known as the *Energiewende,* targeting a competitive low-carbon economy until 2050. Existing mitigation scenarios for Germany describe technological transitions that are driven primarily by exogenous assumptions; little reference is made to the questions of why and how this change comes about and which actors and institutions are decisive in this process. We contribute to filling this gap. Based on a comprehensive literature review we characterize arenas of change in the German electricity system by specifying key actors, their motives and activities and infer implications for the electricity infrastructure of the future. A synthesizing discussion illustrates that the question of how to transform the German electricity infrastructures is ultimately a question of values that need to be resolved in public debate. However, a long latency period in grid-based infrastructure development posits limits on the kind of Energiewende that can be realized in the decade to follow. Based on this characterization of the actor landscape, future research will develop qualitative infrastructure scenarios by engaging the important actors which have been identified.

Keywords: actor landscape, strategic action fields, energy system transformation, mitigation

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1. Introduction

Germany's energy system is in a state of transition known as the *Energiewende*. Four political targets are on top of its agenda: (i) climate mitigation through reducing CO_2 emissions by 80-95% in 2050 relative to 2005, (ii) phasing out nuclear power until 2022, (iii) competitiveness and (iv) security of supply [1], [2]. The two central strategies by which the Energiewende is pushed are to increase the share of renewable energies and to decrease the primary energy demand, i.e. efficiency improvements [2]. A variety of model-based scenario studies showed that it is *technically possible* to achieve these long-term targets *if* a profound transformation of infrastructures along the entire energy chain from conversion (generation technologies) over distribution (electricity grid) to end use (devices that provide energy services) is achieved cf. [3]. However, in reality electricity-related infrastructures are subject to strong path-dependencies, stemming from their high degree of capital intensity, considerable regulation, long life times of physical assets and strong complementarity between system components [4]. The authors of the latest model-based scenario that accomplishes all the government's energy and climate policy targets judge their own scenario as improbable [5]. Essentially, they doubt "whether politics and society possess the required will and consistency for implementing all changes necessary for target attainment today and in the future" [5, p. 378].

Against this background the present paper aims for a better understanding of the Energiewende as a societal change process. Departing from the insights generated by model-based scenario studies it asks: Who are the actors that potentially put the changes necessary for decarbonizing the German electricity system into action? What are their main motives? And under which conditions could they induce even more – and what kind of – productive change in the future?

Literature reveals a long tradition of research on how technological change comes about in societies. The still-prominent theory of large technical systems developed by Hughes [6] considers the electricity system as a complex of interrelated technical and social artefacts, orchestrated so as to achieve the common system goal of an uninterrupted electricity supply. System builders (e.g. inventors, entrepreneurs, finances, managers) create these artefacts. Pinch and Bijker [7, p. 27] add that in large technical systems, technical change is determined by "a scientific consensus on what the "truth" is in any particular instance", followed by technical closure that occurs when the relevant social groups see a problem as being solved. The underlying notion of consensus-orientated social constructivism stresses harmony and cooperation and views conflicts as dysfunctional phenomena. Hård [8] judges this view of technology as functionally arranged socio-technical systems as deeply flawed; a conservative iron cage with no way out. On the contrary he argues that social conflict is *essential* for technology change as "technology is inherently red in tooth and claw" (p.416).

Indeed, the history of the German Energiewende cannot be recounted without reference to the ever-growing anti-nuclear movement that organized large-scale demonstrations and public protest since the 1970s [9]. Finally, in 2001 the new red-green Federal Government enacted the nuclear phase-out until the year 2021. The origin of renewable electricity in Germany also roots in this social movement against high-risk technologies fuelling the desire to develop alternative technologies [10]. In 1990 the first version of a feed-in law for renewables drafted by two members of parliament passed legislation, ultimately supported by all members of parliament. At that time the incumbent utilities did not mobilize, likely because they underestimated the importance of the law and because they were absorbed in taking over the East German electricity sector [11]. In 2000, the feed-in tariff was redesigned with the Renewable Energies Act and from then onwards generated a true boom in renewables deployment, leading to an increase in the share of renewables in electricity generation from 3% in 1990 to 26% in 2014 [12].

Strunz [13] adopts a resilience[1] approach to frame the Energiewende as a shift from a fossil-nuclear regime to a renewables-based regime. He argues that over the past decades the resilience of the fossil-nuclear regime has eroded continuously and its supportive economic-political feedback weakened as liberalization and the rise of renewables in Germany unfolded. Regarding the design of the new renewables-based regime, different actors hold different vision of its final state. They range from the polar archetypes of a highly centralized and supply-side oriented engineering future to the Energiewende being embedded into a deep reorganization of capitalist society towards more decentralized and local structures. A closer look reveals that the types of infrastructure required for either of these archetype visions and the continuum they span is quite different: While the "centralized, supply-side oriented engineering future" hinges on large-scale generation units and pan-European transmission capacities, the "decentralized, demand-side oriented new society" relies on small to medium-scale local or regional solutions involving smart infrastructures and storages. Based on the idea that technological and institutional change are interrelated, Künneke [14] suggests that a more decentralized structure of planning and control of the technical electricity system would be more consistent with a liberalized market that the predominant centralized approach.

To date it remains open which kind of electricity system architecture will govern the supply and demand of electricity in some decades from now. A variety of constellations is conceivable. Due to the long lead-times of infrastructure planning and deployment the type of infrastructures that the German regulator approves *now* will define the character of electricity system *in one or two decades*. However, in Germany there is no single regulatory institution that oversees a coordinated development of the energy system as a whole. While the Federal Network Agency as a central institution determines the regulation of the transmission and distribution grids, the deployment of generation capacities is regulated at county, regional, or communal level. This leads to considerable challenges in the coordination of the Energiewende as a multi-level transformation process and conflicts between local or regional initiatives, large-scale players and the idea of an efficient overarching system structure [15].

In order to advance the understanding of the infrastructure requirements in the German Energiewende this paper pursues a comprehensive literature review to characterize different arenas of change in the electricity system. We do so by specifying key actors, their motives and activities and infer implications for the electricity infrastructure of the future. We define arenas of change as real or virtual fields of interaction on a shared issue, in which actors purposefully or not pursue actions that collectively lead to macroscopic change processes, thereby adapting the technological, economic and legal status quo.

