THE POLITICAL ECONOMY STRUCTURES OF ENERGY TRANSITIONS: FROM SHALE GAS TO RENEWABLE ENERGY

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0. Abstract

We compare two prominent energy transitions, a topic decisively shaping the agenda of the IPE of energy: the US 'shale revolution' and the transition to renewable energy in Germany. Our structuration approach identifies several interests driving an increasing number of actors in these cases and helps us to analyse more comprehensively than existing studies how the various dimensions of structure constrain and enable these actors' operations. As regards resources, technology and infrastructure, both transitions have yielded a new energy mix combining fossil fuel and renewable resources, a goal of its own in the USA, whilst Germany has set a long-term priority for renewables. Regarding finance, markets and business models, the USA features a more market-driven process. Germany creates markets top down, with larger subsidies for near-zero marginal cost production. Regarding institutions, regulatory support in the USA seeks to accommodate the profit interests of the energy business while fostering environmental stewardship, wider socioeconomic interests and security of supply interests. The German transition draws together the interests of the state and of incumbent and emerging producers, and involves consumers more profoundly. Both transitions shape the environment, albeit yielding so far modest decarbonisation gains. The complexity of the two cases challenges neoliberal governance.

1. Overview

This paper compares energy transitions in the USA and Germany. On the supply side, these transitions comprise a switch towards using new resources, thereby affecting the energy system. On the demand side, they have different implications for several sectors in society, while they also differ regarding their wider implications including patterns of global order and the long-term sustainability of the planet. As such, the two transitions also have implications for the research agenda of the international political economy (IPE) of energy, where recent contributions call for multi-perspective, interdisciplinary analysis (Belyi 2016; Belyi and Talus 2015; Kuzemko et al. 2012). We respond to this call by applying the structuration approach to the study of energy transitions. This enables us to propose a more comprehensive analysis of the actors involved in energy transitions, their interests and the structures enabling and constraining their conduct with both material and social characteristics.

The 'shale revolution' evolving in the USA since the late 2000s features the use of shale resources thereby increasing the country's production of oil and natural gas significantly and correspondingly reducing its imports and contributing to oversupply in global markets and decreasing prices. Some expect the possible exports of shale gas from the USA to reduce the EU market's dependence on Russian supplies (Moryadee, Gabriel and Avetisyan 2014), while others expect shale gas to cause a global gas market upheaval owing to the large reserves found, for example, in Argentina, China, Europe and South Africa (Boersma and Johnson 2012, 3). Although the shale revolution prolongs the 'lock-in' into the fossil fuels economy (see Uhruh 2000), and may hamper investment in renewable energy, it is treated here as a part of the overall energy transition in the USA. Nuclear power retains its stabilising role as a base-load resource for the energy system, while the expansion of solar and wind power strengthens domestic production further while also reducing net emissions of CO_2 and other greenhouse gases (GHGs). Shale gas can contribute to the emission reductions by virtue of replacing the use of coal (Jaffe 2014, 1). Yet, because some of the US coal extracted, but not used, ends up being exported to other countries, the net effect on global emissions may be neutral or negative (Dröge and Westphal 2013, 1–2).

The German *Energiewende* features a political process culminating in a decision in 2010 to switch to renewable sources, targeting 60 percent of final energy consumption from renewables and a 50 percent reduction in primary energy consumption by 2050. This would cut emissions more dramatically than the US case. However, because the *Energiewende* also entails the phasing out of low-carbon nuclear power, during the transition period the country has to continue using natural gas and coal – some of which is imported from the USA. On the demand side, the German case implies an ambitious yet challenging societal transformation including energy efficiency measures and the emergence of small consumer-producers (prosumers) (Schmid, Knopf and Pechan 2016), creating 'almost a lab-type situation to study the emergence, success and possibly failure of various governance arrangements in energy infrastructure' (Goldthau 2014, 139).

In short, the American and German energy transitions result in a new energy mix where different resource sectors are interdependent. Our primary interest is in these complex interrelationships among choices vis-a-vis the new resources available and in the difficulty of controlling the outcomes. As the transitions extend to new sectors of society, involving new actors, they must reconcile several interests to be successful, making cross-sectoral policies indispensable. Our focus here is on how old and new actors seek to realise their interests in the emerging structures as new interconnections are formed between several sectors. To comprehend these processes, we propose that the IPE of energy should proceed bottom-up – from the interests of actors towards the institutional structures of which they form part (Hughes & Lipscy 2013, 458–61). Following this research strategy, we will ask: 1) what interests drive the actors in the energy transitions in the USA and Germany; 2) how do the complex structures of political economy enable and constrain their conduct?

We first outline our methodological and theoretical approach, then analyse the American and German cases. In the conclusion we discuss their implications in greater detail vis-à-vis the research agenda of the IPE of energy and summarise our findings vis-à-vis our research questions.

2. Methods

Our application of the structuration approach differs from institutional approaches currently making inroads in the IPE of energy (Aalto 2014; Andrews-Speed 2016; Lockwood et al. 2016). The structuration approach concurs on the importance of institutional and social structures, but extends the analysis to the material characteristics of structures and to what actors make of these structures and how that in turn influences their choices. This means avoiding references to a single causal path or mono-theoretical approaches, keeping our analytical framework purposefully open (Aalto et al., 2012, 2014). This framework is still mindful of the insights of several literatures but renders some seemingly unlikely scenarios comprehensible. For example, how can the liberal interests of profit-maximising market actors exploiting their comparative advantage coexist and mesh with the interests of states regarding security of supply and effect on foreign policy; or how can supply security priorities complement generic interests in global environmental stewardship?

2.1 Qualitative comparative method

Although the energy transitions in the USA and Germany, major economies of global significance pursuing unprecedented measures in the shale and renewable sectors respectively, are both landmark cases for the IPE of energy, no direct comparisons between them exist. The IPE literature commonly treats the USA and Germany as highly adaptable 'open access orders' (see Andrews-Speed 2016, Lockwood et al. 2017, 320-1), owing to the relative openness of political and economic competition, making them environments conducive to the innovation necessary for energy transitions. Yet they exemplify different varieties of capitalism: a liberal market economy in the USA and a more coordinated model in Germany (ibid.). The plethora of studies on each fixes our attention on these varieties and provides the main body of material for our comparative purposes, along with primary source material. Our methodology is informed and guided by the structuration approach, and features a qualitative comparison of the similarities and differences between the cases (Della Porta 2008). Although existing studies accentuate the specificity of each case (Andrews-Speed 2016; Kuzemko et al. 2016; Laes, Gorissen and Nevens 2014, 1130-1), we propose that by minutely comparing and examining these two cases we can better comprehend the conditions for and consequences of the shale and renewable based transitions.

