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The German energy transition as a regime shift

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Abstract: In this paper, I use the resilience framework to interpret the project of transforming the German energy system into a renewable energy sources (RES)-based system, the so-called *Energiewende*, as a regime shift. This regime shift comprises several transformations, which are currently altering the technological, political and economic system structure. To build my argument, I first sketch how technological, political and economic developments reduced the resilience of the conventional fossil-nuclear energy regime and created a new RES-regime. Second, I depict recent changes in German public discourse and energy policy as the shift to the RES-regime. Third, I highlight challenges involved with increasing the resilience of the RES-regime. In particular, sufficient resilience of the electricity transmission grid appears to be crucial for facilitating the transformation of the whole energy system.

Keywords: energy system, energy transition, regime shift, renewable energy sources, resilience

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1. Introduction

In 1980, an environmental think tank coined the notion *Energiewende*, defining it as "growth and prosperity without petroleum and uranium" (Krause et al. 1980, own translation). At that time, the *Energiewende* was only a vision at the left fringe of the German political discourse. Thirty-one years later, in the wake of the Fukushima disaster, a Conservative government committed Germany to phase-out nuclear power until 2022. This constituted a spectacular policy U-turn because the same Conservative government had previously overturned an earlier attempt to ban nuclear power in Germany by a centre-left coalition of Social-Democrats and the Green Party. This policy U-turn also completed a broad political consensus regarding the transformation of the energy system towards a purely renewable energy sources (RES)-based system: Since 2000 substantial support policies have effectively been pushing RES into the electricity market and in 2010 – i.e. already before the Fukushima disaster – Germany had set very ambitious energy policy targets aiming at 80% RES-generated electricity in 2050. The Economist (2012) neatly summarized the history of the *Energiewende*: "It was dreamed up in the 1980s, became policy in 2000 and sped up after the Fukushima disaster in March 2011." At this point, three important questions emerge: First, how did the notion of a RES-based energy system, within 30 years, move from an environmentalist vision to a broadly supported societal project? Second, did the energy transition merely "speed up" in 2011 or does the nuclear phase-out rather mark a substantial turning point? Third, what are the biggest challenges for successfully completing the energy transition?

In order to address these questions, I conceptualize the energy transition from a systemic perspective, which might draw on a range of analytical frameworks. For instance, Fuchs et al. (2012) rely on the theory of strategic action fields (Fligstein and Mc Adam 2012) in order to analyze the interactions of incumbent actors and challenger actors in the German energy sector and to assess the adaptive capacity of governance structures. Yet, as Fuchs et al. (2012) note, the approach of Fligstein and Mc Adam (2012) suggests a problematic dichotomy between incremental and radical change. The transition management approach (Geels 2002, Geels and Schot 2007) could also serve as a conceptual basis for framing the energy transition and has been applied to the Dutch example by Verbong and Geels (2007). Transition management builds on the multi-level perspective (MLP) of Rip and Kemp (1998) that distinguishes between *niches, socio-technical regimes* and *socio-technical landscapes*, focusing on the interactions between these levels. In my view, however, the MLP-approach's delineation of an exogenous socio-technical landscape "beyond the direct influence of niche and regime actors" (Geels and Shot 2007: 400) is questionable because it suggests a hierarchical ordering of the levels.

In this paper, I frame the German *Energiewende* within the resilience approach. Here, I refer to the popular Walker et al. (2004) definition of resilience as ‘‘the capacity of a system to absorb disturbance and reorganize while undergoing change, so as to still retain essentially the same function, structure, identity, and feedbacks’’. Since Holling’s (1973) seminal work, the concept of resilience is used to analyze dynamic systems (ecological, ecological-economic or social-economic) that may shift between multiple regimes (“stability domains”). These regimes fundamentally differ in function, structure and feedbacks. If a system’s current regime is high in resilience, a shift to another regime is unlikely. If, however, the regime’s resilience decreases, it becomes prone to disturbances and possible shifts to another regime. Such a regime shift implies substantial structural reorganization, which may yield catastrophic consequences; for instance, coral reefs may shift from coral to algae dominance and semi-arid rangelands from grasslands to shrubs and bushes that inhibit cattle grazing (Scheffer et al. 2001). Furthermore, large-scale societal transformations have been interpreted as regime shifts, as in the case of industrialization in Europe (Krausmann et al. 2008). In sum, resilience is an important property of dynamic systems in that a high level of resilience helps to avoid undesirable regime shifts while in other contexts a loss of resilience may promote favorable regime shifts.

