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Putting an energy system transformation into practice: The case of the German Energiewende

Eva Schmid*[a], Brigitte Knopf [a,b], Anna Pechan[c]

Abstract

Low-carbon energy system transformations are usually seen from a technical perspective; the decisive societal dimensions of actors and institutions are widely neglected. We contribute to filling this gap by reviewing the German energy transition (Energiewende), which targets a competitive low-carbon economy until 2050, jointly from the three perspectives of technology, actors and institutions. We analyze seven sub-fields of the electricity system that are central for decarbonization from a technology view. For each, we identify and characterize key actors and institutional conditions for future electricity infrastructure developments they favor. The analysis reveals a large variety of engaged actors that differ with respect to their motives and underlying worldviews. Electricity infrastructure visions range from the archetypes of decentralized regional solutions (favored by challengers) to centralized European solutions (favored by incumbents). We illustrate that the determining factors for either development are of institutional nature and will be fought out between actors in the political arena. They are not primarily of technical nature. However, in either case the long latency period in technical infrastructure development requires anticipatory planning.

Keywords: Greenhouse gas mitigation; energy transition; electricity infrastructure; strategic action fields; centralized energy system; decentralized energy system

*Corresponding author: E-mail: eva.schmid@pik-potsdam.de, Tel.: +49 331 288 2674

[a] Potsdam-Institut für Klimafolgenforschung, Postfach 60 12 03, 14412 Potsdam, Germany

[b] Mercator Research Institute on Global Commons and Climate Change, Torgauer Str. 12, 10829 Berlin, Germany, knopf@mcc-berlin.net

[c] Carl von Ossietzky Universität Oldenburg, Postfach 2503, 26111 Oldenburg, Germany, anna.pechan@uni-oldenburg.de

Highlights

- We apply the theory of strategic action fields to the German electricity system
- We identify & characterize actors that can put the energy transition into practice
- They cluster into groups favoring centralized versus decentralized visions
- The two visions contradict more from an institutional than a technology perspective
- Long latency periods for infrastructure deployment require anticipatory planning

1. Introduction

In order to mitigate dangerous anthropogenic interferences with the global climate, energy system transformations are being spurred in many economies worldwide. Germany's energy system is in a state of transition known as the *Energiewende* targeting (i) climate mitigation through reducing CO_2 emissions by 80-95% in 2050 relative to 2005, (ii) phasing out nuclear power until 2022, as well as maintaining high (iii) competitiveness and (iv) security of supply [1,2]. The two central strategies are to increase the share of renewable energies and to decrease the primary energy demand, i.e. efficiency improvements [2]. A variety of numerical, model-based scenario studies have shown that it is *technically possible* to achieve these long-term targets *if* a profound transformation of infrastructures along the entire energy chain from conversion over distribution to end use is achieved [3]. From a methodological point of view, these scenarios describe a technological transition that is generated primarily by means of exogenously imposed constraints on greenhouse gas emissions or technology deployment [4].

However, in reality energy infrastructures are rigid and inert systems due to high degrees of capital intensity, considerable regulation, long life times of physical assets and strong complementarity between system components [5]. The authors of the latest model-based scenario that accomplishes all the government's energy and climate policy targets doubt "whether politics and society possess the required will and consistency for implementing all changes necessary for target attainment today and in the future" [6]. Such concerns provoke questions that can be answered by the toolbox of the social sciences rather than techno-economic numerical modeling only. The need for combining methods and knowledge from distinct disciplines for developing policy-relevant insights in energy transitions research is recognized but still decisively underrepresented [7]. We intend to contribute in filling this gap. Departing from the insights generated by model-based scenarios we aim for a better understanding of the Energiewende as a societal process in which it is endogenous actors that put change into practice.

Conceptions of energy transitions have been greatly influenced by the seminal theory of large technical systems [8]. It frames the electricity system as a complex set of interrelated technical and social artefacts created by system builders (e.g. inventors, entrepreneurs, finances). A central features is that technical change is induced by scientific closure, i.e. "a scientific consensus on what the "truth" is in any particular instance" [9] (p.27), followed by technical closure occurring when relevant social groups see a problem as being solved. The underlying consensus-orientated social constructivism stresses harmony and cooperation and views conflicts as dysfunctional phenomena. Hård [10] judges this view as deeply flawed; a conservative, technocratic iron cage with no way out. He argues that social conflict is *essential* for technology change as "technology is inherently red in tooth and claw" (p.416). Precisely this political economy of energy transitions is often neglected.

The history of the German Energiewende can indeed not be recounted without reference to political economy phenomena, particularly with regard to persistent societally driven and publicly battled conflicts that induced technological change. For example, since the 1970s the ever-growing anti-nuclear movement organized large-scale demonstrations and persistent public protest [11]. Finally, in 2001 the governing coalition of the Social Democrats and the Green Party enacted the nuclear phase-out until the year 2021. Even though the newly established coalition of Christian Democrats and the Liberal Party first prolonged the phase-out in 2010, it abruptly reestablished the original timeline and an immediate moratorium of eight nuclear plants after the Fukushima accident in 2011. The support for renewable electricity in Germany also roots in the social movement against nuclear power as a high-risk technology, fueling the desire to develop alternatives. 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 [12]. In 2000, the feed-in tariff was redesigned with the Renewable Energies Act, leading to an increase in the share of renewables in electricity generation from 3% in 1990 to 26% in 2014 [13]. Through creating a sheltered niche, the Act spurred the variety and number of actors in the field of electricity supply, who since have become increasingly professionalized [14].

Visions of the final state of the renewables-based regime range from the polar archetypes of a highly centralized and supply-side oriented engineering future focusing on large-scale generation and transmission to a deep reorganization of capitalist society towards more decentralized and local structures relying on small- and medium scale generation units in the distribution grid [15]. Postulating that the socio-political economy between large and smaller-scale energy infrastructures differ, namely the one corresponding to the former rooting in centralization and authoritarianism versus the one corresponding to the latter rooting in decentralization and democracy, important questions emerge [16]: First, which actors are involved in the production of either of these energy systems? Second, are these two archetypes of infrastructure development in the German electricity system mutually exclusive, or can they be implemented in tandem with each other – that is: can they coexist?

The first aim of this paper is to pursue a comprehensive theory-based literature review that characterizes the status quo of the German Energiewende in the electricity system from the perspectives of technologies, actors and institution. The second aim is to draw on the insights generated in this overview to discuss the two above-posed research questions. For both aims we rely on the sociological theory of strategic action fields (SAFs) [17,18] as our conceptual framework. We focus on the electricity system and its infrastructures because it represents a key sector for decarbonization of the energy system [3] that relies on particularly inert and technically challenging infrastructures [5] and has shown a very dynamic development over the past decade [2].

Although our analysis is centered on the debate of the German Energiewende, it provides conclusions that are applicable also in the broader European and even international context. In the UK the future of the power grid is discussed in relation to a more “civic energy future” [19]. Scholten and Bosman [20] even hint to geo-political implications related to the change in consumer-producer relationship. In the US, centralized versus decentralized systems are discussed, especially whether grid-connected solar-plus-battery systems will compete with traditional electric services [21]. The latter study points out two different pathways either with integrated grid or with grid defection, a debate that will gain momentum for example also in Africa. In addition, the German Energiewende is monitored internationally. An editorial in *nature* [22] put it this way: “The Energiewende, Germany’s solo effort to radically shift its economy to one dominated by renewable sources of energy, is a pragmatic alternative to the largely fruitless efforts of international climate-change diplomacy.” If it is successful, “it would be cause for renewed optimism in the fight against anthropogenic climate change." In that sense, the Energiewende is not only a national project for Germany, but a global endeavor with lessons to be learned for many countries.

The remainder of this paper is organized as follows. Section 2 elaborates on the theoretical foundations, choice and design of the applied analytical framework. Section 3 characterizes the actors in the chosen strategic action fields and identifies trends for future infrastructure development and necessary institutional enabling conditions. Section 4 provides a synthesizing discussion of the initial research questions, focusing on the interactions between strategic action fields and the question of whether and how the two visions of future infrastructure setup can sensibly coexist. Section 5 concludes.

