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The German Energiewende as a turn towards decentralisation? Impact Assessment of decentralised infrastructure dimensions.

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The German Energiewende as a turn towards decentralisation? Impact Assessment of decentralised infrastructure dimensions

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Abstract: The German *Energiewende* (energy transition) increases the degree of decentralisation in the electricity infrastructure. In this contribution, we propose a framework to assess this technological development from an economic as well as social dimension. For a definition of infrastructure dimensions, we draw on Funcke and Bauknecht's (2016) typology. The impact of decentralisation on these dimensions is then firstly assessed concerning its economic efficiency. It is shown that a decentralised electricity infrastructure has the potential to either increase or decrease the overall system costs, depending on the assessed dimension. Secondly, the social dimension is operationalised through three forms of participation, namely procedural, democratic representative and financial participation. We highlight the chances to increase participation through increasing technological decentralisation and point towards the important role of the project-initiating actors on the local level who decide whether options for participation are realised and in which manner. The contribution at hand does not provide a final answer whether centralised or decentralised electricity systems are preferable. However, it highlights a wide range of dimensions that can be considered when discussing future decentralised electricity scenarios or making decisions on electricity policy.

Keywords: decentralisation; electricity infrastructure; participation; ownership; re-municipalisation; democratisation

1. Introduction

The transformation of the electricity system towards a system based on renewable energy faces a number of uncertainties as to how the future system will or should look like. There are different options and visions, and many of them revolve around the question of whether the electricity infrastructure should be centralised or decentralised (e.g. Lilliestam and Hanger 2016; Schmid et al. 2016; Brondi et al. 2014 in peer-reviewed journal articles and Canzler et al. 2016; Agora Energiewende 2017 from a more practice-oriented position).

The aim of this paper is to propose an assessment of a decentralised electricity infrastructure. This requires an understanding of the underlying technological infrastructure and its various dimensions as well as the perspectives from which an increasingly decentralised infrastructure can be assessed. Concerning the technological infrastructure, we draw on a comprehensive typology by Funcke and Bauknecht (2016) that distinguishes between four dimensions of electricity infrastructure: The grid level of power plants (connectivity), the geographical distribution of power plants (proximity), flexibility options like storages and demand-side management (flexibility) and infrastructure control, i.e. the coordination of generation and consumption (controllability). This is further explained in chapter 2.

While various categories could be taken into account for the assessment, we focus on two perspectives that are widespread in the scientific and practice-oriented debates: (1) The first perspective is concerned with economic efficiency and whether a decentralised infrastructure yields positive or negative economic effects. For a comprehensive economic assessment, different system effects, e.g. on power plants operation or electricity grid investments, need to be analysed jointly (see chapter 3). (2) The second perspective is concerned with the argument that the *Energiewende*[1] does not only aim at reducing the environmental impact, but should also make the energy system more democratically accountable (Radtke 2013; Schwan et al. 2015; German Advisory Council on Global Change 2011). In order to make sense of this argument, we focus on three forms of "participation" that are prominent in debates about local and regional *Energiewende* aspirations: procedural, representative democratic and financial participation (see chapter 4).

The research question is: What kind of effects has a technological decentralisation on a) the economic efficiency and b) the forms of participation? We answer this question concerning all four technological infrastructure dimensions, based on a literature

[1] When referring 'energy transition', we will use the German term *Energiewende* from here on – a term that can increasingly be found in English publications (e.g. Schmid et al. 2016; Hake et al. 2015).

review. While the electricity infrastructure is becoming increasingly decentralised in many countries, our focus is on the situation in Germany, a country that is often seen as a pioneer concerning energy transitions (e.g. Hake et al. 2015).

To the best knowledge of the authors, this paper is the first attempt, to propose a heuristic framework for assessing a (hypothetical) decentralised electricity infrastructure, taking into account both the four technological dimensions and an economic as well as participatory perspective. The framework should provide insights for scientific scholars as well as local and regional actors and decision-makers into a more comprehensive view concerning the assessment and development of decentralised electricity infrastructure.

2. Different technological dimensions of decentralisation

In this chapter, the various technological dimensions of the electricity infrastructure are presented. With these dimensions, different visions that mix different elements can be distinguished. As centralisation and decentralisation is not a binary concept, there is no completely decentralised or centralised electricity infrastructure. The decentralisation of the electricity sector is mainly associated with the shift from an electricity generation in large power plants to a generation of mainly renewable electricity in smaller plants. Although this can be an important element of decentralisation, it does not take into account all infrastructure characteristics.