I argue that the resilience framework lends itself to shed some light on two important characteristics of the energy transition: First, the mutual interdependence of persistence and change on different scales of the energy system and second, the dynamic interplay of gradual processes and a sudden regime shift. To highlight these points, I conceive the energy transition as a shift from a fossil-nuclear energy regime to a RES-based regime. In this view, a successful energy transition requires i) a loss of the fossil-nuclear regime’s resilience and the creation of an RES-regime, ii) an identifiable shift of the system to the RES-regime and iii) a high level of resilience of the RES-regime.

My main argument is that the German *Energiewende* already satisfies i) and ii). In particular, I contend that the political changes in 2011 constitute a shift from the fossil-nuclear to the RES-regime. Yet the energy transition (in large parts) is still a project to be completed in the future and different actors hold different visions of its final state (cf. Section 3c). Some hope that it will yield a fundamental shake-up of capitalist society, clearing the way for a more democratic, locally anchored society, others regard it as a purely technological issue. I address this issue by portraying a middle-of-the-road scenario which I believe to be the most plausible: It neither reduces the energy transition to a matter of technology (= ignoring the social-economic embedment of technology) nor burdens the endeavor with hopes for societal salvation (= neglecting the technological and economic aspects of the energy system).

The remainder of this paper is organized as follows. In Section 2, I outline my conceptual framework in more detail and introduce my understanding of relevant concepts. In Section 3, I portray the energy transition as a shift from a fossil-nuclear to a RES-based regime. I discuss the value added by this analysis in Section 4, highlighting conceptual implications for the resilience framework on the one hand and implications for our understanding of the *Energiewende* on the other hand. In Section 5, I summarize and draw conclusions.

2. Conceptual framework

Resilience, understood as the capacity of a system to absorb disturbances and perform changes without fundamentally altering the system's functional structure (Walker et al. 2004), can be operationalized for dynamic systems that exhibit two or more regimes (also called "stability domains" or "basins of attraction"). These regimes should be identifiable via differences in *function*, *structure* and *feedbacks*. Thus, in order to meaningfully apply the concept of resilience to the *Energiewende* I need to i) define the German energy system and ii) show that it displays these characteristics.

ad i) I take advantage of the observation that system boundaries are arbitrary constructs and pursue an "all-in" approach: I assume that every actor or technological entity that is somehow concerned with energy via producing/trading/consuming energy or discussing energy-related topics is part of the system.[1] Strictly speaking, I focus on the electricity system. Albeit energy is a broader issue that concerns also residential heating, traffic and the more general question of energy efficiency, discussing all these issues and their relations would overburden the paper's scope. Also, the German *Energiewende* discourse focuses on electricity while employing the term energy. Hence, when referring to energy although addressing mainly matters of electricity, I do so for pragmatic reasons.

ad ii) I believe that it is possible to meaningfully delineate two energy regimes that differ in function, structure and feedbacks. Sections 3a and 3c describe the characteristics of the fossil-nuclear (see Table 1) and the RES-regime (see Table 2) in detail. At this point it may suffice to set out the crucial differences: Regarding the regimes' *function*, the fossil-nuclear regime provides energy in an affordable and reliable way while the RES-regime provides energy in an affordable, reliable and sustainable way. Regarding the regimes' *structure*, I differentiate three areas:

- Technological structure: energy generation, transmission and consumption
- Political structure: policies, politics and public discourse, institutions
- Economic structure: economic actors and their relations

[1] The same individual may, therefore, be part of the energy system in several ways.

In each of these areas, the fossil-nuclear regime substantially differs from the RES-regime. While the former is characterized by large-scale production and transmission technology, a concentrated ownership structure and a set of policies and narratives that supported this arrangement, the latter is characterized by a more decentralized technological and economic structure and an alternative, sustainability-oriented set of policies and narratives. The different *feedback* mechanisms of the two regimes result from the interplay of the respective technological, political and economic structures.

By applying the resilience framework, I focus on the interdependence of fast and slow changes as well as persistence and fundamental change on different scales, as presented in Gunderson and Holling (2002). In this perspective, regime shifts are framed as sudden and fundamental changes which are deeply intertwined with slower and more gradual changes. Importantly, there is no hierarchical ordering of levels, so that low and high levels mutually affect each other.

