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The Organisation of an Electricity Sector based on Renewables – A Delphi Study

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Abstract

We conducted a Delphi study on the question of how the electricity sector could be organised in order to make very high shares of renewable electricity generation (80–100 per cent) feasible. In particular, we asked i) how primarily market-based and primarily regulatory-based parts of the system should be divided; ii) who should be responsible for planning each part of the system and the system as a whole; iii) how interaction between the responsible actors/institutions should be governed to ensure effective overall coordination among the components of the system; and iv) how the system would perform in two specific prosumer scenarios.

We found that i) despite the fundamental changes the energy transition implies, the respondents are remarkably confident in the prevailing European electricity liberalisation paradigm; ii) respondents do not, however, equate liberalisation with the absence of regulation; rather, they stress the need for framework setting in market-based systems as well; and that iii) the most obvious future challenges to the current model relate to grid infrastructure in the event of decentralisation, in particular with regard to finance.

An overall conclusion that we draw from our study is that the research community should refrain from being overconfident in the current paradigm of liberalisation and be more ready for 'surprises'. The implications of the aspired transition to very high shares of renewable electricity generation appear so overwhelming that what is unthinkable today may be a matter of course tomorrow. *Social* and *institutional learning* will play a key role in addressing this challenge.

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1. Introduction

Despite the prevailing economic dogma from the 1980s to the 2000s of the superiority of competitive markets, regulatory reform of the – usually monopolistic – electricity sectors in different countries has taken quite different forms. This is particularly true if one compares Germany with the USA. On the whole, Germany has opted for liberalisation. Vertically integrated suppliers have been split – unbundled – along the value chain of generation, transmission and distribution, and wholesale (generation) and retail (distribution) markets have been organised to encourage competition. The USA, by contrast, developed a much larger mix of models from state to state, usually with far less unbundling. Apart from the question of which regulatory model is more appropriate to the 'old' fossil fuel-based system, the crucial question from the German perspective is which model would perform better under the low-carbon energy system aspired to, i.e. once the German *Energiewende* – the transition to variable renewable energies – has been fully implemented.

To shed light on this issue we conducted a workshop and a subsequent Delphi study. This paper summarises the results of the study. It is organised as follows: section 2 gives some background information on the organisation of the electricity sector. In section 3, we provide background information on our workshop, the Delphi method, and the study. Section 4 presents a short overview of the responses from rounds 1 and 2 of our Delphi study, and in section 5 we undertake a closer examination of those responses. Section 6 summarises our findings, while section 7 offers an overall conclusion and outlook.

2. The organisation of the electricity sector

Historically, the electricity sector in many countries tended to be dominated by regional monopoly companies, each of which vertically integrated electricity generation, transmission, distribution and sales. These companies were regulated or even owned by the state. The economic dogma that markets yield the best results when they regulate themselves challenged the traditional organisation of the electricity sector and paved the way for liberalisation. The electricity sector, however, like the railroad or telecommunications sector, posed a specific challenge for liberalisation since it relies on a physical network that is capital intensive. Such network-based industries are generally perceived as *natural monopolies* that need regulation in order to keep market power in check. Typically, states liberalised their respective electricity sectors by unbundling generation from transmission and organising generation as a more or less competitive market, while keeping transmission and distribution regulated.

Yet in an international comparison, different countries implemented this liberalisation in very different ways. Germany, by implementing the European Union energy market liberalisation legislation – at least bit by bit – allowed utilities to keep their generation, parts of their distribution networks, and their sales business, but – ultimately – forced them to unbundle their transmission operations (above a certain size). Since the retail market has been organised to allow for greater competition, customers are free to choose a supplier, and a number of regulations are meant to ensure fair competition when third parties have to compete against incumbent utilities (Correljé and De Vries 2008, 83). In the USA, by contrast, states that liberalised their electricity sectors introduced competition into the wholesale markets, but kept – regionally varying – degrees of price regulations with respect to wholesale and retail markets. Retail markets in particular remained regulated, although alternative retail providers were allowed to compete with each other (Correljé and De Vries 2008, 79–80).