2. Applied Analytical Framework

Due to its dynamic view on organizational fields, its capability to take into account aspects of power and conflict and its focus on actors we apply the sociological theory of strategic action fields (SAFs) [17,18] to study the case of the Energiewende in the German electricity system. The theory of SAFs postulates that action takes place in constructed meso-level social orders, i.e. strategic action fields, in which actors with varying resource endowments vie for advantage [18]. SAFs are socially constructed insofar as their membership is subjective, boundaries shift depending on the issue at stake, a shared understanding of the purpose of the field (including who has power and why) and the field's rules, i.e. the interpretive frame of what goes on. The theory differentiates between three generic types of actors: incumbents, challengers and field-internal governance units. Incumbents possess disproportionate influence and resources within a field; field rules tend to favor them and support their privileged position. Challengers are less advantaged and usually articulate an alternative vision of the field and their position in it. Internal governance units are organizations such as associations that oversee the smooth functioning of the field and typically serve as a liaison to important external SAFs; they usually tend to favor the incumbents. As a micro foundation the theory of SAFs relies on the concept of social skill, i.e. the using of "empathy and the capacity to fashion and strategically deploy shared meanings and identities in the service of institutional projects within fields" [18], p. 53. On the macro side the theory emphasizes that the broader field environment and the ties between SAFs are crucial for understanding field dynamics. Here they distinguish between distant / proximate, dependent / interdependent/ independent and state / non-state fields. The state is conceived as a system of interrelated SAFs that are special in that they set the legal rules by which non-state fields operate; it further has an interest in inducing social stability.

The central purpose of the theory of SAFs is to offer a toolbox for understanding processes of change and stability in societies [18]. Field stability is achieved either through the imposition of hierarchical power by a dominant group through coercion or competition or by a coalition based on the cooperation of a number of groups. SAFs are perceived to be in constant flux with incremental changes being the norm rather than the exception. New strategic action fields emerge, often times based on technology advancements and facilitated by state actors. Initial field settlements are usually characterized by the emergence of internal governance units. Even though in rare cases strategic action fields can be destabilized by internal processes, it is most often ripple effects or shocks from external SAFs that lead to episodes of contention. Field crises are frequently caused by the intentional or unintentional actions of state actors and the invasion of actors from other SAFs. Even though the reestablishment of field stability is in the interest of all actors, their strategies differ: Incumbents will fight tenaciously to preserve the settlement that was the source of their advantaged position. Challengers see an opportunity for the transformation of the field. This can be achieved through the forging of a winning coalition and the seeking of state allies and the ratification of change which entailed a fundamental restructuring of power relationships within the field. Individual actors will be most successful in this power struggle if they possess a high level of social skill.

In the context of the German Energiewende the theory of SAFs has been applied in four cases. Two studies illustrate how local initiatives have been driving the Energiewende in the past as challengers, highlighting the pivotal role of these previously powerless actors in inducing change in the overall electricity system [23], e.g. through grassroots initiatives in urban contexts [24]. Both stress the central feature of emerging local, situational and thereby decentralized governance structures. A dedicated analysis of the incumbent electricity utilities in Germany, the “Big Four” shows how they have ignored and opposed the Energiewende for decades and started to seriously acknowledge the need to reform their business cases as late as the years 2011-2013 [14]. Investigating the case of direct marketing of electricity from renewables, [25] observes an unsettled public dispute between those envisioning a large-scale market integration of renewables, i.e. their integration into incrementally reformed incumbent structures, versus challenger actors demanding radical reform to implement the vision of distributed and small structures. In our analysis we go beyond these studies of individual aspects in the electricity system and aim for a comprehensive overview of fields and actors and implications one can draw for future developments. Before doing so the following briefly illustrates our stance on other prominent theories.

A widespread approach in socio-technical research is the transition management framework [26,27], a governance approach foreseeing the organization of concrete, local transition arenas to induce societal change process in practice. It primarily grounds on the multi-level perspective (MLP) on sustainability transitions highlighting niches as the major source of change in socio-technical regimes [28,29]. However, the MLP does not explicitly account for power, agency and general political economy phenomena. A further drawback in terms of its explanatory power on transitions is its conception that landscape developments, which are the decisive developments that lead to windows of opportunity for regime reconfigurations driven by previously supported niches, are entirely exogenous [15]. While this may be a worthwhile assumption for local case studies facilitated by the transition management framework, it deems not particularly helpful regarding developments on the national scale.

Theories from the realm of public policy analysis that are highly compatible with the theory of SAFs include the advocacy coalition framework (ACF) [30] and the related discourse-coalition approach (DCA) [31] as specific versions of policy networks. The ACF sees the policy process as coalitions of actors competing in policy subsystems, whereby the coalitions form based on shared normative and causal beliefs [30]. It explains policy change through the interaction of competing coalitions, each adopting strategies that envisage institutional innovations thought to further their respective policy objectives.

The DCA goes further to stress the role of language as a medium through which political problems are socially constructed [31]. It posits that rather than by the belief system per se, policy coalitions are held together by narrative storylines interpreting events and courses of actions in concrete social contexts [32]. A discourse coalition consists of "the ensemble of a set of storylines, the actors that utter these storylines, and the practices that conform these storylines, all organized around a discourse" [31]. The notion of "frames" that offer identity and room for interpretation in the theory of SAFs is very similar.

In this study, we consider the German electricity system as one strategic action field with the overarching purpose of electricity supply meeting the electricity demand at any point in time and space in a reliable way. Figure 1 provides an overview of the different sub-fields we consider in this analysis. Departing from the insights generated by model-based mitigation scenarios, they are delimited from a technology perspective: according to their function in the electricity system. The historically incumbent sub-field of conventional power plants, i.e. fossil and nuclear generation, embodies the centralized electricity system structure. However, its share will have to decrease substantially in order to mitigate future greenhouse gas emissions. Instead, a significantly higher share of electricity will have to come from renewable electricity, which is differentiated into small- and medium scale as opposed to large-scale renewables to reflect their structural differences. To accommodate the fluctuating feed-in of wind and solar at least three basic solutions exist: storing electricity to shift supply intertemporally, demand side management to shift demand intertemporally, and the expansion of transmission and distribution grids to relocate the supply of electricity geographically. The sub-fields are sorted to the top or bottom depending on whether they play a decisive role in the centralized or decentralized system structure. Even though the graphical representation in Figure 1 suggests that each of these sub-fields is a separate entity they are in fact proximate and highly interdependent fields. However, throughout Section 3 we will analyze each sub-field individually and reserve the synthesizing discussion for Section 4. For each sub-field we characterize its status and ask: Who (actors) has been active in this sub-field in the past, what (activities) have they done and why (motive, values, storyline)? Based on these elaborations we draw inference on what would be the implications for electricity infrastructures if these trends were to continue, as well as necessary enabling conditions.

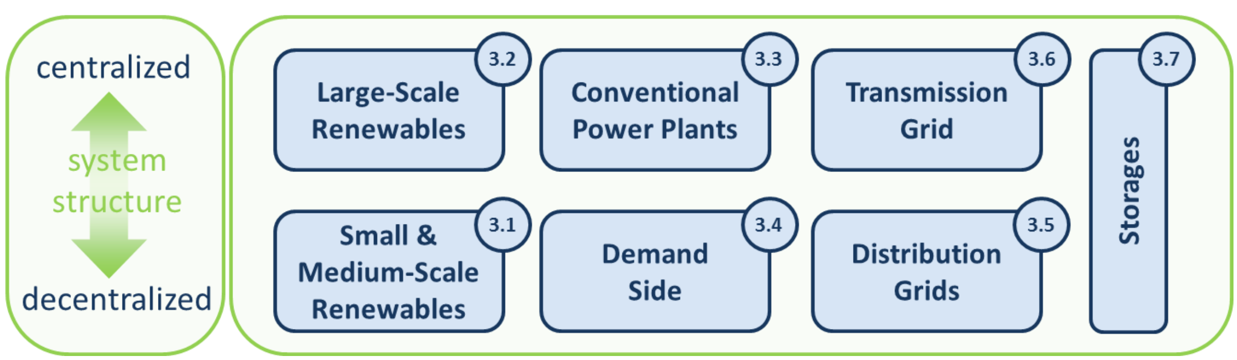

Figure 1. Scope of the analysis: Sub-fields in the German electricity sector delimited from a technology perspective regarding their function in the electricity system. Numbers indicate the subsection they are discussed in.