Relying on the resilience terminology also implies that I do not follow terminological differences made in other approaches. In particular, I use the terms transformation and transition interchangeably, in contrast to much of the transition management literature.[2]

3. Regimes, resilience and transition in Germany's energy system

a. The fossil-nuclear regime

	Energy system	
Function	Providing energy for the whole society in a reliable and affordable way	
Structure	**Technological**	Large-scale production and transmission
	Political	Government support for fossil-nuclear power, narratives highlighting security of supply and affordability
	Economic	Concentrated ownership structure of generation and transmission capacities / oligopoly of four big utilities
Feedback	Large-scale production and transmission requires capital-intensive investments, from big utilities; the latter, in turn, favor large-scale projects to take advantage of economies of scale	

Table 1: The fossil-nuclear regime

[2]For instance: "The concept of transformation is typically used to describe societies and spaces that have experienced an ostensibly wholesale shift in the economic mode of production (accompanied by reordering of political institutions and the restructuring of social landscapes). […]. In contrast, transition is more widely used to denote iterative, incremental processes of change, towards uncertain futures" (Brown et al. 2012: 1608).

The conventional fossil-nuclear regime, which emerged in the 1950s, exhibited a set of specific characteristics. On the technological level, energy was generated mainly by nuclear power and fossil fuels in a centralized production structure before being transmitted to a multitude of consumers. On the political level, the state subsidized and supported conventional power generation over the whole value-chain. The public discourse centered on security of supply and affordability as main targets of the energy system. On the economic level, an oligopoly of four big utilities shared the biggest part of the German energy market. As each of the "big four" disposed of its own transmission network, the regional separation of networks effectively inhibited competition and fostered a very rigid market structure. In sum, the fossil-nuclear regime was very resilient for several decades because technological, political and economic structure mutually reinforced each other. Thus, a positive feedback perpetuated the fossil-nuclear regime's configuration.

However, the regime's resilience steadily decreased when political changes spilled over to the economic and the technological areas. After the environmental movement had become an important agenda setter in German politics, RES-support policies were initiated in 1991 and significantly extended in 2000. This RES-support led to technological improvements and increasingly decentralized energy production. In consequence, from 1996 to 2012, the share of energy generated by RES increased from 4% to 23% (BDEW 2013). Decentralized, small-scale energy production by households or local/regional cooperatives significantly changed the energy market structure, thereby threatening the fossil-nuclear power oligopoly. In contrast to conventional energy sources, RES in Germany are predominantly owned by new actors, which have formerly not been engaged in energy production. As of 2010, 40% of all RES capacities were owned by private persons, 14% by project managers, 11% by banks and funds, 10% by farmers and 9% by businesses. Only 6.5% of renewable capacities were owned by the "big four" (the rest being dispersed among other utilities; Trendresearch 2011: 45). Additionally, the liberalization of the electricity market within the European Union empowered consumers and forced producers to unbundle production and transmission. Consequently, the energy market grew more competitive and the positive feedback mechanism in favor of large-scale energy production and transmission weakened.

From a conceptual perspective, the same processes that lowered the fossil-nuclear regime's resilience created a RES-based regime. "Institutional entrepreneurs" (Westley et al. 2011), who advanced sustainability and RES-support on the political agenda, may have played a key factor in building a politically and technically feasible alternative to the fossil-nuclear regime. Over time, the *Energiewende* narrative grew more popular and finally occupied the centrist mainstream of German politics: In 2010, the Conservative coalition under Chancellor Merkel laid out an energy concept which aimed at over 80% RES supply in 2050 and substantial reductions in energy consumption as well as greenhouse gas emissions.[3]

Yet, until 2011 the main beneficiaries of the fossil-nuclear regime successfully prevented a regime shift by putting forward the narrative that a nuclear phase-out would endanger security of supply. While the aim of a RES-based energy system gained support, nuclear power was still praised as an indispensable bridging technology by the "big four" utilities and their political peers. Thus, in 2010, an earlier attempt to phase out nuclear power by a centre-left coalition of Social-Democrats and the Green Party was reversed by the Conservative coalition under Chancellor Merkel. The administration justified this move by referring to security of supply and affordability which, they argued, RES could not guarantee in the short and medium term.[4]

b. The regime shift

The Fukushima Daiichi nuclear disaster starting on march 11, 2011 had a profound impact on German energy policy. Chancellor Merkel reasoned that "Fukushima has forever changed the way we define risk in Germany" (Schwägerl 2011). Only three days after the multiple reactor meltdown at Fukushima had got under way, Chancellor Merkel effectuated a moratorium which required the seven oldest nuclear power plants in Germany to be immediately taken off the grid. In Mai 2011, the government ordered the old reactors not to be ramped up again and decided that the remaining German nuclear power plants will have to shut down until 2022. This nuclear phase-out had repercussions on all aspects of the energy system:

