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Storage Technologies for the Electricity Transition: An Analysis of Actors, Actor Perspectives and Transition Pathways in Germany

Ulrich J. Frey ^{1,*} , Sandra Wassermann ² and Marc Deissenroth-Uhrig ³

¹ Institute of Engineering Thermodynamics, German Aerospace Center (DLR), 70569 Stuttgart, Germany

² ZIRIUS, University of Stuttgart, 70174 Stuttgart, Germany; sandra.wassermann@ziri.us.uni-stuttgart.de

³ School of Engineering, University of Applied Science Saarland (htw saar), 66117 Saarbrücken, Germany; M.Deissenroth-Uhrig@htwsaar.de

* Correspondence: ulrich.frey@dlr.de

Abstract: This article analyses actors in the storage niche during the German electricity transition. Thus, we develop a more differentiated understanding of actors and their storage activities. For that, we employ the analytical multi-level-perspective (MLP) framework to focus on interactions between old and new storage technologies. Using data from expert interviews, we investigate whether the storage pathway resembles any of the four ideal types of transition pathways for interactions between niche and regime. Through our interviews, we identify five types of actor in the storage market: Big 4 (EnBW, RWE, E.ON, Vattenfall), project developers, innovative municipal utilities, small rural municipal utilities and independent green electricity providers. For each actor, we analyse four main aspects (1) previous orientation and motivation, (2) structural strategies, (3) institutional strategies, and (4) product-related strategies. Parallel to the classification of actors, we also classify available storage technologies according to their primary field of application. We conclude that interactions between regime and niche actors are cooperative, but weak, and no specific actor type currently dominates the niche activities. Hence, applications in the storage niche are not yet ready for a larger market. In sum, our results point to a future system that is characterized by reconfiguration, not substitution or transformation of current market actors.

Keywords: electricity transition; storage; actor analysis; transition pathway



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1. Introduction

Electricity production in Germany is increasingly shifting to larger and larger shares of renewable energy sources (RES), currently about 54% for electricity and 39% for heat [1]. This transition is accompanied by challenges in regard to adjustments in the system architecture, most notably market design [2,3], grid expansion [4] and storage [5]. Although a study from 2014 [5] predicted that in the next 10 to 20 years there would be no urgent requirement for new storage technologies, recent RES expansion and future plans of the German government have accelerated since then [6], making storage technology attractive by anticipating future needs.

Currently, we see increasing global investments in storage facilities (e.g., by Tesla or Volkswagen) [7], which will have an impact on storage in electricity production. Another reason for the growing importance of storage is the increasing role of flexibility options in the electricity system. The future electricity system architecture will be largely shaped by flexibility options which can be operated by different (competing) actors with different strategies and motivations [8–10]. Hence, storage options will be a crucial part of that. In the near future, we assume that the pathway of the German electricity transition will no longer be characterised by technologies for generating electricity and the corresponding actors alone. Rather, it will also be shaped by storage applications. Storage will, therefore,

be used to supplement power trading on national markets as well as to develop local business models.

Up to now, the focus of electricity transition analyses has been on electricity consumption as well as on RES generation. In contrast, this article analyses storage activities. We choose Germany as an example to illustrate general patterns, since Germany is a pioneer regarding RES and represents a sizeable share of RES markets in Europe. By analysing in detail the main actors involved, their motivations, products, and strategies, we are able to characterise the transition pathway of the storage sector [5,11]. From that analysis, we deduce probable future directions of the storage pathway.

Using data from expert interviews and document analysis, we investigate whether the storage pathway resembles the pathway for electricity generation. Since actors are partially the same (big 4, like RWE), it is also an interesting question whether their strategies are the same or are changed, i.e., modified to the niche. By analysing how actors develop future business models and describing whether new niche actors follow mainly decentralised strategies, this article sheds light on the transformation pathway of the storage sector, consisting, for example in new technologies, new institutional strategies and business models.

Actor analyses help to develop a more detailed understanding of transitions of large technical systems [8], especially the role of infrastructure and system architecture, since they study the interactions of the institutional side and actors with e.g., decisions for a certain technology. Other pathways, e.g., the current hydrogen revival (the first wave having been in the year 2005) for a decarbonised energy system, may be similar. Understanding these transformations helps to adapt environmentally friendly measures in a timelier manner.

Since transitions have been described as a blend of structures, culture and practices [12] with various drivers and tensions exerting stress on the system, such an analysis must extend beyond infrastructure. For example, as we will discuss in this article, current challenges for storage as well as innovation strategies of actors do not only affect the technical dimension, but also the development of business models. We follow the business model definition by Osterwalder [13], according to whom a business model covers four main areas: customers, offer, infrastructure and finances. Different actors with their business models coupled with different storage technologies result in many potential ranges of application. For example, batteries can be used on a (very) large or on a small (private) scale. Furthermore, storage can be used to optimize local electricity use, optimize a portfolio, conduct arbitrage or achieve profits on control power markets.

The article is structured as follows: Section 2 introduces the background, the state of the art, and the research questions of the article. Section 3 sketches the methods introducing our case studies as well as conceptual considerations and definitions. In Section 4, we present our results of the actor analysis and in Section 5 we take up these results in order to discuss if the storage pathway, i.e., the transition of the storage sector, in particular its actors, is similar to the specific characteristic of the German RES generation pathway or any other type of pathway. Finally, in Section 6 we summarize our results.

2. Germany's Electricity Transition Pathway in the Multi-Level Perspective

Sectoral innovation research—especially when dealing with large technological systems like the electricity system [14]—has increasingly made use of transition concepts like the multi-level-perspective (MLP) [15] in order to focus on interactions between old and new technologies. We will use it as an analytical framework for our research questions. As for each concept various definitions exist [16], we specify the exact definition used.