3. Characterizing sub-fields of the German electricity system

3.1. Small and Medium-Scale Renewables

The sub-field of small and medium-scale renewables embraces all infrastructure assets that generate small or medium quantities of electricity per site, drawing on the primary energies solar irradiation, wind, biomass or hydro energy (small). They are mostly owned by local actors, i.e. individual or collectively organized citizens that dwell in relatively close geographical proximity. Such 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 [33]. The main reasons for this substantial share of citizens as investors for solar, onshore wind and bioenergy technologies are found within the institutional framework conditions, technology-specific aspects and financial characteristics of these projects [34]. Small-scale renewable projects are financially unappealing for large energy companies with expected yields of 4-6%. Cooperatives have experienced a boom in the energy sector, increasing from 35 in the year 2005 [33] to 635 involved in electricity and heat generation by 2013 [35]. 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 [36].

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 [37]. 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 [38], corresponding to around 4% of installed renewable generation capacity [39,40]. 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 [41]. 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 [42].

Next to visionary engineers and institutional entrepreneurs, German state actors have played a pivotal role in the formation of the strategic action field of small and medium-scale renewables. Important landmarks were the enactment of the feed-in law in 1990 and its successor the Renewable Energy Act in 2000. Especially the latter designed the feed-in tariff system so as to minimize the investee’s exposure to risk [43], enabling the abovementioned variety of actors to participate in the electricity system. They are best conceptualized as challengers in the strategic action field of the electricity system as a whole, but as incumbents in the sub-field of small and medium-scale renewables. In fact, due to the geographically dispersed character of local renewables this sub-field is best understood as a heterogeneous aggregate of local arenas on the communal or municipal level, i.e. a host of local SAFs.

Signs that field formation was achieved as early as 1990 were the foundation of the federal association for renewable energies and other technology-specific associations that support the interests of renewable electricity generation in the overarching field and with respect to competing sub-fields like conventional power plants. Recently, associations that explicitly represent the interests of individual and collectively organized citizens have been founded, e.g. in 2014 the alliance of citizen energy. This coincides with the announcement of the 2014 reform of the feed-in tariff towards an auctioning system which is likely to be unfavorable for small actors due to higher investment risks, thereby causing the relatively stable field to enter an episode of uncertainty.

If the overall trends in this sub-field 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 consider an investment, (b) an increasing share of local actors is motivated to engage financially in the energy transition as opposed to other investment opportunities, and (c), locally, security of supply is maintained at a high level (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

The sub-field of large-scale renewables embraces all infrastructure assets that generate large quantities of electricity per site, drawing on the primary energies solar irradiation, wind, biomass or hydro (large). From an actor perspective they are mostly owned by corporate actors whose primary aim to maximize shareholder value drives large-scale generation capacities to be sited where the resource potential is most favorable, which may be remote areas far from electricity demand centers. Institutional and strategic investors owned 41.5% of all renewable capacities in 2013 [33], including 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 [33]. Deducting the 4% that are owned by public utilities (cf Section **Fehler! Verweisquelle konnte nicht gefunden werden.**) renders the four corporate utilities that are active in Germany with a joint share in renewables capacities of less than 9% in 2012. It was not until the post-Fukushima phase that the “Big Four” signaled a stronger orientation towards renewables in Germany [14]. By now all four incumbent utilities have communicated strategic readjustments that include, amongst other options, the dedicated growth in renewable energy generation, representing a rather disruptive change in their respective business models [44].

Next to sizeable onshore wind and PV parks and combined heat and power plants (CHP) fueled by biomass, particularly the offshore technology lends itself for large-scale investments. Due to substantial inherent risks and large upfront investments, offshore wind projects are manageable only for investors that can diversify risk and have a relatively favorable cost of capital. Actors in large-scale renewable energy have an investment horizon stretching beyond German borders. Therefore, potential sites are in direct competition with those outside of Germany, which are often times more favorable in resource quality. 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 [45]. Not to be neglected is also eventual costs for the engagement of local residents fearing visual, audible or other impact and might turn into passive or even active opponents. 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 [46], leading to a lack of support [47] and maybe even protest. Both experience and research suggest that active forms of citizen participation in all stages of project development 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 [48]. In this context weak forms of participation [49] like informing and consultation may not lead to local acceptance and support.

A number of model-based scenario studies show that pan-European approach to decarbonization is characterized by high economic efficiency, because electricity can be generated in places with favorable wind and solar potential, i.e. where capacities are utilized best, and then transported to demand centers with sufficient long-distance transmission capacities [e.g. 50,51,52]. A significant part of Germany's electricity demand would then be satisfied by electricity imports [53,54]. Creutzig et al. [55] 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 corporate, large-scale renewables it is inter alia necessary that the exploitation of favorable potentials takes place in some form of coordinated manner. This involved e.g. joint measures such as a harmonized European renewable support scheme, which is not high on the political agenda to date. Also, energy mixes are subject to national sovereignty under current legislation (cp. §194 TFEU).

We argue that the strategic action field of large-scale renewable energies is a spin-off of the field of small and medium-scale renewables that has slowly seceded as technology development accelerated and larger players have entered the renewables arena. Even though both sub-fields are engaged in the generation of renewable electricity they differ with respect to pivotal characteristics such as technology choice, geographical focus and expectations regarding returns on investment. Nevertheless, the sub-fields are proximate and situationally highly interdependent as in some cases there might be a competition for resources, e.g. specific wind sites that are accessible for both types of generation. The sub-field of large-scale renewables is still under development and incumbent actors of this field are to a certain extent challengers on the overarching field of the German electricity system. However, as incumbent utilities increasingly enter the large-scale renewables field it is likely that interests of this field becomes ever more dominant and they increasingly appropriate an incumbent position in the overall electricity system.

If this sub-field 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 primarily driven 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 corporate 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 3.6). Ideally, (d) renewable support strategies were coordinated or at best harmonized across Europe and (e) the aggregate economic efficiency of corporate, large-scale renewable visions accrues as postulated.

3.3. 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%) [13]. The dominant actors in this sub-field are the profit-maximizing incumbent private utilities, the Big Four, as well as the larger public utilities, which mainly own the gas capacities. However, the prosperous years for electricity utilities as the historically incumbent actors in in the German electricity system are over [14,44]. 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. This means that through institutional reform the regulator as a state actor willingly diminishes the entire sub-field of conventional power plants over time. An additional mechanism in this regard is the negative feedback effect from the growing prioritized feed-in of renewable electricity that leads 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 is estimated to increase to 14-16€/MWh in 2016 [56]. This has a direct negative effect on the profitability of conventional power plants. During windy and sunny middays renewables already provide more than 50% of the German load on a regular basis [57], substituting gas plants and requiring hard coal and sometimes even lignite capacities to ramp down. Hence, from the perspective of the incumbent actors in this sub-field the dominant theme is de-growth of the existing business case in a pessimistic framing or the opportunity to venture to alternative technologies and business models, that is other sub-fields, in an optimistic framing.

From a system perspective, conventional power plants are likely to remain important over the next decades to cover residual load, defined as load minus variable feed-in from the fluctuating sources wind and solar, particularly during overcast and non-windy periods. 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 [58] generated some consensus that such a full-fledged capacity market is not necessary in the short- to mid-term and a strategic reserve suffices [59]. In the long-term a capacity mechanism is ideally considered on the European level [60]. Conventional power plants also earn income on balancing markets [61], and may do so increasingly.