- *Technological structure:* The most immediate effect of the nuclear phase out consisted of a sharp drop in nuclear power's share as the oldest reactors were ordered off the grid. While in 2010 nuclear power contributed 22% to the overall energy mix, in 2012 the share had dropped to 16% percent. Until 2022, the remaining share will have to be substituted. The effect on the technology portfolio is strong because feed-in from nuclear power is much more stable than feed-in from volatile RES. The 2011 decision represents a break-up of technological path-dependency as it forces energy providers and transmission operators to adapt within a restricted time-frame.
- *Political structure:* A long-standing and at times not only rhetorical battle between supporters and opponents of nuclear power in Germany has been won by the latter. The established Conservative newspaper *Frankfurter Allgemeine Zeitung* opines that in 2011 an

[3] http://www.bundesregierung.de/Content/EN/Artikel/2010/12/2010-10-01-energiekonzept-bt_en.html?nn=447030
[4] http://www.bundestag.de/dokumente/textarchiv/2010/32009392_kw43_de_atompolitik/

"ideological Thirty Years' War" ended (Kohler 2011). Vitally, it was a Conservative government that always had argued in favor of nuclear power, which made the decision. It is questionable whether any possible newcomer to the German political landscape would be interested in reanimating the debate. Since May 2011, the question "should Germany phase out fossil and nuclear energy?" is unanimously replaced in public debates by the question "how does Germany best achieve full RES energy supply?" Importantly, the former beneficiaries of nuclear power agree on this point as well. For instance, the new CEO of RWE, one of the "big four" utilities, recently conceded that "the nuclear power chapter has come to an end" (Teichmann 2012).

- *Economic structure:* Economically, nuclear power was a very important domain of the big utilities since it demands very high investment costs but entails low variable costs once a plant is running. In Germany the introduction of nuclear power had been heavily subsidized (Meyer and Küchler 2010), so the plant owners could significantly lower their up-front capital costs while reaping the benefits of their soon to be depreciated plants. The nuclear phase-out thus deprives the "big four" of the most profitable assets within their technology portfolio and further diminishes their declining market shares. This, in turn, means that the phase-out substantially lowers the political bargaining power of the fossil-nuclear oligopoly.

Using the resilience framework's terminology, my argument can be summarized as follows: the 2011 broad political consensus on Germany's future energy trajectory and the nuclear phase-out's repercussions on the technological and economic structure of the energy system constituted a shift from the fossil-nuclear towards the RES-regime. In this view, the Fukushima disaster acted as an exogenous disturbance initiating the regime shift.

c. The RES-regime

	Energy system	
Function	Providing energy for the whole society in a reliable, affordable and sustainable way	
Structure	**Technological structure**	Mix of production capacities of all scales: from small units on household scale (e.g., geothermal energy and photovoltaics) to very large units (e.g., off-shore wind-farms); large-scale transmission network
	Political structure	Support policies for RES; *Energiewende* narrative
	Economic structure	Mixed ownership structure of generation and transmission capacities: from households, communal cooperatives to pension funds and large utilities
Feedback	Small- and medium-scale RES benefit from a decentralized ownership structure; a high share of RES makes those conventional energy sources superfluous (nuclear and coal are slow to ramp up and incompatible with a system mainly based on volatile RES) that are traditionally a domain of the "big four" while calling for back-up facilities (fast to ramp up gas turbines) that are often operated by smaller communal utilities	

Table 2: The RES-regime

In the RES-regime, energy is to be provided in a sustainable way – what exactly this means, however, becomes less clear on closer inspection and a matter of debate. The common denominator of alternative visions of the final state of the energy transition is that dependence on fossil fuels and nuclear energy needs to end. This might be achieved by a broad range of combinations of specific RES and different spatial allocations thereof. In particular, RES might be allocated in a centralized or a decentralized way. As personal preferences differ and every specific combination of technologies entails a corresponding set of costs, opinions on the best combination and allocation of RES diverge.