2.1 Structuration of the political economy of energy transitions

The structuration approach aptly serves our argument favouring a multi-perspective, interdisciplinary analysis. The approach, introduced by Giddens (1984), stresses the interrelationships between actors and structures in domestic society and today forms part of the constructivist debate in international studies (e.g. Aalto et al. 2014; Banerjee 2015). In the IPE of energy, existing applications of the approach have focused on the fossil fuel economy (Aalto et al. 2012, 2014; Aalto 2016; Sharples 2016), the renewables sector (Aalto and Tynkkynen 2012; Smeets 2017), and nuclear energy (Hermwille 2016). Here for the first time we apply the approach to energy transitions where, alongside the expanding renewable sector, fossil fuels remain part of the energy mix, and where resources simultaneously represent only one material instance among the several transforming structures. Our structuration approach contributes to the wide field of energy transitions through an interdisciplinary theorisation of these structures, incorporating into the same framework problem areas pinpointed as deserving more attention by two prominent literatures: studies on sociotechnical systems and institutional approaches (Araújo 2014).

Studies on sociotechnical systems, including the 'multi-level perspective', originate in the study of technological change (Geels 2002). They analyse how innovators seek to introduce new technologies that challenge the existing 'energy regime' which, in turn, consists of the rules, practices and skills peculiar to the main actors of the energy system, and the wider 'sociotechnical landscape' (Geels 2002). Institutionalist approaches for their part seek to bolster the analysis of political actors, structures and both informal and formal institutions, which remains somewhat opaque in the sociotechnical systems literature, given its primary focus on companies and the end users of energy (Andrews-Speed 2016; Kuzemko et al. 2016; Lockwood et al. 2017; cf. Aalto 2014). Although the various institutionalisms convey a range of economic, historical, sociological and discursive approaches enriching the study of energy transitions, they cannot cover everything. Andrews-Speed (2016, 223), for example notes how in the case of China the availability of financial and human capital compensates for deficiencies in institutional adaptability. Uhruh (2002), for his part, combines institutions and technologies with the concept of techno-institutional complexes.

In short, the sociotechnical systems literature and institutional approaches complement each other but cannot alone comprehend the full scope of the structures shaping energy transitions. Neither, due to its preoccupation with social structures in the constitution of society, can the structuration approach in its original format comprehend the complex materialities of energy. Our application of the structuration approach proposes a more comprehensive analysis by identifying four analytically separable dimensions of structure wherein the materialities of technology matter alongside institutional decisions and path-dependencies, and other structures, with the precise ratio between the material and social factors being subject to empirical research. This broad scope renders our approach deployable to a wide range of IPE questions beyond energy issues, as is exemplified in the application of the approach to examining ecology or infrastructure (see Gritsenko and Efimova 2017; Tynkkynen 2014). Here our contribution concerns the study of energy issues.

The existing commentary on the structuration approach to the energy field notes its core focus on energy policy formation rather than on implementation (Nyman 2015; Smeets 2017). This limitation is only natural; structuration theory is not a fully-fledged policy analysis tool, and is appropriate in the present context of two energy transitions in their initial phases, expected to last for decades (Andrews-Speed 2016, 218; Laes, Gorissen and Nevens 2014, 1131). Further frequent comments call for the expansion of the structuration approach to the social, security or climate change dimensions of energy. We propose to address such calls by referring to *interests*, namely social, security and climate interests, which among others drive the actors of the energy system (cf. Bilgin 2010). Actors pursue their interests vis-à-vis the constraints and enabling qualities of the structures forming the context of their interaction which subsequently evolves specifically because of that interaction. Our treatment of interests as the link between actors and structures differs from other applications to the energy field of structuration theory, making such a linkage by referring to narratives (Hermwille 2016). This focus on interests rather than narratives to link actors and structures renders our approach somewhat more rationalistic than existing applications of Giddens' original framework (see also Banerjee 2015). Yet we propose that actors often have a wide set of interests, not all of which are easy to promote simultaneously or are readily reconcilable. Hence, in practice rationality is bounded and outcomes often sub-optimal (Aalto et al. 2014). The actors are unlikely to discern the interconnectedness of different interests.

2.1 Actors and their interests

Our structuration approach builds on a typology of the actors involved in energy transitions and their respective interests. Because the American and German transitions involve complex processes crosscutting several sectors and because they have global consequences, federal and state actors are inevitably drawn in (Aalto et al. 2014a). Federal ministries and agencies retain responsibility for *security of supply*, given how the two states use the transitions to lessen the dependency on imported fossil fuels. Since the late 2000s, the US shale revolution has helped to decrease net imports of primary energy from over a quarter to 11 percent in 2016 (US EIA 2017a). In Germany, expansion of the renewable energy sector should eventually decrease imports – which covered over half of the primary energy consumption in 2011; 88 percent of natural gas and 98 percent of oil were imported (BMWi 2012, 6). Moreover, renewables should replace nuclear power by 2022 and eventually also coal, both imported and domestic.

Federal–level state actors and individual states in both cases retain an interest in the wider *socioeconomic implications* of the renewable and fossil fuel sectors, including *employment*. In the USA energy sectors have provided half a million jobs since the late 2000s (Jaffe 2014, 2). In Germany the pace is even more impressive: the transition created some three hundred and eighty thousand jobs a year in 2011 and 2012 (Pegels and Lütkenhorst 2014, 529). The most rapidly growing sectors, solar and wind, may well continue to be labour intensive. The rising oil prices of the late 2000s served as proof of the economic implications of energy and threatened competitiveness in Germany, where electricity prices remain about 50 percent higher than the EU average (Eurostat 2017), although due to energy efficiency measures their share of household expenditure is moderate. In this economic sphere, the interests of state and market actors are interlinked: federal–state actors have *fiscal interests, namely* in tax and other revenue while market actors provide these through *profits.*

Market actors are taken here to include large and small, public and private energy companies, start-ups, equipment manufacturers, likewise service, maintenance and consultancy providers. Despite their differing business models, they share an interest in profits. Land and property owners, small-scale producer-consumers (prosumers) and co-operatives are among the various actors that can also benefit economically from the transition. Simultaneously promotion of *R&D and innovations* is a prerequisite for new business to emerge. While the role of R&D is more significant in the US transition than is commonly thought, Germany's policy of making renewable energy technology the spearhead of its industrial export portfolio is well known (Laes, Gorissen and Nevens 2014, 1136). This interest in exports may also involve *foreign policy interests*. However, foreign policy interests more commonly concern the global trade in fossil fuels rather than trade in renewable energy technology which in the long run may challenge the linkage between energy and foreign policy. Moreover, market actors developing large-scale, investment-intensive energy infrastructure – such as natural gas and oil transport, offshore wind power parks, solar parks and biomass-fuelled plants producing both heat and power – depend to some extent on international financial institutions (IFIs) (Schmid, Knopf and Pechan 2016, 272). In Germany, IFIs directly owned 13 percent of renewable power-generating entities in 2012 (Matthes 2015, 76). However, other private and public bodies may also provide finance.