A socio-technological regime is a dominant constellation of structures, culture and practices that guides activities of incumbent actors. A niche is characterised by uncertainty, unstable rules and small support networks where radical innovations, testing of technology designs and experimental projects can take place. The socio-technical landscape is “the external and social context that enable and constrain the possibilities for regime

change, including structural socio-economic, demographic, political and international developments . . . ” [15,16].

In our research context, incumbents refer to the big four conventional electricity system companies E.ON, RWE, Vattenfall, and EnBW who are central to the regime of a centralised market. The storage niche is a mostly decentralised conglomerate of different small actors with different goals, business models and technologies, most of which are not yet profitable. Within this niche, we focus on independent green electricity providers and battery storage. Both regime and niche actors are characterized in detail in the Results section.

Typical niche processes have been analyzed in the literature of strategic niche management [17] as well as in many empirical case studies and meta-studies within the MLP [18,19]. The main elements identified are expectations, social networks and learning processes. Apart from analysing typical niche-processes, MLP studies describe interactions between old and new actors with regard to agency and power as particularly important [18,20,21]. For this reason, some authors have suggested integrating additional theories (e.g., neo-institutional, cf. [22] and field concepts [23]) into the MLP framework. Such neo-institutional approaches are widely used to understand the institutional embeddedness of actors. According to them, organizations reflect expectations of their environment, due to their dependence on external legitimacy [24,25].

Concerning transition pathways, Geels and Schot [26] suggest four ideal types of transition pathway for interactions between niche and regime. These pathways are, in the typology of Geels and Schot [26]

- “transformation” (regime actors react towards moderate pressure from outside when niche-innovations are not yet ready. They modify their innovation activities and a new regime grows out of the old regime through cumulative adjustments and reorientations by incumbent actors.),
- “reconfiguration” (symbiotic niche innovations are adopted by the regime to solve local problems. Gradually, this is followed by adjustments of the basic architecture of the regime.),
- “de-alignment and re-alignment” (sudden landscape change leads to erosion of regime, but no niche-innovation is ready to take-over. As a consequence, multiple niche-innovations develop and compete to become the core of a new regime.) and
- “substitution”. We describe a prime example for a substitution pathway in the next few paragraphs.

Other important factors within pathways are the pressure within the landscape, the interactions between niche and regime (competitive or symbiotic), the actor type dominating the niche and finally the temporal dimension (focusing on the question if niche innovations are ready to take-over in the case of a window of opportunity; see [26]).

For example, in Germany, the electricity transition resembles the “technological substitution pathway” up to now [27]. In this regime, actors find no answers towards strong pressure from outside and niche innovations are ready to take-over. This leads to strong market competition and power struggles between old and new firms. Disruptive niche-innovations, pioneered by new firms, replace existing technologies and lead to the downfall of incumbent firms [26]. Some of these innovations go beyond cutting-edge technologies by changing the socio-technical setting itself. Examples include consumer involvement by making them prosumers; introduce leasing schemes; decentralise the grid by establishing sharing communities, or to buy out small, cutting-edge companies by large, incumbent companies. Developments in the German electricity sector over the last 25 years are very close to this ideal description.

Moreover, renewable energy installations are mainly operated by new entrants (small municipal utilities, energy cooperatives, farmers and privates [28–30]). They use quite mature technologies. Due to these new actors, the structure of the system has changed from a centralized to a more decentralized system [31]. All those changes were partly accompanied by strong conflicts [27]. Both mature technologies and strong conflicts clearly suggest a substitution pathway.

The historical development of the electricity transition in Germany as substitution pathway leads directly to our research questions. Given the rising shares of variable renewables in the electricity mix and the increased importance of flexibility technologies, the storage transition pathway moves into focus: Are we able to identify the pathway for the storage sector in Germany, analogously to the electricity transition? This means analysing the actors, their institutional strategies, business models and technologies in detail. For example, do we see a substitution pathway more characterised by central or decentralised RES generation? It is important to note that future storage development is not so much a technical question but rather one of utilisation: for what tasks will future storage technologies be applied, resulting in which system structures? To answer these questions, we develop a clear definition of different storage options (see Section 3.2) by extending the usual differentiation between central and decentralized power generation that has been widely used for analyzing electricity transitions.

3. Methods

The primary data of our study stems from 10 semi-structured interviews as well as from a systematic document analysis of company web sites. Interviewees were representatives of storage and electricity associations (the Federal Association of German Energy and Water Management (BDEW), the Association of Municipal Enterprises (VKU) and the Federal Association for Energy Storage (BVES)) and representatives (innovation managers, chief executive officers (CEOs)) of seven very different storage operators, varying from the Big 4 to small independent green electricity providers.

Interviews were conducted in 2015, taped and transcribed. The transcripts provided the input data for the subsequent qualitative data analysis. The evaluation method applied is based on summary content analysis by Mayring [32]. The first step in a summary content analysis is the development of a category system according to which the material is evaluated. The main categories were deductively formed using a theoretical approach and were assigned to the guiding questions of the interview. Subcategories were created inductively. This procedure ensures a content-related connection between theory, research questions, interview guideline and evaluation. After category formation and coding, the coded material was reduced to the aspects pertaining to our research questions. Duplications were eliminated, each category by category was evaluated, analysed and interpreted across all categories. The evaluation was carried out with the software program MAXQDA.

These actor analyses were complemented with further primary data, e.g., position papers of the relevant associations and with secondary sources (academic books, articles, committee reports). Press releases and web site of each actor were monitored. The identification of typical actors who are active in this field was based on various criteria, such as geographical (only actors from the German electricity system), active participation in the storage sector (operation of a storage facility, participation in storage research projects), or positioning e.g., via statements in regard to evaluation of the new regulatory framework. As is also usual in the analysis of network members and relationships, in a further step the examined actors themselves were asked which other actors are currently active developers of storage projects or new business models and should, therefore, be interviewed.