In order to condense a plethora of suggested pathways for the energy transition, I contrast two opposing poles: First, some, especially on the left wing of the German political spectrum, conceive the *Energiewende* as an integral part or catalyst of a more thorough transformation of the whole society. Following Foxon (2013) this might be called the "Thousand Flowers" vision. Proponents of this view hope for the energy transition to deliver a more equitable and less capitalist society. They emphasize the social dimension of sustainability and argue for a fully decentralized energy supply in order to empower local communities. Energy cooperatives and local energy autonomy would render any large energy infrastructure, and hence big utilities, superfluous. In this “Thousand Flowers” view, decentralized and socialized provision of energy will clear the path for an aspired participatory form of democracy. For instance, a left-alternative think tank holds that “socialization of electricity-, gas- and water grids […] is a requirement of the emancipatory, social-ecological conversion of society and an important element of democracy’s renewal” (ISM 2011: 17, own translation).

Second, a competing vision reduces the energy transition to a purely technological endeavor, which should be implemented in the most efficient manner. Adherents of this “Engineering” vision emphasize economies of scale and suggest a highly centralized RES infrastructure. This implies a concentration of wind energy close to the sea as well as off-shore and substantial trans-boundary or trans-continental transmission of RES, such as imports of solar energy from Northern Africa. For instance, Keilhacker and Bruhns (2013) argue that from a physical and economic perspective current policies favoring decentralized production of RES are counterproductive. Instead, they hold, the allocation of RES should exclusively follow geographic conditions and investments in transmission grids should be dramatically increased in order to facilitate cost-efficient deployment of RES.

The RES-regime put forward in this paper and depicted in Table 2 represents a middle-of-the-road scenario between those poles. It includes components of both visions; it builds on a mix of RES production on all scales and thus a mixed ownership structure. Neither is all energy provision decentralized, nor is it completely centralized. This technological and economic setting implies a positive feedback: An energy mix dominated by volatile RES makes slow to ramp up-power plants (coal and nuclear) redundant. The more volatile RES are present, the less traditional large-scale power plants serve as technologically appropriate and economically profitabel parts of the system. This, in turn, further promotes a diverse ownership structure and benefits small-scale producers of RES. Yet, a full decentralization seems unlikely because even full RES-provision *on average* cannot avoid situations where neither RES are available and large-scale back-up facilities need to jump in. Also, recent studies that analyze the feasibility of 100% RES-supply by 2050 demonstrate that if the latter is to be achieved, substantial centralized RES and storage facilities are indispensable (e.g., SRU 2011).

Given the opposing “Thousand Flowers” and the “Engineering” visions – and the many additional versions in between these poles – how do I justify the portrait of a single RES-regime? The actual unfolding of the *Energiewende* will depend on future technological developments (e.g., will there be significant progress in small-scale electricity storage, which would make households more independent?) and a set of other factors such as prices and consumption patterns. As it is beyond the scope of this paper to devise a full set of scenarios, the interested reader may consult studies that specifically conceive and examine different possible scenarios (ibid.). Moreover, I portray what seems to me as a very plausible path to a RES-based energy system. The scenario is aligned to current policies, which include incentives for both decentralized and centralized energy production. Also, current expansion plans for transmission infrastructure hint that large-scale production (and thus ownership structure) will remain present within the next decades. Furthermore, both the “Thousand Flowers” and the “Engineering” vision rely on implausible presumptions: The “Thousand Flowers” vision over-emphasizes the social dimension of the energy transition and neglects its technological and economic aspects. In my personal view, full decentralization is unrealistic given current technologies and institutions. For instance, complete regional autarky would require either game-changing technological progress in small-scale electricity storage capacities or consumers’ willingness to accept extreme shifts in demand following volatile RES supply. At the other extreme, the “Engineering” vision ignores the social dimension of the energy transition. Without support of and participation from the civil society, the energy transition is likely to produce substantial public resistance because citizens then would primarily bear the current costs of the transition, while its benefits mainly accrue to later generations. Here, costs include monetary as well as aesthetical and environmental costs, which may be hard to quantify. Already, NIMBYism related to the location of transmission lines and RES facilities (e.g., biogas) can be observed. Hence, the public acceptability of the transition depends on individuals and communities directly being involved in and benefitting from the transition process. Furthermore, the “Engineering” vision is economically blind on one eye in that it only refers to RES production costs. It fails to consider the crucial question of path dependency: The “big four” naturally tend to incremental adaptions in order to defend their dominant market positions. Substantial commitment to RES by members of the former energy oligopoly hinges on strong incentives from an increasingly decentralized market structure. In sum, by portraying a middle-of-the-road scenario, I intend to condense a broad range of plausible pathways, stressing that neither dimension of the energy transition should be neglected.