[1] Resilience is the "capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" [101].

By focusing on actors in potentially conflicting arenas of change as structuring units of analysis we explicitly take into account the sociological dimension of technology development. In due course this line of research targets to develop more holistic Energiewende futures: Qualitative infrastructure scenarios that can serve as a point of reference for both quantitative modeling exercises and the public discourse. As a first step this paper delivers a structured overview of the actor landscape in the German Energiewende that is of value to other modelling as well as non-modelling energy transition researchers.

The remainder of this paper is organized as follows. Section 2 elaborates on the analytical framework, arenas of change. Section 3 selects and characterizes arenas of change in the German Energiewende and identifies implication for their respective electricity-related infrastructure requirements. Section 4 provides a synthesizing discussion. Section 5 concludes.

2. Analytical Framework

We introduce the term "arenas of change" in the context of low-carbon energy transitions as a concept that combines elements of several existing theories and ideas, namely a social conflict perspective on technology [8], issue arenas [16], strategic action fields [17] and transition arenas model [18], [19]. Regarding a larger theory of change we see the idea of an arena of change embedded in the resilience framework [20], more specifically as applied to the energy system by Strunz [13]. The following elaborates on our understanding on arenas of change and in what way the concept is useful. It further outlines the scope of the analysis at hand by motivating the concrete arenas of change we characterize in Section 3.

Arenas of change are real or virtual fields of interaction on a shared issue, in which actors purposefully or not pursue actions that collectively lead to macroscopic change processes – thereby endogenously adapting the technological, economic and legal status quo. Social fields are networks of actors who share the issue at stake but have different agendas and views about what the outcomes of action in the field should be, motivated at least partially by their political ideology [17], [21], [22].

The ancient Roman arena was a place that hosted fighting contests. Metaphorically speaking, the arena of change also refers to an open but confined virtual space in which competitions take place – competitions on change. The notion of the arena is suggestive of an implicit social conflict perspective posing that social conflict is a cause of innovation, diffusion, transfer and applications [8]. Having established this basic premise, the question arises of how to make the concept of arenas operational as a framework for analysis, i.e. how to delimit an arena. Here, we draw on the concept of issue arenas [16], a dynamic stakeholder model that combines insights of stakeholder theory and issues management in the public relations realm. They consider Schattschneider's [23, p. 74] definition of what an issue is: it becomes one when "the battle is joined and conflict occurs"; the scope of an issue is defined by the number of actors involved, the visibility in different media and the level and intensity of the debate. An issue arena is the place where the public debate about an issue is conducted with the dynamic interaction taking place in the traditional or virtual media. In this struggle of power all players, e.g. private, political, and non-governmental, have their own agendas and strategies. According to the theory of strategic action fields, individual actors will be most successful if they possess a high level of social skill – the "cognitive capacity for reading people and environments, framing lines of action, and mobilizing people in the service of these action "frames"" offering identity and room for interpretation [17, p. 7]. Social skill rests on the notion that people want to produce collective action by engaging others to cooperatively create and maintain stable social worlds.

What types of actors are present in arenas of change? From an issue arena perspective, the answer was all organizations, governmental units, non-governmental groups, civil society actors and private persons that have a stake in the debated issue. From a strategic action field perspective it is social actors that are either incumbents or challengers, potentially also from related fields, as well as the state. For transformative change to occur the theory of strategic action fields posits that a strategic action field is first destabilized, followed by a transformation led by challengers, i.e. socially skilled strategic actors, and potentially assisted by state actors [17]. In order to be classified as transformative change there needs to be a fundamental restructuring of power relationships within a field. The transformation may well result in the formation of a new strategic action field. The necessity of purposive action in the governance of a socio-technical transition is also a major aspect in the concept of a transition arena, defined as the field in which actors involved in long-term innovation can interact, cooperate, discuss and compete [18], [19]. This network of change agents is one of the pillars of the transition management approach – next to envisioning, experiments, learning, evaluating and monitoring [24].

The abovementioned theories have been applied to case studies in energy systems research before. Luoma-aho and Vos [25] performed a content analysis to characterize the issue arena of nuclear energy in Finland finding a rather shallow and not very passionate debate. Bosman et al. [26] show evidence for discursive regime destabilization in the Dutch energy debate by outlining the how the incumbent's dominant storyline is slowly eroded by potentially disruptive storylines including the German Energiewende and decentralization of the energy system. Fuchs [27] applies the theory of strategic action fields to the German energy supply system and show how the dynamic development of photovoltaic systems represents a transformation that was dependent on the bottom-up establishment of a new support coalition, which created a new form of governance for the promotion of renewable energies – against the opposition of incumbent actors. In a similar manner, Wassermann, Reeg and Nienhaus [28] investigate the development of direct marketing of renewables as an emergent sub-field of the German electricity system. Here, incumbents have been more successful in contesting new visions on an alternative regulative framework by challengers. They conclude that the transformation process for integrating rising shares of renewable energies in the German electricity system has still a long way to go and is highly dependent on innovative actors. Transition arenas have been used by the Dutch Ministry of Economic Affairs to structure their energy transition process. An initially experimental process led to the "commitment of hundreds of professionals to a shared agenda and concrete projects […], more sense of urgency for the issue and political attention for the subject" [19, p. 255].

On a final note we address the question of how different scales interact in the arenas of change framework. A distinctive conceptual characteristic of strategic action fields is that they represent a meso-level social order that themselves contain a number of lower-order strategic action fields, like a Russian doll [17]. In addition, the theory postulates that the more connected a strategic action field is with others and the higher it is in the hierarchy, the more stable it is. This means in turn that the lower a strategic action field is in the hierarchy, the more unstable it is. However, in this regard we would like to deviate from the theory of strategic action fields and embed the conceptualization of arenas of change in the resilience framework. Strunz [13, p. 156] argues that "in the Energiewende, resilience on a specific lower scale contributes to transformability on a higher scale, and not vice versa". This is a very compelling argument, as for example a resilient distribution grid in the presence of high shares of fluctuation renewables locally (low scale) is a necessity for the political Energiewende to take place on the national level (high scale). The resilience framework also foresees a non-hierarchical level connection of levels known as panarchy [20] that allows for low and high levels (local versus global) to mutually influence each other dynamically. This implies that change in the resilience framework is a non-linear rather than a gradual process [13].