Funcke and Bauknecht (2016) introduced a typology which describes four technological dimensions of the electricity infrastructure. Each of these dimensions can be designed in a centralised or decentralised way and, taken together, describe the corresponding infrastructure. Table 1 shows an overview of these different technological dimensions and their possible configurations. The four different dimensions are *connectivity* and *proximity* of power plants, as well as balancing generation and demand through *flexibility* and *controllability*.

Table 1: Possible configuration of technological infrastructure dimensions

	Connectivity	**Proximity**	**Flexibility**	**Controllability**
Decentralised	Power plants are connected to the distribution grid level.	Power plants are located close to demand.	Flexibility is connected to the distribution grid.	Generation and demand are primarily balanced via distribution grid or prosumers.
Centralised	Power plants are connected to the transmission grid level.	Power plants are located at optimal locations, i.e. cost reducing or output maximising.	Flexibility is connected to the transmission grid level.	Generation and demand are primarily balanced via the transmission grid.

Source: Based on Funcke and Bauknecht (2016).

The dimension of *connectivity* describes on which grid level power plants are connected to the electricity grid. While decentralised power plants are connected to the distribution grid, centralised power plants are connected to the transmission grid. Connectivity does not distinguish between power sources as the majority of technologies can in principle be found on each grid level. The dimension of *proximity* describes the spatial distribution of generation that can also be organised in a centralised or decentralised way. A decentralised distribution refers to locations close to consumption centres, whereas a centralised distribution does not take into account the geographical distribution of consumption, but is mainly geared towards locations with the highest generation potential or lowest generation costs. For example, if the implementation of renewable generation is oriented towards areas with lowest production costs and highest electricity yields, as can be observed in Germany (AEE 2016), this can entail a centralisation of generation in this dimension.

As with power plants the connectivity of *flexibility* options can be designed in a centralised or decentralised way. Decentralised flexibility options are connected to the distribution grid level, such as the flexibility that can be provided by households. Centralised flexibilities on the other hand are connected to the transmission grid as e.g. pumped hydro storages. Finally, *controllability* describes different types of system balancing. Ideas and concepts for decentralised controllability are rather new and apply the subsidiarity principle to this problem. This can refer to self-consumption approaches, but also includes cell concepts that envisage the electricity infrastructure consisting of several cells, in which local balancing takes place (VDE 2015; N-ERGIE Aktiengesellschaft 2016). In utility-based infrastructure, balancing generation and demand is most commonly organised on a national level by the transmission grid operators with increasing international coordination, e.g. in the European internal electricity market.

3. Economic assessment

This section contains an analysis of the potential economic effects that a technological decentralisation, as described in chapter 2, entails. The discussion of a stronger decentralisation often focuses only on a specific cost component (e.g. grid expansion) rather than the overall system or the impacts a change on one dimension has on others (see e.g. BUND 2015). In the following, we provide a framework, that allows to consider infrastructure dimensions separately but ensures that no dimension is neglected in the evaluation process.

As we want to evaluate the economic efficiency of a technological decentralisation, the three main cost indicators of electricity infrastructure, namely power plants, grids and flexibility options, are applied against each of the four infrastructure dimensions. Table 2 shows an overview of the different dimension/indicator combinations and how costs tend to be affected by an advancing decentralisation. Other important indicators such as greenhouse gas emissions or energy efficiency are not further evaluated as they exceed the scope of this study.

Table 2: The impact of technological decentralisation on the economic efficiency of the electricity infrastructure

Dimensions of electricity infrastructure	Cost of Power Plants (A)	Cost of Grid (B)	Cost of Flexibility Options (C)
Connectivity (1)	=	-	=
Proximity (2)	-/=	+/=	=
Flexibility (3)	=	+/-	=
Controllability (4)	-	+/=	-

"=": no impact; "+": cost reduction; "-": cost increase.

The evaluation is based on a literature research with a focus on quantitative scientific articles and empirical studies that determine the impact of decentralised and centralised infrastructure configurations on costs. Evaluated literature focussed mainly on the national infrastructure level.

3.1 Connectivity

Decentralised connectivity means power plants that are connected to the distribution grid (cf. chapter 2). Connectivity does not distinguish between electricity sources as the majority of technologies can in principle be found on each grid level.

1A: Connectivity on Cost of Power Plants

Costs caused by power plants are either related to investment or operation. In dependence of its connectivity, these costs may vary. Investments used to follow the logic of economy of scale to reduce the share of initial costs that are part of the costs of each generated unit (see e.g. Christensen and Greene 1976). In today's electricity sector however, this logic does not necessarily apply. The variety of generation technologies and their cost structures has become increasingly heterogeneous.