If the German Energiewende targets are to be fulfilled, 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.

3.4. Demand Side

The demand side is constituted of two kinds of actors: Those selling electricity and those demanding electricity. 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 [13]. Since liberalization customers are free to choose their supplier; however, 80% of households remained with their basic supplier in 2012, just more than half of which have left the basic contract and opted for a customized contract [62]. Basic suppliers are defined as the ones with the highest market share in the region. The share of households actively switching to one of the on average 80 competing suppliers increased steadily but slowly, with around 1 percentage point per annum [62]. This is very different for industrial and commercial customers, virtually none remain in basic contracts [62]. 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 ultimately has to be delivered by consumers through either more efficient devices and usage habits or less consumption of energy services (known as sufficiency). Second, a prospectively potent integration option for renewables is demand-side management (DSM), aiming to adapt the temporal pattern of electricity demand to that of fluctuating electricity supply.

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 [63] on the so-called energy-efficiency gap [64] or efficiency paradox [65], 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 [66]. An empirical analysis finds that for German small and medium enterprises high investment costs and a lack of capital are the two main barriers [67]. 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 [63], energy service contracts as business cases [68] or the societal shift from a consumerist towards a sharing economy [69]. 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 [70] are particularly interesting for assets with high investment costs and high idle times like (electric) cars.

DSM is currently used only with a small number of large industrial customers; more cost-efficient intertemporal flexibility potential is expected in the manufacturing industry [71]. DSM in the residential sector is attributed a lesser relevance today due to its lower share in total electricity demand. Here 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 [72]. Commercial and residential DSM is particularly consistent with local renewable generation and posits an important local flexibility option. A technical prerequisite for DSM is the widespread rollout of smart meters, which is under development (cf. Section 3.5).

As a strategic action field the demand side is best viewed from the sales perspective. With regard to the industrial, commercial and service sectors it is a highly competitive action field in which at least 100 suppliers [62] vie for customers that do actively switch contracts. The household sector is much more rigid, here incumbent basic suppliers still have a market share of nearly 80%. The share of customers that actively choose one of the more than 80 available competitors is slowly increasing. Incumbent actors of the relatively distant strategic action field of telecommunications emerge as challenger actors, e.g. the German Telekom is active in developing a smart home business case. Also, prosumers that use small or medium-scale renewables technologies maybe even enhanced with small battery systems are challengers in this field, as this setup significantly reduces sales volumes for suppliers. Overall this SAF exhibits strong competition and may see a significant reshuffling of incumbent and challenger actors over the next decades, depending on how innovative business cases embracing efficiency and DSM are appreciated by customers.

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) legal and behavioral 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 develop.

3.5. 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 [62]. 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 [73]. 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€ [74]. These halve under an optimal combination of innovative planning concepts and intelligent technologies. However, the current regulation does not incentivize investments for DSOs, and particularly not such innovative solutions for the integration of renewables in distribution grids [74–76]. The Federal Network Agency acknowledges these deficits in its first evaluation of the incentive regulation scheme [71] and proposes improvements.

Hence structural change in this SAF will only take place if the incentive regulation is altered. In the near-term it can be expected that the prohibitively long time lags between investment and remuneration of up to seven years are reduced and new rules target at 'intelligence instead of power lines' [71], 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 [75]. 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 [71]. 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 [75,77]. 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 [78]. The German Government prepares a regulation on smart measuring devices to ensure data security and interoperability as well as a subsequent rollout of smart meters by customer classes, due in 2015 [2]. Actors from the ICT sector can be important catalysts for smart grids [79]. Smart grids are also a prerequisite for demand side management (see Section 3.4), which might play an important role in the medium- to long-term future. Important challenges remain, for example the question of how to establish redundancy for the smart communication system in the situation of a power system outage.

With the liberalization of the electricity market the strategic action field of distribution grids has been formed; during the 1990s most communes privatized their distribution grids. With concession contracts lasting on average 20 years, the SAF has largely experienced stability ever since. It consisted of a large amount of regionally incumbent actors due to the natural monopoly a distribution grid comprises. Field rules have been challenged by two types of actors recently. First, the current wave of tender procedures for renewed concessions led to a trend known as remunicipalisation, i.e. local municipalities or collectively organized citizens that win concessions. Second, DSOs that have a high share of renewable electricity to cope with challenge field rules by demanding a more active role and consequently more responsibility with regard to system stability. These actors are hence not only challenging the field rules of distribution grids, but also its subordinate relationship to the dominant field of transmission grids, which currently possesses the capacity to ensure system stability.

If rising capacities of local renewable energy generation (cf. Section **Fehler! Verweisquelle konnte nicht gefunden werden.**) 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.

3.6. 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 [71]. 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 [80]. The underlying scenario frame 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.

This sub-field 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. The 2014 public consultation 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 [80]. 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[1]. 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[2] 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 [80] literature has shown before that local acceptance is often times lower than general acceptance and cannot be equated with support [47,81]. 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 [82]. In fact, the latter ignored concerns on corridor D by noting that specific interests will only become relevant in the subsequent planning approval procedure [80].

For TSOs the European context plays an important role. The EU's third legislative energy package created ENTSO-E, the European Network of TSOs, and gave it the responsibility to develop biannual ten-year network development plans. It identifies the need for 50,000km of power lines to be refurbished or newly built across Europe; however, implementation progress is rather slow [83]. The European Commission requires all Member States to realize these projects of common interest (PCI) within the next ten years [84]. 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 [85] and for the large-area pooling of fluctuations, which reduces the need for flexible generation [86]. 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 [85,87]. These projections are, however, highly uncertain in the long-run and depend on a multitude of assumptions [52]. 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 [88]. Also, European infrastructure regulation may be reworked with respect to how the financial burden is split between countries [89]. Political and governance-related issue also often lead to gridlock in cross-country connection projects [90].

The SAF of transmission grids was founded with the European unbundling regulation in the early 2000s. As a highly regulated field the transmission grid is very proximate to the corresponding state actors. Due to the natural monopoly situation the SAF consists of four incumbent TSOs and the challenger actors composed of active protest groups against transmission grid expansion. In the overarching field of the

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

German electricity system, TSOs are also incumbent actors as they have a preference to preserve the status quo and have strong historical ties with the incumbent utilities. Due to their responsibility for system stability the SAF of transmission grids dominates the SAF of distribution grids.

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 residents to refrain from protest, (b) investment opportunities are worthwhile from the perspective of the TSOs and (c) welfare and efficiency gains accrue as promised.

3.7. 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 [91]. The lack of profitability is in fact the dominant theme in this sub-field, 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 [92,93]. It is helpful to differentiate between daily storages and storages for dark, calm periods and the respective services they can provide [94]. 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 have 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 [95]. Some commercial battery packs start to participate in the primary and secondary reserve market, [e.g. 96]. 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 [97]. 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 sub-field, depending on the technology in question. Modular grid-connected PV battery systems could be owned by private persons or firms 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 [98].

The SAF of storages is still in an early phase. The federal association for storages as an internal governance unit has been founded in 2013; a large variety of firms and research institutions are its members. Its major mission is to foster the development of suitable legal field rules by state actors and thereby establish storages as an important pillar of the Energiewende. A clear structure of incumbent and challenger actors is yet to be developed depending on which field rules manifest themselves. Very likely, short-term storages will pave the way as they are already now techno-economically feasible.

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

4. Discussion

We start with the first research question of which social groups are involved in the production of a particular energy system. The elaboration of the different sub-fields revealed a large variety of actors that may shape the future of the German electricity system. Table 1 summarizes the actor types, their motives and conceivable roles each can adopt in the future. Rows indicate from top to bottom whether actors classify more as challengers or incumbents in the overarching SAF of the German electricity system. Note how many actors potentially play a role in several sub-fields simultaneously, which is yet another indicator of how proximate the different sub-fields are. A central finding is that challenger actors are likely to adopt active roles in SAFs that are more consistent with a decentralized, regional system structure. On the contrary, incumbent actors tend to adopt active roles in SAFs that are more consistent with a centralized, European solution. The variety of actors and their motives and potential roles on the decentralized side of the solution space is significantly more diverse than on the centralized side. With the exception of DSOs and public utilities all social groups attributed the status of challenger actors have not been involved in the generation and management of electricity some two decades ago.