Drawing on these considerations, what are the biggest challenges for successfully achieving the energy transition? That is, how to operationalize resilience of the RES-regime and how to increase this resilience? First, the share of RES in overall energy supply may be a good indicator for the regime’s resilience: The higher the RES-share, the stronger the technological feedback favoring RES and discouraging investments in fossil-nuclear capacities.

Second, a rising share of regional dispersed RES would entail declining market power of the big utilities. In other words, a further decentralization would strengthen the economic feedback in favor of small-scale RES. However, the “big four” utilities naturally try to defend their market shares and thus promote large-scale RES deployment, such as off-shore wind.

Third, the expenses for RES-deployment have sharply increased in recent years and have driven up household electricity prices. Critics argue that the energy transition should be implemented in a more cost-effective way and warn of reduced public acceptability and social imbalances if current cost developments continue (Gawel et al. 2013 summarize the criticism and offer a rebuttal).

Fourth, the transmission grid must be adapted and expanded to cope with increasingly small-scale, local electricity generation while providing the possibility for large-scale RES dispatch, particularly by transferring wind power from Northern Germany to industrial areas in Southern Germany. Yet the official plan for accelerated expansion of the transmission grid is a contentious issue. Some experts argue that the proclaimed expansion needs are overstated because some of the proposed new transmission lines would mostly serve to guarantee continued feed-in from coal power plants instead of promoting additional feed-in from RES (Gerbaulet et al. 2013).

Fifth, whatever the actual RES-related requirements of expansion, the resilience of the transmission grid is crucial for the continuous transformation of the whole energy system for another reason: As security of supply traditionally constitutes a prioritized aim of German energy policy, the transformation process should not adversely affect the system's overall performance with regard to reliability of energy supply. Blackouts or intentional emergency shutdowns of parts of the grid would threaten to undermine public trust in the reliability of a RES-based system. The transformation process of the whole energy system therefore draws on sufficient resilience of the transmission grid: Indeed, the ability of the transmission grid to withstand disturbances is generally seen as a prerequisite for a reliable energy system (Oren 2003).

Summing up, the overall challenge for accomplishing the *Energiewende* may be formulated as follows: It is about adapting/transforming the technological structure of the system while ensuring resilient energy provision and social acceptability of the transition process and its (side-)effects. As the technological structure of the energy system cannot be re-constructed from scratch, it has to be adjusted while running. In more poetic words, this challenge is well described by Otto Neurath's famous metaphor:

> *We are like sailors who on the open sea must reconstruct their ship but are never able to start afresh from the bottom. Where a beam is taken away a new one must at once be put there, and for this the rest of the ship is used as support. In this way, by using the old beams and driftwood the ship can be shaped entirely anew, but only by gradual reconstruction.*

In terms of the conceptual framework from Chapter 2, increasing the resilience of the RES-regime requires strengthening the positive feedback for RES so that the system provides energy in a more and more sustainable way. Importantly, however, this process must not impair the system's other functions of providing energy in a reliable and affordable way.

4. Discussion

In the following, I first discuss how this analysis may contribute to the resilience framework itself; second, I ask what it implies for further conceptual research on the energy transition.

First, my approach raises two questions for the conceptual framework of resilience. Referring to Walker et al.'s (2004) definition of resilience as the capacity to "reorganize while undergoing change, so as to still retain essentially the same function, structure, identity, and feedbacks", I applied and contextualized the categories *function, structure* and *feedbacks.* Regarding *identity*, however, I did not find any meaningful way to operationalize the term and am somewhat skeptical as to its applicability: Identity proved to be rather elusive as a system property and seemed much less specifiable than function, structure and feedbacks.[5] Furthermore, my analysis suggests that the question how to integrate the concept of transformability into the resilience framework should be discussed further. Following Folke et al. (2010: 1), transformability is a prerequisite of resilience in that "transformational change at smaller scales enables resilience at larger scales". However, I believe that the German energy transition provides an example where resilience of a very specific part of the system facilitates the transformation of the whole system: Resilience of the transmission grid is a necessary condition for continued public support for the energy transition. I therefore argue that in the context of the *Energiewende*, resilience (on a specific lower scale) contributes to transformability (on a higher scale), and not vice versa.