As Correljé and De Vries (2008, 74–75) explain, the different approaches of the EU and the USA can be ascribed to a variety of factors, among them vested interests, path dependencies, 'mental models' due to policy traditions and socio-political backgrounds, and the bounded rationality of policymakers and consultants. They hold that

> *"This may explain the differences in market design between the United States and Europe, where many believe their own model is the best choice. Starting conditions were quite different, with much of the industry in the United States privatized before the restructuring process. Perceptions are also different, with European countries emphasizing the need for "national champions," among others, as a balance against the large national energy companies that supply Europe with natural gas or against foreign electricity suppliers that would give preference to supplying their home country, in case of problems. This focus on national (or state) "champions" is absent in the United States."*

Remarkably, in the USA there has never been a consensus on the merits of electricity liberalisation, either on the descriptive or the normative level. In fact, only about half of the states in the USA actually liberalised their electricity generation in the sense in which this was done in Germany and the EU (i.e. based on private markets for bilateral contracts). Instead, a wide range of design options has been implemented both within the USA and elsewhere, and it is not clear what design is best. This suggests that local factors or, more precisely, a locally specific mix of the influence factors identified by Correljé and De Vries (2008) matter. It

can be assumed, moreover, that engineering management is sufficiently developed regardless of the market design (Chao et al. 2008, 40).

The Californian experience around the millennium, however, showed that market rules need to be designed in such a way as to prevent participants from gaming on those rules (Chao et al 2008, 40). The most prominent examples of this were rolling blackouts and the Enron scandal. However, there are also striking differences in how the European target model of liberalisation has been implemented by member states (leaving aside the fact that many member states were slow to implement the target model in the first place). For example, although both Germany and the Scandinavian countries where quick to introduce bilateral contracts on the wholesale market – which served as a role model for European electricity market liberalisation – transmission grid companies are privately owned in Germany and state-owned in Scandinavia (Chao et al. 2008, 32; Boltz 2013, 207f.).

From the outset, some electricity experts raised doubts about the efficiency gains envisioned by the advocates of electricity liberalisation (see for example Rosen, 2000; Lave et al., 2004; Blumsack et al., 2006). In a nutshell, their critique focused on two issues: firstly, the question of whether truly competitive generation markets could be created and if so, whether they would actually make electricity generation itself more efficient, i.e. cheaper. Secondly, it was suggested that even if these aims were achieved, the *additional* costs generated by unbundling the electricity system could offset any efficiency improvements in generation.

Taking an interdisciplinary approach, we propose combining three specific perspectives – those of *systems theory, industrial organisation* and *energy economics* – to investigate the organisation of the electricity system. While there is a wealth of literature on this question in the fields of electrical engineering, industrial organisation, and energy economics, an interdisciplinary approach is what sets our analysis apart from previous research.

In terms of *systems theory*, due to its engineering features the electricity sector easily qualifies as a *complex dynamic system*. Electricity is a peculiar good since it relies on grids for transmission and operation. It cannot easily be stored, and demand always has to equal supply. It is well known in electrical engineering that the operation of networks for transmitting and distributing frequency-controlled, three-phase alternating current is a challenge in its own right, particularly in the case of fluctuating supply or demand (Bayer et al., 2017). Dispatching power stations entails mathematical optimisation while taking complex network constraints into consideration. In integrated utilities, these tasks relied heavily on the *embedded organisational knowledge* of the complex dynamic system being operated. Unbundling undermines integrated organisation and has a negative impact on embedded knowledge by adding further complexity and rendering existing knowledge and routines obsolete or even illegal. Thus from a systems science perspective, it is in no way obvious that an unbundled new system would be more efficient than a traditionally integrated one.

The same argument applies when the electricity sector is perceived from the *industrial organisation* perspective. Liberalisation replaced the traditional state-regulated regional monopoly with a combination of a state-regulated regional grid operator and an oligopoly. The latter has been progressively transformed with the rise of renewable generation. In his path-breaking monograph on industrial organisation, Nobel Laureate Jean Tirole conveyed a sense of the rich market dynamics that oligopoly markets can generate, depending on the specific features of the particular market under consideration (Tirole, 1988). Both the USA and Germany, despite their different approaches to liberalisation, have witnessed very controversial discussions about the extent to which oligopolistic structures were able to execute market power and unduly raise the market price (see Rudkevitch et al., 1998; Ockenfels, 2007). Also from an industrial organisation perspective, it is thus not clear whether a liberalised electricity sector yields a better result than a more traditionally organised one.