Secondary sources were mainly used for a technology analysis of different storage technologies. The main focus of this analysis was (a) identifying various applications for the technologies and (b) estimating the diffusion phase of the respective technologies.

Altogether, the aim of our investigations is to synthesize all available information in order to achieve a detailed understanding on the storage niche in the German electricity sector. An important part of this detailed description of the niche is the characterization of all relevant types of storage operator, their technological focus as well as their plans for storage applications and future business models.

In our analysis, we concentrate on those actors who operate in the field of electricity generation and trading. Of course, technology providers and actors from the heat

and mobility sector (keyword “sectoral coupling”) are also of great importance for the developing field.

3.1. Actor Analysis of the Storage Sector

In order to answer our research questions, an actor focus was chosen to overcome a too monolithic notion of niche actors vs. regime actors [22]. This is important, because unlike in the RES generation niche, the storage niche is characterized by the fact that incumbents are also very active, i.e., regime actors are also involved in niche development. The actor analysis was guided by arguments from neo-institutional analysis as well as concepts of typical niche analyses aimed at niche mechanisms [33–35]. For each actor, we analyse four main aspects—(1) previous orientation and motivation, (2) structural strategies, (3) institutional strategies, and (4) product-related strategies (see Section 4). The next section briefly introduces these four aspects in more detail.

3.1.1. Previous Orientation and Motivation

Following neo-institutionalism, the perspective of different actors on storage is shaped by different environmental expectations and legitimacy orientations. This means that incumbents’ orientation in the field of electricity generation is shaped by large and centralized technologies and trading structures. Traditionally, pumped storage technologies are used to optimize the profitability of their (mainly fossil) portfolio-mix. Therefore, it is most likely that their vision of future storage is to support their core business strategies and technology in the field of electricity generation. For challengers, who concentrate on decentralized and small-scale technologies and applications, it is most likely that they will try to influence storage activities in order to further strengthen a more decentralized pathway. Often, challengers (like Lichtblick) are deeply rooted in the renewable energy community and have the very same guiding principles as environmental movements [36]. Consequently, their actions have to be legitimised by their customers—hence, certain pathways are simply not available for them.

3.1.2. Institutional Strategies

We define institutional strategies as actions that are directed towards influencing institutional structures. Actions may target modification, transformation or even abolishment of such structures in a strategic manner.

For example, at the beginning of the German electricity transition, incumbents (E.ON, RWE, Vattenfall, EnBW) used “institutional strategies” [37] and fought against the regulatory framework which was designed to support RES. They took legal action and tried to discredit renewable energies, accusing them of being too expensive and not safe [38].

In the period after that, they ignored RES as a serious option for a long time [27,39]. Only after the pressure for change became very strong did they start an “incorporation” strategy [23] by also investing in renewables. However, this action came with a focus on large-scale technologies like off-shore wind farms. For the storage sector, it is now interesting to analyse what kinds of institutional strategy are used by incumbents. Do they use their institutional power in order to strengthen the storage market for incumbent technologies, or do they invest in (centralised) applications for new technologies? Complementarily, challengers’ institutional strategies may not even exist, since they are often small. However, if they do, are these competing attempts of influencing the regulative framework directed towards more decentralized business models?

3.1.3. Structural Strategies

In order to handle new and radical innovation strategies, structural adjustments like building new infrastructure, re-organising human resources, etc. are needed. Hence, we analyse if and what kinds of structural strategy are chosen by incumbents and challengers. A part of the structural strategy is to build-up strategic networks. We know from the niche literature [18,40–42] that a typical nurturing mechanism is to enlarge the supporting

coalition of niche actors by resourceful actors. Therefore, we also analyse the kind of networks and coalitions incumbents and challengers have built up in order to enlarge their respective niche.

3.1.4. Product-Related Strategies

Both previous orientation and strategies result in a different focus on storage technologies and applications. According to various historical analyses of sectoral transition, radical new technological innovations are mainly driven by new challenging actors, whereas incumbents are typically engaged in incremental innovation of established technologies [26,43]. Hence, the assumption is that with regard to storage, the incumbents' main focus will be on the improvement of marketing established technologies, such as pumped hydro storage (PHS). In case incumbents will also invest in completely new technologies, it is likely that they will prefer central, large-scale plants, such as compressed air energy storage (CAES) or power to gas (P2G). Furthermore, they will focus on established applications such as trading on the control power market. In contrast, challengers will focus on completely new technologies (batteries, also P2G) and/or on new decentralized business models (e.g., batteries as home storage applications).

3.2. Definition and Conceptualization of Storage Technologies

Parallel to the classification of actors, we also classify available storage technologies according to their primary field of application. A reason for this step is the close interplay between actors and their respective preferred storage technology. Hence, a short overview of storage technologies, their applications and business cases is given.

In general, storage helps to compensate differences in demand and production profiles, given that in most systems both daily and seasonal differences exist. In times of low demand and high electricity generation through renewable energies, storage can serve as demand and absorb the generated electricity. In contrast, in times of high demand and low production, stored energy is fed into the grid as electricity, or used for self-consumption, e.g., solar roof-top panels coupled with battery storage.

Thus, storage options allow the time-delayed use of electricity. They are profitable if price differences between charging and discharging are large, and price fluctuations are frequent. They can be used in combination with RES and thus counterbalance fluctuations within a system with a high share of renewables, thus increasing system stability [44].

However, depending on technology, applications differ. Important differences exist in regard of installed capacity (in MWh) and the loading and unloading power of storage (in MW) as well as the quotient of capacity and power, the E2P (energy to power) ratio.

Sterner and Stadler [44] define suitable usages for different storage technologies. Figure 1 shows selected usages for an electrochemical battery, two mechanical energy storages—PHS and CAES—and chemical storage application P2G via electrolysis. Furthermore, PHS and CAES can be seen as a central technology whereas P2G and batteries can also be used locally.

