Routledge Explorations in Environmental Economics
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National Pathways to Low Carbon Emission Economies

Innovation Policies for Decarbonizing and Unlocking

Edited by Kurt Hübner

Routledge
Taylor & Francis Group
LONDON AND NEW YORK

5 The transition to a low carbon economy in Germany's coordinated capitalism

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Introduction

This chapter presents the key patterns of technological and institutional change in Germany's transition towards a low carbon economy and explores which actor constellations and institutional configurations in its political-economic system have shaped its path, with particular emphasis on efforts in technological innovation. This question is explored within the framework of a comparative capitalism approach perspective in which Germany is characterised as a coordinated market economy (CME), This leaves considerable room for manoeuvring relational and associational governance modes in the coordination efforts of firms. Accordingly, it is important to examine the institutional scaffolds of the German variety of capitalism. Especially how they relate to the challenges of coping with the complex and radical institutional and technological changes that are required in the formation of a sustainable low carbon setting of economic affairs.

The first section of the chapter outlines the empirical patterns and structures of carbon emissions and related indicators in the development of the German economy. The second section highlights the institutional specifics of the German variety of capitalism as a CME. The third section explores innovation efforts in the formation of a low carbon economy. The final section examines those actor constellations and policy strategies that drive institutions towards a low carbon economy in Germany.

German emission patterns and structures

In exploring greenhouse gas (GHG) emissions in Germany, the fact that power generation before the start of low carbon transition was from fossil fuels and nuclear power, augmented by minor shares of hydropower and oil, needs to be reiterated. Hard coal provided the traditional backbone of this energy mix, yet the structural crisis in the coal and steel industries led to massive closures of mines and plants in key regions, such as Ruhr and Saar, during the 1980s, leaving only a handful of highly subsidised coal mines. Brown coal, however, largely remained in the market because of its cost

advantages. Its relative decline since the 1990s was mostly due to the closure of mines in Eastern Germany (Jacobsson and Lauber 2006). Also, it is prudent to remember that Germany is highly dependent on the import of energy; more than two-thirds of the German energy supply, most prominently oil and gas, are imported from abroad (BMWi 2012). This situation already underpins the transnational dimension of economic decarbonisation and alludes to the limits of those strategic actions that are confined to the national domain. Given these constraints, Germany has made significant efforts in the domain of environmental affairs, in particular with regard to CO_2 emissions reduction. A study commissioned by the European Research Area Board states: 'Today, Germany is one of the world leaders in environmental issues, climate protection, greenhouse gas emission reduction and alternative energy technology' (Leijten *et al.* 2012, p. 109). This may appear surprising given that Germany is one of the leading global industrial net exporters. Based on available data, the German reduction in carbon emissions seems to have been quite successful since the 1990s.

Figure 5.1b offers a first glimpse at the profile of GHG and carbon emissions in Germany since 1990.

First, the data provide telling evidence for the relative success of German efforts on GHG emissions, which were reduced by 27.9 per cent between 1990 and 2015. Yet recent developments indicate a slowdown in emissions reduction, especially when considered with the more precipitous downward trend seen recently for the EU as a whole (see Figure 5.1a). A factor in this development may be the general increase in energy use resulting from economic and population growth, combined with a lack of energy productivity

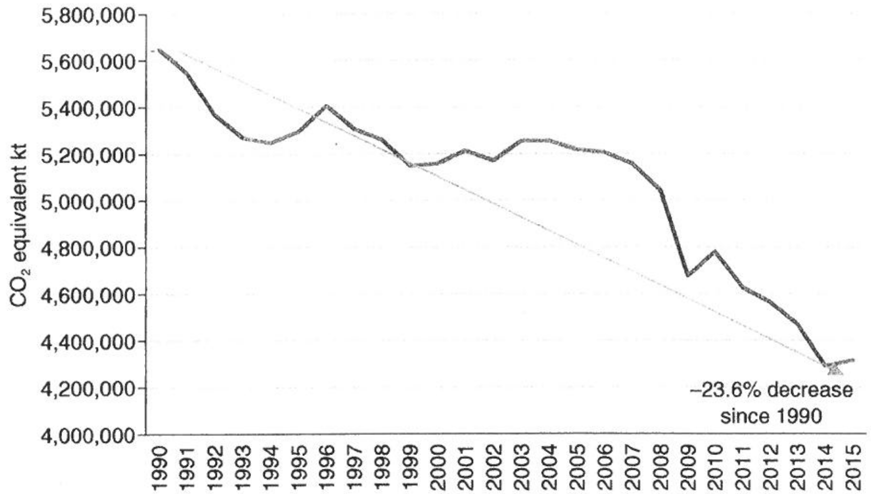

Figure 5.1a EU GHG emissions.

Source UNFCCC Data Interface, 2017.

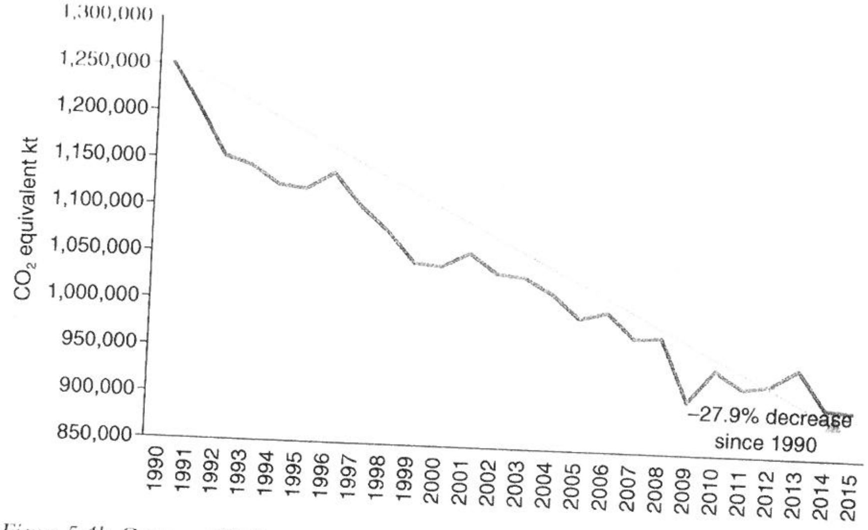

Figure 5.1b German GHG emissions.