The non-governmental organisations relevant for energy, for their part, typically promote global *environmental stewardship*, an interest shared by ever more actors and currently enshrined in the Paris commitments to reduce CO_2 emissions. Many actors also have an interest in *efficiency*. This is because natural resources, such as shale gas and oil, are finite, whereas renewable energy depends on infrastructure and equipment, requiring metals and rare earths, which are also finite (see Barry 2013). Whereas in the fossil fuels sectors efficiency pertains to the extraction, production and conversion technologies, in the German case in particular it extends from production to the demand side and is ultimately linked to emissions reduction objectives (BMWi 2012, 4–9; Pegels and Lütkenhorst 2014, 522–3). Transport and distribution system operators and infrastructure developers complete the panoply of actors and may subscribe to any of the interests mentioned.

2.2 Structures and their dimensions

Actors pursue their interests enabled and constrained by structures. The structure thus forms the *operating* or *policy environment* the actors must master or 'navigate': their actions and interactions, in turn, shape this environment. We identify four analytically separable dimensions among these structures, each with both material and social qualities. The dimensions represent analytical devices helping us to theorise the qualities of structure. Consequently, the actors do not necessarily 'map' or 'screen' the structure according to our classification of the dimensions, but simply make sense of it as best they can. Should they fail to take account of the most significant qualities of the structure, they are unlikely to satisfy their interests (cf. Aalto et al. 2012, 2014). Typically, the success in pursuing a certain interest depends on the qualities of more than one dimensions of the structure.

Along the dimension of *resources, technology and infrastructure*, actors are currently in transition away from being inextricably locked into large concentrations of fossil fuel resources (Goldthau 2014, 136). Now, to pursue profits, they may choose to extract shale from one site, then another, within a few weeks. Or, they may seek profits or efficiency gains in the use of resources by installing solar panels, solar thermal collectors or heat pumps, or both, avoiding much time-consuming permitting or licencing. However, large-scale solar and wind power installations, like biomass and waste-burning plants, remain locked into locations. The technologies vary from innovative combinations of established extraction techniques – as in the case of shale gas – to consolidating and emerging renewable energy technologies (see below). Between 1990 and 2009, the USA applied for more renewable energy patents than any other nation (Japan was second; Germany, third). Such advanced economies also obtain patents for products with the highest economic and export value (Bayer, Dolan and Urpelainen 2013, 288–9). Infrastructure needs vary: many new shale extraction sites require pipeline or railroad access; owing to their intermittent, weather-dependent production patterns, wind and solar power require network automation and energy storage to effectively balance supply of and demand for the end products, electricity and heating/cooling.

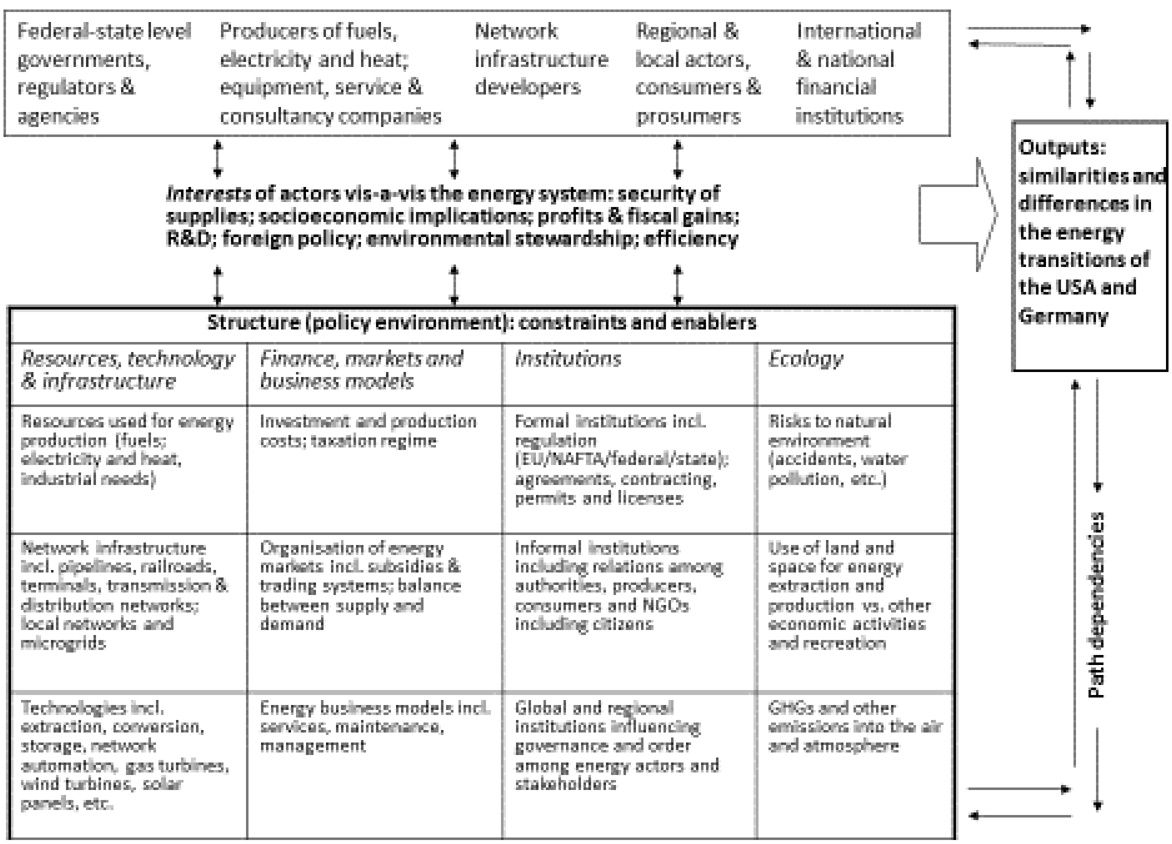
On the *finance, markets and business models* dimension, actors face both established and evolving structures. Unlike shale, solar and wind power *production* costs hardly anything. Nevertheless, there are investment costs; offshore wind, in particular, entails maintenance costs; taxation costs apply in all cases. Although the market entry of shale gas and oil once benefited from federally funded R&D, shale production now depends on demand on the markets. The renewable energy market includes a mixture of stand-alone and subsidized production, Germany and the USA being its largest supporters (Appunn 2017). Solar and wind power imply new business models including aggregators of small-scale production and operators of storage and services.