If we compare different technologies according to their fields of application,

- for batteries, there is a usage potential on the spot market and control power market, especially on the primary reserve market. Batteries might also be of use for reactive power.
- PHS is very well suited for all applications, except primary control reserve (PR) for which it is technically feasible.
- CAES show high potential for all applications except for MR with a very high potential.
- P2G seems not to be appropriate for reactive power, but might be used on the spot market and is very well suited for all three reserve power applications.

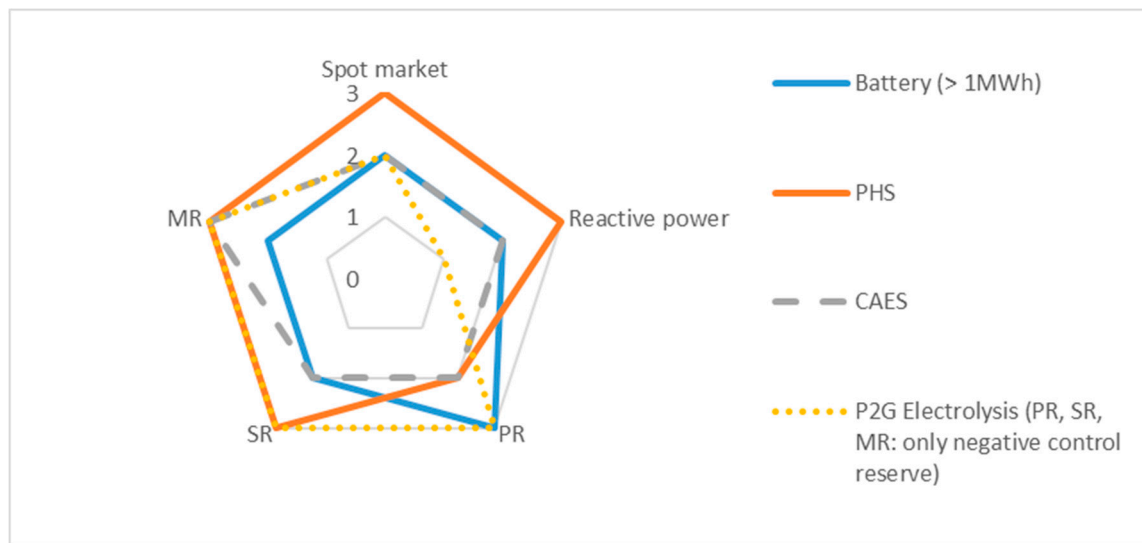


Figure 1. Potential applications for different storage technologies. 0 = no application, 1 = potential, but more research needed, 2 = technically feasible, 3 = technically very feasible (based on Sterner and Stadler 2014). Note: PR = Primary control reserve, SR = Secondary control reserve, MR = Minute control reserve, CAES = compressed air energy storage, PHS = pumped hydro storage, P2G = power to gas.

To conclude, all technologies shown are more or less equally suited for the presented applications and markets (expect P2G for reactive power).

However, the reactive power market still does not exist and arbitrage at the spot market is still not very attractive, so control power markets are the actual markets to participate in. As of now, it is difficult to estimate the future development of these markets, which includes which markets will be suited best for which technology.

Yet another technology gets increasingly attractive for private households with photovoltaic (PV) modules at the moment: small scale batteries <20 kW. These small household batteries are primarily used to enhance self-consumption. In the future, they might also enhance activities on the spot market or frequency stabilizing services. This requires a good battery management system being able to cope with the many and complex battery operation possibilities. A more diverse use of batteries might allow to increase income [45] and is, therefore, a likely strategy for owners. In case this strategy is followed by a broader base, small household batteries might compete with big batteries operated by utilities by participating in the control power markets and trading on the spot market. A model like this is offered for example by Sonnen [46]. Such a scenario would be a mixture of the strategies shown in Table 1 below.

Table 1. Combinations of the connectivity and coordination define the possible energy system architectures with the respective storage technologies associated. Note: P2G = power to gas; PHS = pumped hydro storage; CAES = compressed air energy storage.

Connectivity	Coordination/Markets		Storage Technology
	central decentralised	National weak medium	Local non-existent strong P2G, PHS, CAES home storage, big batteries

Another likely scenario might be that utilities use big battery storages as community energy storage for the enhancement of self-consumption of some prosumers of their supply area and compete in such a way with household batteries. At least from an economic perspective this would require new sophisticated business models and their economic feasibility depends on the regulatory framework [47].

These two scenarios show how the success of a storage business model is closely related to the system infrastructure in which a storage technology is embedded as well as the market options available. Besides social structures, these two dimensions (system infrastructure and markets) are the basic building blocks for a central or decentralised electricity system. Furthermore, economic, social and technological structures influence each other [48].

Since we are interested in the influence of actors and their strategies on potential transition pathways that may lead to altered electricity system structures, we need to structure storage technologies. Our structure *only* takes techno-economic infrastructure aspects [48] into account—flexibility technologies are discussed and four infrastructure dimensions are defined. Table 1 thus shows how technologies are situated within the current system architecture—which is independent of the actors' analysis and the storage niche. A simple example: pump storage will not be a driver of a decentralised, local storage system.

Due to our focus on storage technologies, a reduction to the two dimensions “connectivity” and “coordination/markets” (named “controllability” in [48]) allows an adequate definition for the studied system structure (see also Table 1). The first dimension, connectivity, refers to technological aspects, i.e., a central technology is connected to the transmission grid, whereas a decentralised technology is connected to the distribution grid. The second dimension, coordination, discriminates, according to this definition, between a market in which national electricity bids and demand are processed and which is responsible for central coordination in contrast to local or regional markets. We structure our actors' analysis alongside these dimensions (see Section 4).