3. Arenas of change in the German Energiewende

The major insights generated by model-based scenario studies for the German energy system are as follows. In order to mitigate greenhouse gas emissions, the share of electricity generated from fossil energy has to decrease substantially. Three strategies to deliver electricity in the future include increasing the share of electricity generated from renewable energy sources domestically, importing renewable-based electricity and decreasing total electricity demand [3]. To accommodate the fluctuating renewables wind and solar these scenarios explicitly or often times implicitly assume the deployment of energy storages and demand side management to achieve an inter-temporal shift in electricity supply and demand as well as an expansion of transmission and distribution grids to relocate electricity geographically. We comprehend each of these insights to represent an issue in the solution space from an energy system perspective. Hence we delimit the arenas of change accordingly; Figure 1 provides an overview. The generation of renewable electricity is split into large-scale and local renewables to accommodate their structural differences. We ask for each arena of change the questions: Who (actors), what (activities) and why (motive)? Based on these elaborations we indicate the implications for electricity infrastructure and outline necessary enabling conditions.

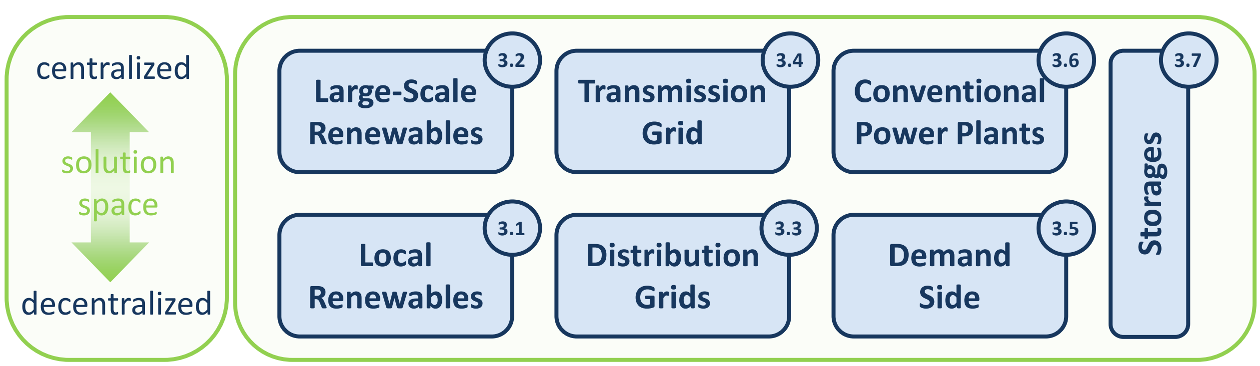

Figure 1. Overview of the scope of the analysis: Arenas of change in the German electricity sector delimited by function from an energy-systemic point of view. Numbers indicate the Subsection they are discussed in.

3.1. Local Renewables

Local renewables refers to all infrastructure assets designed to convert the primary renewable energies solar irradiation, wind, biomass or hydro energy (small) into electricity and are owned by individual or collectively organized citizens that dwell in relatively close geographical proximity. Local actors owned 46% of the installed renewable generation capacities in 2012, consisting of individual citizens and farmers (25%), cooperatives and other forms of citizen organizations (9%), jointly referred to as citizen participation in the narrow sense, and minority or interregional citizen participation models (12%), known as citizen participation in the wider sense [29]. The main reasons for this substantial share of citizens as investors for solar energy, onshore wind energy and bioenergy technologies are found within the institutional framework conditions, technology-specific aspects and financial characteristics of these projects [30]. Small-scale renewable projects are financially unappealing for large energy companies with expected yields of 4-6%. The technologies are accessible to individuals due to their modular, simple and reliable character next to low maintenance requirements lead times. Institutional framework conditions have been favorable because the German feed-in tariff system was designed to minimize the investee's exposure to risk [31] and the German development bank (KfW) provided favorable loans. Cooperatives have experienced a boom in the energy sector, increasing from 35 in the year 2005 [29] to 635 involved in electricity and heat generation by 2013 [32]. Cooperatives differ from private companies in that they are user-oriented instead of investor-oriented and intrinsic values of the cooperative model include collaboration, democracy, social-responsibility and the provision of quasi-public goods [33].

In addition communal and municipal utilities, referred to as public utilities hereafter, have a strong tradition in Germany. They root in the constitutional right of self-determination of communes, which also according to the treaty of the European Union have the task to provide the basic services for the public [34]. Even though the portfolio of public utilities is still dominated by thermal generation, almost 10% of their electricity generation was already based on renewables in 2013 [35], corresponding to around 4% of installed renewable generation capacity [36], [37]. The majority of public utilities prioritize a strategic adjustment towards a portfolio with more renewables and considers themselves as a central actor in the implementation of the Energiewende due to their local or regional roots [38]. It is noteworthy that between 2010 and 2013 more than 70 public utilities have been newly founded and, reportedly, their top three targets were achieving the Energiewende targets locally, improving the local value added and cross-financing important communal tasks [39].

Due to the geographically dispersed character of local renewables this arena of change is best understood as a heterogeneous aggregate of local arenas of change on the communal or municipal level in which conflicts are concrete. A frequent source of conflict is the siting of renewable generation capacities next to opposing abutters that fear visual, audible or other impact, particularly in case of wind turbines. Both experience and research suggest that active forms of citizen participation improve the public acceptance of renewables, defined as the constantly changing result of a social valuation process that takes into account not only landscape changes, the type of technology itself and economic issues, but also distributive and procedural justice in the mode of deployment [40]. In this context weak forms of participation [41] like informing and consultation may not lead to local acceptance and support.

If the overall trends in this arena of change continue, the implications for electricity infrastructures are likely that future generation capacities will increasingly (i) be owned by actively engaged citizens as well as locally rooted public energy service providers, (ii) consist of small and middle-sized modular units that are installed in geographical proximity to the owner(s), and (iii) be guided by motivations that exceed the target of generating electricity and include especially societal values and local benefits.