Along the *institutional* dimension, the energy transitions require new, direct regulatory measures or pricing instruments – particularly, for renewable energy. Policies reinforcing competitiveness of renewables subsequently create interest groups requiring increased support from formal institutions (Aklin and Urpelainen 2013). In turn, the emergence of smaller actors and consumers (and prosumers) disrupts informal institutional relationships among actors and shakes some established path-dependencies in energy chains, for example how incumbent actors such as the owners of large-scale power plants can make profits. Institutional approaches afford several conceptualisations of the informal institutions involved, path-dependencies, path-creation and institutional change (e.g. Aalto 2014; Lockwood et al. 2017, 323-5); we cannot delve deep into these here. And although our two transitions utilise domestic resources, these are not isolated from regional – or, in the case of Germany and the EU, supranational – institutional processes, or from global constellations of order.

Finally, on the *ecological dimension*, actors pursuing any of these interests face environmental risks (shale gas and oil) and land and biomass use issues (renewables) alongside wider biospheric implications. The GHG and other emission constraints on the shale industry are significant. In the renewables segment, constraints centre on the industrial chain enabling the market entry of biofuels used in transport and the carbon sink implications of using biomass for energy.

In summary, the structuration approach postulates actors pursuing their respective interests, interconnections between the actors within the energy system in transition and the structure (policy environment) with four dimensions along which they operate (Figure 1).

Figure 1: The structuration model of energy transitions (s*ource*: Authors)



3. Results

3.1 The American case

The rapid increase in shale gas and oil production spearheads the energy transition in the USA alongside the expanding renewable energy sector. We argue that the transition seeks to attain a new energy mix simultaneously reconciling several interests. The stable generation of nuclear power in old plants, their already recovered investment costs, increasing renewable power generation with near-zero production costs, help to keep electricity costs low and control emissions, to the detriment of coal. In 2015 nuclear energy accounted for 8 percent of the energy mix; coal production had diminished to 21 percent, having peaked in 2008. The expanding natural gas sector reached a record 32 percent share; oil temporarily halted its declining trend, accounting for 28 percent while renewable energy rose to 11 percent (US EIA 2017b). In 2016, the further expansion of the natural gas sector added 9 GW to the US power grid, wind power 8.7 GW and solar power 7.7GW (US EIA 2017c).

3.1.1 Resources, infrastructure and the technology dimension

The USA has vast shale gas and oil reserves in various formations around the country, enabling production of natural gas, gas condensates and crude oil. The expansion of natural gas production – especially in Texas and North Dakota – partly replaced coal-generated electricity and doubled natural gas plant liquids (NGPL) between 2005 and 2010

(US EIA 2017b). Since 2008, those states have contributed a slight increase in oil production, which since 1970 had steadily decreased. Simultaneously, renewable energy reached a record high production of 9.7 quadrillion Btu in 2015, a result of wind and solar power development.

Few have appreciated how the US federal government's R&D focus on energy technologies served the profitmaking interests of the shale industry and subsequently the fiscal interests of the USA as a whole. The federal government was directly involved in drilling in the 1970s, introduced tax incentives in the 1980s and funded research in the 1980s and 1990s. This paved the way for two significant technological innovations – horizontal drilling and hydraulic fracturing – which are the basis of the shale revolution, enabling better productivity and efficiency, controlled production costs and ultimately, via a combination of bankruptcies and successes, large-scale, profitable development (Anderson 2013). Horizontal drilling enables directional drilling of horizontally located thin shale formations. Hydraulic fracturing (pressured application of a mixture of water and slick water or hybrid fluid) creates channels in rocks through releasing a flow of oil and gas. The Government's Energy Policy Act (2005) accelerated the shale-based transition, granting land for exploration, extraction and development by companies working above and below ground. The willingness of private landowners, who under the US legislation also own sub-soil shale resources, to lease it for shale development served to increase production.

Renewable energy has also enjoyed federal R&D support as an essential element of the energy transition. The socioeconomic interest of the federal government is to facilitate the generation of low-cost electricity which, in turn, is possible in the long run by means of renewables. Low electricity prices encourage competitiveness and employment in the non-energy manufacturing industries. The USA has twenty-three offshore federal state sponsored wind projects (more than 16 GW, total capacity) enabled by technological development in materials, design application and know-how, resulting in superior performance (Wiser and Bolinger 2016) as well as energy storage within the wind turbine tower and enhanced operability and system integration (US DOE 2017a). With solar, the focus is on photovoltaic technology, including material improvements in the use of crystalline silicon, electrical and optical techniques and surface analysis (US DOE 2017b, 2017c).

The dense network of state and interstate pipelines and other infrastructure facilities of the fossil fuels economy support the shale revolution in the USA, and the private sector has made significant new investments (INGAA 2016) in search of profits. Overall, we find close coordination among the federal government, companies and other actors along this dimension. In particular, federally supported R&D is a necessary cause for the transition.

3.1.2 Finance, markets and business models dimension

Along this dimension the implicit rationale of the transition presupposes balancing of the interests of the shale and non-shale industries. The nuclear sector has fewer such sectoral interrelationships. It has long ago recovered its investment costs and has well-established markets.

The radically decreasing production costs of shale gas pushed Henry Hub spot market prices down from around \$6/MMBtu in 2007 (despite a peak of about \$12/MMBtu in 2008). Prices have lingered around \$3/MMBtu since 2009, despite occasional peaks (EIA 2017d). The market entry of shale gas intensified gas-to-gas competition in the US wholesale market, resulting in free price formation and thousands of actors in the supply chain. Downstream, local gas distribution companies usually act as natural monopolies, using a combination of long-term contracts and spot market purchases to control their risks. This allows them to regulate the prices for their smaller customers so that the margins of distribution companies and the cost of electricity to the end consumer remain manageable (Talus 2014, 29). Nevertheless, improvements in efficiency and reduction in the production costs of wind and solar power have enabled the renewable energy sector to compete with falling gas prices, along with federal government support (Federal Production Tax and Investment Tax Credit) and other subsidies, including Renewable Portfolio Standards (EIA, NCSL) in twenty-nine states. The costs of wind power decreased from over \$0.55/kWh (in current dollars) in 1980 to an average of \$0.0235 today (US DOE 2017a). The costs of solar PV panels and solar electric systems have decreased respectively by 60 percent and 50 percent since 2010 (US DOE 2017b, 2017c).