From an *energy economics* perspective, it is important to understand how liberalisation has changed the pricing of electricity. In both traditionally regulated and liberalised electricity markets, power stations were and continue to be dispatched according to their place in the *merit order*, which means that power

stations with low variable costs are used first before moving up the ladder of variable costs. However, in the traditional system, this optimization would only take place within the market area of each monopolistic supplier as the cross-supplier market did not yet exist. Furthermore, the price of electricity was determined on the basis of *system costs*, including the capital costs of all system components. By contrast, in competitive generation markets, pricing is a complex market feature based on prices bid into the energy market. In simple terms, oligopoly dynamics determines to what extent *merit-order* pricing works as an anchor for pricing. In the textbook version of merit-order pricing with no mark-ups, the variable costs of the *marginal* power station determine the market price. At times when demand approaches capacity, scarcity pricing is allowed in liberalised generation markets, and the market price exceeds the variable costs of the power station with the highest marginal costs. Conversely, when there is an abundance of supply due to privileged feed-in of renewables and must-run capacity, markets can see prices that are lower than the marginal costs of the power station with the lowest marginal costs – sometimes substantially below zero, if a generating unit has to be dispatched for some reason. A further complication arises from transmission constraints that, depending on the actual organisation of an electricity system, often result in a market-clearing price that is higher or lower than it otherwise would be. The pricing schemes in a specific market thus depend on the actual implementation of liberalisation, the oligopoly dynamics in this market, and the interplay of the respective generation technologies and network constraints.

The debate in Germany on electricity market design for conventional backup capacities has focused on the so-called *financing function* of the energy-only market (EOM) in the light of the energy transition. As the EOM explicitly only pays for amounts of energy (MWh) delivered, the discussion revolved around the question of whether a reform of the EOM (aka: EOM 2.0) that abolished all remaining constraints that hinder energy-only markets from operating fully would suffice to resolve the *missing money problem*, i.e. the lack of an income stream to cover the fixed costs of generation, or whether additional mechanisms, like capacity markets, are necessary. *A capacity market* paid for on a MW basis would explicitly reward the provision of – sometimes idle – capacity and would therefore provide producers with an additional, stable income stream (cf. SRU 2013, sections 5.1–5.2; BMWi 2014). In the end, Germany opted for the EOM 2.0 – that is, against capacity markets – and introduced a capacity reserve (also called strategic reserve) as a backup measure. The strategic reserve would be activated in case the electricity market does not find a solution, i.e. if demand is larger than the available supply (BMWi 2015).

The more fundamental function of the EOM, however, is the *coordination or dispatch function*, which follows the merit order. In Germany, there seems to be a consensus that the EOM (or EOM 2.0) will be capable of providing the dispatch function even when the overriding share of capacity consists of variable renewable energies (VRE; such as wind and photovoltaics) with a marginal cost of (nearly) zero – as foreseen by the goals of the German energy transition. Most analyses, therefore, do not explicitly address the issue of the market coordination of a completely renewables-based system that relies on VRE as its backbone (the state when the energy transition is fully implemented). A notable exception is SRU (2013, section 4.1), where the basic argument is set out that in a sufficiently flexible and interconnected system, there will always be enough demand to keep prices above zero and ensure the coordination function. That is, once 'normal' demand from households and industries is already covered by VRE production, additional, price-driven demand from within the electricity sector (pumped hydro storage, exports) would kick in. In addition, further demand from other sectors (heat pumps, power-to-gas, electric vehicles) – known as sector coupling – would also stabilize prices before they decreased towards zero. That means that despite an inelastic supply, prices will stay above zero if the elasticity of demand is high enough, unless VRE capacities are insufficiently high. From this perspective, it comes down to the question of sufficient demand flexibility and optimal VRE capacities in the system. However, the actual future demand flexibility and VRE capacities are uncertain issues. If future demand flexibility is not sufficiently high and/or the VRE capacities are sub-optimal (i.e. too large), there could be major complications for dispatch.

3. The Delphi study and method

The Delphi method is a multi-round interview and forecasting method. There are different variations of the method, and we chose what is known as 'conventional Delphi' (Linstone et al. 2002, 5), where interviewees answer questionnaires. The distinguishing feature of these interviews is that after the first round, the interviewees receive the anonymised answers of all interviewees and have the opportunity to revise – or reinforce – their own position in the light of the 'group wisdom'. The process is repeated until stable results are achieved, which may also reflect disagreement. The idea is that anonymity makes it easier for an interviewee to 'stand up' in front of their own peers and stick to outsider positions without running the risk of embarrassment or being dominated by peer leaders. In the present study, we found the field of answers sufficiently stable – including some stable disagreement – after the second round, and therefore refrained from a further iteration.