Table 1. Selection of actor types, primary motives and conceivable roles in the sub-fields under analysis sorted by their tendency to fit the attribution challenger type (top) or incumbent type (bottom) in the overarching field of the German electricity system; acknowledge that the attribution can shifts depending on the sub-field of analysis. Black (grey) indicates active (passive) roles. Abbreviations: Renewables (RES), maximize (Max.), small (S), medium (M), large (L), revenue (rev.), Shareholder value (SV).

Actor types (Who?)	Motives (Why?)	Conceivable roles in sub-fields, current and prospective (What?)						
		Small-M scale RES	Distribution Grid	Demand Side	Storages	Large-scale RES	Transmiss. Grid	Convent'l Power Plants
Citizens (Households)	*Energy services & other individual*	Resident Opponent Owner Operator	Customer Supplier	Consumer Manager	Owner (S)	Resident Opponent	Resident Opponent	Resident Opponent
Farmers	*Max. income & other individual*	Resident Opponent Owner Operator	Customer Supplier	Consumer Manager	Owner (S-M)	Resident Opponent	Resident Opponent	
Cooperatives	*Provide quasi-public good*	Owner Operator	Supplier Owner	Supplier Service provider	Owner (S-M)			Opponent
Virtual Power plant	*Max. profit/SV*	Operator	User	Operator	Operator	Operator	User	
ICT firms	*Max. profit/SV*	New smart solutions				Refine existing technologies		
DSOs	*Provide secure grid*	Owner	Owner Operator	Supplier & service provider	Owner (S-M)		Sub-ordinate	Owner
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)			
Public Utility	*Max. local value added*	Owner Operator	Supplier Owner	Supplier Service provider	Owner (S-M)			Owner (gas) Operator
Communes/ Municipalities	*Max. local welfare*	Tax rev. Approval	Concession (20 years)	Consumer Manager	Tax rev. Approval	Tax rev. Approval	Resident Opponent	Tax rev. Approval
Project developers	*Max. profit/SV*					Planner Developer		
Strategic investors	*Max. profit/SV*				Owner (M-L)	Owner Operator	Supplier	
Institutional investors	*Max. profit/SV*				Owner (M-L)	Owner Operator	Supplier	
TSOs	*Provide secure grid*		Ordinate				Owner Operator	
Private Utilities	*Max. profit/SV*		Owner	Supplier & service provider	Owner (M-L)	Owner Operator	Supplier Owner	Owner Operator
State Actors								
German Government	*Diverse set of motives*	Support Scheme		R&D funding	R&D funding	Support Scheme		Market rules
Federal Network Agency	*Max. federal welfare (regulator)*		Determine revenues				Determine revenues	

challengers ↔ incumbents

decentralized ← system structure → centralized

Overall, the table illustrates that there is a rather clear distinction between the social groups that favor the development of either a renewables future built on the pillars of small-scale renewables, smart distribution grids, efficient and flexible demand side management as well as small to medium-scale storages as opposed to one built on the pillars of large-scale renewables, an integrated European transmission grid and large-scale, seasonal storages. The distinction between these two opposing camps is vividly illustrated by the narratives embraced by protagonists of either archetype. Local value added, true citizen participation, democratic control and an active role of the demand side are the primary principles of the association of citizen energy [99]; a cornerstone 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. On the contrary, efficiency, market solutions, competition and economies of scale are the primary principles of the storyline articulated by proponents of the centralized version of Energiewende, e.g. economists of the ordoliberal school[3] who demand the feed-in tariff to be reformed towards a technology-neutral and location-neutral market-based system that fosters the most efficient use of generation capacities where the potential is most favorable [100]. A quota system is preferred, at best harmonized across Europe.

Second, we elaborate on the research question of whether the centralized versus decentralized paths of infrastructure development are mutually exclusive, or whether they can coexist. We will do so each from the three perspectives of technologies, actors and institutions. From a technology perspective they can certainly coexist to a certain degree, as this is the case already today in Germany. Even though the overall efficiency of the system is likely lower the higher the degree of coexistence between centralized and decentralized electricity infrastructures, it is nevertheless technically possible to have both.

From an actor perspective, the two paths are likely more mutually exclusive than from a technology perspective. As the ownership of infrastructure assets like generation and distribution capacities by challenger actors such as individual or collectively organized citizens constitutes the highest form of citizen participation, this clearly implies a redistribution of power [49]. In principle there can only be one incumbent coalition of actors in the German electricity system. If the interests and perceptions of the purposes of the field are too conflicting between actors viewing for large-scale versus small-scale infrastructures will forge a coalition it is unlikely that they will be in one coalition. The theory of strategic action fields posits that it is ultimately the social skill of coalitions that determine their success in the implementation of policy objectives. Whilst in the year 2000 the support coalition for renewables was successful in creating a new form of governance for the promotion of renewable energies with the feed-in tariff against the opposition of incumbent actors [101], the situation these days seems slightly different. Regarding the direct marketing of renewables on the electricity market incumbents have been successful in contesting new visions on an alternative regulative framework by challengers [25].

From an institutional perspective the two paths are likely even more mutually exclusive than from the actor perspective. If institutions, i.e. the rules of the game [102], are set up such that they enable a

[3] Ordoliberalism is the German strand of social liberalism, emphasizing the role of the state in setting rules within which free markets deliver. It is the political philosophy underlying the German social market economy model.

decentralized, polycentric governance system, they cannot at the same time provide for a highly centralized governance system. That means, the coordination challenge the Energiewende posits cannot be solved in two contradicting manners at the same time, e.g. the responsibility for system stability cannot be held by DSOs and TSOs simultaneously. The preexisting rather centralized coordination rules that were designed for a centralized system are already challenged by the rising share of decentralized fluctuating feed-in of renewables. In order to safeguard the functioning of electricity infrastructure coherence between institutional and technological practice is necessary [103]. Highly decentralized systems are most adequately governed by more decentralized governance systems such as a polycentric approach that blends scales and engages multiple stakeholder groups [104].

At this stage of the Energiewende the key factors determining its future development towards either a more centralized or decentralized future will be decided in the political arena, rather than from a technological perspective. More precisely it will be a function of which coalition of actors will become incumbent and set the rules for the future. Institutional enabling conditions such as the specific design of regulatory frameworks will ultimately determine which technologies are viable for business cases. The ultimate question of which coalition will be incumbent in some decades from now cannot be answered satisfactorily based on this research. However, we can conclude some attributes. It will be the one that consistently utilizes a high level of social skill, produces innovative and timely business cases that are well received by customers as well as directly and indirectly affected actors and systemically aligns technology and institutional practice most effectively. The latter is not only to be expanded to the heat and transport sector, which we have neglected to discuss explicitly in this study, but also to more general technology trends such as the highly decentralized internet, smartphones and the like.

5. Conclusion

The Energiewende is at its heart a power struggle between a large variety of actors that differ as profoundly as with respect to their motives and underlying worldviews. Currently, half of the installed renewable electricity generation capacities are owned by citizens or farmers that dwell in geographical proximity to the generation units. The increase of such decentralized renewable feed-in on the distribution grid level requires structurally different infrastructure investments as compared to the increase in mostly corporate, large-scale renewables capacities that are installed where potentials are most favorable. The latter require the reinforcement of existing and deployment of new transmission capacities across Europe. Even though from a technological perspective the two paths are not mutually exclusive, we have illustrated that the determining factors for either development are of institutional nature and will be fought out between actors in the political arena. They are not of technical nature. A deep implication of this insight is that a greater awareness for values, worldviews, takes on democracy and other normative aspects is imperative when contemplating or debating on the future of the German energy system. However, this insight is equally valid for energy transitions around the globe. Yet, as long as they are conceived as engineering endeavors conflicting values will remain the elephant in the room.