Necessary enabling conditions for a continuously increasing share of local renewable electricity generation are that (a) remuneration schemes for investments remain simple enough and investment risks low enough for local actors to invest, (b) an increasing share of local actors engages financially in the energy transition, and (c), locally, security of supply is maintained at a high (cf Section 3.3). Also, (d) sufficiently many local renewable energy sites are approved for deployment by communes, (e) the societal values are credibly maintained by the involved actors and (f) local benefits accrue as promised.

3.2. Large-Scale Renewables

Large-scale renewables refers to all infrastructure assets designed to convert the primary renewable energies solar irradiation, wind, biomass or hydro energy into electricity and are owned by institutional or strategic investors as well as private or larger public utilities that are primarily driven by the motivation to maximize the expected financial return on investment. Institutional and strategic investors owned 41.5% of all renewable capacities in 2013 [29]. These actors include companies from the manufacturing and processing industry (e.g. the wood industry), institutional investors who pursue investments for others (e.g. banks, insurances, investment companies, corporations) and project developers. Only the remaining 12.5% of renewable capacities was owned by utilities [29], whose primary business field is the generation of electricity. Deducting the 4% that are owned by public utilities (cf Section3.1) renders the four corporate utilities that are active in Germany with a joint share in renewables capacities of less than 9% in 2012. In 2014 e.on was the first private utility to announce a strategic readjustment that explicitly includes, amongst others, the vision to become an internationally leading provider of large and mid-scale wind and photovoltaic solutions [42].

Next to sizeable onshore wind and PV parks and combined heat and power plants (CHP) fuelled by biomass, particularly the technologies offshore wind and concentrated solar power (CSP) are interesting for large-scale investments. Due to their substantial inherent risks and large upfront investments, offshore wind and CSP projects are manageable only for investors that can diversify risk in their investment portfolio and have a relatively favorable cost of capital. The actors involved in large-scale renewable energy deployment are primarily international corporations that have an investment horizon stretching well beyond German borders. Therefore, from the perspective of the investor, potential sites in Germany are in direct competition with those outside of Germany, which are often times more favorable in resource quality for both wind and solar. However, it is not only the resource potential that enters the investment valuation, costs for e.g. permitting procedures, lease of land, insurance and expected electricity prices matter, too [43]. Not to be neglected is also eventual costs for the engagement of local citizens, particularly abutters, to avoid costly public protest. If locals perceive the planning process as closed and the project to be only for the benefit of distant and private investors then their acceptance is often times low [44], leading to a lack of support [45] and maybe even protest.

The most prominent vision for a European electricity future based on large-scale renewables is the "Desertec" idea, proposing to site renewables in areas with the comparatively most favorable potential and then built sufficient long-distance transmission capacities to transport the electricity between North Africa, central Europe and the Nordic countries. Their major argument is the high economic efficiency, because electricity is generated where capacities are utilized best. A variety of analyses suggest that a European/North African integrated solution is economically efficient both from the perspective of the region as a whole [46]–[48] and Germany individually [49], [50]. Creutzig et al. [51] argue that under certain conditions the deployment of large-scale renewables in the European periphery can also help alleviate the impacts of the economic crisis in these countries. However, in order to develop a pan-European electricity system that is based on large-scale renewables it is necessary that the exploitation of favorable potentials takes place in a coordinated manner. This involves, for example, a harmonized European renewable support scheme, which is not high on the political agenda. Also, energy mixes are subject to national sovereignty under current legislation (cp. §194 TFEU).

If this transition arena manages to be dominant in the future, the implications for electricity infrastructures are likely that future generation capacities will (i) be owned by corporate utilities, institutional or strategic investors from Germany or abroad, (ii) consist of rather large-scale generation units that have a tendency to be installed where the resource potential is most favorable, and (iii) are motivated by the intention to maximize return on investment. Necessary enabling conditions for a continuously increasing share of electricity generated by large-scale projects are that (a) the expected return on investment exceeds the cost of capital by a margin that is judged acceptable by the investor, (b) local residents do not oppose the large-scale projects by means of legal procedures or other inhibiting forms of protest, and (c) sufficient transmission capacity exists to transport electricity from sites with good potential to demand centers (see Section 3.4). Ideally, (d) renewable support strategies are coordinated or at best harmonized across Europe and (e) the aggregate economic efficiency of large-scale renewable visions accrues as postulated.

3.3. Distribution Grids

In 2014 the German distribution grids were owned by 884 distribution grid operators (DSOs), of which 812 had less than 100,000 customers [52]. In order to foster efficiency gains, revenues are capped for all grid operators under an incentive regulation scheme. Originally designed to distribute centrally generated electricity to end-users, distribution grids are operated 'blind' – meaning data such as load flows or voltages at nodal points are not available to the DSOs. With rising shares of local renewable electricity generation the distribution grids are increasingly put under stress. One study estimates that roughly 135,000km of low- and medium-voltage lines need to be built until 2030 to accommodate growing renewable capacities connected to distribution grids, tantamount to around 27 bn€ of investments [53]. Another study finds that under current planning standards between 130,000 and 280,000 km are necessary until 2032, requiring investments of 23-49 bn€ [54]. These halve under an optimal combination of innovative planning concepts and intelligent technologies. However, the current regulation does not incentivize investments for DSOs, an particularly not such innovative solutions for the integration of renewables in distribution grids [54]–[56]. The Federal Network Agency acknowledges these deficits in its first evaluation of the incentive regulation scheme [57] and proposes improvements.

Against this background it becomes clear that structural change will only take place in this arena if the incentive regulation fosters DSOs to invest in the first place, at best in innovative solutions. In the near-term it can be expected that the prohibitively long time lags between investment and remuneration in a regulation of up to 7 years are reduced and new rules target at 'intelligence instead of power lines' [57], e.g. controllable local transformers, intelligent generation management as well as its consideration in grid planning. The optimal combinations are highly case-specific and need to be decided by the local DSO, there is no single blueprint package [55]. Also, not all DSOs are equally affected: In 2014 the 10 (20) DSOs with the highest installed capacities of renewables jointly account for 60% (80%) of the total installed capacity in Germany [57]. This skewed distribution of local renewables leads to high investment needs and proportionally higher grid fees for consumers in the zones of the respective DSOs, illustrating that the incentive regulation needs to accommodate the heterogeneity of DSOs.