This definition allows three combinations of connectivity and coordination. The combination of a central technology and a local market is excluded by definition, although, in theory, there could be regional markets with centralised plants; compare discussion about zonal pricing, e.g., by (Egerer et al. 2015).

The first combination represents the case of a national market. Here, electricity from centrally connected technologies is traded, reflecting a traditional electricity system structure. A second combination is national/decentralised—it occurs if the majority of traded electricity on the national market stems from decentralised technologies. A third combination may be labelled a system architecture with strong coordination and connectivity, if both connectivity and coordination take place on the distribution grid level and are not steered by a central authority. Characteristically, both latter architectures allow using local generation and reducing the distribution via the transmission grid or promoting self-supply to enhance local grid stability. Such a system may, in much later stages, become the system architecture. In the following we focus only on local markets on the distribution grid level, but not on self-consumption models like individual households with PV and a battery.

Having both defined and conceptualised the actor analysis and the technologies, we can now move on to the results of the expert interviews with the representatives of seven very different storage operators (varying from the Big 4 to small independent green electricity providers).

4. Results—Actors' Analysis

With our interviews, we identify five types of actor in the storage market—the big 4, project developers, innovative municipal utilities, small, rural municipal utilities and independent green electricity providers (Table 2). The following sections demonstrate two of these actor types in more detail. Due to space reasons, we cannot include our analyses of all actor types in this article. Therefore, we chose to present the two most dissimilar types, (1) “incumbents”—the big 4 (E.ON, RWE, Vattenfall, EnBW), and (2) the typical challenger's type—the independent green electricity provider.

Table 2. Storage operator types.

	Big 4	Project Developer	Innovative Municipal Utility	Small, Rural Municipal Utility	Independent Green Electricity Provider
Focus of innovation and business activities	PHS CAES P2G Batteries	P2G Batteries	P2G Batteries	Batteries	Batteries

Both actor analyses are structured according to the previously described aspects (see Section 3.1, Methods):

- Previous orientation and motivation.
- Structural strategies.
- Institutional strategies.
- Product-related strategies.

4.1. Incumbents (Big 4)

4.1.1. Previous Orientation and Motivation

The big 4 (E.ON, RWE, Vattenfall, EnBW) are incumbent actors of the conventional electricity system. In the course of the liberalization of the electricity market in the late 1990s, they became dominant market players and produced about 90% of the electricity generated in Germany in 2003 [39]. In addition, until 2009, they were also responsible for the transport of electricity as transmission and distribution network operators and are still active in this field.

Their motivation to invest into storage is two-fold. On the one hand, their old business model ceased to work in the course of the electricity transition. They search for new market options for their old (regime) technologies, e.g., PHS. On the other hand, their activities are also motivated by trying to maintain their previous role as key players in the power sector (interview with a representative of the big 4), with the help of new storage technologies. With these new technologies, they also aim to become service providers.

4.1.2. Structural Strategies

Structurally, the big 4 have responded similarly but at different speeds to the new challenges, i.e., the need to develop and test future business models for storage technologies. Each one of them has created new innovation centres and new “agile” research units to examine and test flexibility options systematically. With this strategy, the big 4 try to demonstrate that they are establishing a new innovation and creativity culture, similar to start-ups.

In addition to corporate restructuring and the formation of innovation centres, another structural strategy of the big 4 is to build up external knowledge, for example by buying out small technology manufacturers [49–51], and building up cross-sectoral coalitions (interview with a representative of the big 4)—a typical niche-strategy in order to enlarge the niche [17].

4.1.3. Institutional Strategies

As incumbents, the big 4 have been dominating the field of power generation and are used to having a considerable influence on the rules of the game. In addition to direct contacts to politics, institutional strategies are played out via associations, such as the Federal Association of the Energy and Water Industries (BDEW), which traditionally has supported the big 4.

Institutional strategies that support incumbent technologies are typical for incumbent actors. It is also very common for institutional strategies to be used for fighting against radical niche actors. But unlike at the beginning of the electricity transition, this strategy does

not apply for storage. However, the strategy is still maintained for renewables. So, the big 4 still demand that the further promotion of renewable energies via the EEG (Erneuerbare-Energien-Gesetz) feed in tariff (FIT) is stopped. The justification, however, is now the reference for storage: storage applications could become more attractive, when storage processes would not have to pay the EEG-surcharge (interview with a representative of the big 4).

Given that all storage technologies have been affected by regulatory barriers for a long time, the big 4 and all kinds of old (BDEW) and new association (especially the German Energy Storage Association (BVES), founded in 2011) have worked to reduce these barriers for all kind of storage technologies. As part of the adjustments to the EEG 2017, the first regulatory barriers to storage have since been removed. According to §61k EEG 2017, the mix of a niche-related and other business models are now supported, because earlier double payments of the EEG surcharge are now banned [3]. In particular, the big 4 express expectations that such combined models may help to scale-up their activities and that a market for ancillary services will develop in particular in regard to new business models for old technologies.

4.1.4. Product-Related Strategies

Technologically, the big 4's innovation activities cover the whole bandwidth of possible storage technologies, showing a "multi-optional strategy" (interview with a representative of the big 4). Activities focus on achieving efficiency increases and cost reductions. To achieve this, the big 4 show typical niche-related learning-activities: they participate in numerous pilot projects, like testing the use of batteries in the distribution network [52] or working with P2G-facilities.

Another goal of the multi-optional strategy is the search and development of future business models [13]. In the field of RES generation, the big 4 first had fought the market for decentralised technologies and then ignored it for a long time [53]. However, for storage applications, they emphasise that this niche-related market should not be left to small challenger actors (interview with a representative of the big 4).

Business models have to be adapted in mainly two ways: (1) the big 4 analyse how the classic arbitrage business of PHS can be adapted to the changed conditions of a system with high proportions of solar and wind energy; (2) the big 4 search for business models for new technologies. For such business models they are open for all technologies and for all business models.