An important political implication is that the dominant technocratic, elite-theoretic paradigm of democracy in Germany appears problematic. A sign for this is that the call for an ex-post “social acceptance” of the proposed measures by governmental and ministerial agencies is omnipresent in their rhetoric. As discussed before, adopting more participative and deliberative means to developing infrastructure projects is likely fruitful with regard to establishing and maintaining positive normative attributes. A particular feature of more deliberative means is that legitimacy is not only established via outputs in the form of fulfilled targets, but also via inputs to the process [105]. Adopting representative democracy as the normative worldview indeed renders energy system transitions as an original democratic process; under a pluralism paradigm it was stakeholders that participated in the transition and establish their legitimacy [105]. The dominant elite-theoretic, technocratic reasoning is that energy system transitions are about innovation and not about democracy; the legitimacy of the transition is established via the output, i.e. the results of transition programs, and indirectly via the status and knowledge of the advisory actors [105].

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References

[1] Federal Government. Energiekonzept für eine umweltschonende, zuverlässige und bezahlbare Energieversorgung 2010. http://www.bundesregierung.de/ContentArchiv/DE/Archiv17/_Anlagen/2012/02/energiekonzept-final.pdf?__blob=publicationFile&v=5 (accessed April 30, 2015).

[2] BMWi. Die Energie der Zukunft - Erster Fortschrittsbericht der Energiewende 2014. http://www.bmwi.de/BMWi/Redaktion/PDF/Publikationen/fortschrittsbericht,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf (accessed January 6, 2015).

[3] Schmid E, Pahle M, Knopf B. Renewable electricity generation in Germany: A meta-analysis of mitigation scenarios. Energy Policy 2013;61:1151–63. doi:10.1016/j.enpol.2013.06.105.

[4] Hughes N, Strachan N. Methodological review of UK and international low carbon scenarios. Energy Policy 2010;38:6056–65.

[5] Markard J. Transformation of Infrastructures: Sector Characteristics and Implications for Fundamental Change. J Infrastruct Syst 2011;17:107–17. doi:10.1061/(ASCE)IS.1943-555X.0000056.

[6] Schlesinger M, Hofer P, Kemmler A, Kirchner A, Koziel S, Ley A, et al. Entwicklung der Energiemärkte - Energiereferenzprognose 2014. http://www.bmwi.de/BMWi/Redaktion/PDF/Publikationen/entwicklung-der-energiemaerkte-energiereferenzprognose-endbericht,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf (accessed January 5, 2015).

[7] Sovacool BK, Ryan SE, Stern PC, Janda K, Rochlin G, Spreng D, et al. Integrating social science in energy research. Energy Res Soc Sci 2015;6:95–9. doi:10.1016/j.erss.2014.12.005.

[8] Hughes T. The Evolution of Large Technological Systems. In: Bijker W, Hughes T, Pinch T, editors. Soc. Constr. Technol. Syst. New Dir. Sociol. Hist. Technol., Cambridge: The MIT Press; 1987, p. 51–82.

[9] Pinch T]., Bijker WE. The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other. In: Bijker WE, Hughes TP, Pinch TJ, editors. Soc. Constr. Technol. Syst. - New Dir. Sociol. Hist. Technol., Cambridge: The MIT Press; 1987, p. 17–50.

[10] Hård M. Beyond Harmony and Consensus: A Social Conflict Approach to Technology. Sci Technol Human Values 1993;18:408–32. doi:10.1177/016224399301800402.

[11] Rucht D. Campaigns, skirmishes and battles: anti-nuclear movements in the USA, France and West Germany. Organ Environ 1990;4:193–222. doi:10.1177/108602669000400304.

[12] Lauber V, Mez L. Three decades of renewable electricity policy in Germany. Energy Environ 2004;14:599–623.

[13] BMWi. Energiedaten: Gesamtausgabe 2014. http://bmwi.de/DE/Themen/Energie/Energiedaten-und-analysen/Energiedaten/gesamtausgabe,did=476134.html (accessed August 1, 2014).

[14] Kungl G. Stewards or sticklers for change? Incumbent energy providers and the politics of the German energy transition. Energy Res Soc Sci 2015;8:13–23. doi:10.1016/j.erss.2015.04.009.

[15] Strunz S. The German energy transition as a regime shift. Ecol Econ 2014;100:150–8. doi:10.1016/j.ecolecon.2014.01.019.

[16] Sovacool BK. What are we doing here? Analyzing fifteen years of energy scholarship and proposing a social science research agenda. Energy Res Soc Sci 2014;1:1–29. doi:10.1016/j.erss.2014.02.003.

[17] Fligstein N, McAdam D. Toward a General Theory of Strategic Action Fields*. Sociol Theory 2011;29:1–26. doi:10.1111/j.1467-9558.2010.01385.x.

[18] Fligstein N, McAdam D. A theory of fields. New York: Oxford University Press; 2012.

[19] Barton J, Emmanuel-Yusuf D, Hall S, Johnson V, Longhurst N, O'Grady Á, et al. Distributing Power. A transition to a civic energy future. 2015. http://www.realisingtransitionpathways.org.uk/publications/FINAL_distributing_power_report_WEB.pdf (accessed August 11, 2015).

[20] Scholten DJ, Bosman R. The geopolitics of renewables: a mere shift or landslide in energy dependencies? 12th Polit Sci Conf Polit Ghent, Belgium, 30-31 May 2013 2013.

[21] Bronski P, Creyts J, Crowdis M, Doig S, Glassmire J, Guccione L, et al. The Economics of Load Defection 2015. http://blog.rmi.org/blog_2015_04_07_report_release_the_economics_of_load_defection (accessed August 11, 2015).

[22] Nature. Energy crossroads. Nature 2013;496:137–8. doi:10.1038/496137b.

[23] Fuchs G, Hinderer N. Sustainable electricity transitions in Germany in a spatial context: between localism and centralism. Urban, Plan Transp Res 2014;2:354–68. doi:10.1080/21650020.2014.960096.

[24] Blanchet T. Struggle over energy transition in Berlin: How do grassroots initiatives affect local energy policy-making? Energy Policy 2014. doi:10.1016/j.enpol.2014.11.001.

[25] Wassermann S, Reeg M, Nienhaus K. Current challenges of Germany's energy transition project and competing strategies of challengers and incumbents: The case of direct marketing of electricity from renewable energy sources. Energy Policy 2015;76:66–75. doi:10.1016/j.enpol.2014.10.013.

[26] Rotmans J. Societal Innovation: between dream and reality lies complexity. ERIM Inaug Address Ser Res Manag 2005.

[27] Loorbach D. Transition Management: new mode of governance for sustainable development 2007. http://repub.eur.nl/pub/10200 (accessed January 16, 2015).

[28] Geels FW. The multi-level perspective on sustainability transitions: Responses to seven criticisms - Geels 2011 EIST response to seven criticisms.pdf. Environ Innov Soc Transitionsocietal Transitions 2011;1:24–40.

[29] Geels FW. From sectoral systems of innovation to socio-technical systems. Res Policy 2004;33:897–920. doi:10.1016/j.respol.2004.01.015.

[30] Sabatier PA. An advocacy coalition framework of policy change and the role of policy-oriented learning therein. Policy Sci 1988;21:129–68.

[31] Hajer M. Discourse Coalitions and the Institutionalisation of Practice: The Case of Acid Rain in Great Britain. In: Fischer F, Forester J, editors. argumentative turn policy Anal. Plan., Duke University Press; 1993, p. 43–76.

[32] Fischer F. Reframing Public Policy : Discursive Politics and Deliberative Practices. OUP Oxford; 2003.

[33] trend research, Leuphana Universität. Definition und Marktanalyse von Bürgerenergie in Deutschland 2013.

[34] Yildiz Ö. Financing renewable energy infrastructures via financial citizen participation – The case of Germany. Renew Energy 2014;68:677–85. doi:10.1016/j.renene.2014.02.038.