This study is a follow-up to the workshop "The Organisation of Electricity – A Multi-perspective Inquiry" that was held at the IASS on 8 and 9 January 2015. The workshop was held to explore the issues described in section 2 together with stakeholders from academia, think tanks, industry, finance, and civil society as well as grid operators and policymakers from Europe and the US.[1] Most of the participants of rounds 1 and 2 of our study were drawn from the experts who had previously attended this workshop – 23 out of 24 participants in round 1 and 21 out of 23 participants in round 2. Although they knew each other, the answers are still anonymous. A further 11 experts who had not attended the workshop were also asked to participate in the study. In total, 26 experts participated in the Delphi exercise; of them, 22 (17 workshop, 5 non-workshop) were German, and 4 (2 workshop, 2 non-workshop) were US-American. 20 experts participated in both rounds; of them, 8 indicated that they did not wish to change their answers, while 12 made some edits without necessarily changing their position. Furthermore, two new participants joined the second round (numbered 25 and 26). These 'newcomers' received the analysis of round 1 before they provided their answers. The majority of the study participants came from academia and think tanks (13 workshop, 4 non-workshop group), while the rest comprised representatives of business (3 workshop, 2 non-workshop), NGOs and lobby groups (2 workshop, 1 non-workshop), and policy (1 workshop).

After the first round, all the answers were collated in order to create a better overview of the 'group wisdom'. The individual answers were also anonymised with a reference system for easy reference. The overview was then sent out to each interviewee together with his own answers from the first round.[2]

[1] We would like to thank IASS Founding Director Klaus Töpfer for mooting the idea of this Delphi study as a follow-up to the workshop.

[2] In reference to individual male or female respondents we have chosen to use the pronouns he/him/his.

There are many different conceivable formats for asking questions in a Delphi exercise, and some studies work with a large number of very specific questions and ask the interviewees for their degree of agreement (e.g. bdew et al., 2016). However, given the major uncertainties associated with the issue at hand, we restricted our study to very few questions and asked for free-text answers in order to give the respondents a maximum degree of freedom to 'think outside the box'. We posed the following five questions:

- Question 1: What should be the division, if any, between primarily market-based and primarily regulatory-based parts of the system?

- Question 2: Who should have responsibility for planning each part of the system? Who should have the responsibility for planning the system as a whole?

- Question 3: How should the interaction between the responsible actors/institutions be governed so as to ensure an efficient and effective overall coordination among the components of the system?

- Questions 4 and 5: After having answered the questions above, please tell us how you think your suggested scheme would perform in a scenario in which both households and industry each produce (Q4) 25% and (Q5) 50% of their own electricity consumption?

We aimed to cover quite a range of issues without prejudicing our interviewees or becoming too atomistic. With questions 1 to 3 we wanted to find out which system each interviewee prefers, i.e. whether they tend towards supporting the liberalisation paradigm or challenging it. We also sought to determine their views on the following issues: the role of markets within the electricity system; market design and regulation; and how governance of the system should be organised, i.e. who should be responsible for which part of the system, how the different parts of the system should interact, and who should be responsible for the overall system. We deliberately asked general and open questions in order to give each interviewee enough leeway to answer them from the perspective of their expertise, be it systems science, industrial organisation, energy economics, or another field, and according to their respective preferences.

With questions 4 and 5 we turned to the issue of how the German renewable energy transition might make a difference, i.e. whether the system preferred by each interviewee would be compatible with two specific prosumer scenarios in which a quarter or even half of all electricity customers produced the electricity they consumed themselves. Here too, we kept our questions as open as possible and left it to the interviewees to choose the perspective from which they wanted to approach this issue.

4. Overview of the responses

All answers are documented in detail in the appendix.[3] There, they are tagged with individual identifiers for easy reference. The usual format is 'A.R', where 'A' denotes the answer to the respective question, and 'R' denotes the respondent. For example, '3.15' refers to the answer to question 3 given by respondent 15. We use the 'XX.R' format in reference to answers or general remarks that are not tagged to a specific question.