If local renewable electricity generation increases in magnitude in the medium-term a more active role of DSOs in managing the stability of the regional distribution grid posits a promising avenue to foster an efficient regional electricity system [55], [58]. At present DSOs assigned a passive role because transmission grid operators (TSOs) are exclusively responsible for ensuring grid stability. An important prerequisite for a more active role is the widespread deployment of information and communication technology (ICT) to make the distribution grid intelligent, providing real-time measurement and then even *smart,* involving an active management component like remote access. This ultimately leads to the vision of smart grids, embracing an electricity network that can intelligently integrate the actions of all users connected to it, generators, consumers and prosumers, in order to efficiently deliver sustainable, economic and secure electricity supplies [59]. The German Government prepares a regulation on smart measuring devices to ensure data security and interoperability, due in 2015 [2, p. 141]. Actors from the ICT sector can be important catalysts for smart grids – an empirical analysis of actors involved in 450 smart grid projects finds that incumbent firms from the ICT sector have gained influence and drive energy system transformation [60]. Innovative business cases such as virtual power plants also play an important role in this context. Smart grids are also a prerequisite for demand side management (see Section 3.5), which might play an important role in the medium- to long-term future.

If rising capacities of local renewable energy generation (cf. Section 3.1) need to be integrated in distribution grids, the implications are likely that distribution grids will (i) be structurally refurbished where high infeed of renewables need to be accommodated, (ii) play a central role in future energy system management, (iii) have a multitude of producers, prosumers and consumers connected with two-way communication technology and (iv) are owned by DSOs that actively manage regional grid stability. Necessary enabling conditions for the large-scale roll-out of smart distribution grids are that (a) the incentive regulation is reformed so as to incentivize investments and intelligent planning procedures taking into account the heterogeneity of DSOs, (b) sound legal frameworks for intelligent and smart applications are defined, and (c) suitable protocols assure a safe exchange and processing of data.

3.4. Transmission Grid

In the course of liberalizing the European electricity market, unbundling led to the formation of four regulated corporate transmission system operators (TSOs) in Germany that own, operate and maintain the high voltage transmission grid, being responsible for its stability, reliability and performance. In the short-term this goal is achieved through load management, e.g. redispatch measures and reserve markets. In the medium-term the preferred strategy is to refurbish the grid to alleviate notorious congestions. However, the planning of new high-voltage power lines is a highly complex process that has to result in concrete, legally incontestable transmission corridors, which usually takes a decade or more. Aiming to speed up these processes a law has been passed in 2009 that specifies 23 grid expansion projects of national importance; however, until 2014 only 438 of the 1887 envisaged grid km have been finalized [57]. Since 2001 the necessary infrastructure investments for the coming two decades are determined by the four TSOs in a rolling process that generates an annually published grid development plan [61]. The underlying scenario frame, which specifies crucial assumptions like installed capacities of renewables for four different scenarios, is approved by the federal grid agency, who also puts it out for public consultation. Based on the grid development plan of 2012, the federal grid agency selected 36 projects that are prioritized under the federal requirement plan law. These are ready to enter the stage of planning approval procedure, to identify the concrete siting of the power lines.

This arena of change is characterized by severe conflicts on the necessity of new high voltage transmission lines, particularly on the new direct current (DC) technology that serves to transport electricity over long distances with minimal losses. The federal requirement plan law foresees three north-south DC corridors in Germany to strengthen the connection between the windy Northern areas with South Germany. During the 2014 public consultation process the federal grid agency received 26.041 comments, of which 25.569 were by private persons (98% serial letters), 212 by communes, 72 by associations, 66 by citizen initiatives, 47 by companies and some more by environmental associations, government agencies, political parties and others [61]. The majority of responses are related to the eastern DC corridor between Saxony and Bavaria (Corridor D) with the recurring theme that the necessity of the line is put into question. Local support for the Corridor D is very low and more than 200 newly organized citizen initiatives all along the corridor have started organized protest[2]. Their common denominator is that they argue in favor of a decentralized, regional energy transition for which the large-scale DC line is not necessary; it only served the financial interests of the large energy utilities. Likewise for the 800km DC corridor from Northern Germany to the South (Südlink) the association of opposing citizen initiatives[3] also demands a decentralized energy transition and a more just distribution of costs and benefits. Whilst the federal grid agency campaigns for the acceptance of new power grids [61] literature has shown before that local acceptance is generally lower than general acceptance and cannot be equated with support [45], [62]. The public consultation process has been criticized on the grounds that very little consequence on the side of the TSOs and the federal grid agency has followed [63]. In fact, the reaction to the concerns on corridor D are ignored by noting that specific interests will only become relevant in the subsequent planning approval procedure [61, p. 113].

[2] http://trassenwahn.de/buergerinitiativen
[3] http://buergerinitiativen-gegen-suedlink.de/

For TSOs the European context plays an important role. ENTSO-E, the European Network of TSOs develops biannual ten-year network development plans which have identified the need for 50,000km of power lines to be refurbished or newly built across Europe; however, progress is rather slow [64], [65]. The European Commission [66] requires all Member States to realize these projects of common interest (PCI) within the next ten years, in the process of which domestic one-stop-shop permitting authorities need to be set up. Yet, it remains unclear whether any form of sanctions will be applied. From a long-term perspective European transmission capacity expansion is motivated by the necessity for transporting electricity from peripheral supply centers with favorable renewables potential to mainly central-European demand centers [67] and for the large-area pooling of fluctuations, which reduces the need for flexible generation [68]. It can be shown that a European-wide expansion of renewables with large capacities of long-distance transmission leads to a more cost-efficient energy system [67], [69]. These projections are, however, highly uncertain in the long-run and depend on a multitude of assumptions [70]. In order to realize the grid projects identified by ENTSO-E, TSOs require unprecedented capital expenditures in the next decade, which may not be met with the traditional ways of financing and require alternative models [71]. Also, European infrastructure regulation may be reworked with respect to how the financial burden is split between countries [72]. Political and governance-related issue also often lead to gridlock in cross-country connection projects [73].