Source UNFCCC Data Interface, 2017.

and resource efficiency (Wörlen and Gebauer 2017). Second, the data illustrate the massive carbon footprint that is caused by economic activities in Germany when compared with the European Union 28 countries. GHG emissions in Germany accounted for almost one-fifth of the EU 28 whole during the 1990s and 2000s, making it the largest national emitter in the EU and the third largest in the OECD after the United States and Japan. However, in terms of emissions per capita, or relative to GDP, Germany remains well below the OECD average (Klein 2012). The sheer size of the German economy, its manufacturing base and its specific energy mix translate into a relatively high national share of European carbon profiles.

All these efforts towards the formation of a low carbon economy are within the context of international commitments and regulations, most prominently represented by the Kyoto Protocol. Germany reached its Kyoto commitment for 2012 early, namely a 21 per cent reduction of GHG emissions from 1990 levels, having already reduced GHG emissions 26 per cent below the 1990 baseline by 2009. This is one of the best performances among high-income OECD countries. To proceed further, additional national goals in the reduction of emissions have been put forward, aiming at a 40 per cent reduction relative to 1990 by the year 2020. This emissions target seems to underline further advances in the decarbonisation of the German economy (Leijten *et al.* 2012). More recent trends cast some doubt on Germany's previous success. The slowdown in emissions reduction, in tandem with the level of ambition in these 2020 targets, means there is some concern they will not be met. According to a recent report from Germany's environment ministry, the country is at risk of missing its 40 per cent reduction target. The ministry had expected greater emission cuts from government policies and has now had to revise these forecasts upwards (Reuters 2016). This could have implications for the Paris Agreement. The EU Effort Sharing Regulation 2021–2030, which underlines the expected contribution for each member state leading up to the EU's 2030 Paris commitment, expects Germany to reduce emissions by 38 per cent from 2005 levels (European Commission DG Climate Action 2017a). For comparison, since 2005 levels are lower than 1990 levels, the 40 per cent reduction since 1990 for 2020 was actually a 14 per cent decrease from 2005 (EUR-Lex 2009). This 2030 commitment is quite a lofty goal given current trends.

Figure 5.2 provides an overview of GHG emissions by sector in selected years since 1990. The largest share of these emissions consistently emanated from the energy supply. When it comes to the sectoral dynamics of emissions reduction, the reductions in manufacturing, trade and construction illustrate decarbonisation efforts in the domain of Germany's industrial specialisation. Also, contrary to many other OECD countries, emissions were even slightly reduced in the transport sector, notably in road transportation, which is strategically relevant for the German automobile industry – the key industry in the German export-oriented manufacturing sector. Higher gasoline prices and the implementation of the so-called eco tax and energy standards in the automotive sector played a major role in creating related incentives for energy savings all the way through the 2000s (OECD 2011b).

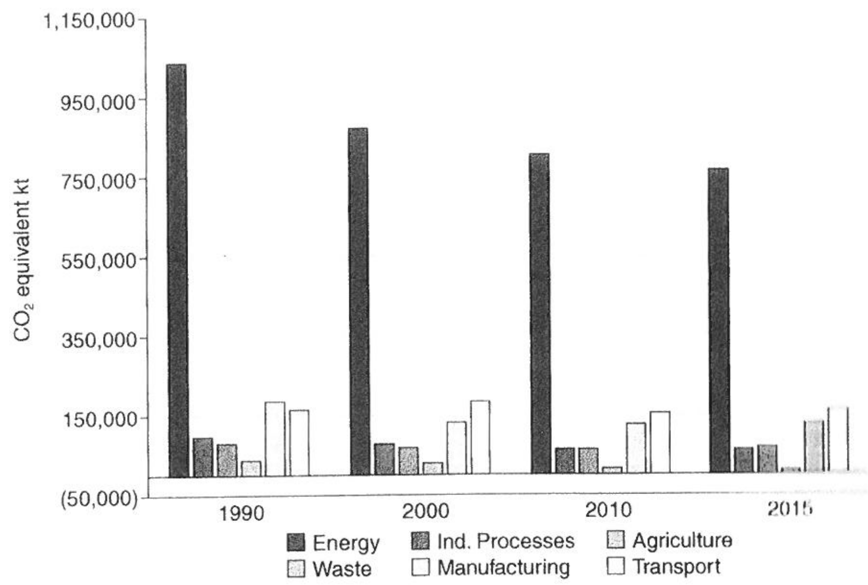

Figure 5.2 German GHG emissions by sector.

Source: UNFCCC Data Interface, 2017.

The same pattern holds for sectoral carbon emissions (Umweltbundesamt 2012). However, as outlined above, recent data on carbon emissions underline setbacks, as the trend of decreasing GHG emissions has been slowing down. The rise of carbon emissions results from an increase in coal burning and it is lessened only slightly by the impact of a parallel increase in renewable energy replacements (Umweltbundesamt 2013a). This development may be viewed as the unintended outcome of the *Energiewende* – the 'energy turn' project discussed below. However, the revival of coal in the energy mix of the German economy is the key challenge for future efforts on emissions reduction (Umweltbundesamt 2013b). Relations between carbon emissions, stationary facilities of industry and energy supply in Germany confirm the trend of carbon emissions reduction, which is intimately related to the activities of energy suppliers (Umweltbundesamt and Deutsche Emissionshandelsstelle 2012).

Patterns in the generation of electricity during the 1990s and 2000s provide further evidence for changes in the specific mix of energy sources. Germany's electricity production has been shockingly carbon intensive. This is due to a relatively high share of fossil fuels, in particular coal, in the energy mix. Levels of coal use are considerably higher than the average levels in other European OECD economies (Égert 2011). Still, the largest shares of electricity generation that came from both brown coal and stone coal declined from a share of 56.7 per cent in 1990 to 44.2 per cent in 2012. From 2011 to 2012, however, the percentage of electricity generated from coal rose again from 42.8 per cent to 44.2 per cent, while the share of nuclear energy was reduced from 17.6 per cent to 15.8 per cent in both years, remaining way below the 1990 level of 27.7 per cent. During the same period from 1990 to 2012, the percentage of renewables in electricity generation increased continuously from a level of 3.6 per cent to 22.6 per cent (Arbeitsgemeinschaft Energiebilanzen 2013). In 2016, shares of energy types in gross electricity generation were: brown coal 23.1 per cent; hard coal 17 per cent; nuclear 13.1 per cent; renewables with a share of 29.5 per cent, of which wind held 12.3 per cent, biomass 7 per cent, and solar photovoltaic and geothermal 5.9 per cent (BMWi – AG-EE-Stat 2017).