4.1 Round 1

Of the 24 responses in round 1, we would classify 21 of them as being explicitly or implicitly in line with the mainstream view in the European electricity community, i.e. they support the liberalisation paradigm where generation and retail are organised as a competitive market, while those parts of the sector that form a natural monopoly are regulated by the state.

Only 3 out of 24 respondents challenged this view, namely respondents 5, 19 and 20. Respondent 24 did not reject the liberalisation paradigm outright, but wondered whether market-based systems can mobilise sufficient capital for their investment needs. From a financing perspective, respondent 7 highlighted that regulatory-based instruments bear political risks, while market-based instruments bear competitive risks. Respondent 6 represented the somewhat radical position that only ownership should be market-based and the rest should be regulated (we are not quite sure how to interpret this position).

Another radical position was adopted by respondent 1 in answer to question 3 on the potential for coordinating the different components of the system. In his view, the sheer complexity of the electricity system means that neither the regulator nor the market can coordinate its components *effectively*. In contrast to political institutions, the market would at least be able to basically coordinate the components, although not effectively.

A closer inspection of the 21 mainstream responses allowed us to divide the field of answers into two groups: the answers to questions 1 to 3 all basically support the liberalisation paradigm, although they do reveal a broad spectrum of opinion when it comes to defining the domain of the competitive market vis-à-vis the regulated domain, and the interface of these two domains. By contrast, the answers to questions 4 and 5 are more heterogeneous: while the majority of respondents saw no real problems with our two prosumer[4] scenarios, respondents 15 and 21 pointed to serious issues concerning their viability. Respondent 4 thought that the 50 per cent scenario is unrealistic, while respondent 10 expected a flat rate for the network services in this scenario. Two respondents did not address the two scenarios at all, while four respondents did address them, but did not actually answer our question.

[3] The appendix is a separate document that can be retrieved under the following Digital Object Identifier (DOI): 10.2312/iass.2017.013.

[4] In their answers, the respondents did not uniformly address prosumerism with exactly this notion. Besides the very notion of prosumerism, also other notions like own production, own generation, or autoproduction, were used. For easiness of reading, we stick to the notion prosumerism in this paper. The original answers with the unchanged wording can be found in our appendix.

4.2 Round 2

In what follows, we stick to the classification used in the assessment of round one and speak of 21 mainstream respondents and 3 non-mainstream respondents who participated in round one.

Of the 21 mainstream respondents of round 1, 18 also participated in round 2. Of these 18 respondents, 8 respondents did not change their answers. Of the ten respondents that did, seven did not depart radically from their original answers, and three of them qualified what they had written on regulatory issues (respondents 2, 9 and 17). Of the three remaining mainstream respondents, respondent 8 highlighted the need for strong collaboration between different actors in Europe, respondent 13 argued that social learning will be vital to the future development of the electricity sector, and respondent 14 focused on how to deal with the investment risks associated with renewable generation and pointed to the need for regulating generation in this respect.

Of the three challengers of the mainstream view in round 1, respondent 20 did not depart from his original position and indeed backed it up with more arguments, respondent 5 did not participate, and respondent 19 did not change his answers at all.

Respondents 25 and 26, who joined the study in round 2, voiced the mainstream position, but both were rather critical of the high shares of prosumerism proposed in questions 4 and 5.

5. Question-by-question analysis of responses

5.1 Question 1: What should be the division, if any, between primarily market-based and primarily regulatory-based parts of the system?

The first question concerns the principal governance setup or design paradigm of the electricity sector. Respondents 4, 8, 10, 13, 14, 15, 17, 18 and 20 modified their answers in round 2 or added comments, but none of them fundamentally changed their position. Respondents 25 and 26 participated in round 2 for the first time. One respondent in the first round complained that the question was not put clearly enough (1.8) and another (1.18) suggested that the answer would oversimplify matters.

The respondents raised a whole host of issues, including promotion schemes for renewables, capacity mechanisms, demand-side management, etc. However, we want to focus on the more fundamental or paradigmatic issues. These are listed in table 1 with the numbers of participants making that statement.