If the large-scale renewable generation increases within Germany and Europe, the implications for electricity infrastructures are likely that transmission grids will (i) need to be expanded substantially, (ii) remain the focal level for system stability, and (iii) serve as a means for the system and market integration of renewables. Necessary enabling conditions are that (a) a mode for planning and deployment procedures at the European, national and local levels is found that is perceived as sufficiently fair for local abutters to refrain from protest, (b) investment opportunities are worthwhile from the perspective of the TSOs and (c) welfare and efficiency gains accrue as promised.

3.5. Demand Side

The aggregate actor groups demanding electricity are industry (43%), households (27%), the commercial and service sector (15%), public facilities (9%), transport (3%) and agriculture (2%); together they consumed 502 TWh in the year 2012 [12]. As actors do not demand electricity per se but rather energy services, they each own different kinds of conversion devices, ranging from long-lived infrastructure assets like machines in the industrial sector, white goods in households or trains in transport to medium- or short-lived devices like light-bulbs, computers or TVs. From an energy system perspective two major trends affect demand-side actors, potentially altering the amount and timing of electricity consumption. First, the central Energiewende strategy of increasing energy efficiency requires a more efficient use of electricity, which ultimately has to be delivered by the consumers through either more efficient devices and usage habits, or less consumption of energy services (known as sufficiency). Second, a prospectively interesting integration option for renewables is demand-side management (DSM), aiming to adapt the temporal pattern of electricity demand to that of fluctuating electricity supply. The shift towards a more active role of the demand-side in the electricity system is not yet very pronounced; developments are yet slow in this arena of change.

Even though a decisively more efficient use of electricity is a core strategic target of the Government, progress has been slow – the ratio of GDP per unit of electricity consumption increased by on average 1.1% per year since 2008, reaching 4.49€/kWh in 2014 [2]. Literature provides a long-standing debate [74] on the so-called energy-efficiency gap [75] or efficiency paradox [76], contemplating why cost-effective energy-efficiency measures are often times not implemented by firms and households. Proposed theoretical barriers are diverse and include concepts such as limited access to capital, hidden costs, risk, imperfect information, credibility and trust, bounded rationality, power and culture [77]. An empirical analysis finds that for German small and medium enterprises high investment costs and a lack of capital are the two main barriers [78]. Innovative solutions are required for overcoming this lock-in to inefficient electricity conversion infrastructures. While the development of more efficient technologies is crucial, a reconsideration of social practices is equally important. This could be the widespread diffusion of energy management in firms [74], energy service contracts as business cases [79] or the societal shift from a consumerist towards a sharing economy [80]. Here consumers no longer own the devices that convert electricity in energy services, but access them through rent, lease or swap, usually organized via online intermediaries. Business cases delivering access-based consumption [81] are particularly interesting for assets with high investment costs and high idle times like (electric) cars.

Demand-side management is currently used only with a small number of large industrial customers; more cost-efficient intertemporal flexibility potential is expected in the manufacturing industry [57, p. 241]. DSM in the residential sector is attributed a lesser relevance today due to its lower share in total electricity demand. If smart grids shall exploit more than the passive potentials of fridges or washing machines it is important to acknowledge the central role of smart users, who are likely skeptical as to ‘being managed’ but rather want to become a manager in the process of consumption and maybe also generation [82]. Hence, residential DSM is more consistent with local than large-scale renewable generation and may posit an important flexibility option in this context.

If the German demand side actors venture towards a more efficient provision of energy services and the widespread deployment of DSM, the implications for electricity infrastructures are likely that (i) less electricity needs to be supplied as compared to a counterfactual, (ii) demand-side infrastructure will be shared or leased and to a lesser extent owned privately, and (iii) electricity demand becomes increasingly flexible and manageable by a smart grid. Necessary enabling conditions are that (a) barriers to energy-efficiency investments are overcome, (b) a dynamic market for the provision of energy services evolves, and (c) institutional modes for unleashing DSM potentials are developed.

3.6. Conventional Power Plants

Conventional power generation jointly provided 71% of the German electricity demand in 2013, split between inflexible nuclear power (15%) and lignite combustion (26%), moderately flexible hard coal combustion (20%), and moderately to highly flexible gas combustion (11%) [12]. The dominant actors in this arena are the profit-maximizing incumbent private utilities (the “big 4”) as well as the larger public utilities, which mainly own the gas capacities. In the liberalized European electricity market their core business case is to sell and trade the electricity either on the spot market, the futures market or in bilateral wholesale contracts. In 2013 the sport market of the European Energy Exchange AG (EEX) had registered 89 private utilities and traders, 33 public utilities, 34 financial service providers, 6 commercial customers and 2 TSOs [52, p. 119]. The EEX spot market forms its prices based on the merit order, implying that the marginal bid sets the price. In recent years the increased feed-in of wind and solar generation led to a structural reduction in electricity prices known as the 'merit-order effect'. It decreased average German wholesale electricity prices by 6€/MWh in 2010, by 10€/MWh in 2012 and estimated to increase to 14-16€/MWh in 2016 [83]. This directly affects the profitability of conventional generators. During windy and sunny middays renewables already provide more than 50% of the German load on a regular basis [84], substituting gas power plants and requiring hard coal capacities to ramp down. Due to the priority feed-in of renewables, sometimes even lignite plants reduce their output.

The prosperous years for electricity utilities in Germany are over. In the next six years nuclear capacities have to close down subsequently to implement the societal consensus on the nuclear phase-out. The combustion of lignite, hard coal and gas leads to CO_2 emissions that are to be mitigated almost completely by 2050, either through carbon pricing or phase-out policies. Hence, from the perspective of actors the dominant theme in this arena of change is de-growth of the existing business case in a pessimistic framing or the opportunity to venture to alternative technologies and business models (e.g. large-scale renewables) in an optimistic framing. In fact a survey of high-level staff in the European power utility industry finds that 46% of respondents expects utility business models to be transformed significantly by 2030, another 46% thinks they will be similar but with important changes [85].