Although companies are the main actors shaping electricity markets in the USA, the interests of the shale and renewable energy segments are also coordinated with those of the country as a whole, resulting in a highly competitive, reasonably priced electricity market – a combination of natural gas, wind and solar, plus nuclear power. The interrelationships between the different resource sectors are nevertheless complex. For example, the wind power industry expects an average capacity addition of eight thousand MW/year from 2016 to 2020. This, however, is likely to decrease between 2021 and 2023, owing to low natural gas prices, moderate growth in national electricity demand and the growing significance of solar energy in certain states (US DOE 2017b, 2017c). This all means that the main public sector authority, the US Energy Administration, cannot evaluate individual energy products in isolation from the others; it must consider every interest underpinning market behaviour, the energy mix and the combined actions of and effects on all market participants.

The business model of shale producers requires a flexible startup of operations and closure of production on a given site depending on output and evolution of prices. American renewable energy developers must adjust their business models to a more competitive environment than those of Germany, including less generous subsidies (Kavanagh 2016).

3.1.3 The institutional dimension

The formal regulatory framework governing energy transition in the USA has historically developed in conjunction with diversification of the energy mix. We identify four phases of regulation and amendments from 1920 to 2015, corresponding to instances where actors have had to reconsider how to promote their interests when encountering challenges in the policy environment, for example concerns about nuclear safety, coal emissions and the environmental risks of shale production, or security-of-supply problems like the oil crises of the 1970s (see Congress 2017; Box 1).

Box 1. US Legal Acts 1920—2017

1920—1974: legislator support for hydropower, networks, oil and gas and nuclear energy: Federal Water Power Act (1920), Public Utility Holding Company Act (1935), Rural Electrification Act (1936), Natural Gas Act (1938), Atomic Energy Act (1946), Energy Reorganization Act (1974).

1970—1980: focus on security of supply while institutionalizing environmental regulations: Energy Policy and Conservation Act (1975), Department of Energy Organization Act (1977), National Energy Act (1978), Clean Air Act (CAA, 1970), Clean Water Act (CWA, 1972), The Toxic Substances Control Act (TSC, 1976) (EPA 2017).

1980—2005: emphasis on supply diversification and increasing the shares of renewable energy, shale oil and gas while minimizing the negative externalities: Energy Security Act (1980), Ocean Thermal Energy Conversion Act (1980), Nuclear Waste Policy Act (1982), Energy Policy Act (1992) and Farm Security and Rural Investment Act (2002).

2005—2017: a broader integral approach, reconciling security of supply with employment, manufacturing and environmental priorities: Energy Policy Act (2005) Energy Independence and Security Act (2007), Food, Conservation, and Energy Act (2008), American Recovery and Reinvestment Act (2009), Clean Power Plan (2015); Frank R. Lautenberg Chemical Safety for the 21st Century Act (2016).

Source: Authors, gathered from researching US Congress bills and lists.

The fourth phase of legislation, since 2005 until the appointment of the Trump administration in 2017, concerns the forceful emergence of the environmental stewardship interest regarding specific issues such as underground water and air quality, along with wider economic considerations regarding availability of resources at low cost. However, there are important differences between individual states regarding how they use legal flexibility and espouse environmental interests, as demonstrated by the Clean Power Plan of 2015. In short, the individual states decide on which resources or solutions to favour. Under President Trump (2017—), the USA is likely to continue to leave room for the priorities of the respective states in support of interests in security of supply (especially regarding oil and gas production) and in ensuring low electricity costs.

Overall, the federal actors have shaped the policy environment significantly through regulatory instruments. Regulation not only paved the way for the transition, but supported the profit interests of market actors by setting policy and technology priorities in response to changing priorities at all levels (also global). This bottom-up method of regulation organized and institutionalized the current energy transition in the USA.

3.1.4 The ecological dimension

This dimension is less crucial for the energy transition in the USA than the three others. Nevertheless there are significant contradictions in how actors in the shale industry, conventional gas and renewable energy sectors seek to realise their interests vis-à-vis this dimension through legal acts and in various expert committees.

The environmental risks of shale gas stem from the chemicals used in hydraulic fracturing, including air and water quality issues potentially leading to public health hazards. Shale extraction may contaminate underground water resources if, for example, the casing of the well is poor. Some companies claim they inject the chemicals below underground water deposits, eliminating the risk of contamination. Some academic reports support this argument, while others have found higher levels of methane, arsenic and heavy metals in groundwater close to fracturing sites (Tulloch 2013). To resolve such controversies and risks, and ultimately, to facilitate a compromise among different interests, representatives of universities, research centres and shale companies work on joint committees (API 2017).

The shale industry also affects the landscape at sites, including intensive truck traffic to deliver the fracking liquid, water, sand and chemicals. A single well site may require up to three thousand diesel-powered truck trips

(Smil 2015, 181–2). When the production moves to new locations, a frequent event, it leaves large areas temporarily undermined.

Regarding emissions, several studies broadly support the 2011 findings of the National Energy Technology Laboratory, that on average, natural gas (merging conventional and shale gas products) caused GHG emissions 53 percent lower than coal-based power generation when measuring the entire process, from extraction to conversion. In addition, coal use emits sulphur dioxide, mercury and other climate change–inducing particles. Even so, follow-up studies disagree on whether shale extraction causes greater or lesser methane emissions than coal technologies. This controversy originates in the imprecision of measurements from widely varying drilling conditions, which cannot reliably report the methane leakage nationwide (Smil 2015, 175–80).

3.2 The German case

The *Energiewende* originates in the initiatives by grassroots level actors since the 1970s (Morris and Jungjohann 2016) and incremental policy responses by successive German governments compelled to take account of the material constraints of the resource base and the interests of incumbent companies (Cherp et al. 2017). In the 1970s the German energy debate concerned safety, environment and security of supply. The environmental risks of nuclear power were pivotal concerns after the Three Mile Island accident in the USA, alongside the risks of dependence on Middle East oil, while the renewable energy initiatives of the time failed to take off. By the 1980s public support for nuclear power had dwindled. Climate change issues entered the debate in the 1990s and renewables emerged in the early 2000s (Hake et al. 2015, 534–8). This restructuration process gradually raised to prominence the *environmental stewardship* interest. It articulates the environmental risks associated with nuclear power, and the effort to reduce GHG emissions (Laes, Gorissen and Nevels 2014). In this light, the quest for a new energy mix prioritising renewables is comprehensible, given that energy consumption accounts for some 80 percent of the country’s GHG emissions. By 2016 renewable sources accounted for 12.6 percent of primary energy consumption – primarily derived from biomass, wind, solar power and waste products. Oil accounted for 34 percent, natural gas 23 percent, hard coal 12 and lignite 11 percent and nuclear power 7 percent. From 2010, the share of renewables in power generation grew from 20 to 29 percent, largely a result of rapid expansion of wind and solar power and biomass-based production (Appunn 2017).