While investment costs for power plants drawing on renewable energy sources for electricity generation (RES-E) are comparably high, the operational costs are rather low, as no fuels need to be acquired (an exception to this are biomass power plants). The installation of small-scale technologies shows, due to its modularity (Lovins et al. 2002), a higher flexibility of investment while it remains possible to combine several small-scale power plants to larger capacities on higher grid levels through virtual power plants. Centralised power plants, irrespective of the used technology, entail high investment costs due to its size which determines the actors or organisations that can stem such an investment (cf. section 4.1 concerning financial participation of citizens). From this follows that the concrete impact on the overall cost efficiency of a decentralisation of power plants is not clear. The two effects of economies of scale to relativise high investment costs and on the other hand the variable costs of close to zero and the modularity of decentralised power plants may lead to similar effects on a system level.

1B: Connectivity on Cost of Grid

The increasing amount of power plants connected to lower grid levels came along with the emergence of RES-E technologies. This shift may lead to an increase in bidirectional load flow, which may cause regulatory and technological challenges, as it opposes today's logic. A shift as well as an increase in costs on different grid levels may follow from this (Agora Energiewende 2013). Decentralised generation that causes load flows towards higher grid levels may lead to voltage fluctuations or bottlenecks if large capacities are installed. Investments in grid infrastructure will become necessary in the future to secure the functionality of the grid and the transportation of electricity (Ackermann et al. 2014). Therefore, a cost increasing effect can be observed in the scope of grid investments that follows from the decentralisation of power plants.

1C: Connectivity on Cost of Flexibility Options

An impact of connectivity on the costs of flexibility could not be found in the scope of this research.

3.2 Proximity

Decentralised proximity points towards the questions whether power plants are located close to the place of consumption. A centralised distribution on the other hand, is mainly geared towards locations with the highest generation potential or lowest generation costs and does not take into account the distribution of demand. Whether power plants are spatially distributed in a centralised or decentralised manner has different impacts on costs of power plants, grid and flexibility.

2A: Proximity on Cost of Power Plants

Decentralised RES-E power plants in close proximity to load centres cannot necessarily be placed at sites with the highest natural potential, which results in potentially higher generation costs. Centralised proximity, on the other hand, at sites with high full load hours (Consentec 2013; Hobbie and Möst 2014) leads to a reduction of needed capacity and decreases investment needs due to higher generation of individual power plants (Wimmer et al. 2014).

2B: Proximity on Cost of Grid

Decentralised power plants in close proximity might lead to stable grid costs or a cost reduction in comparison to power plants at sites with lowest production costs (i.e. centralised proximity). Centralised proximity potentially leads to an increase in necessary grid expansion due to increasing transmission needs from generation to consumption sites as Hobbie and Möst (2014) showed by analysing the spatial distribution of wind turbines in Germany. Also RES-E curtailment may increase with centralised proximity (Wimmer et al. 2014). However, a study by Reiner Lemoine Institut gGmbH (2013) showed that different spatial distribution patterns of power plants do not necessarily lead to different grid expansion needs, especially in scenarios close to a full supply with RES-E. The reason for this is a similar distribution pattern that results from high shares of renewables.

2C: Proximity on Cost of Flexibility Options

Unlike grid costs, the spatial distribution of power plants hardly influences the flexibility costs of infrastructure. Wimmer et al. (2014) found that scenarios for both centralised and decentralised distribution lead to the same capacity needs to supply the residual load.

3.3 Flexibility

Decentralised flexibility options are connected to the distribution grid level, such as the flexibility that can be provided by households. Centralised flexibilities on the other hand are connected to the transmission grid as e.g. pumped hydro storages.

3A: Flexibility on Cost of Power Plants

Flexibility in general helps to operate power plants more efficiently. Inflexibility of power plants with low variable costs can be compensated by the operation of flexibility, which shifts electricity from times of low to times of high demand (Ela et al. 2013). This applies to central as well as decentral flexibility options. Despite the general positive economic effect on the costs of power plants due to the shifting of electricity, an increased generation of low-cost fossil power plants, e.g. lignite power plants, and an increase of emissions may follow (Bauknecht et al. 2015). A decentralisation of flexibility thereby has no positive or negative effect on the cost efficiency of the system. An optimisation of generation costs will follow from flexibility operation, independently of its grid connection level.