When it comes to the expansion of renewable energy in Germany, results are outstandingly positive and have taken off in a most remarkable manner since the mid-2000s. The corresponding pattern of transition resembles a process of technological substitution driven by the entry of new firms and actors challenging the incumbents. This has been possible because electricity technologies in Germany are represented by small-scale decentralised actors in onshore wind, solar photovoltaic and biogas (Geels *et al.* 2016). Figure 5.3 outlines the generation of electricity from renewable energy sources in Germany between 2004 and 2015. The share of electricity from renewable energy sources in gross electricity usage accounted for 9.4 per cent in 2004 and continuously rose to 30.7 per cent by 2015, in fact exceeding the share present in the EU as a whole, despite having had a smaller proportion of

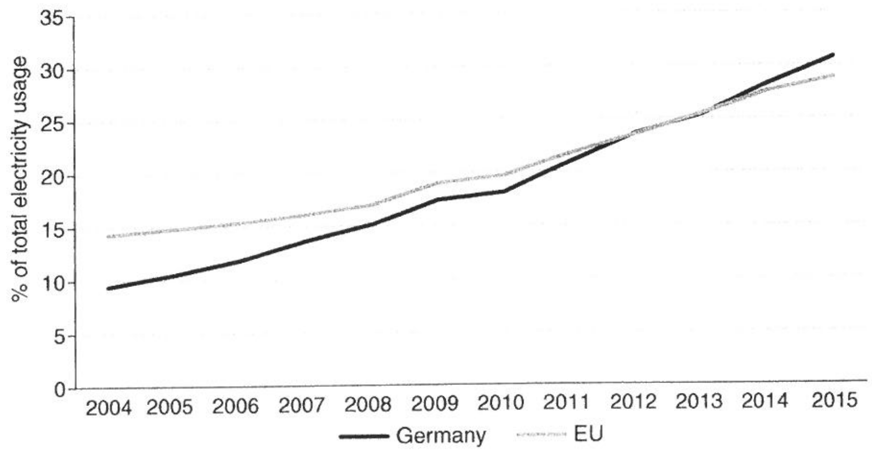

Figure 5.3 Share of renewable energy in electricity.

Source: Eurostat, 2017.

renewables in the energy mix just over a decade prior. The EU 28 has also seen significant growth with an increase from 14.3 per cent to 28.8 per cent. This expansion is mirrored by German renewable electricity generation capacity and not just usage. Between 2000 and 2015, conventional capacity stayed roughly the same from 100 to 110 gigawatts. Total renewables, however, accounted for an increase from 11.75 to 97.92 gigawatts – with onshore wind increasing from 6.1 to 40.99 and photovoltaics from 0.11 to 39.7 gigawatts. Indeed, during the 2000s and 2010s, electricity from renewables has almost reached the total gigawatt level of conventional capacity (BMWi 2016).

Energy consumption also provides a rather positive picture. Figure 5.4b illustrates Germany's primary energy consumption since 1990. Notably, the level of primary energy consumption was reduced by over 10 per cent during this time despite significant GDP growth, whereas the performance of the EU 28 proved less convincing, with less significant decreases in primary energy consumption. The fact that renewables only account for roughly one-third of energy consumption, despite much higher shares in electricity generation capacity, is due to the fact that wind and solar power are only temporarily available under given environmental conditions in Germany (BMWi 2016; BDEW 2016). In terms of resource sustainability, similar patterns hold for energy intensity in Germany, defined as primary energy supply over GDP. It decreased in a manner that was well above the OECD average, thus standing out as a success (Klein 2012). Mirroring these developments, Germany's resource productivity, defined as gross domestic product to the domestic use of natural resources, has improved throughout the 2000s. Figure 5.5 provides evidence for these efforts that parallel related patterns in Europe.

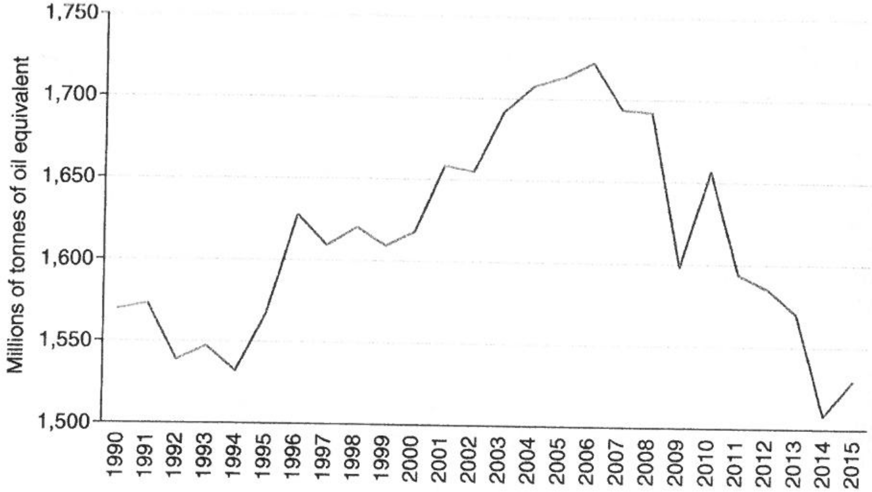

Figure 5.4a EU primary energy consumption.

Source: Eurostat, 2017.

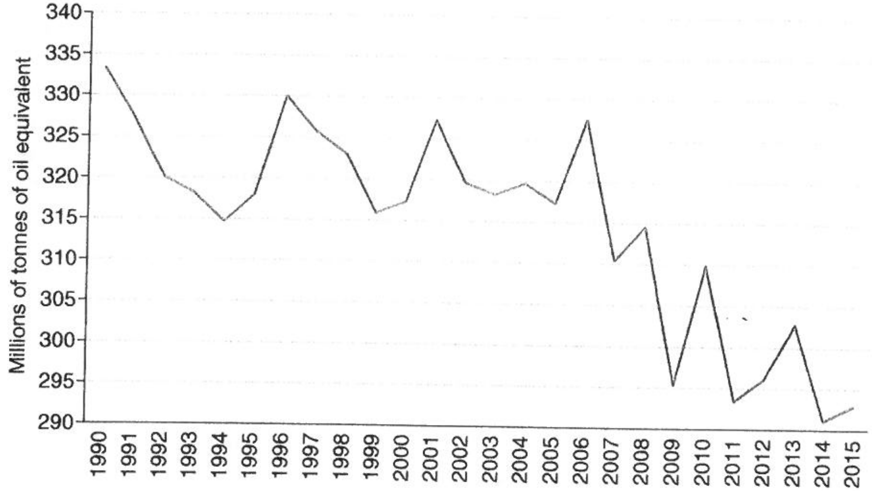

Figure 5.4b German primary energy consumption.