Issues and respondents	Σ
Support for electricity market liberalisation paradigm	
■ Explicit support: 1–4, 9–12, 15–17, 21, 22	13
■ Broad support: 7, 8, 13, 14, 18, 19, 23, 24, 25, 26	10
■ Explicit opposition: 5, 6, 20	3
Support for regulation in market-based system	
■ 4, 8, 10, 13, 14, 18, 20, 25, 26	9
Issues that are considered more important than liberalisation	
■ Increased financing risk is important, but it is not clear whether market or political risks are bigger: 7, 14	2
■ Different risk preferences and externalities call for minimum coordination: 10, 20	2
■ The quality and interplay of the various instruments is more important than liberalisation: 23	1
■ The potential for institutional learning is more important than any specific institutional setup: 13	1

Table 1: Tendencies in answers to question 1

Degree of support for the electricity market liberalisation paradigm: The overwhelming majority of respondents favours the current European paradigm of electricity market liberalisation. Thirteen respondents explicitly stated that generation/wholesale and retail/service/trade should be market-based, while transmission and distribution should remain regulated. Only three respondents explicitly disagreed with the current paradigm of electricity market liberalisation. Statements by the remaining ten respondents were generally consistent with the current liberalisation paradigm (e.g. "policy sets targets and rules, regulation monitors them, and the market fulfils them.").

Need for regulation: Nine respondents argued that the European paradigm of liberalisation is not simply about opting for either a market or a regulatory approach. Rather, they stressed that market-based systems also require some degree of regulation, especially in terms of framework setting. One of these respondents stated that the system is already highly regulated and asked whether the current regulation is still appropriate to the German energy transition.

Issues considered more important than liberalisation: Two respondents argued that predictability/risk implications are more important than liberalisation, and one of them reinforced this point in round two. Seen from this perspective, the higher financing risks of capital-intensive technologies (renewable energies and nuclear) require more regulation, and regulation should focus on handling risks. Neither respondent, however, indicated which risks – market or political – are more decisive. Two other respondents pointed to the need for a minimum of coordination due to different risk preferences and the presence of externalities. One respondent claimed that the quality and interplay of the various instruments is more important than liberalisation per se. And another respondent suggested that the potential for institutional learning is more important than any specific institutional setup (where an optimum does not exist).

5.2 Question 2: Who should have responsibility for planning each part of the system? Who should have responsibility for planning the system as a whole?

The second question was geared more towards stakeholders and their respective roles and responsibilities for planning the system and its different parts. Respondents 1, 2, 10, 13, 14 and 20 modified their answers in round two or made additional comments, without fundamentally changing their positions.

As Table 2 shows, the answers to question 2 largely mirror the support for the European paradigm of electricity market liberalisation that was already clear in the answers to question 1.

Issues and respondents	∑
Planning should be the responsibility of different parts of the system, in accordance with the electricity market liberalisation paradigm.	
■ 1, 2, 4–7, 9–17, 19, 21, 22, 24	19
Governments should be responsible for political/system planning as a whole.	
■ 3–11, 15–17, 22, 23	14
There is a need for target setting.	(not to be added)
■ 'governmental' (RE, CHP, DSM): 4, 5, 9, 10, 12, 16, 17, 21	8
■ 'political' (climate, energy efficiency):12, 17, 21	3
■ 'by an independent authority' (security of supply): 4, 5, 10	3
There should be more decentralised decision-making (e.g. prosumers), but also greater coordination by the responsible distribution system operators (DSO) in the case of prosumerism in its network area.	
■ 13, 20	2

Table 2: Tendencies in answers to question 2

Planning responsibility for parts of the system: More than half of the respondents – largely the same group that explicitly supported liberalisation in Table 1 – argue that for the market-based parts of the system those who take the risk/own the assets should take responsibility for the respective planning of their own asset. By the same token, they agree that an independent authority (US: Independent System Operator (ISO), Germany: Federal Network Agency (BNetzA)) should have responsibility for the regulated parts of the system.

Planning responsibility for the system as a whole: Furthermore, around half of the respondents – again largely from the same group that explicitly supported liberalization in Table 1– believe that governments should be responsible for political and system planning as a whole, with three of them arguing in favour of stakeholder participation.

Decentralisation: Two respondents raised issues concerning the interlink of system planning and decentralisation. One of them argued for greater coordination by the responsible DSO in the case of prosumerism in its network area. The other suggested that there should be more scope for decentralised decision-making in the case of more decentralised renewable generation.

Without detailing all the changes respondents made to their answers in round 2, we would like to point out that two respondents deviated significantly from the European mainstream position, with one underlining the need to plan grid and generation activities jointly and the other seriously doubting the need for electricity markets altogether.

5.3 Question 3: How should the interaction between the responsible actors/institutions be governed so as to ensure an efficient and effective overall coordination among the components of the system?