From a system perspective, conventional power plants will remain important over the next decades to cover residual load, defined as load minus variable feed-in from the fluctuating sources wind and solar. During overcast and non-windy periods, conventional capacities are still essential to guarantee security of supply. Flexible gas turbines are ideal to balance the fluctuations of wind and solar on short notice. Acknowledging this, the so-called "market-design-debate" vividly discusses whether in the presence of rising shares of renewables the energy-only market, following a merit-order pricing scheme, is capable of delivering pricing signals that lead to an adequate capacity portfolio in the future. The heated debate [86] generated some consensus that such a full-fledged capacity market is not necessary in the short- to mid-term and a strategic reserve suffices [87]. In the long-term a capacity mechanism is ideally considered on the European level [88]. Apart from the energy-only market, conventional power plants earn income on the German balancing markets [89], and may increasingly do so in the future. To date it remains unclear what kind of market design will be in place in the next decades.

If the German Energiewende targets fulfill (rising share of renewables and CO_2 mitigation) actors that own and operate conventional power plants need to adapt. If they manage doing so the implications for electricity infrastructures are that during the transition conventional generation capacities will be (i) providing flexible generation, (ii) earning income either during few hours of scarcity prices on the energy-only market, on balancing markets or through capacity mechanisms, and (iii) are driven by the intention to maximize return on investment. Necessary enabling conditions for the provision of flexible and back-up generation capacities are that (a) the future market design is adapted to create sensible business cases, (b) sufficient investors find these business cases attractive, and (c) the self-perception of actors changes from representing the integral form of electricity generation towards the role of providing residual load plus eventually new forms of core business areas.

3.7. Storages

The only significant form of storage with a long tradition in Germany is pumped-hydro storage. On top of the existing 7.6 GW installed capacity, another 4.7 GW is under planning and could be realized in the coming years, even though profitability remains a major challenge [90]. The lack of profitability is in fact the dominant theme in this arena of change, which is located mainly in research and development departments. Assessments on the role of storages for the German Energiewende indicate that in order to achieve mid-term targets over the coming decade or two it is not necessary to wait for breakthroughs in storage technologies [91], [92]. Conceptually, it is helpful to differentiate between daily storages and storages for dark, calm periods that serve for more long-term periods and the respective services they can provide [93]. Daily storages such as batteries are useful for frequency control and ancillary services, load leveling, standing reserve, electro mobility, uninterrupted power supply and residential storage systems. As the name suggests, storages for "dark, calm" periods are long-term storages with large reservoir sizes that serve to bridge sustained periods of low renewable electricity generation, e.g. power-to-gas, pumped hydro, compressed air storage or heat storages.

Today, only few business cases exist for storages on the electricity markets and many barriers to their deployment persist [94]. Some commercial battery packs start to participate in the primary and secondary reserve market, e.g. [95]. Only the application for uninterrupted power supply has a longer tradition, but these storage systems serve to bridge power outages and not required to be competitive on any market. The current market design is not adequate in reflecting the full value of flexibility that can be provided by storages [96]. Currently, the services that can be provided by storages are provided by other technologies on a more competitive basis, primarily conventional (coal) power plants. Only if they exit the market will the demand for storage solutions rise. Likewise, the demand for storage to overcome dark, calm periods emerges only in systems with very high shares of renewable electricity.

Prospectively, a variety of actors may be active in this arena of change, depending on the technology in question. Modular grid-connected PV battery systems these could be owned by private persons or firms with rooftop PV systems that wish to optimize their own consumption. Daily storages could also be owned by virtual power plant managers to complement their portfolio or active distribution system operators to provide local system services. Such applications could be provided by modular battery packs or even more centralized and larger-scale storages like pumped hydro, thermoelectric or compressed air storage. A survey expects public utilities to be the driving force in the deployment of battery storages, next to end-customers and owners of renewable generation capacities [97].

If this arena of change manages to develop storage solutions that are techno-economically feasible, the implications for electricity infrastructures are likely that – in case of modular (centralized, larger-scale) storages connected to the distribution (transmission) grid – (i) more local (large-scale) renewable electricity can be integrated, (ii) the provision of local or regional (centralized) frequency control and ancillary services is possible also without coal power plants, and (iii) less (more) transmission grid capacities are required. Necessary enabling conditions for the deployment of storage solutions are that (a) technology development leads to enhanced techno-economic performance, and (b) expectations on business cases for storage solutions make the substantial upfront investments financially attractive.

4. Discussion

Having characterized each arena of change as delineated from an energy system perspective, this Section turns towards a synthesizing discussion. We intend to come back to the initial questions that this paper asked at the outset: Who are the actors that potentially put the changes necessary for decarbonizing the German electricity system into action? What are their main motives? And under which conditions could they induce even more – and what kind of – productive change in the future?

The previous Section identified many different actors that may shape the future of the German electricity system. Table 1 summarizes the actor types, their motives and potential roles each one can play in the different arenas of change currently and prospectively. Active roles are indicated in black and passive roles in grey font. The columns are arranged so that the more decentralized solutions are on the left and the more centralized solutions on the right. The rows are arranged so as to achieve the tendency for a clustering of actors that play an active and productive role in the more decentralized (centralized) solution space in the top left (bottom right) quadrant.

Reflecting on this table reveals that a large variety of actors with substantially different motives are involved in the German electricity system, many of which play a role in several arenas of change. Now, recall that in the prominent theory of large technical systems technical change is determined by a scientific consensus on the "truth" is, being followed by technical closure that occurs when the relevant social groups see a problem as being solved [6], [7]. However, the literature review has illustrated that there is no scientific consensus on what the "truth" would be regarding the optimal deployment of electricity infrastructure in the future. Also it is completely unclear who the "relevant" groups are, e.g. it is highly likely that "relevant" groups on communal, municipal, county and federal level would not be able to find a consensus on this question. A social conflict perspective indeed grasps the character of the problem more accurately: there exist highly contrasting political narratives on how the future electricity system shall be governed, who shall own the assets and which shall be the focal level of action.