Source: Eurostat, 2017.

Regarding the combined industry and market structures, it is worth noting that the liberalisation of the electricity sector in the late 1990s happened in the context of a system of monopolistic structures. Specifically, there were nine vertically integrated, strictly regulated and regionally demarcated public utilities, accompanied by a set of regional supply companies and municipal

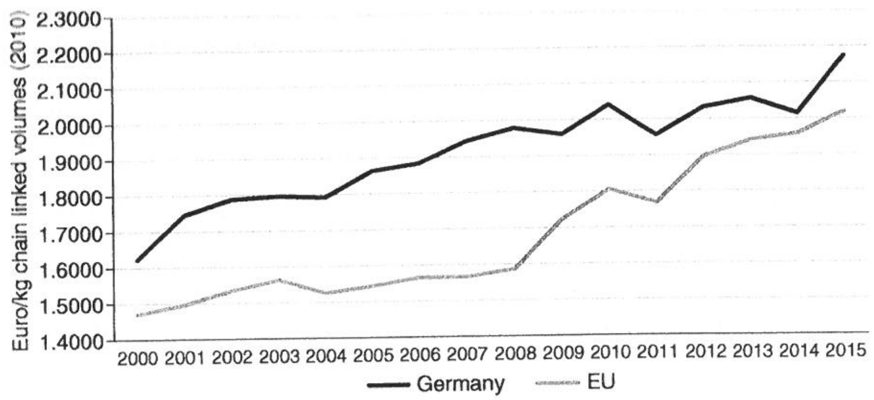

Figure 5.5 Resource productivity.

Source: Eurostat, 2017.

utilities. The result of liberalisation has been a distinct set of suppliers that form the oligopolistic structure of Germany's current energy supply market. These 'big five' energy suppliers are RWE, Vattenfall, E.on, Evonik and EnBW. They emitted a volume of 240 million tons CO_2 in 2011. In relation to the total volume of CO_2 emissions of 351 million tons, this amounts to a share of almost two-thirds of total emissions, predominantly caused by brown coal power stations in Western Germany. Moreover, with approximately 107 million tons of CO_2 emissions in 2011, RWE alone produced by far the largest amount among Germany's 'big five' and it is also a leading player in the European market for energy supply. The operations of the other firms have been recorded as: Vattenfall emitted 73 million tons; E.ON emitted 38 million tons; Evonik emitted 13 million tons; EnBW emitted nine million tons. In comparison, all the emissions of Germany's joint venture power plants, operating on the level of local authorities, amounted to 15 million tons (Umweltbundesamt und Deutsche Emissionshandelsstelle 2012). In view of the challenges of innovation in energy markets, most of these large suppliers have diversified into renewable energy supply since the late 2000s and have set up new divisions: RWE Innogy, Vattenfall Europe New Energy, E.on Climate and Renewables, and EnBW Renewables. However, their activity in Germany has so far remained marginal.

The observed pattern of industrial concentration in energy supply parallels the spatial differentiation of carbon emissions across Germany. Regional profiles of energy-related carbon emissions, which are produced during the conversion and use of energy, underline that the Nordrhein-Westfalen region stood out with a share of almost one-third of German emissions in 1990, followed by Sachsen, Bayern and Baden-Württemberg. During the 1990s and 2000s, all *Bundesländer* (the German name for these regional subdivisions) exhibited a more or less pronounced decline in carbon emissions. In Nordrhein-Westfalen, the hotbed of Germany's carbon-intensive industry, these changes were comparatively modest. This reduction of emissions shows a distinct East–West differentiation after reunification. Indeed, carbon emissions in Sachsen and the other Eastern German regional states have been cut by about 50 per cent during the two decades since 1990. Regional levels of process-related emissions, produced during the use of energy for the purpose of industrial production, also show a decline in emissions. The most impressive efforts are recorded for Nordrhein-Westfalen, a core industrial area of the German economy that has been shifting away from its basis in the heavy industries (Länderarbeitskreis Energiebilanzen 2013).

German efforts to reduce carbon emissions need to be evaluated in the context of the extended industrial basis of the German economy, with its specialisation in manufacturing industries, such as automobiles, and its continued use of coal as a politically shaped energy source. Both of these areas are crucial to the issue of decarbonisation and German efforts to reduce emissions tend to take place in a challenging and highly politicised industrial context. However, as the de-industrialisation of the former Eastern Germany, following reunification in 1991, is included in the data profiles, it needs a more concise interpretation of the general data. A large proportion of reduced carbon emissions may be due to the effects of industrial change related to market-oriented systems transformation in the former Eastern Germany. These are set apart from strategic concerns and concerted policy efforts for decarbonisation. During the 1990s, 50 per cent of the reduction of carbon emissions occurred thanks to the restructuring of the East German economy as heavy industries largely broke down. Outsourcing of manufacturing industries to Eastern Europe also contributed to this effect (Weidner and Mez 2008). Obviously, Germany is no longer going to benefit from these one-off reductions. As the overall trend in the reduction of emissions has been rather promising so far, it remains to be seen whether future developments keep that pattern, or whether it is going to be halted or possibly even reversed.