3.2.1 The resources, technologies and infrastructure dimension

The transition towards new resources presupposes overcoming many vested interests and path-dependencies bent on maintaining existing technologies and infrastructures. The profit interests of the incumbent large private companies EnBW, E.ON, RWE and Vattenfall relate to this constraint. In the early 2000s they first expanded by acquisitions of assets, and then developed new coal- and natural gas–fired production. Then they faced reduced demand, from 2008 onwards, following the financial crisis, and were forced to shut down eight of their nuclear reactors after the 2011 nuclear accident in Fukushima. These decisions and setbacks induced the incumbents to try to slow down the development of renewables, supporting carbon capture and storage technologies (Kungl 2015, 13–19). The attempted gradual conversion of the whole economy to renewables, however, is constrained by the oil-consuming vehicle fleet, the abandonment of battery development by the German automobile industry after the government cut support and the natural gas–based heating system (see Smith Stegen and Steel 2013). Germany’s biofuel quota and targets of a million electric cars by 2020, and six million by 2030 (ibid., 1484), can only pave the way for a transition of the vehicle stock in a country with eighty million people.

The conversion to renewable resources hits fewer material constraints in the electricity sector, which accounts for roughly one third of primary energy production. However, reaching the 50 percent target set for 2030 – 80 percent by 2050 (BMWi 2012) – requires an overhaul of the current structure. This sector’s rapidly growing renewable generation component momentarily meets almost the entire electricity demand. However, when wind and sun produce too little power, the system must supplement them with base-load and back-up services of coal and natural gas, in particular as nuclear generation is decreasing (Pegels and Lütkenhorst 2014, 531–2).

Wind and solar power are the technological spearheads of the German energy transition. Wind power technology has so far produced more R&D and innovations than solar technology, created more employment and reduced more German emissions, and at a lower subsidy cost (Pegels and Lütkenhorst 2014). While wind power technology is mature, solar power technology is an emerging sector where German providers experience intense competition from China. The long-term progress of the two technologies, and their ability to substitute coal and gas-fired production, depends on the development of adequate storage technologies to counter the weather-dependent nature of wind and solar power. Batteries can provide short-term storage and hydrogen interim storage; long-term storage solutions include power-to-gas, pumped hydro, compressed air storage or heat storages (Schmid, Knopf and Pechan 2016, 270).

The expansion of renewable sources also affects the infrastructural limitations of the regional and local electricity distribution grid, originally designed for distributing centrally produced power to consumers from large fossil fuel and nuclear power plants. Renewable production requires investments in the region of €23 to €49 billion by the 2030s for smarter distribution grids enabling two-way flows to and from small-scale prosumers. This affects distribution system operators differently; not all regions develop renewables at the same rate. Moreover, development of high-voltage national transmission lines encounters local protesters maintaining that they serve the profit interests of centralised production and large companies at the expense of the emerging decentralised system (Schmid, Knopf, Pechan 2016, 268–70). However, the large-scale wind parks built in the northern parts of Germany require these transmission lines to serve the electricity-intensive areas in the south (Nordensvärd & Urban 2015). Moreover, large wind parks need interconnections with the European level to sell their surplus production and correspondingly enable imports when wind generation is low. Ultimately, reconciling the interests of centralised and decentralised infrastructure may affect the profit interests of all stakeholders.

3.2.2 The finance, markets and business models dimension

The producers of renewable energy can pursue their profit interests with the help of the feed-in tariff sanctioned by the federal government that compensates for the higher average investment costs for renewables than those of the fossil fuels–based production. Consumers bear the final costs through an annually adjusted reallocation surcharge and several taxes. Moreover, as individual states *Länd*er built more wind power than expected, the costs unintentionally increased, leading to a higher aggregate surcharge. This compelled the federal government to consider restrictions on the expansion of renewables capacity (Smith, Stegen and Seel 2013, 1484). The federal government also adjusted the subsidy scheme several times throughout the 2010s. At the same time, the expansion of renewables generation, with near-zero production costs, brings wholesale prices down. Low fossil-fuel prices in turn also help to keep wholesale prices low (Matthess et al. 2015, 20). Energy-intensive industrial consumers, who buy directly from the wholesale market, benefit from these downward pressures in that market. This cost structure locks the stakeholders of the wind industry into the feed-in-tariff system, despite their uncertainty regarding its future (Nordensvärd and Urban 2015, 160). However, the industrial-scale producers do not think the scheme offers sufficient profits (Smith Stegen and Seel 2013, 1484). Furthermore, the new lock-in does not support R&D interests, since it does not encourage innovation (Nordensvärd and Urban 2015).

The resulting structure enables renewable production to enter markets rapidly. However, the market design favours large-scale onshore and capital-intensive offshore wind production since these receive higher subsidies. On the consumption side the interests of energy-intensive industries buying from the wholesale market are privileged. Small-scale producers and small consumers must buy from the retail market where prices are higher (Nordensvärd and Urban 2015, 163). To some extent, improvements in energy efficiency compensate for the effect of higher retail prices by reducing the share of energy costs in the disposable incomes of households. Yet the subsidised transition treats the spectrum of socioeconomic interests differently across society. Concomitantly it is also true that the subsidies on renewables are merely half of the direct subsidies and tax subsidies enjoyed by the fossil fuels sector. In 2013 renewables received €5.3ct/KWh; in 2012 fossil fuels took in €10.2 ct/KWh, receiving a total subsidy of €40.3 billion (Pegels and Lütkenhorst 2014, 525).

The emerging business models vary widely but revolve around various support schemes like feed-in premiums (Penttinen 2016). In a ‘wind package’ model, one company can operate wind farms, carry out maintenance and service, sell the electricity and act as an insurer (Nordensvärd and Urban 2015, 161). A virtual power plant operator aggregates small-scale production into a larger resource, enabling flexibility. This is crucial in a decentralising system where private individuals own a third of the renewable power capacity (Matthes 2015, 76). Some companies may assume niche roles in the provision of equipment, maintenance, service and consultancy. The turnover in the renewable energy business, including supply of fuel and services to renewable energy power plants, was €14.7 billion in 2015 (BMWi 2015).