Second, what does my approach add to understanding socio-technological transitions and how does it compare to related literature? The resilience-framework emphasizes two important characteristics of the energy transition: i) Gradual change and sudden shifts are interdependent; ii) Resilience on a lower scale contributes to transformational change on a higher scale. These points seem to be in danger of being lost if, for instance, the MLP-approach (Geels 2002) was used to frame the energy transition. As the MLP-approach treats high-level developments as exogenous, it may induce underestimation of the immediate transformative effect of adaptation and transformation on lower levels. Consider this passage from Verbong and Geels' (2007: 1036) analysis of the Dutch energy transition:

[5] In a conference discussion of this paper, it was proposed that the energy transition changes the system's identity from conventional producer-consumer relations to a multiplicity of prosumers (both producing and consuming) related by a smart grid. While this might be one illustration of a possible trajectory of the energy transition, other images and trajectories would be equally plausible.

“This means that we do not agree with all the rhetoric that major sustainability gains can only be achieved through major shifts to new systems. This does not mean, however, that transition policy should only support incremental adjustment options. It is also important to keep the other, more radical options alive, and facilitate learning processes and network building. But it does not seem wise at this moment to choose for massive investments and stimulation programmes for more radical options. The reason is that ongoing regime developments do not (yet) provide a window of opportunity.”

In my understanding, this conclusion might be paraphrased as follows: Niche innovations should be supported so that they can benefit from a window of opportunity. Yet, unless such a window appears, these support policies just need to “keep the innovations alive”. Moreover, substantial sustainability gains can be achieved without transforming the current system configuration. I believe that the above analysis yields rather different conclusions: a) The transition to a sustainable energy system should be interpreted as a major regime shift because substantial changes in function, structure and feedbacks occur. b) The same processes that decreased the resilience of the fossil-nuclear regime *created* the RES-regime and thus a setting in which an exogenous disturbance caused more substantial changes than in other countries. That is, without the “massive investment and stimulation programmes” (ibid.) that Germany implemented in the 2000s, the Fukushima disaster would not have led to a regime shift. In a sense, the gradual transformation processes facilitated the “window of opportunity” in the first place (cf. Dolata 2011).

5. Conclusion

In this paper, I frame the *Energiewende* as a shift from a fossil-nuclear to a RES-based regime of the energy system. This analysis provides fruitful insights on the energy transition in two ways. First, the resilience framework’s focus on scale elucidates the interdependency of persistence and change on different scales of the energy system: On the system level, resilience of the fossil-nuclear regime needs to be decreased and resilience of the RES-regime needs to be increased in order for the energy transition to succeed. Yet on a lower scale, the technological structure must continuously fulfill its function to generate and distribute electricity – in particular, the electricity transmission grid requires sufficient resilience to avoid blackouts and other disruptions which would undermine public support for the overall transformation process. Second, the resilience framework’s focus on dynamic processes highlights the interplay of gradual transition and sudden shifts: While the energy transformation occurs on a timescale of decades, the Fukushima-shock and the ensuing German energy policy consensus in 2011 constitute a sudden regime shift. Since then, the issue whether

Germany should phase out fossil-nuclear energy has been replaced by an argument over the best way to achieve full RES energy supply.

Furthermore, this paper suggests that the relations of different concepts within the resilience approach need further discussion. In particular, the analysis demonstrates that resilience on lower scales may be a prerequisite for transformation on higher scales. Thus, the energy transition provides a counterexample to the view that transformational change at lower scales facilitates resilience at higher scales. While there may be cases in which transformability is a prerequisite for resilience, the energy transition shows that the reverse dependency may also hold.

Sure enough, there are limitations to the approach carried out in this paper. In particular, the analogy of a regime shift inevitably breaks down at some point: The sudden and substantial shift in 2011 occurred mainly on the political level. On the technological and economic levels, the shift is slower and more gradual since positive feedbacks between the energy system's technological and economic structure only change in the long run. Also, it proved hard to denote explicit variables and threshold values determining the regime boundaries although such parameters would be necessary to precisely measure resilience (Carpenter et al. 2001).

Nevertheless, I believe that resilience in this paper is more than a shallow metaphor: The *Energiewende* can be meaningfully framed as a shift from a fossil-nuclear to a RES-based regime with corresponding changes in system function, structure and feedbacks.

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