A major challenge comes from more immediate emissions reduction requirements, which task Germany to reduce its emissions not covered by the European Union Emissions Trading System a further 14 per cent by 2020, as compared to 2005 levels. This target is set by the binding regulations of the Effort Sharing Decision within the European Union. The latest data actually suggest that Germany is currently not on track to meet this target. Projections of emissions scenarios indicate that Germany will only meet its 2020 Effort Sharing Decisions targets if additional measures are implemented across the economy (Donat *et al.* 2013). This buttresses the recent report by the environment ministry that current measures might be insufficient to meet the challenge of the even more ambitious 2030 Paris targets, embodied in the 2021–2030 Effort Sharing Proposal with current policies. However, the implementation of additional measures relies on a political agenda of the major players – which is currently the subject of debate on the potential for

further emissions reduction to put a damper on the competitiveness of German industry. So far, it seems that the *Energiewende* – the so-called energy turn, with its phasing out of nuclear energy and its promotion of renewables – has successfully promoted the latter. Yet, counter to its original intentions, it has also been pushing the use of electricity production from brown coal, which has reached its highest level since the early 1990s, while the share of gas-fired power has been declining. Germany's prominent use of coal as an energy source continues to mark its position as the economy with the highest per capita carbon footprint in the European Union (Rhys 2013). A net effect of this confluence of energy factors has been a short-term increase in the emission of GHGs. The political dimension of this problematic scenario becomes clear when it is put in the context of Germany as the world's largest miner of brown coal, with a regional concentration of mining in Nordrhein-Westfalen, a contested battleground for all political parties (*The Economist* 2014). In order to understand the institutional aspects that interlink the economic and political systems, and their role in shaping the trajectories of transition towards a low carbon economy, it is useful to reference the varieties of capitalism approach. This analytical approach addresses the German model of capitalism with its decidedly associational and relational modes of coordination.

An outline of the German variety of capitalism

In the varieties of capitalism tradition, Germany belongs in the CME category. These economies exhibit a dominant pattern of strategic coordination through investment in specific assets. The strategic behaviour of firms is coordinated to a much larger extent through non-market mechanisms than in liberal market economies (LMEs), such as the United States or the United Kingdom. This incorporates long-term company finance, cooperative industrial relations, high levels of firm-specific vocational training in support of technological learning, and inter-firm cooperation in technology transfer. Firms in CMEs are said to prefer incremental innovations within stable organisational settings, based on consistent skills upgrading, long-term capital investments and cooperative labour relations (Hall and Soskice 2001; Soskice 1994). An important implication of this view on complementarities, is that viable policy change must be compatible with existing institutional patterns, that is, they must be incentive compatible with the coordination mechanisms of the prevailing political-economic system. This includes its particular bent towards market, or non-market, coordination. The predominant dynamism of institutional change is predicted to be incremental, for it needs to contain a wide array of linkages among the institutional sub-systems. Accordingly, proponents of the varieties of capitalism approach consider those economies that are situated between the poles of the liberal and coordinated varieties as being less efficient than the pure types. Despite market-oriented reforms in the latter variety, coordinated types are not seen as fragile. Thus, there is no political system implies that institutional changes are predicted to be incremental, involving relational decision-making through industry associations and civil society.

This holds for the hybridisation of the German variety of capitalism, which is a result of reform efforts driving a flexibilisation of the institutional constraints on business strategies since the early 2000s. For instance, the local flexibilisation of wage bargaining, industrial relations and labour market regulations, all contribute to a restructuring of German neo-corporatism in its industrial core areas, which combines market and non-market elements in a hybrid model of coordination (Streeck 2009). All this has contributed to a less egalitarian outlook in economy and society. Still, the institutional core of industrial affairs in German capitalism remains within the framework of a CME, with a strong grounding in relational and associational governance (Hall 2007; Carlin and Soskice 2009; Glassmann 2009). Also, despite reforms to strengthen financial markets, Germany's bank-based financial system differs considerably from market-based liberal systems in the United States and the United Kingdom. Most relevant global innovation has been propelled by the advent of venture capital. The emergence of rather volatile stock market segments for entrepreneurial ventures in Germany indicates that institutional transplants from a liberal variety of capitalism may be unsuccessful due to an institutional mismatch (Vitols and Engelhardt 2005; Busch 2005). In conclusion, it seems apparent that the German variety of capitalism is well characterised as a hybridised type of coordinated capitalism. One that combines market and non-market modes of coordination, in accordance with the logic of selective adaptation to ever changing internal and external conditions (Bathelt and Gertler 2005).

The transition towards a low carbon economy is a part of these adaptive efforts that are set to restructure institutional complementarities, in line with the prevailing patterns of industrial and technological specialisation. This transition to a new path of economic growth requires major efforts in technological innovation, which implies the introduction of new products and production processes in an established economic system; a view that also addresses the use of new sources of energy and increases in energy efficiency. This puts the knowledge base of firms and the dynamism of entrepreneurship at the centre of any analytical endeavour. Yet this 'greening' of national and regional innovation systems is driven by strategic coalitions of change, whose formation cannot be taken for granted – and which can be obstructed by adverse coalitions. The structuration of governance regimes in the German energy sector, provides a telling example of specific market and non-market coordination features in the transition towards a low carbon economy.

As outlined above, German energy markets are oligopolistic, with the largest shares being held by the 'big five' companies. In considering the energy supply structure in Germany, it is imperative to address ownership and governance aspects of the involved firms. First of all, four of Germany's 'big five' – RWE, E.on, Evonik, and EnBW – are essentially German companies

when it comes to their ownership structure and corporate headquarters. This implies that the internationalisation of large firms in the German energy market is less nuanced than, for instance, in the UK. This home nation bias reflects the fact that energy supply has traditionally been considered a public good, to be provided by public sector monopolies. Deregulation and privatisation efforts, which have been prevalent since the 1980s in most OECD economies, promoted a more dynamic approach to business activities with an international scope. While Germany's big energy suppliers evolved as players in international markets, they still held a firm grip on their home market. E.on emerged out of VEBA AG and VIAG AG, two major German energy suppliers. It is currently the largest German company in the energy sector. RWE emerged out of Rheinisch-Westfälisches Elektrizitätswerk AG, a key German energy supplier based in the Ruhr area. Currently, RWE is the second largest company in the German energy sector. EnBW, Energie Baden-Württemberg AG, is the third largest company in the Germany energy sector. It is owned by the state government and regional authorities in Baden-Württemberg, Germany's primary location for manufacturing industries. Evonik emerged out of Ruhrkohle AG, a major company in coal and mining production from the Ruhr area. Finally, there is a foreign company among the 'big five': Vattenfall, a state-owned Swedish company. All these companies are subject to the kind of institutional legacy of relational governance and non-market coordination that is usually associated with the capitalist varieties found in Western Europe and Scandinavia. Accordingly, from a varieties of capitalism perspective, societal negotiations on strategies towards a reduction of GHG emissions will be deeply entrenched in the political domain.