[35] Yildiz Ö, Rommel J, Debor S, Holstenkamp L, Mey F, Müller JR, et al. Renewable energy cooperatives as gatekeepers or facilitators? Recent developments in Germany and a multidisciplinary research agenda. Energy Res Soc Sci 2015;6:59–73. doi:10.1016/j.erss.2014.12.001.

[36] Flieger B. Energiegenossenschaften Eine klimaverantwortliche, bürgernahe Energiewirtschaft ist möglich. In: Elsen S, editor. Solidar. Ökonomie und die Gestaltung des Gemeinwesens Perspekt. und Ansätze von unten, AG SPAK; 2011, p. 305–28.

[37] Rogall H. 100%-Versorgung mit erneuerbaren Energien. Bedingungen für eine globale, nationale und kommunale Umsetzung. Marburg: Metropolis-Verlag; 2014.

[38] VKU. Kommunale Erzeugung aus erneuerbaren Energien. VKU Zahlen, Daten, Fakten 2013. http://www.vku.de/grafiken-statistiken/energiethemen.html (accessed January 22, 2015).

[39] VKU. Hintergrundpapier zur aktuellen Erzeugungsabfrage zum kommunalen Kraftwerkspark 2013. http://www.vku.de/fileadmin/media/Bilder/140919_Presse-Hintergrundpapier_Erzeugungszahlen.pdf (accessed January 23, 2015).

[40] BMWi. Erneuerbare Energien in Zahlen Nationale und internationale Entwicklung im Jahr 2013 2014. http://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/erneuerbare-energien-in-zahlen.pdf?__blob=publicationFile&v=5 (accessed January 23, 2015).

[41] Kompetenzzentrum Öffentliche Wirtschaft und Daseinsvorsorge Universität Leizpig. Die Energiewende und deren Herausforderungen für die Stadtwerke 2012.

[42] Berlo K, Wagner O. Stadtwerke-Neugründungen und Rekommunalisierungen. Energieversorgung in kommunaler Verantwortung 2013:105. http://wupperinst.org/uploads/tx_wupperinst/Stadtwerke_Sondierungsstudie.pdf (accessed April 30, 2015).

[43] Klessmann C, Nabe C, Burges K. Pros and cons of exposing renewables to electricity market risks—A comparison of the market integration approaches in Germany, Spain, and the UK. Energy Policy 2008;36:3646–61.

[44] Bontrup H-J, Marquardt R-M. Die Zukunft der großen Energieversorger | Greenpeace - zukunft-energieversorgung-studie-20150309.pdf. 2015.

[45] Dinica V. Renewable electricity production costs - A framework to assist policy-makers' decisions on price support. Energy Policy 2011;39:4153–67.

[46] Walker G, Devine-Wright P. Community renewable energy: What should it mean? Energy Policy 2008;36:497–500. doi:10.1016/j.enpol.2007.10.019.

[47] Batel S, Devine-Wright P, Tangeland T. Social acceptance of low carbon energy and associated infrastructures: A critical discussion. Energy Policy 2013;58:1–5. doi:10.1016/j.enpol.2013.03.018.

[48] Schweizer-Ries P. Energy sustainable communities: Environmental psychological investigations. Energy Policy 2008;36:4126–35.

[49] Arnstein SR. A Ladder of Citizen Participation. J Am Plan Assoc 1969;35:216–24.

[50] Hagspiel S, Jägemann C, Lindenberger D, Brown T, Cherevatskiy S, Tröster E. Cost-optimal power system extension under flow-based market coupling. Energy 2014;66:654–66. doi:10.1016/j.energy.2014.01.025.

[51] Eurelectric. Power Choices - Pathways to Carbon-Neutral Electricity in Europe by 2050 2011.

[52] Schmid E, Knopf B. Quantifying the Long-Term Economic Benefits of European Electricity System Integration. Fond Eni Enrico Mattei Work Pap Ser 2014;2014.003.

[53] Pregger T, Nitsch J, Naegler T. Long-term scenarios and strategies for the deployment of renewable energies in Germany. Energy Policy 2013;59:350–60. doi:10.1016/j.enpol.2013.03.049.

[54] Nagl S, Fürsch M, Paulus M, Richter J, Trüby J, Lindenberger D. Energy policy scenarios to reach challenging climate protection targets in the German electricity sector until 2050. Util Policy 2011;19:185–92. doi:10.1016/j.jup.2011.05.001.

[55] Creutzig F, Goldschmidt JC, Lehmann P, Schmid E, von Blücher F, Breyer C, et al. Catching two European birds with one renewable stone: Mitigating climate change and Eurozone crisis by an energy transition. Renew Sustain Energy Rev 2014;38:1015–28. doi:10.1016/j.rser.2014.07.028.

[56] Cludius J, Hermann H, Matthes FC, Graichen V. The merit order effect of wind and photovoltaic electricity generation in Germany 2008–2016: Estimation and distributional implications. Energy Econ 2014;44:302–13. doi:10.1016/j.eneco.2014.04.020.

[57] Burger B. Stromerzeugung aus Solar- und Windenergie im Jahr 2013 2014. http://www.ise.fraunhofer.de/de/downloads/pdf-files/aktuelles/stromproduktion-aus-solar-und-windenergie-2013.pdf (accessed April 30, 2015).

[58] Häseler S. Procuring Flexibility to Support Germany’s Renewables: Policy Options. Zeitschrift Für Energiewirtschaft 2014. doi:10.1007/s12398-014-0128-x.

[59] Neuhoff K, Diekmann J, Gerbaulet C, Kemfert C, Kunz F, Schill W-P, et al. Energiewende und Versorgungssicherheit: Deutschland braucht keinen Kapazitätsmarkt. DIW-Wochenbericht 2013;80:3–4.

[60] Böckers V, Giessing L, Haucap J, Heimeshoff U, Rösch J. Braucht Deutschland einen Kapazitätsmarkt für Kraftwerke? Eine Analyse des deutschen Marktes für Stromerzeugung. DICE ordnungspolitische Perspekt 2012;24.

[61] Hirth L, Ueckerdt F. Redistribution effects of energy and climate policy: The electricity market. Energy Policy 2013;62:934–47. doi:10.1016/j.enpol.2013.07.055.

[62] Bundesnetzagentur, Bundeskartellamt. Monitoringbericht 2014 2014. http://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Allgemeines/Bundesnetzagentur/Publikationen/Berichte/2014/Monitoringbericht_2014_BF.pdf?__blob=publicationFile&v=4 (accessed January 26, 2015).

[63] Backlund S, Thollander P, Palm J, Ottosson M. Extending the energy efficiency gap. Energy Policy 2012;51:392–6. doi:10.1016/j.enpol.2012.08.042.

[64] Jaffe AB, Stavins RN. The energy-efficiency gap What does it mean? Energy Policy 1994;22:804–10. doi:10.1016/0301-4215(94)90138-4.

[65] DeCanio SJ. The efficiency paradox: bureaucratic and organizational barriers to profitable energy-saving investments. Energy Policy 1998;26:441–54. doi:10.1016/S0301-4215(97)00152-3.

[66] Thollander P, Palm J, Rohdin P. Categorizing Barriers to Energy Efficiency: An Interdisciplinary Perspective. In: Palm J, editor. Energy Effic., Sciyo; 2010. doi:10.5772/266.

[67] Fleiter T, Schleich J, Ravivanpong P. Adoption of energy-efficiency measures in SMEs—An empirical analysis based on energy audit data from Germany. Energy Policy 2012;51:863–75. doi:10.1016/j.enpol.2012.09.041.

[68] Sorrell S. The economics of energy service contracts. Energy Policy 2007;35:507–21. doi:10.1016/j.enpol.2005.12.009.

[69] Heinrichs H. Sharing Economy - Im Zeitalter des Homo collaborans. Polit Ökologie 2013;135:99–106.

[70] Bardhi F, Eckhardt G. Access Based Consumption: The Case of Car Sharing. J Consum Res 2012;39:881–98.