3B: Flexibility on Cost of Grid

When it comes to the impact on grid expansion and designated costs, an increase in costs is mainly caused by transport of electricity through several grid levels and thereby results from the proximity of flexibilities rather than its grid connection level (Schaber et al. 2013; Ackermann et al. 2014). On the other hand, the operation of decentralised flexibility may lead to a stabilisation of grid operation and reduction of generation peaks in the distribution grid. This may lead to a reduction of grid expansion needs (Ackermann et al. 2014). The net effect of decentralised flexibility is unclear and therefore whether a cost increasing or a cost decreasing effect will outweigh.

3C: Flexibility on Cost of Flexibility Options

The grid level of flexibilities has hardly an impact on the overall costs of the flexibility provided. Flexibilities with high and low costs can be found on central and decentral grid levels as well as throughout different technology types (Bauknecht et al. 2015). Hence, the combination of technologies may influence the flexibility costs rather than the level of grid connection. The effect on the cost of the flexibility in the system is therefore not clear.

3.4 Controllability

Controllability describes different types of system balancing. Decentralised approaches refer to increasing control via distribution grids or prosumers, but can also include cell concepts that envisage the electricity infrastructure consisting of several cells. A centralised approach focuses on balancing generation and demand on a national level by the transmission grid operators with increasing international coordination, e.g. in the European internal electricity market.

4A: Controllability on Cost of Power Plants

A prerequisite of decentralised controllability is the presence of decentralised generation and flexibility to match supply and demand. Although RES-E capacities are installed on decentralised grid levels, these have to be complemented by a sufficiently large amount of flexible capacities to balance variable generation with a region's demand (e.g. battery storages or DSM) (VDE 2007). Additionally, a decentralisation may only be possible in rural areas that provide enough space for RES-E power plants. In urban areas, the renewable potential is hardly sufficient for this kind of optimisation (Peter 2013). A decentralised control and optimisation therefore leads to an increase in costs of power plant investments.

4B: Controllability on Cost of Grid

A regional balance of supply and demand requires investments into the distribution grid. However, these investments might already be necessary following the expansion of renewable energies on this grid level (Deutsche Energie Agentur GmbH et al. 2012). If operated in a self-sufficient way, a connection to the transmission grid becomes obsolete, which leads to a reduction in costs. Generally, this development is not desirable because of the large amount of costs incurred for power plants and flexibility options.

4C: Controllability on Cost of Flexibility Options

To achieve a high degree of decentralised controllability or autarky, large amounts of generation capacities and flexibilities are necessary, which would increase the costs for both (Schmidt et al. 2012). This confirms the findings of Peter (2013), who showed that, apart from rural areas with large biomass potential, self-sufficiency can hardly be achieved. A decentralised controllability of a region therefore leads to high investments in flexibility capacities and therefore an increase in costs.

4. Assessing decentralised electricity infrastructure from a perspective of participation

In this section, the economic assessment that is proposed in section 3 is complemented by a closer look at the social perspective. We elaborate on the consequences that a technological decentralisation (cf. chapter 2) has on participation on the local and regional level[2]. We focus on three forms of "participation" that are prominent in scientific as well as practice-oriented literature about local and regional[3] *Energiewende* aspirations in Germany. However, we are not assuming to cover all aspects concerning these forms, as the debates are rather widespread. We namely focus on (1) procedural participation, (2) representative democratic participation, and (3) financial participation in the electricity infrastructure. We emphasise the role of citizens, acting directly as individuals (e.g. as an investor into a RES-E power plant) or a collective (e.g. as a cooperative), or indirectly through elected representatives. As we consider the impacts of a technological decentralisation, the focus for these forms is on the local and regional level. The three forms can be described as follows:

1) Procedural participation: The planning processes of electricity infrastructure, e.g. for grids or new power plants, and the participation of citizens are subsumed in this form of participation. We analyse the impact of an increasing technological decentralisation on the possibilities of citizens to participate procedurally. Generally, it can be observed that the way a community perceives infrastructure projects highly depend on the participatory conditions as well as the type of stakeholders that are involved in the process. Ideally, the local population is included from the beginning of a participatory process and the corresponding project is carried out by stakeholders from the region (Hildebrand et al. 2012) to benefit the region (Messinger-Zimmer and Zilles 2016). This configuration increases the likelihood of a project being successful and accepted by a community.
2) Representative democratic participation: A democratic participation through representatives is the usual path for many political decisions in Germany. As we consider the local and regional scale, we focus on how elected representatives influence the *Energiewende* process on this scale. As the main options for these actors, policy-making (e.g. through local or regional energy concepts) as well as the control of public local utilities can be identified.