This is not to say that market competition does not matter. In fact, recent regulatory initiatives have contributed markedly to the introduction of competitive market pressures in the German energy sector, in particular when it comes to the supply of electricity. Since 2007, the unbundling process and the appointment of an independent regulator, the *Bundesnetzagentur*, has contributed to a slight fall in the market shares of the biggest players, while integration with EU energy markets further progressed in a potentially competition-enhancing manner (Bundesnetzagentur 2010). Even more obviously, market competition is quickly developing in the environmental goods and services markets, which are of particular relevance to the domain of renewable energy. The entrepreneurial drive in the evolution of renewable energy industries, such as photovoltaics, has been well documented and is clearly a key aspect in its performance (Brachert and Hornych 2011). Remarkably, these entrepreneurial efforts tend to contradict the predictions of the varieties of capitalism framework, with its claim that CMEs will face a dearth of entrepreneurial initiatives, due to an unfavourable institutional setting. However, the large proportion of these endeavours that are exported implies that international market competition puts enormous pressures on local firms. These domestic companies tend to face difficulties in preserving their markets. For instance, the German export market share of the global market in photovoltaics decreased from over three quarters in 2004 to only one-third in 2009, while photovoltaic equipment was increasingly imported from China and Japan. A different picture emerges with regard to wind energy with three-quarters of equipment bought in Germany produced by German manufacturers. At the moment, the manufacturing expertise of German industry still pays off (Klein 2012).

The relative success of wind energy also relates to historically rooted political-institutional factors that shape the path dependence of electricity supply systems. In the case of Germany, the prevailing multi-level supply system has allowed for the evolution of alternative technological trajectories at local and regional governance levels. This is best exemplified by the entrepreneurial dynamics of wind power energy in Germany, whose small-scale local dynamics are in contrast to more monopolistic settings in other segments of the energy sector. These other segments are prone to lock-in effects, which prevent path alterations in the transition to a new energy system (Simmie *et al.* 2014). Consequently, it may be argued that the German production and innovation regime, with its reliance on high-quality and knowledge-intensive manufacturing, is set to successfully continue on its low carbon path. This is fundamentally due to the multi-level and multi-actor bargaining processes that are typical of Germany's CME, for they allow for the seamless inclusion of new interest groups and political parties, such as those emerging from the environmental movement (Geels *et al.* 2016). In coping with the low carbon transition, therefore, the varieties of capitalism perspective hints at two interrelated factors. First, the dynamism of technological innovation in support of a low carbon economy and its embeddedness in the institutional configurations of the national innovation system. Second, the political making and shaping of the transition towards a low carbon economy, which is subject to policy interventions and interest group activities.

The 'greening' of the German innovation system

From the varieties of capitalisms perspective, it is commonly argued that the German innovation system is biased towards continuous learning and incremental innovation. These are set apart from the types of radical change that are driven by the disruptive introduction of new technologies, based on strong science–industry linkages that contribute to the evolution of new paradigms of knowledge. This modelled constellation allegedly reflects the specialisation pattern of the German production model and its key complementarities. Chief among these are relational monitoring in corporate governance, bank-based long-term finance, a skilled workforce that is subject to continuing training and education, and modes of technology transfer that allow for cooperative relations framed by industry associations. The resulting pattern of long-term coordination that combines market competition with relational and associational governance, has been relatively successful in past settings of established technological paradigms. However, it may lead to

rigidities and a loss of efficiency in the context of rapid and disruptive technological change, compared to more flexibly adaptive and short-term market-oriented approaches (Harding and Soskice 2000; Hall and Soskice 2001). When it comes to the underlying competitive strategies, German firms tend to pursue a strategy of non-price competition in favour of an approach based on product characteristics and quality features. this is inherently grounded on incremental innovations (Vitols 2001). In effect, the combination of established industrial skills and capabilities, along with new knowledge on low carbon technologies and their innovative implementation, poses a key challenge for the German innovation system. This includes its role as a sub-system of the German variety of capitalism that consists of quite a number of key players.

The main institutional actors in the German innovation system are the Federal Ministry for Education and Research (BMBF), the Federal Ministry for Economy and Technology (BMWi) and other ministry departments that deal with science, research and innovation on the federal level, augmented by the regional ministries of the *Bundesländer* that retain key competences in the education domain. This actor assemblage also exhibits strong ties with innovation policies at the European level. The science system is well represented by the national research association *Deutsche Forschungsgemeinschaft* and related public organs of the science system such as the *Wissenschaftsrat*. Non-profit organisations that run specialised research institutes include the *Max Planck-Gesellschaft*, with a focus on basic research across the natural and social sciences, the *Helmholtz-Gesellschaft*, with a focus on basic research in the natural and life sciences, the *Leibniz-Gesellschaft*, with its applied research across the natural and social science disciplines, and finally the *Fraunhofer Gesellschaft*, with its focus on applied research across the natural and social sciences. This last hosts the *Fraunhofer Institute for Innovation Research* in Karlsruhe, which is a key player in applied technology and innovation research. This set of organisations is engaged in partnerships with universities (predominantly public ones) and the business sector, shaped in its innovation activities by both large firms and the *Mittelstand* of small- and medium-sized enterprises (Ebner 2010; Ebner and Täube 2009).

Since the 2000s a number of key technological innovation policy programmes have been launched. First, a pact for research and innovation, *Pakt für Forschung und Innovation*, has run since 2005 and was recently extended until 2020. It provides governmental funding for non-university research institutes and in its current phase receives a 3 per cent increase in its funding each year (German Federal Ministry of Education and Research 2016). It is meant to operate as a counterpart to the *Exzellenzinitiative*, which provides additional funding for research and teaching excellence at select universities. The federal government's High-Tech Strategy is designed to push innovation in new technologies and industries, which are expected to become integral in the future economy. This strategy has recently been developed further with an aptly named New High-Tech Strategy. This strategy has a distinct ecological bent, targeting the sustainable economy and energy as one of six priority tasks (German Federal Ministry of Education and Research 2014). It combines these concerns with 'future projects' such as the decarbonisation of cities, the broad-based use of renewable energy and an intelligent energy supply that uses smart grids. A further initiative geared towards innovation in promising economic and technological fields, is the Central Innovation Programme of the Federal Ministry for Economy and Technology, which is meant to support the innovation efforts of small- and medium-sized enterprises. The Ministry of Education and Research governs a distinct Framework Programme for Research and Sustainable Development, with a focus on climate and energy issues, paralleled by the Master Plan for Environmental Technologies with a focus on lead markets and resource efficiency in new environmental technologies. Further programmes with an explicit focus on the support of technological change as a key force in the low carbon transformation of the economy, relate to the Integrated Energy and Climate Programme that has been running since 2007. Its key objectives follow the European Union 20-20-20 goals. These include a reduction in GHG emissions by 20 per cent, an increase in the share of renewables in primary energy consumption to 20 per cent, and ameliorating fuel efficiency by 20 per cent, all to be achieved by 2020 (Leijten *et al.* 2012; OECD 2012a).