This question focuses on the interaction and coordination of the system parts. In round two, respondents 1, 2, 9, 13, 14 and 20 modified their answers by making additional specifications, but, again, none of them fundamentally changed their positions.

Many of the responses are similar to those given to the first two questions, with most respondents either explicitly referring to their previous answers or repeating points already made there.

5.4 Questions 4 and 5: After having answered the questions above, please tell us how you think your suggested scheme would perform in a scenario in which both households and industry each produce (Q4) 25% and (Q5) 50% of their own electricity consumption?

These two questions address the interplay of regulation and decentralisation in a decarbonised energy system. Respondents 1, 2, 9, 13, 14, 15 and 20 modified their answers to questions 4 and 5 in round 2, without straying far from their previous positions. New respondents 25 and 26 also responded.

Feasibility of decentralisation: On average, respondents were optimistic about decentralisation. Eight of them (the same for question 5) believe that the system would work in either scenario. Only two respondents thought that the 25%-scenario was unrealistic or uneconomic, and two more said the same of the 50%-scenario. One of the respondents who saw problems with the 25%-scenario in the first round provided a number of technical reasons to defend his position in the second round. The other one argued that prosumer scenarios are uneconomic and rejected them outright, noting that they would require economically inefficient incentives to come about in the first place. Four respondents (the same for question 5) did not see decentralisation as the main point or crucial question.

Changing grid requirements I – planning: Five respondents highlighted changing grid requirements, with some of them questioning the feasibility of a grid for the 50%-scenario. One of the five mentioned decreasing grid capacity requirements and another one the need to adapt grid planning for both scenarios. Yet another one mentioned the need for rising backup capacities.

Changing grid requirements II – challenges of grid finance: Many respondents pointed to the need for a new financing model for the grid in the light of decentralisation, and to related feasibility challenges. In round 1, five respondents highlighted the need for new financing models to recover the fixed costs of the grid, either for the 25%-scenario or the 50%-scenario, or for both. There were proposals for capacity prices, base tariffs and flat rates, among other instruments. One respondent even argued that the grid should be regarded as a social good.

5.5 Additional remarks by respondents

5.1.1 Round 1

Respondent 21 referred to distributional aspects and core beliefs on how the sector should be organised, noting that changes to market design depend on the share of renewable electricity generation and the number of installations rather than on prosumerism (XX.21). Respondent 24 pointed to the effect of the energy consumption of buildings, behind-the-meter resources and feed-in tariffs on the grid (XX.24). For both remarks, please refer to the respective entries in appendices 1 or 2.

5.5.2 Round 2

Respondent 15 raised a fundamental issue: while the workshop had focused on whether the renewable-based energy system of the future needs to be centrally planned and how the system can be financed, in his view our Delphi exercise did not address these questions (XX.15).

Issues and respondents	Σ
Decentralisation (both scenarios) is	
■ realistic: 8, 11, 12, 14, 17, 18, 23, 24	8
■ unrealistic: 25%: 15, 25; 50%: 4, 15, 20, 25	2; 4
■ not the main point or crucial question: 1, 3, 21, 22	4
Changing grid requirements	
■ Planning needs to be adapted in the light of decreasing grid requirements: 2, 9, 13, 16, 19	5
■ There is a need for a new financing model: 6, 10, 11, 13, 15, 17, 20, 21, 23	9

Table 3: Tendencies in answers to questions 4 and 5

6. What we learned from conducting this study

On the basis of the two rounds of our Delphi exercise, we want to condense what we learned from conducting this study into four findings:

Finding 1: Despite the fundamental changes the energy transition implies, the respondents are remarkably confident in the prevailing European electricity liberalisation paradigm.

The overwhelming majority of the respondents have a high level of confidence in the prevailing European electricity market liberalisation paradigm, thus mirroring the consensus among the European energy research community.

Most respondents believe that only natural monopolies (i.e. the grid) should be regulated and that the rest (generation, wholesale, retail) should be market-based. This is somewhat surprising given that the German energy transition is likely to entail fundamental changes in terms of technologies and organisational models along the entire value chain, and these may require quite a different regulatory framework. It is probably safe to say that it is impossible to understand all of the implications of the German energy transition for business models and regulatory schemes. Yet this uncertainty has not shaken the belief in the prevailing liberalisation paradigm.