[2] Participation in the development of centralised elements of the infrastructure (see e.g. Steinbach 2013 for the case of transmission grid expansion) can also be enhanced and organised according to criteria like openness or inclusiveness, but are outside of the scope of this contribution.

[3] With "local and regional", we mean the lowest political levels in Germany of municipalities and administrative districts.

3) Financial participation: The third option for citizens to participate in the electricity supply is through financial involvement. Generally, it is possible to invest into centralised or decentralised elements of the infrastructure. However, investments into centralised elements (e.g. large-scale power plants or grids) are usually done indirectly, e.g. through buying shares or bonds of companies. More direct investments can be carried out on the local or regional scale, e.g. into photovoltaic systems or battery storages. For this, land or roof areas are required which is not easily available to all citizens. Therefore, collective ownership (e.g. through cooperatives) is an important option to consider on this form of participation.

As with the economic assessment (cf. chapter 3), we elaborate on the question what kind of effects a technological decentralisation of the electricity infrastructure has on these three forms of participation. In detail, we want to elaborate if a continuing technological decentralisation enhances or simplifies participation in different forms or if it has no or even negative effects.

Differentiating between these forms leads to Table 3 that shows the four technological dimensions of decentralisation in the first column, while the three forms of participation are shown in the first row. The resulting combinations are presented separately in sections 4.1 to 4.4. Results should be considered as an approximation and not definitive answers whether a decentralised infrastructure is the preferred choice from a social perspective.

Table 3: The impact of technological decentralisation on three forms of participation

	Procedural participation (A)	**Representative democratic participation (B)**	**Financial participation (individual and collective) (C)**
Connectivity (1)	More people affected by increasing number of power plants connected to distribution grid More possibilities for procedural participation, but not necessarily more or "better" participation processes	Trend towards politically adopted local energy concepts and re-municipalisation or new foundations of local utilities Hence: generally more options for representative democratic participation	Liberalisation and EEG led to low-risk options for citizens to invest into RES-E power plants connected to distribution grids Decentralisation of property and profits followed to a certain extent Power plants for own consumption still offer high security of investment But: question of fair distribution of profits remains
Proximity (2)	Certain power plant technologies are often concentrated in specific regions; e.g. PV predominantly in the German south and wind in the north Only citizens in close proximity of decentralised power plants can (potentially) participate in their planning processes; but: process-design depends on local actors, not on technology	Geographical as well as economic situation of the municipality influence the room for manoeuvre for elected representatives However, it is up to the elected representatives to support, oppose or ignore these developments	Homes as well as land and roof areas owned by citizens can be utilised for financial investments into local/ regional decentralised electricity generation Some cooperatives have a 'local clause': only citizens within the region can invest
Flexibility (3)	Decision on decentralised flexibility options (e.g. V2G or battery-storage for apartment complex) often made by individuals Whether others are included (e.g. residents) in the planning procedures depends on the owners/ planners	Elected representatives can influence the development of decentralised flexibility through local utilities or energy concepts (e.g. through development of local distribution grid or storage systems) However, it is up to them to support, oppose or ignore these possibilities	Investment into flexibility options (e.g. CHP with heat storage or battery system, V2G) becomes more attractive for financial reasons in the context of self-consumption. Decentralised flexibility enables active market participation of larger number of actors
Controllability (4)	In regions striving for autarky, citizens might increase their participation in designing their local energy system. However, key question is to what extent this can be achieved by the development of local generation capacity (see Connectivity and Proximity) or to what extent this also requires local control to match local generation and demand	Competitive electricity market across large regions can be at odds with local attempts to pursue energy policies, e.g. to set up certain plant types, because in a harmonised competitive market only least-cost technologies are viable However, a more effective policy approach compared to fragmented markets will most likely be to set up overarching policies like renewable feed-in laws that are more targeted and do rely less on local initiatives	Willingness to invest may also increase if electricity can be produced "on-site" or if there are real-time local electricity products. The key question remains how relevant this effect is, i.e. how many market participants find this more attractive. Financial participation may become more attractive if self-consumption provides some form of risk-hedging.

4.1 Connectivity

Decentralised connectivity means power plants that are connected to the distribution grid (cf. chapter 2). When these power plants are spatially concentrated due to geographic or other reasons (as is in Germany with e.g. PV predominantly in the south), they can still be connected to the distribution grid, but are not proximate to all consumers.