Part of the business model development activities is to identify new potential professional and private customers in the field of RES generation. The attempt of the big 4 to reinvent themselves as service providers and, in the future, also in the retail market [54,55] is most visible here. In collaboration with technology manufacturer and ICT companies they develop PV home storage and ICT solutions (interview with a representative of the big 4).

In pilot projects, the big 4 try to figure out which kind of application for private home owners is economically feasible, since they assume that an upscaling of self-consumption by clustering 20 or 30 households is cheaper than offering storage applications for each single household. Furthermore, the big 4 test options for trading electricity of their customers on national markets in case their customers do not require the electricity (interview with a representative of the big 4). The idea can be interpreted as a typical "incorporation strategy" [23], where incumbents give up resistance towards new and radical technologies and try to shape them according to their business model. Thus, the original focus of the big 4 is to supplement traditional regime-oriented strategies. In contrast, niche-oriented strategies initially were not in the focus of the big 4's considerations. One main reason for that is that they already have trading platforms and trading companies; hence the technical and operational requirements for trading on national markets with stored electricity are already in place.

In the storage field, the big 4 have an edge over many smaller players who would need cooperation partners for such business models. The change of paragraph EEG § 61k allows decentralised business models to use storage locally as well as on national markets. Thus, it is yet unclear if these business models are economically feasible. In consequence, this business model is still far from being established. In contrast, a niche-oriented market for self-consumption storage has stabilised in recent years (due to a market incentive program for storage). Therefore, the big 4 are now involved in the development of niche-oriented applications for battery systems (interview with a representative of the big 4, see also [50,56]). Other plans include testing cross-sector business models. For P2G in particular, diverse solutions and future applications are tested and discussed. Ideas include the distribution of gas (hydrogen or methane) for the heat sector for which first experiences are made in pilot projects [57] and first sale ideas have been set up and implemented. In addition, longer-term ideas for the mobility sector are also being developed, ranging from considerations for a hydrogen-based mobility with fuel cell drives and natural gas vehicles to examination of possibilities for ways to develop synthetic fuels (interview with a representative of the big 4).

These considerations indicate that the big 4 stand ready to engage in niche-related business ideas in the retail sector in order to build up technological competences and to establish themselves as service providers. In addition, they are also in search of new business fields that better fit their regime-oriented business models. For the latter, they plan to cooperate with other major players, such as the chemical industry, to realize future P2G applications (interview with a representative of the big 4).

4.2. Independent Providers of Green Electricity

4.2.1. Previous Orientation and Motivation

This type of actor is rooted strongly in the renewable energy scene and reflects the guiding principle of non-governmental organizations (NGOs) and environmental movements. It has a similar holistic and cross-sectoral approach in his claim to compete with the big 4, but with a green and niche-oriented focus. The retail business for electricity from RES is the classic core business of this actor, which now is extended towards storage.

Independent providers of green electricity are highly innovative. They are motivated by contributing towards a niche-oriented electricity transition. This not only includes further expansion of renewable energies, but also strengthening decentralized and local structures [36,58]. A further goal is to improve the acceptance of the electricity transition. For example, one reason for their advertisement of tenant electricity projects is that this could reduce electricity costs for tenants and would thus strengthen the “social energy transition” [58].

4.2.2. Structural Strategies

Compared to the big 4, this actor type is very small in terms of size. One ambition is to become a green utility [11]. Therefore, activities in the area of storage and networks are strengthened (interview with a representative of an independent green electricity provider). This growth process is also accompanied by professionalization and organizational differentiation. In addition, similar to the big 4, these actors seek to integrate external knowledge through the acquisition of technology providers and competitors. For example, Naturstrom took over the start-up Grünstromwerk and offers tenant electricity products under this name [58]. Some of the green electricity providers, e.g., LichtBlick, are characterised by a strong commitment to social media. LichtBlick operates a special internet blog with high customer immersion and thus maintains close, friendly contact with customers. Customers are addressed less as customers but as allies in a joined electricity transition project [59].

Due to their self-styling as opponents of the established energy industry, which also reflects the expectation of many customers, cooperation with the big 4 is rejected. On the other hand, cooperation is being sought at the municipal level, especially with small, newly founded municipalities in addition to green power supply agreements [60]. Cooperation

with energy cooperatives also exist (energy cooperatives are important actors in the RES niche. They have shaped the previous substitution pathway of the German electricity transition. But in the storage niches they do not yet play a major role. Support from more professional actors such as green electricity providers could help them join the niche). Hence, similar to the big 4, green electricity provider build up social networks in order to enlarge the niche.

4.2.3. Institutional Strategies

Like the big 4 and other actors in the field, independent green electricity providers try to influence the regulatory framework. This is mainly done via renewable energy associations and directly by participating at stakeholder boards of ministries (interview with a representative of an independent green electricity provider). In addition, they also write their own positional papers. These do not focus so much on the subject of storage, but on the further development of the EEG and questions of a future electricity market design. The point is on strengthening the position of small players and maintaining the diversity of actors [61].

The providers of green electricity also call for a strengthening of local supply concepts. One example is the effort to exempt local electricity consumption from small size PV and combined heat and power plants (CHPs) from the EEG surcharge. However, their general position for reducing regulatory barriers for storage is similar to that of the big 4 and of other storage operators.

Very specific institutional strategies are applied by independent green electricity providers in order to strengthen niche-related system structures. They have been the first actors in Germany to set up pilot projects for tenant electricity. To support this business model, they participated in campaigns, joined with other actors and associations, such as the cooperative association, and eventually this led to the German government in the summer of 2017 finally issuing a tenant electricity law [62].

4.2.4. Product-Related Strategies

The technological focus of independent green electricity providers clearly is on battery storage. They participate in research projects and offer technologies and associated services on the market. The strategy of the independent green electricity providers is multi-optional and cross-sectoral, similar to that of the big 4. Yet, their focus on the end customer segment and on niche-related business models is a distinct difference to other players. In addition, new business areas are being set up—with limited resources in contrast to the big 4.