[71] Bundesnetzagentur. Evaluierungsbericht nach §33 Anreizregulierungsverordnung ARegV 2015. http://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Allgemeines/Bundesnetzagentur/Publikationen/Berichte/2015/ARegV_Evaluierungsbericht_2015.pdf?__blob=publicationFile&v=3 (accessed January 26, 2015).

[72] Goulden M, Bedwell B, Rennick-Egglestone S, Rodden T, Spence A. Smart grids, smart users? The role of the user in demand side management. Energy Res Soc Sci 2014;2:21–9. doi:10.1016/j.erss.2014.04.008.

[73] dena. dena Verteilnetzstudie- Ausbau und Innovationsbedarf der Stromverteilnetze in Deutschland bis 2030. 2012. http://www.dena.de/fileadmin/user_upload/Projekte/Energiesysteme/Dokumente/denaVNS_Abschlussbericht.pdf.

[74] Büchner J, Katzfey J, Flörcken O, Moser A, Schuster H, Dierkes S, et al. Moderne Verteilernetze für Deutschland (Verteilernetzstudie) 2014. http://www.bmwi.de/BMWi/Redaktion/PDF/Publikationen/Studien/verteilernetzstudie,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf (accessed January 26, 2015).

[75] Nykamp S, Andor M, Hurink JL. "Standard" incentive regulation hinders the integration of renewable energy generation. Energy Policy 2012;47:222–37. doi:10.1016/j.enpol.2012.04.061.

[76] Mani S, Dhingra T. Critique of offshore wind energy policies of the UK and Germany—What are the lessons for India. Energy Policy 2013;63:900–9.

[77] IZES gGmbh, E&E Consult, Öko Institut e.V., SUSI, BET Aachen GmbH, Dr.Dornbach&Partner GmbH. Optimierungsstrategien Aktiver Netzbetreiber beim weiteren Ausbau erneuerbarer Energien zur Stromerzeugung (OPTAN) 2008.

[78] European Commission. European Technology Platform SmartGrids Vision and Strategy for Europe's Electricity Networks of the Future 2006. ftp://ftp.cordis.europa.eu/pub/fp7/energy/docs/smartgrids_en.pdf (accessed April 30, 2015).

[79] Erlinghagen S, Markard J. Smart grids and the transformation of the electricity sector: ICT firms as potential catalysts for sectoral change. Energy Policy 2012;51:895–906. doi:10.1016/j.enpol.2012.09.045.

[80] 50Hertz Transmission GmbH, Amprion GmbH, TenneT TSO GmbH, TransnetBW GmbH. Netzentwicklungsplan Strom 2014 2014. http://www.netzentwicklungsplan.de/_NEP_file_transfer/NEP_2014_2_Entwurf_Teil1.pdf (accessed January 27, 2015).

[81] Aas Ø, Devine-Wright P, Tangeland T, Batel S, Ruud A. Public beliefs about high-voltage powerlines in Norway, Sweden and the United Kingdom: A comparative survey. Energy Res Soc Sci 2014;2:30–7. doi:10.1016/j.erss.2014.04.012.

[82] Luhmann H-J. Das Verfahren der Öffentlichkeitsbeteiligung in der Stromnetz-Ausbauplanung - eine erste Bewertung. Energiewirtschaftliche Tagesfragen 2013;63:32–6.

[83] ENTSO-E. 10-Year Network Development Plan 2012 2012. https://www.entsoe.eu/major-projects/ten-year-network-development-plan/tyndp-2012/.

[84] European Commission. Regulation (EU) No 357/2013 2013.

[85] Tröster E, Kuwahata R, Ackermann T. European Grid Study 2030/3050 2011. http://www.energynautics.com/downloads/competences/energynautics_EUROPEAN-GRID-STUDY-2030-2050.pdf (accessed April 30, 2015).

[86] Huber M, Dimkova D, Hamacher T. Integration of wind and solar power in Europe: Assessment of flexibility requirements. Energy 2014;69:236–46. doi:10.1016/j.energy.2014.02.109.

[87] Fürsch M, Hagspiel S, Jägemann C, Nagl S, Lindenberger D, Tröster E. The role of grid extensions in a cost-efficient transformation of the European electricity system until 2050. Appl Energy 2013;104:642–52.

[88] Henriot A. Financing investment in the European electricity transmission network : consequences on long-term sustainability of the TSOs financial structure. Florence Sch Regul Policy Briefs 2013;2013/03.

[89] Meeus L, He X. Guidance for project promoters and regulators for the cross-border cost allocation of projects of common interest. Florence Sch Regul Policy Briefs 2014;2014/02.

[90] Puka L, Szulecki K. The politics and economics of cross-border electricity infrastructure: A framework for analysis. Energy Res Soc Sci 2014;4:124–34. doi:10.1016/j.erss.2014.10.003.

[91] Steffen B. Prospects for pumped-hydro storage in Germany. Energy Policy 2012;45:420–9. doi:10.1016/j.enpol.2012.02.052.

[92] Pape C, Gerhardt N, Härtel P, Scholz A, Schwinn R, Drees T, et al. Roadmap Speicher 2014:126. http://www.energiesystemtechnik.iwes.fraunhofer.de/content/dam/iwes-neu/energiesystemtechnik/de/Dokumente/Studien-Reports/2014_Roadmap-Speicher-Langfassung.pdf (accessed January 5, 2015).

[93] Sterner M, Thema M, Eckert F, Moser A, Schäfer A, Drees T, et al. Stromspeicher in der Energiewende 2014:152. http://www.agora-energiewende.de/fileadmin/downloads/publikationen/Studien/Speicher_in_der_Energiewende/Agora_Speicherstudie_Web.pdf (accessed January 5, 2015).

[94] Fuchs G, Lunz B, Leuthold M, Sauer DU. Technology Overview on Electricity Storage 2012.

[95] Bhatnagar D, Currier A, Hernandez J, Ma O, Kirby B. Market and Policy Barriers to Energy Storage Deployment 2013. http://www.sandia.gov/ess/publications/SAND2013-7606.pdf.

[96] Youncios AG. Younicos and WEMAG to build Europe's biggest Battery Park - Press Release 30 April 2013. http://www.younicos.com/en/media_library/press_area/press_releases/013_2013_04_30_WEMAG.html (accessed August 8, 2014).

[97] Ruester S, He X, Vasconcelos J, Glachant J-M. Electricity Storage: How to Facilitate its Deployment and Operation in the EU. Florence Sch Regul Policy Briefs 2012.

[98] Kondziella H, Brod K, Bruckner T, Olbert S, Mes F. Stromspeicher für die „Energiewende" – eine akteursbasierte Analyse der zusätzlichen Speicherkosten. Zeitschrift Für Energiewirtschaft 2013;37:249–60. doi:10.1007/s12398-013-0115-7.

[99] die Bürgerenergiewende. Energiewende-Charta 2014. http://www.oekologische-plattform.de/wp-content/uploads/2013/07/charta_info_a4_unterschriftenliste.pdf (accessed January 30, 2015).

[100] acatech (Ed.). Towards a financially viable transition to sustainable energy. Efficient regulation for tomorrow's energy system (acatech Position Paper) 2012. http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Publikationen/Englisch/acatech_POSITION_Energiewende_Englisch_WEB.pdf (accessed March 13, 2015).

[101] Fuchs G. The Governance of Innovations in the Energy Sector: Between Adaptation a nd Exploration. Sci Technol Stud 2014;27:34–53.

[102] North DC. Institutions. J Econ Perspect 1991;5:97–112.

[103] Künneke RW. Institutional reform and technological practice: the case of electricity. Ind Corp Chang 2008;17:233–65. doi:10.1093/icc/dtn002.

[104] Goldthau A. Rethinking the governance of energy infrastructure: Scale, decentralization and polycentrism. Energy Res Soc Sci 2014;1:134–40. doi:10.1016/j.erss.2014.02.009.

[105] Hendriks CM. Policy design without democracy? Making democratic sense of transition management. Policy Sci 2009;42:341–68. doi:10.1007/s11077-009-9095-1.