1A: Connectivity on Procedural Participation

In Germany, the total amount of RES-E power plants connected to the distribution grid has increased in recent years due to the design of the feed-in tariff (FiT) for expansion of RES-E and the lower energy density as well as smaller capacities of RES-E power plants in comparison to fossil and nuclear-based plants. This technological trend towards more decentralised connectivity can be regarded as double-edged. On the hand, more people are affected by power generation, which can decrease acceptance. On the other hand, there is also the potential to have a larger share of the population procedurally participate in the developoment of these new power plants. However, while there is evidence that "direct and substantial involvement of local people in a project" leads to a more positive public response to the project and RES-E technologies in general (Walker and Devine-Wright 2008), it depends on the relevant regional actors how the participation processes are designed and how easily and with what kind of influence citizens can take part. Additionally, resistance might develop independently from how the participation process is designed, e.g. due to predefined levels of acceptance concerning certain technologies. It can be summarised that there are criteria that define good-practice for procedural participation (e.g. concerning openness and inclusion of the local population). However, it depends on the local actors and initiators of power plant projects if these are applied.

1B: Connectivity on Representative Democratic Participation

In the last years, many German municipalities and districts have strived to develop their own ideas and visions for a renewable and more decentralised electricity supply. As a part of these endeavours, an increasing number of politically adopted local or regional energy concepts as well as re-municipalised or newly founded local utilities can be observed (e.g. IdE 2013; Berlo and Wagner 2013).

These general trends offer more options for representative democratic participation and it is observable that democratically elected representatives can play an initiating, enabling or supportive role in these efforts (Süsser et al. 2017; Musall and Kuik 2011). At the same time, the local political representatives are embedded in governance networks with a multitude of actors that might support or obstruct decentralised electricity initiatives (Moss et al. 2015). In municipally-owned utilities, the influence to change the course of these companies is often limited for elected representatives, especially as those companies more and more reside in the legal form of limited liability companies (Kluge and Schramm 2011).

1C: Connectivity on Financial Participation

The investment into power plants connected to the distribution grid, especially RES-E plants under the FiT, are rather unattractive for utilities in Germany[4] as the return rates on equity are low and the transaction costs high. At the same time, the EEG enabled business models for new actors such as citizens and cooperatives with return rates in the margin of 4 to 6 percent and a high security of investment (Yildiz 2014). It can be argued that these developments have led to a stronger financial participation among a larger group of people. However, the question of fair distribution remains. For instance, Yildiz et al. (2015) and Rommel et al. (2016) point out that cooperatives, which are thought to be a rather democratic type of company, show a strong bias of membership towards well-educated older men with high incomes. A more equal and inclusive financial participation could, according to Walker (2008), be achieved through investments by community trusts or charities that would allow a whole region to benefit.

4.2 Proximity

Decentralised proximity points towards the questions whether power plants are located close to the place of consumption. In case of RES-E, the natural potential at specific sites has a strong influence on whether a participation is possible, as it can only take place in locations where infrastructure is present.

2A: Proximity on Procedural Participation

As has been pointed out before, it can be observed that certain power plant technologies are often concentrated in specific German regions; e.g. photovoltaic systems predominantly in the German south and wind turbines in the north (AEE 2016). Other drivers of RES-E deployment, like the involved actors or the economic circumstances in a given region, also influence the regional uptake of RES-E (Lutz et al. 2017). This leads to different levels of public exposure to these power plants. Hence, only people within proximity to decentralised power plants can (potentially) participate in their planning processes. As already concluded in section 4.1, the question whether

[4] The regulation concerning RES-E in Germany has been changed in recent years. Proponents of ownership in the hands of citizens or cooperatives assume that it already has become more difficult for these actors to invest into RES-E power plants (e.g. Müller et al. 2015). According to Schwan et al (2015), RES-E can still be built by these actors, as the amended EEG continues to offer a high security of investment for power plants build mainly for own consumption.

planning processes consider practices that enhance openness and inclusiveness depends on the local actors and initiators of power plant projects.

2B: Proximity on Representative Democratic Participation

The possibility to participate in terms of local *Energiewende* processes for democratically elected representatives in a given municipality has increased due to the possibilities of a technological decentralisation. In a specific municipality the room for manoeuvre might be different as it depends on the geographical location as well as other factors. Generation technologies need the right geographical circumstances to be economically viable and a re-municipalisation depends on the duration of the concession contract. On a social dimension, the electricity infrastructure is characterised by a large heterogeneity. Rural regions can be seen as the energy transitions arenas of change, in which an ongoing technological decentralisation faces municipalities or regions. However, the structure of the locality may differ in its economical, ecological and cultural characteristics and therefore the local population may perceive the process of infrastructure expansion differently.