According to the political narrative of the *"Bürgerenergiewende"* the 'energy citizen (Bürger)' should the driving force behind the Energiewende, be it individually or organized in cooperatives, regional small and medium businesses, communes or public utilities [98]. The Charta of the association of citizen organizations demands the "rapid replacement of the fossil-atomic, centralized system through a new, decentralized energy provision" [98, p. 1]. Local value added, true citizen participation, democratic control and an active role of the demand side are the primary principles of this narrative. A cornerstone of the citizen-driven Energiewende is the feed-in tariff system, which is to be reformed towards a "citizen energy law" to foster the Energiewende as a true collective project of all citizens.

The most contrasting narrative on how the Energiewende will become a success is told by the "*Initiative New Social Market Economy*", an influential cross-party NGO funded by the employers' associations of the metal and electrical industries. Their position [99] demands the feed-in tariff to be reformed towards a technology-neutral and location-neutral quota system that fosters the most efficient use of generation capacities where the potential is most favorable, at best harmonized across Europe. Efficiency, market solutions, competition and economies of scale are their primary principles.

Table 1. Overview of actor types, primary motives and current and potential future key roles in the Energiewende arenas of change. Blue (green) indicates passive (active) roles. Abbreviations: Renewables (RES), maximize (Max.), small (S), medium (M), large (L), revenue (rev.), Shareholder value (SV).

Actor types (Who?)	Motives (Why?)	Possible roles in arenas of change, current and prospective (What?)						
		Local RES	**Distribution Grid**	**Demand Side**	**Storages**	**Large-Scale RES**	**Transmiss. Grid**	**Convent'l Power Plants**
Citizens (Households)	*Obtain energy services*	Abutter Owner Operator	Customer Supplier	Consumer Manager	Owner (S)	Abutter Opponent	Abutter Opponent	Opponent
Farmers	*Max. income*	Abutter Owner Operator	Customer Supplier	Consumer Manager	Owner (S-M)	Abutter Opponent	Abutter Opponent	
Cooperatives	*Provide quasi-public good*	Owner Operator	Supplier Owner	Supplier Service provider	Owner (S-M)			
Public Utility	*Max. local value added*	Owner Operator	Supplier Owner	Supplier Service provider	Owner (S-M)			Owner (gas) Operator
Industry firms	*Max. profit/SV*	Owner Operator	Customer Supplier	Consumer Manager	Owner (S-M)			
Service Firms	*Max. profit/SV*	Owner Operator	Customer Supplier	Consumer Manager	Owner (S-M)			
Communes/ Municipalities	*Max. local welfare*	Tax rev. Approval	Concession (20 years)	Consumer Manager	Tax rev. Approval	Tax rev. Approval	Abutter Opponent	Tax rev. Approval
Virtual Power plant	*Max. profit/SV*	Operator	User	Operator	Operator	Operator	User	
German Government	*Technology development*	Support Scheme		R&D funding	R&D funding	Support Scheme		
ICT firms	*Max. profit/SV*	New smart solutions				Refine existing technologies		
DSOs	*Provide secure grid*	Customer	Owner Operator	Supplier & service provider	Owner (S-M)		Sub-ordinate	
TSOs	*Provide secure grid*		Ordinate			Customer	Owner	
Federal Network Agency	*Max. federal welfare (regulator)*		Determine revenues				Determine revenues	
ENTSO-E	*Coordinate regulators*						European interests	
Electricity market	*Clear the market*	Coordinative price signal						
Private Utilities	*Max. profit/SV*		Owner	Supplier & service provider	Owner (M-L)	Owner Operator	Supplier	Owner Operator
Institutional investors	*Max. profit/SV*				Owner (M-L)	Owner Operator	Supplier	
Strategic investors	*Max. profit/SV*				Owner (M-L)	Owner Operator	Supplier	
Project developers	*Max. profit/SV*					Planner Developer		

The “citizen energy” as opposed to the “European efficiency” narrative requires structurally different electricity infrastructure architectures, both from the technical point of view and in terms of institutions. The conditions which influence the future course of the German Energiewende fundamentally depend on the legal framework that the Government sets and the decisions of the Federal Network Agency, the regulatory authority for the distribution and transmission grid. It is yet unclear which direction will be taken. However, companies have a strong influence on political-decision making and have been found to shape the German energy transition via a policy network with governmental actors in the past [100]. The ideal of the energy citizen is also fuelled by latent mistrust in corporations and such policy networks. As the ownership of infrastructure assets like generation and distribution capacities by citizens constitutes the highest form of citizen participation, this clearly implies a redistribution of power [41].

This discussion illustrates that the question of how to transform the German electricity infrastructures is ultimately a question of values. This normative conflict between different societal groups cannot be resolved by scientists speaking the “truth”. There cannot be a “truth” on what the optimal infrastructure architecture will be in the future, because the question of optimality hinges on the criteria. To put it pointedly: If values such as local welfare, local value added, collaboration and social collaboration are prioritized, then some form of decentralized Energiewende and policies that foster investments in local renewables, smart distribution grids and energy-efficiency measures will be optimal. If the maximization of shareholder value is put first, then the extreme of a highly centralized, private-utility driven Energiewende will score high, which goes along with policies to foster the acceleration of deploying large-scale renewables, transmission capacities and the reviving of the private utility business model.

Reversely, the argument goes such that strategic decisions on which electricity infrastructures are planned for and developed in the near-term implicitly determine which kind of Energiewende can be realized in the decade to follow. For example, if the legal and regulatory framework does not soon incentivize the structural reinforcement and upgrading of distribution grids towards smart grids, then the vision of a regionally-focused Energiewende cannot be delivered in the decade after. The substantial latency period in grid-based infrastructure development posits limits on the kind of Energiewende that can be realized long after decisions are made.

5. Conclusion and Outlook

This paper advanced the understanding of the infrastructure requirements in the German Energiewende by characterizing the actors and their motives in different arenas of change delineated by a systemic view of the electricity system. We have identified crucial aspects of the Energiewende as a societal change process, which are not represented in the model-based scenarios studies that inform the policymaking to date. In particular these relate to the underlying value systems. Future research will engage the key actors identified in this review to develop consistent qualitative infrastructure scenarios for the German electricity system that equally take into account the technology, institutional and actor dimension of the challenge.

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