Finding 2: Respondents do not, however, equate liberalisation with the absence of regulation; rather, they stress the need for framework setting in market-based systems too.

On closer examination, the acceptance of the liberalisation paradigm goes hand in hand with a general acknowledgement that framework setting is necessary in a market-based system, even in liberalised parts of the system.

A number of respondents stressed that the government should be responsible for overall system planning. In addition to target setting, they point to other areas that require a regulatory framework, including market-based renewable electricity generation promotion schemes, the inclusion of externalities, the strengthening of the European Union Emissions Trading System, and the introduction of capacity mechanisms. This shows that liberalisation – when done properly – does encompass regulation at many different levels and the concept of liberalisation may carry further than originally thought. In the discourse on these issues, however, liberalisation is all too often misconceived as the absence of regulation. Thus, one respondent defined 'market-based' as free price formation.

Interestingly, liberalisation is viewed with indifference at the 'core of the economy', i.e. by respondents with a background in finance. For those respondents, the handling of risk is the main factor, but it remains unclear whether market risks or political risks are more decisive. What is clear, however, is that higher risks require a higher degree of regulation.

Finding 3: The future challenges to the current model that are seen most clearly relate to grid infrastructure in the event of decentralisation, in particular with regard to financing and system coherence.

The fact that many respondents elaborated on their statements on this issue in the second round indicates that it is currently a hotly discussed topic among experts.

Although most respondents have a positive view of decentralisation, some of them pointed out that it would render the current kWh-based scheme unsuitable. In their opinion, high shares of fixed infrastructure costs are not compatible with volume-based financing schemes at times when prosumerism substantially decreases the volumes of electricity transported through the grid. In fact, they never were, but that didn't matter as long as prosumerism was negligible. Now this is changing, and respondents proposed capacity prices, base tariffs and flat rates in the light of these new circumstances. The idea mooted by one respondent that the grid is a social good – and the implication that it should be financed by the public budget – is more unconventional. Here, different forms of financing are conceivable. A proposal has already been made to set up a publicly financed fund (Matschoss and Töpfer 2015a, b).

At the same time, some of the aforementioned respondents remain critical of prosumerism in its current form for two reasons: firstly, the current business model for grid parity is based on saving the kWh-based fees. As the grid costs need to be divided among the remaining consumers in the system, this leads to rising kWh-based fees for them. This, in turn, reinforces the business model for grid parity, a phenomenon called 'band-wagon-effect'. Secondly, in making the distinction between prosumerism and autarky, they point to the continued need for the grid and its services in the future. Therefore, there is a need for intelligent incentives to make prosumers contribute to the system.

Finding 4: Against the backdrop of the prevailing European electricity liberalisation paradigm, we find individual contributions helpful and inspiring.

On closer examination, the powerful opinion field around the prevailing European electricity liberalisation paradigm is remarkably differentiated and heterogeneous. Some singular contributions to the discussion gave us pause for thought and should be investigated more thoroughly. One example is the idea that there is a trade-off between market risks and political risks. As yet it is unclear which of these risks is more detrimental to the engagement of private investors in the energy transition. Another example is the statement that rather than a specific institutional setup – where an optimum does not exist in the first place – it is the potential for institutional learning that really matters.

7. Outlook

An overall conclusion from our study is that the research community should not be overconfident in the current paradigm of liberalisation and should be more ready for 'surprises'. The implications of the transition to very high shares of variable renewable electricity generation appear so overwhelming that what is unthinkable today may be a matter of course tomorrow.

As one respondent noted, *social learning* and *institutional learning* will play a key role in rising to this challenge. We suggest framing the challenge as one of organising a search process to explore institutional and organisational possibilities. Right now, the scope of possibilities that are being screened and discussed in both American academia and policy is much wider than that in Europe. In our view, this entails considerable risks, both for the long-term economic and political sustainability of the European electricity sector and for the transition to very high shares of renewable electricity generation. To mitigate these risks, we believe it is crucial to create a space for innovative and daring points of view on alternative models for organising the electricity sector. Scientific and political pluralism should be encouraged here. In particular, we propose mobilising the synergies that arise from combining the perspectives of *systems theory, industrial organisation* and *energy economics*. There is also a need to engage with stakeholders from the electricity industry, academia, think tanks, finance and civil society as well as electricity customers, grid operators and policymakers from Europe and the US in order to integrate them into a stakeholder-based science operation.

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