Existing strategies for electricity sales and direct marketing [11] are also being implemented in the area of storage. Green electricity providers place particular emphasis on “tenant electricity” products, which they have developed systematically since 2012 [63,64]. Tenant electricity products based on combined PV systems, CHPs and battery storage are now available [65]. The holistic green approach guarantees customers green electricity from local RES power plants [64,66].

Besides, trading competences on national markets are built up. One example of this is the planned crowd battery (“Schwarmbatterie”) from LichtBlick [65] or Sonnen: storage units installed in private residential buildings are grouped together by the utility company to provide control power. As early as 2009, LichtBlick began developing the SchwarmDirigent® IT platform. The platform now spans a network of more than 1000 decentralized combined heat and power plants as well as electric vehicles, PV systems and battery systems [36]. The targeted development of holistic, cross-sectoral approaches and business models thus becomes clear: heat, mobility and electricity from RES are to be coupled for end customers for an overall green supply. In addition, global trends of sharing [67] and platform [68] economies support business models like these.

4.3. Other Actors

For lack of space, the activities of the other storage operators from the electricity sector (project developers, innovative municipal utilities and small, rural municipal utilities; see also Table 2) are not further described in this article. They can be characterised as being in a middle position between the big 4 and the independent green electricity providers. For a detailed description of all five identified actors, see [69].

Since we limit ourselves to actors from the electricity sector in our study, we do not consider other important groups of actors. These include technology manufacturers, some of which now also offer services in addition to their technology products [46]. Furthermore, there are actors from other energy sectors, such as the heat and the mobility sector. Some of them already have great importance for the field. For example, Tesla is responsible for the sharp drop in battery prices in recent years [70]. Some of these actors could become very important in the near future, such as German automobile companies with their market power.

5. Discussion—The Present and Future Transition Pathway for Storage

Before characterising the storage pathway in more detail, we briefly summarise how this article fits with existing research. First, the actor analysis of the storage sector in Germany and comparing the underlying structural elements of both the transition of renewable energies and the storage sector may help to uncover similar patterns in other countries and analogous transitions. This is important, since we note that there has been quite a lot of research on the transition of renewable energy production structures, but less so on the transition of the entire system, which prominently includes the storage sector. A concrete example for Germany is the preparedness of incumbents to learn from new actors in the storage sector, which was almost completely absent during the transformation of the system by renewable energies. Hence, this article aims to contribute to a better understanding of the socio-technical pathway of storage technologies, especially home storage. In the following section, we discuss how the storage pathway can be characterised based on our results and in which direction it might develop. A first observation is that the storage field is not in the focus of energy transition-related discourses. They seem rather to be shaped by the opinion that there is still no urgent need for storage within the next years [5]. Hence, this opinion, e.g., among the big 4 strongly influences the business case for storage and thus the development of the technologies under discussion.

In order to interpret our results in the light of the ideal types of transition pathways [26], recall the aspects discussed in the introduction: we have to assess the pressure through the landscape (i.e., the larger social-political environment), the interactions between niche and regime (are they competitive or symbiotic?), the main actors within the niche and finally the temporal dimension (maturity of niche innovations in the case of a window of opportunity; see [26]). We start with landscape pressure.

Pressure is put on niche-oriented activities by other developments within the landscape: global trends of sharing [67] and platform economies [68] support business models which build up sharing solar communities (e.g., Schwarmatterie by LichtBlick). Landscape pressure has also been building up through the Fukushima reactor accident and the ever more pressing warnings and signs of climate change that have reached mainstream politics in Germany. Hence, there is almost no party that does not support (at least outwardly) the accelerated expansion of renewable energies. Moreover, storage prices have dropped significantly and storage is available for companies and private households alike.

Based on our actor analysis, we conclude that landscape pressure, therefore, seems to be at least moderate to high.

Next, we analyse interactions between regime and niche players. Interestingly, both incumbents (via their research departments or start-ups) and challengers are active in the storage field. Hence, the question about interactions is more a question of interactions between incumbents and challengers within the niche than it is between the niche and the regime itself. According to MLP-theory incumbents acting within the niche are by

definition niche players, which is visible e.g., in the way they act, like founding start-ups with only loose ties to the main company. Our findings of storage niche activities show that there are strong differences in actors' orientations and strategies. Incumbents do not target primarily local markets on the distribution grid level (see above). However, their attempts to influence regulative rules are similar. Thus, it can be concluded that the nature of interaction between regime and niche is symbiotic, but weak.

Both research departments and start-ups of the incumbents which try to mimic, to a certain extent, niche players and challengers are active within the niche. While challengers develop national, but decentralized business models, these applications are also favored by incumbents and it seems very likely that such business models will be dominated by incumbents in the course of stabilization processes, once they leave the niche.

In contrast, niche-oriented applications are developed by challengers and incumbents acting like niche players alike. For example, there are pilot projects where storage serve for local grid stability or organize electricity sharing in a neighbourhood. However, these still do not work under the current regulative framework [47]. Given the various statements of the interviews and the qualitative market analysis, we conjecture as a preliminary hypothesis that both incumbents (via research departments etc.) and challengers are active in the niche.

Finally, a last aspect to be assessed for classifying the transition pathway of the storage niche is to analyze the level of the niche's stabilization. Geels and Schot [26] suggest four proxies as

“... reasonable indicators for the stabilisation of viable niche-innovations that are ready to break through more widely: (a) learning process have stabilised in a dominant design, (b) powerful actors have joined the support network, (c) price/performance improvements have been made (...) and (d) the innovation is used in market niches, which cumulatively amount to more than 5% market share” ([26], p. 405).