3.2.3 The Institutional dimension

The chief formal institutions supporting the German transition include the Electricity Feed-in Act and the Act on the Supply of Electricity from Renewable Energy Sources into the Grid, both of which came into force in 1990. This regulation subsequently underwent several modifications in order to adjust for the falling costs of renewable power and to comply with EU regulation on state aid (Penttinen 2016). The relative regulatory continuity includes guaranteed subsidies for twenty years, paid for generation output and reducing the investor’s risk in predicting output or demand. This ensures the investor’s profits, assuming the investor estimates the costs correctly. The regulation has provided incentives for a wide range of actors and ensured extensive institutional support for the transition (Matthes et al. 2015, 31). The 2011 political decision on the *Energiewende* brought an additional package regulating the promotion of renewables in electricity generation, expansion of the electricity grid, restructuring of the energy industry, , public contracts, nuclear energy, climate measures on the local level and the establishment of an Energy and Climate Fund (BMWi 2012, 7).

This structure of formal regulation brings incumbent and emerging market actors together around a common profit interest in continued feed-in tariffs. They also employ various lobbying strategies vis-à-vis decision-makers on the federal and state levels in order to maintain the system. The federal actors remain open to lobbying on this complex subject, and unlike those in many other countries, emerging companies are integral parts of the system. Yet the four large incumbent companies simultaneously seek to protect the profitability of coal- and gas-fired power plants through their direct access to decision-makers (Sühlsen and Hisschemöller 2014). However, in recent years the political decision-makers have shown decreasing support for the system they created.

Some of the institutional change takes place on the EU level, where energy market and environmental regulation, and the evolving of the Energy Union, shape national measures. For example, the EU-level constraints are direct regarding the policies for renewable energy subsidies. Indirect constraints for national policies are likely to form via the integrated energy and climate planning obligations under the proposed EU Governance Regulation (European Commission 2016). All of this will Europeanise national policies on renewable energy, supporting the German transition with back-up capacity through cross-border trade in electricity and natural gas, and through appropriate policy coordination.

3.2.4 The ecological dimension

Germany's energy transition will eventually reduce environmental and ecological risks. It will reduce the risk of accidents during oil transport if we assume the electrification of transport to progress, and that vehicles will need less oil. For example, decreasing the tanker traffic across the shallow and ecologically vulnerable Baltic Sea would reinforce this effect. However, the transition in the transport sector faces enormous infrastructural constraints, of which dealing with existing gas filling stations, the renewal of the vehicle fleet, the need to develop battery-loading facilities of electric cars are only a few. Therefore, as long as oil retains a share in transport, the existing risks to the maritime environment can only diminish to the extent that maritime tanker traffic decreases. It will not necessarily decrease much or fast if it merely replaces the existing transit of oil and oil products from Russia and Central Asia – suppliers providing half of the oil used in Germany – which takes place through aging pipeline infrastructure and via East and Central European transit countries with which Russia experiences frequent transit conflicts (Balmaceda 2012). The phasing-out of nuclear power by 2022 will reduce the risks of nuclear accidents but will not remove the risks of treating and storing spent nuclear fuel.

The development of wind and solar power is changing the landscape. Wind power companies identify 'inhibitive' constraints for onshore installations such as the federal regulation on the location and height of wind power turbines. For offshore installations, the companies face regulatory constraints owing to the requirement by Germany for greater distance of wind turbines from the shoreline than, say, Denmark and the UK. This leads to siting in deeper waters and exposure to harsher weather conditions (Stegen and Steel 2013, 1484–6). The ecological constraints of bioenergy crops – the dominant form of biomass in the country – pertain to land use, biodiversity and ecological balance. These are exacerbated by the conversion of grassland into farmland and water management issues. The bioenergy sector, in the meantime, has failed to support the German interest in R&D through the renewable transition. Since the amendments to the Renewable Energy Act in 2014, the federal government consequently favours the better-performing solar and wind power segments, limiting support for any further biomass projects (Matthes 2015, 57, 78). The government also applies tightening sustainability criteria for biofuels whereby the net contribution to GHG emission reductions must rise from 3.5 percent in 2015 to 7 percent by 2020. Bioenergy encounters the further constraint that practically the full energy potential of waste is already in use in Germany.

The GHGs and other emissions traceable to Germany's energy transition mostly relate to the temporary substitution of nuclear power by means of coal, and the emissions from part of the biomass burning plants and from biofuels. The German transition is ceasing to develop these solutions further or is abandoning them altogether in the long run.

4. Conclusions

4.1 Discussion

The energy transitions in the USA and Germany are benchmarks for many other countries. Although both countries have diversified their energy mixes and will utilise both fossil fuels and renewables for decades to come, they differ fundamentally in terms of the long-term role envisaged for fossil fuels and the way they manage the transition. Our structuration approach directs attention to how they formulate cross-sectoral policies ascertaining the interconnectedness of the structures of which they are part, and the consequences of their own actions in order to synchronise long-term strategic goals with more tactical and operational measures (see also Laes, Gorissen and Nevens 2014, 1133-5). In the USA a diversified energy mix reconciling several interests simultaneously is a tacit long-term goal in its own right. In Germany the explicit long-term strategic goal is the predominance of renewables, favouring the environmental stewardship interest although other interests also warrant attention.

This fundamental difference means that the US transition deliberately maintains many path-dependencies of the fossil fuels–based economy while it emerges alongside a new renewable economy. It addresses environmental issues with regulatory constraints imposed by the government to prevent risk to profits and the wider economic effects that they expedite. The German transition targets the reduction of the risks of nuclear energy domestically in the short-to-medium term, and in the long term, a reduction of GHG emissions in line with EU and global level commitments. To this end, tactical and operational measures must break several path-dependencies on the demand side, or domestic society in favour of a more decentralised energy system involving more citizen and prosumer participation and flexible consumption. However, owing to the complex interrelationships among resource sectors, the German transition has not so far delivered more vis-à-vis its long-term objectives than the US case. By 2016 emissions from the electricity sector were 13 percent less than in 2007, but no similar reductions occurred in other sectors (EIU 2017). In the USA, from 2007 to 2015, the transition reduced energy-related emissions by 12 percent. The power sector accounted for 68 percent of the reductions (EIA 2016). Controlling the outcomes remains challenging because of the back-up solutions required by weather-dependent solar and wind power – especially since Germany is phasing out nuclear power. The federal government aims, initially, to provide 17GW from new coal- and natural gas–fired capacity by 2022, alongside better energy efficiency and enhanced cross-border trade in electricity (BMWi 2012, 8–9).