Lalli (1989) describes the phenomenon of “regional identity”, which has a high impact on the way communities perceive change in their region. A strong regional identity and “emotional relationship” with a region can be observed if a region yields satisfaction for a community, shows a distinctive landscape or other characteristics that lead to a binding between community and region. Communities with a high degree of regional identity tend to strongly oppose uncontrollable changes in their region by e.g. infrastructure projects, as these may raise the feeling of alienation (Hildebrand et al. 2012). Opposition to infrastructure projects can already be observed, such as conflicts regarding the grid expansion, e.g. the 800 km long *Südlink* project (Messinger-Zimmer and Zilles 2016). On the other hand, as Hildebrandt et al. (2012) point out, the regional identity can be enhanced if municipalities or regions plan and realise infrastructure projects themselves and retain the ownership. However, in the end it is up to the elected representatives to support, oppose or ignore the option to shape the local energy supply.

2C: Proximity on Financial Participation

The trend towards power plants connected to the distribution grid has allowed more citizens to directly invest into their own power plants (cf. 1C in section 4.1) such as photovoltaic systems or small-scale CHP plants. For the installation of these power plants, homes or land and roof areas are needed. Another option to invest into proximate electricity generation capacity is through cooperatives, of which many have a ‘local clause’ that only allows citizens within a given region to become a member.

4.3 Flexibility

Flexibility options allow the balancing of generation and consumption in electricity infrastructure at all times. Among the available flexibility technologies are grids, storage systems, load management and flexible power plants. As a general rule, it can be argued that from an infrastructure perspective, the need for flexibility increases with the growth of variable RES-E generation. While transmission grid expansion as one centralised flexibility option has been high on the political agenda in Germany (Steinbach 2013), the question of small-scale electricity storages, sector-coupling (e.g. Vehicle-to-Grid, V2G) or smart grid approaches combining these aspects, is also gaining interest in science and society as well as political support. In the following subsections, we analyse the (potential) influence of increasing decentralised technological flexibility on the three dimensions of participation.

3A: Flexibility on Procedural Participation

The decision on the investment into decentralised flexibility options are often made by individuals or companies. While individual purchase decisions such as the purchase of a car that can be used as a V2G system are entirely the decision of single actors, the development of e.g. residential areas can be open for participation. However, whether citizens (or - as in the above example - residents) can participate in planning procedures and how the participation process is carried out depends on the owners or planners of the respective project.

3B: Flexibility on Representative Democratic Participation

The progress in technological solutions for decentralised flexibility in recent years (e.g. battery storage systems) leads to the possibility of including these technologies in regional energy concepts or into the business models of local utilities. Additionally, the re-municipalisation of distribution grids is an option in many German municipalities. Therefore, elected representatives can influence the development of decentralised flexibility. While battery storages are still a niche phenomenon, the re-municipalisation of distribution grids has been high on the local agenda in many municipalities. Often, the aspirations of re-municipalisation are connected to promoting the regional *Energiewende* (e.g. Becker et al. 2012) as well as enhancing the local and regional democratic control (e.g. Landsberg 2013). The call for nationalisation, however, includes both the decentralised distribution as well as the centralised transmission grid. As the connection to democratic control is only visible on the local level, it seems like proponents of decentralisation recognise the possibility for stronger democratic control only in decentralised governance settings on the local or regional level (as shown for instance by Rommel et al. 2016 for the discourse on degrowth). How elected representatives react to the possibilities offered by decentralised technological flexibility, however, depends on their own decision.

3C: Flexibility on Financial Participation

Yildiz (2014) points out that citizens investing into flexibility options have not been giving much attention from neither scientists nor policy-makers. This seems to start changing in recent years as, in the context of self-consumption, these investment become more financially attractive. Additionally, decentralised flexibility options in the hands of citizens enable active market participation of a larger number of actors.

4.4 Controllability

A decentralisation on the three other technological infrastructure dimensions does not necessarily entail a decentralisation on the level of controllability. Hence, changes are less likely on this level. The pursuit of autarky, however, can be an exception to this general observation. As a region, quarter or household striving for autarkic supply of electricity the question of controllability becomes vital. As of to date, cases of decentralised controllability are rather rare. The following examples are therefore a cautious approximation to the issue and point towards potential future developments.