When we apply these four criteria to the storage niche, we find that national and decentralized business models for trading electricity on the spot market or on the control power market are developing, but not on a larger scale. The new business models of incumbents for PHS, CAES, and P2G are not economically well-established, either. Since old business models are not feasible any more, projects of mature technologies are often on hold or are even cancelled. As long as there is no stronger external or internal pressure, a new regulative framework or new markets for ancillary services cannot be established. In these aspects, there are no signs of a stabilized niche.

However, in stark contrast to these applications, niche-oriented business models demonstrate activities of a stabilising niche due to the following findings:

- The increasing installations of solar-battery systems in Germany are based on lithium-ion (Li-Io) and lead-acid battery with a slight trend to an increasing proportion of the Li-Io technology [71].
- The costs of Lithium-Ion battery packs are decreasing [67].
- Big actors have also joined the coalition and are undertaking research and development (R&D) for batteries, like Tesla [67].
- More and more batteries are used by households in order to complement an already installed PV module. Due to price parity in Germany, PV owner like to increase the share of use of own generated electricity. Furthermore, suppliers start to sell PV + battery packages to customers (interview with a representative of the big four).

While there is not yet too much demand for new storage for the time being, niche-oriented business models increase the overall demand for storage. In combination with support schemes and regulatory advantages, this makes the niche attractive. Given the radical nature of some concepts, like community storage (“Schwarmatterie”), such business models may be profitable in the near future.

Therefore, three out of four proxies as indicators for developed niche innovations have to be assessed as existing: a dominant design (Li-Io battery), powerful actors having joined the support network (Tesla, housing industry etc.), and price improvements are being observed. The fourth proxy “market shares” is hard to determine, as there is no defined storage market. Many companies offer a combination of PV + battery, which shows a high readiness level of niche-oriented applications. Around 50–60% of all roof-top PV installations are equipped with a battery [72] with a rapidly increasing tendency [73]. Those niche-oriented activities seem to be the only stable ones and, at least for this aspect, indicate a developed niche.

In sum, these niche-oriented activities point to the reconfiguration pathway (see Table 3). This would imply that both challengers and incumbents are the main actors in the field of storage and its respective applications. Neither of them will dominate the field. Most likely, new alliances will be created with symbiotic interactions between actors.

Table 3. Four possible transition pathways including their indicators to characterise each pathway with the indicators for the storage niche. Bold = actual situation for storage as of now.

Indicator	Transformation	Substitution	Reconfiguration	De—and Realignment	Storage (Time of Now)
Landscape pressure (exogeneous)	Moderate	High	Moderate	High	Moderate to High
Main actors	Incumbents	Challengers + Incumbents	Challengers + Incumbents	Challengers	Challengers + Incumbents
Interactions between actors	Weak, symbiotic	Strong, adversary	Strong, Symbiotic (“new alliances”)	Weak, adversary	Weak, Symbiotic
Readiness of niche	Not Ready	Ready	Ready	Not Ready	Applications are ready

What can be learned from this analysis for other countries? We have to be careful in generalizing, since Germany’s “Energiewende” is rather special, because it was driven by challengers, not incumbents. Yet, countries with similar pathways may try to promote activities in the storage niche and make favorable regulations for challengers.

6. Conclusions

Using actors’ analysis, we characterize the German storage sector, its associated technologies and the corresponding transformation pathway. We identify and differentiate three energy system architectures: national and centralized, national and decentralized, as well as local and decentralized. Niche-oriented activities develop mostly around decentralized technologies (batteries). These activities develop business models where electricity stored in decentralized technologies is traded on national markets. Finally, regime-oriented activities develop central technologies (such as P2G, CAES) for trading electricity on national markets.

Typical niche mechanisms like learning, building up social networks and the formulation of expectations could be demonstrated and associated with the origin of different actor types in the storage field. These mechanisms clearly shape their strategies and business models. We also demonstrated how the experiences the actors made in their fields of origin (e.g., the incumbents ignoring public acceptance and potential of RES generation) influence their electricity-transition related activities in the storage field. This explains why the focus of incumbents is indeed regime—while challengers are niche-oriented. It also explains why incumbents are engaged in niche-oriented applications via their research departments and start-ups, while challengers set up business models that are, in terms of technology, decentralized on a national level.

Currently, both centralized and decentralized business models on a national level are not profitable. Niche-oriented activities seem to be the only stable one and, in this case, indicate a rather developed niche. Incumbents e.g., reconfiguring themselves as start-ups as well as challengers are the main actors of the niche. Furthermore, a broad actor coalition has entered the niche, such as actors from the housing industry. Niche-oriented activities, both by challengers and incumbents, seem to benefit from the following facts:

- (1) As long as the other storage technologies are not profitable, actors focus on these activities and substantially invest in it.
- (2) Niche-oriented storage applications are also supported by developments in the higher-level settings (landscape): global trends of sharing [67] and platform economies [68] seem to strengthen local concepts of building up a sharing solar community.

The current storage field, shaped by niche-oriented activities, provides evidence that it is developing in the direction of a reconfiguration pathway. In the case that regime-oriented activities also stabilize, the storage pathway could shift to a transformation pathway. A prerequisite would be that the external or internal pressure increases. As a consequence, a new regulative framework or the formation of new markets for ancillary services could become a reality and regime-oriented business models could profit.

What follows from this analysis for future policies? A better understanding of the transition pathway of the storage niche may improve planning for future legislation. For example, since the interactions between incumbents and challengers are definitely not adversary, like during the pathway of electricity generation, different policies are called for. Another example is the estimation of future infrastructure needs—again, actors' analysis, technology readiness levels and niche size may improve planning leading to better adapted policies.

Hence, we hope that policies can be adapted to the peculiarities of the actors and their institutional and political strategies in order to better understand the direction, dimensions and costs of this particular transition pathway and to avoid possible technological lock-ins at an early stage. This would help to elevate and further the role and potential of storage options in future electricity systems.

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