In terms of output, the regular set of indicators allude to the German innovation system's strong performance in terms of a sustained output of triadic patents (patents for the same product are filed at the European Patent Office, the Japan Patent Office and the United States Patent and Trademark Office) (OECD 2016). In terms of inputs, Germany has a shortage of human capital in high-tech industries, an insufficient supply of private venture capital and slow growth in knowledge-intensive services (Ebner and Täube 2009; EFI 2009; Grupp, Schmoch and Breitschopf 2008). The strengths of the German innovation system, however, are still predominant. Indeed, it is safe to state that Germany remains one of Europe's most innovative economies. According to the European Innovation Scoreboard, Germany is established within the group of innovation leaders, with an innovation performance far above the EU 28 average – although they remain the laggard among those countries regarded as innovation leaders, and in real terms performance has declined relative to the EU by 3.7 per cent (European Commission DG Internal Market, Industry, Entrepreneurship and SMEs 2017). The share of German gross expenditures on Research and Development (GERD), when compared to GDP, equalled about 2.5 per cent during the 2000s, approaching 3 per cent at times, and thus operating well above OECD average, with both public and private research and development (R&D) expanding. From a comparative perspective, this German GERD/GDP ratio is way ahead of other major European OECD economies such as the United Kingdom and France. At the same time, basic research accounts for only 20 per cent of overall R&D, far below the OECD average. This is exacerbated by the fact that international R&D investment in Germany amounts to just under 20 per cent in overall R&D efforts, a notably low figure (OECD 2012b). Moreover, data for gross expenditures on R&D by sector of performance in the year 2014 show that private business accounted for a strong share of almost two thirds of total R&D expenditures (OECD 2017).

The R&D profiles reflect patterns of industrial specialisation in medium tech industries with a strong presence of manufacturing industries. The corresponding pattern of revealed technology advantage "is defined as a country's share of patents in a particular technology field divided by the country's share in all patent fields" (OECD 2009). During the 1990s and 2000s, this pattern highlighted German advantages in manufacturing industries such as automobiles (Tylecote and Visintin 2008). More specifically, industrial contributions to GERD are predominantly based in traditional high-skill, high quality industries such as automobiles, electronics, chemicals, pharmaceuticals, mechanical engineering and machine tools, whereas newly emerging high technology industries like biotechnology are comparatively underrepresented. The same applies to services at large. This assessment still holds despite recent advances in technological niches, such as nanotechnology and environmentally friendly technologies (Legler, Krawczyk and Leidmann 2009; Rammer *et al.* 2004; Prange 2005). When it comes to the transfer of new technological knowledge into productive uses however, the German nexus between R&D and manufacturing seems to generate positive stimuli for the introduction of low carbon innovations that drive the transition path towards a low carbon economy. Building on these existing skills and capabilities in competitive industries provides the foundations for a technological transition that is set to establish new comparative advantages in an environmentally friendly low carbon setting. The institutional set-up of the German innovation system has maintained a focus on supporting innovation for research consortia among large established firms. This is reflected by the empirical tendency for public institutions in scientific research to be most intimately connected to the R&D facilities of large enterprises. Whereas entrepreneurial spin-offs, which tend to be highly relevant in newly emerging science based industries, remain comparatively underdeveloped (Belitz and Kirn 2008). Thus, the bias towards mature industries in the German model of diversified quality production may obstruct entrepreneurial start-up dynamics, which are typically most relevant in new industries with a high level of new market entrants (Sapir *et al.* 2003). Indeed, German small and medium enterprises (SMEs), and especially entrepreneurial new firms that could trigger more radical innovations, are lagging behind other more entrepreneurial OECD economies. During the late 2000s only 7 per cent of patents were filed by firms less than five years old, half of the corresponding US-share (OECD 2010b).

Nonetheless, evidence on new knowledge-based industries, such as biotechnology, suggests that CMEs may provide a niche for these science-based industries as a result of cooperative research and commercialisation agreements between firms, universities and non-university research institutes (Knie and Lengwiler 2008; Kaiser and Prange 2004). In biotechnology, for instance, this may hold more for areas that are specialised in platform technologies, and less in the high-risk domain of research in therapeutics (Casper and Kettler 2001; Casper, Lehrer and Soskice 1999). Therefore, the distinct style of Germany's CME does not preclude entrepreneurial dynamics in general, but does seem to delineate certain niches for thriving entrepreneurial activity (Ebner 2010). According to the methodology of the European Commission's Innovation Scoreboard, there are positive signs of a German entrepreneurial turn that should be taken into account. Germany is well above the EU average regarding the sheer number of SMEs innovating in-house, SMEs with product/process innovations and the average R&D spending among top R&D enterprises (European Commission DG Internal Market, Industry, Entrepreneurship and SMEs 2017). At the same time, young high-tech firms in Germany are mainly financed by cash their flow and their own resources, as venture capital financing is comparatively underdeveloped (EFI 2011). Thus, it is fair to state that the evolution of cooperative relations between research institutes, large enterprises, new ventures and capital providers will be decisive in the further greening of Germany's production and innovation regime.

Germany is considered the economy with the strongest record on green innovation in Europe, with a performance that is in the upper range of OECD countries, particularly in the domain of environmental technologies. Germany excels with an innovation score that is well above its revealed comparative advantage. In terms of industrial specialisation, the pattern of green innovation in Germany holds in particular for motor vehicles, with a green innovation score of 2.2 and a revealed comparative advantage score of 1.2. The domain of 'parts and accessories for automobiles' comes with a green innovation score of 1.6 and a revealed comparative advantage score of 1.5; whereas 'other fabricated metal products' stands at a green innovation score of 1.6 and a revealed comparative advantage score of 1.3 (Fankhauser *et al.* 2012). Thus, in terms of green innovation performance, Germany's key manufacturing industries, such as automobiles, perform most impressively.