4A: Controllability on Procedural Participation

In regions striving for autarky, stakeholders might increase their participation in designing their regional energy system. The aim of a 100% RES-E region is an aim that needs to be accepted and designed by participants in a region. Kompetenznetzwerk dezentrale Energietechnologien (2010) states that "[…] the participation of actors is a central task throughout the process (of defining the goal of a 100% RES-E region) […]"[5]. Some of the 100% RES-E regions aim, among other objectives, for a regional balance of demand and supply which necessitates a decentralisation of control. Depending on the level of decentralisation, a participation of stakeholders may be inevitable, e.g. in the case of households, as large amounts of flexibility will become necessary to realise the regional or local balancing task. Although this participation of citizens may be necessary for a successful implementation of decentralised controllability, the question remains whether this kind of control is necessary for the development of regional energy concepts.

4B: Controllability on Representative Democratic Participation

The decentralisation of controllability could lead to an increase in regional energy policies and, in parallel, representative democratic participation. Different approaches

[5] Translation by the authors.

to realise decentralised controllability are possible such as regional electricity markets, nodal pricing or fragmented cell-like structures (see e.g. VDE 2015), as these approaches can take regional properties into account. Electricity markets across large regions might oppose these regional endeavours of implementing regional energy policies. The reasoning behind this being that a central market leads to a least cost optimisation of the market area (see chapter 3 on controllability and cost of power plants). Regional policy approaches rather pursue a fitting energy design for their region, which can be defined e.g. by certain plant technologies (IdE 2014). Although these approaches might be regionally optimal, they are not necessarily cost efficient. Therefore their profitability might be threatened as they compete with centralised cost efficient power plants in the central market.

4C: Controllability on Financial Participation

A prerequisite for a financial participation is a financial attractiveness of decentral RES-E concepts. This attractiveness may derive from support mechanisms such as the EEG in Germany, which led to large numbers of investments by private households and regional cooperatives in the past (trend:research and Leuphana Universität Lüneburg 2013). Also increasing energy prices and lower technology costs may act as incentives to invest in self-consumption technologies when grid parity is reached. Additionally, the investment into controllability measures to increase self-consumption might become more attractive for prosumers as a mean of risk-hedging against rising electricity prices in the future.

The introduction of regional real-time RES-E products (BMWI 2016) that are generated in the region or “on-site”, may also have a higher value to regional consumers compared to generic electricity products from a central market and therefore face a significant demand (Agora Energiewende 2017). It is, however, unclear how large this effect in practice might be.

5. Conclusion

The transformation towards an electricity infrastructure based on RES-E is often connected to the vision of decentralisation. For a comprehensive evaluation of this vision, a multidimensional approach is required. First of all, decentralisation is a multi-faceted concept and different dimensions need to be distinguished when analysing the technological decentralisation of electricity infrastructure (Funcke and Bauknecht 2016). Second, decentralisation can be assessed both from an economic and from a social perspective. The economic perspective looks at whether the transformation towards RES-E can be more efficiently achieved with a centralised or a decentralised infrastructure. Costs are a relatively straightforward indicator, but the challenge is to jointly consider cost effects of the various infrastructure elements, i.e. power plants, the electricity grid and flexibility options. We have shown that a technological decentralisation of electricity infrastructure leads to potentially increasing costs concerning power plants, while grid costs are generally reduced. The impact on the economic efficiency regarding flexibility options is limited.

From a social perspective, it is often stated that decentralisation is not just about costs, but also about increased democratic control or participation in the energy system. This is part of a larger argument that energy transformation is not just about expanding RES-E and mitigating climate change (and a least cost approach to achieve this) but should also aim at a more democratic energy supply and facilitate general democratic innovations. Our analysis shows that a technological decentralisation on the dimensions of *Connectivity*, *Proximity* and *Flexibility* has the potential to increase options for participation. However, it depends on the local and regional decision-makers and actors that initiate respective projects, if they consider participation as a desirable aim within their *Energiewende* efforts. Concerning the dimension of *Controllability*, it can be argued that while a technological implementation is possible at comparably high costs, it remains questionable whether participation options are realised for more than small numbers of the population.

An evaluation of decentralised visions needs to look at the various elements and combine them into a comprehensive assessment. This article has shown that many analyses are already available for the various elements. We contribute a first approach towards a joint framework for the assessment of increasingly decentralised infrastructure, bringing together economic as well as social aspects. It could help to guide decision-making on the local and regional level as well as the scientific debate concerning the aspects that should be considered for a comprehensive assessment.

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