The two transitions also have consequences on the global level, where resource sectors are likewise interconnected and outcomes difficult to control. The German energy transition explicitly supports technology exports as a federal level objective, having first adopted wind power technologies from Denmark in the 1990s (Cherp et al. 2017, 615), and then diffusing these further, facilitating innovation, learning and cost reduction that will gradually make subsidies redundant. In the USA, renewable technology export interests exist more on the level of individual companies. In this sector, the primary competitors come from Denmark, Spain and China. The competitiveness of renewable energy technologies and solutions depends furthermore on the global prices and trade in competing energy resources, including oil and natural gas, and the effects of the shale revolution (see de Jong, Auping and Govers 2014, 14). The US shale industry established its own pricing mechanism and contractual terms that became effective in pricing – directly, in the domestic markets and indirectly, overseas (Talus 2014, 28–34). The rapid market entry of shale gas released large amounts of Qatari LNG into the European market in place of planned sales on the US market. This, together with market liberalisation, decreased demand following the financial crises in 2008 and more gas-to-gas competition, reduced European prices and also reduced the pricing power of Russia's Gazprom vis-à-vis individual EU Member States (Talus 2014, 31). Furthermore, shale gas offers new supplies and reduces prices on the Asian market, competing with established supply and other fuels from the Persian Gulf and Russia, and with emerging supplies from Australia and Myanmar (Moryadee et al. 2014). This increasing global competition among fossil fuel exporters affects the global competitiveness of the renewable sector.

The two cases affirm the centrality of R&D as a major driver of the transition, as studies on sociotechnical systems suggest. Here the broad horizontal focus of the structuration approach on several dimensions of the structure and on their interconnections becomes important. The innovation niches, which our framework relates to the dimension of resources, technologies and infrastructure, depend on the dimension of finance, markets and business models in terms of finance available and incentives provided by federal actors. The niches also depend on the institutional dimension in terms of reciprocal actions by local, state and federal regulatory institutions. Other actors such utilities, universities, research centres and civil society (especially landowners whose permission is crucial for shale production) are part of the process. Our analysis also shows that on the institutional dimension, most of the tactical and operational level policies in the USA pertain more to the supply side of the energy system. In Germany, measures targeting the demand side are more widespread even though they run into constraints on our institutional dimension for example in the form of inadequate coordination vis-à-vis regulations on buildings and transport, and on our financial dimension in terms of insufficient policy innovation to keep up with market developments (see Kuzemko et al. 2017).

The two transitions have different consequences for market structures. Markets created by formal regulation, as in Germany, carry risks not occurring in the more bottom-up facilitated market in the USA, such as market malfunctioning, lack of private investment and potential miscalculations of the impact of regulatory choices. Concomitantly, the German model more forcefully reforms the demand side of the market by creating demand for new services in fields such as planning, consultancy, equipment installation and energy efficiency, while it also facilitates the emergence of new actors such as prosumers and aggregators of small-scale production. On the US market, the transformation is limited mostly to the supply end, with a proliferation of actors extracting shale gas. Little steered markets have downsides too in being unable to cater for the wider interests of the state and society in the transition, for example vis-à-vis energy efficiency. Yet this dilemma of serving disparate interests simultaneously remains unresolved in the German context. For example, the long-term aim of more decisively converting towards intermittent and partly emerging technologies in the power markets does not serve security of supply interests as straightforwardly as does the relatively established and consistent production of shale-derived oil and gas in the USA. Yet the associated decentralisation of production and infrastructure could offer other security gains by improving the resilience of the German system to external shocks or terrorism.

The differences in the uses actors make of the tools of the institutional dimension, coupled with the ambiguous outcomes, leads us to involved contestations. Although the US transition stems from liberal features of the market economy, our case study shows that full autonomy in markets will not produce an energy transition, let alone one that is environmentally sustainable. That the more coordinated capitalism of Germany also faces numerous constraints and unintended consequences, brings us to the debate on state transformation, in particular to the thesis of the plurality of possible state responses (Levy 2015). Here our structuration approach draws attention to the need to reconcile state policies with the structural context including all its relevant dimensions. The cognitive difficulties of this balancing exercise mean that the state is not the omnipotent geopolitical force portrayed by some realist approaches to oil and natural gas (see Aalto et al. 2014) – even though the shale transitions may make such a simple assumption tempting. Nevertheless, in China, for example, the country's new developmentalism – using state capacity to build a low carbon economy (Dent 2012) – is producing impressive results in the renewable energy technology sector. Hence, although states very much remain part of the actor landscape, their responses vary widely, while our analysis has shown that no actor fully controls energy transitions or their consequences, especially if they extend deep into the demand side.

4.2 Findings

Regarding our first research question on the interests driving the energy transitions in the USA and Germany, our comparison revealed multiple interests defining both cases. These include interests in security of supply, profits of companies, the associated fiscal interests of the country as a whole and other public actors and R&D. Regarding the wider economic implications, low energy prices are indispensable to the USA, whereas in Germany large industrial consumers benefit from policies to this effect; employment gains feature similar positive externalities in both cases. In the USA environmental stewardship narrowly targets the negative externalities like environmental risks and excessive emissions of production. In Germany, it takes the broader form of controlling risks of nuclear energy and combatting climate change in the long run, although progress so far has been modest. Foreign policy interests surface more directly in the case of the US shale revolution. In this fossil fuels sector, control and competition over resources retains its significance unlike in the case of renewables, which are available, worldwide, in different forms. This shifts the focus from resources as such to technology exports enabling the utilisation of these plentiful resources. Energy efficiency is more a German than a US concern. Such a multiplicity of interests uncovered is a function of our structuration approach, which does not prioritise any single actor or interest *a priori* and is uncomfortable with mono-causal explanations, particularly in a complex area such as energy transitions involving an expanding number of actors.

Regarding our second question – how the structures of political economy constrain and enable the operations of the actors involved in the two energy transitions – we analysed four analytically separable dimensions that remain interlinked in practice. The materialities of the resources, technology and infrastructure dimension constitute the foundation for any analysis of the IPE of energy and owing to their 'sticky' character, account for the inertia and path dependencies characteristic of this field. Regarding the finance, markets and business models dimension, energy transitions may be market-driven or state-driven but require other actors, including individual citizens, in various capacities. Although the end products of electricity and heat/cool remain the same, energy production no longer occurs predominantly in remote locations or in power plants in the suburbs, but becomes a more integral part of everyday life and landscape, regardless of whether we speak of armies of shale gas wells on farmers' fields or of solar panels on rooftops. Increasing use of renewable sources, however, will require a profound transformation of society and therefore wider mobilisation of energy consumers (and prosumers) in terms of our institutional dimension. Finally, the constraints of the ecological dimension also hamper renewable energy and make outcomes uncertain without a long-term perspective. This complex end result serves as a reminder of how the structuration approach assumes several interrelated structures in its attempt to account for the structures of energy transitions more comprehensively than existing approaches do. If this theoretical choice is a compromise in theoretical parsimony, its advantage is that it reveals the difficulty for actors 'out there' to consistently steer energy transitions in a given direction.

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