German input indicators for green innovation depict a mixed performance. The share of public R&D expenditure in the relevant 'green' domains of 'control and care for the environment' and 'production, distribution and rational utilisation of energy' in total public R&D expenditure has been negligible, amounting to about 3 per cent on average all through the 2000s. Still, this is above corresponding expenditure levels in the United Kingdom (Aghion, Veugelers and Serre 2009). Moreover, the general tendency has been for expenditure to increase, R&D in energy and environment as a percentage of total public R&D expenditures in 2011 increased to a moderate level of 7.1 per cent (OECD 2012a). However, in assessing R&D data, it should be taken into account once again that German industry is not specialised in high-tech segments with gargantuan R&D intensive activities. Rather, German manufacturing industries are predominantly active in medium-tech segments. Thus, many innovations are not necessarily recorded by R&D data, for they will be related to more informal procedures of learning by doing.

The performance profile on the input side of the innovation process, corresponds to a mixed specialisation on the output side, as measured by patenting activity. The same caveat as with R&D as an innovation input indicator applies. Namely that patents may not show the true level of outputs as a consequence of slow and incremental change in medium technology not requiring patents. Green technology patents during the 2000s exhibited the following country shares and specialisation patterns for Germany. The German contribution to world patents for energy generation was 13 per cent of total global patents, which amounts to a clear-cut specialisation. The German share for transportation was at 31 per cent, which is also a clear indicator of industrial specialisation. Another domain of specialisation is environmental management with a 13.1 per cent share. Germany applied for 11.2 per cent of total patents in technologies for emissions mitigation, which is also indicative of related specialisation efforts (OECD 2012a). Between 1988 and 2007 the relative strength of Germany in green patenting could be observed as follows. On average, 15.2 per cent of patents originated from Germany, amounting to half of all European patents in that segment, and almost at the same level as the United States with its 15.9 per cent, while Japan stands out as the global leader with a share of 29.7 per cent (Veugelers 2011). In 2007 Germany was the third largest producer of triadic patents in renewable energy sources; it also ranked third with the number of patent applications in technologies related to climate change mitigation (OECD 2010a).

A related overview of the OECD ranking of the main patenting countries in clean energy technologies from 1988 to 2007 shows that Germany takes the rank of third overall in performance among clean energy technologies, leading in Europe yet well behind the global leader Japan and second place United States. In particular, German rankings in the diverse technology fields under consideration are: third for solar photovoltaics, first for solar thermal, first for wind, second for geothermal, second for hydro/machine, second for biofuels, second for carbon capture, fourth for carbon storage ranks, and third for integrated gasification combined cycle. Thus, German industry is most prominent in areas of clean energy technologies such as solar thermal and wind, accompanied by similarly good rankings in geothermal, biofuels and carbon capture (OECD 2012a). This assessment is in line with calculations that depict German comparative technology advantages in green innovation between 1988 and 2011 as a marked pattern of technological advances in the areas of solar thermal, wind, geothermal, and biofuels (Veugelers 2011).

This positive performance persisted during the 2010s. In 2011 applicants from Germany held half of the European patents in climate change mitigation technologies – with German performance in the renewable energy domain four times higher than that of second ranked France, while its lead in the domain of road transport technologies is even higher. Major German inventive businesses in the field of climate change mitigation technologies are Siemens and Robert Bosch – with Siemens dominating the field of clean energy technologies (EPO 2016). When it comes to patents in renewable energy technology, patent registrations with the German Patent Office indicate consistently strong performance, with solar and wind comprising major segments. In 2013 more than 900 patents were registered for solar photovoltaics, while about 800 were registered for wind. Crucially, as indicated by the German Patent Office, the newly established legal framework for the support of renewable energies may have played a stimulating role in this regard (Morris 2014).

The dynamic setting of green innovation is also reflected by the market performance of green-tech firms and the overall profile of green investment in Germany. First of all, in 2011, German green-tech firms attained a 15 per cent share of global markets for clean technology and resource efficiency. These firms represent a booming global industry, which has already seen major increases in market shares in the preceding years from 2007, with corresponding increases in growth projected for the forthcoming years (BMU 2012). A technological take-off for wind energy was recorded for the 1990s, while solar energy took off in the early 2000s (Jacobsson and Lauber 2006; Wong 2005). These developmental dynamics of green-tech industries in Germany feed upon the established knowledge base of the economy, with its set of industrial skills and capabilities in manufacturing. This is augmented by the science and technology infrastructure of the German innovation system. An example is the evolution of competitive advantages in the industrial domain of wind turbines, which has developed from existing expertise in the related industrial domain of high-precision machining. This field is notable as a particularly outstanding area of expertise in the quality-oriented German production model (Huberty and Zachmann 2011). This view of the formative role of manufacturing industries is further corroborated by re-examining the spatial dimension of green innovation in Germany; that is, its geographical concentration in regional centres of green innovation, the states of Baden-Württemberg and Bayern. Both are also key locations for the most competitive branches of German manufacturing industries.

Germany still holds its place for the highest volume of small distributed capacity investments. Yet investment in low carbon innovation requires the availability of adequate financial resources. When it comes to the types of finance that comprise green investment, the most usual forms of asset finance are small distributed capacity, public markets and venture capital – private equity can also be taken into account. Germany is ranked behind China and the United States with regard to the overall volumes of green investment in 2012, with these two economies possessing especially pronounced investment capacities when compared to their global counterparts. In comparison to most other major economies, Germany is characterised by green investment in which small distributed capacity makes up the largest share, more than asset finance, venture capital or public markets (McCrone *et al.* 2013). Also public

credit facilities play a considerable role in the allocation of loans and related financial support for the use of renewable energy and environmentally friendly technology. A highly relevant initiative is the *Marktanreizprogramm*, which provides financial incentives for green investment. Administered by Germany's third largest bank, the public Kreditanstalt für Wiederaufbau, this programme provides low-interest loans and grant support to installations using heat emanating from renewable energy in residential buildings. In effect, it contributed significantly to the expansion of technologically advanced heat networks with reduced carbon emissions. In 2012 the German government increased the financial volume of the programme, with a focus on solar thermal power, biomass installations and heat pumps (Donat *et al.* 2013).

The innovation dynamics of the low carbon transition in Germany are also well developed in terms of lead markets. Altogether, five lead markets with distinct submarkets can be explored. These include: environmentally friendly energies, with the submarkets of renewable energies and storage technologies; energy efficiency, with submarkets of energy efficiency of buildings and efficiency-oriented technologies in industry; sustainable water management, with submarkets in decentralised water management and effluent disposal; sustainable mobility, with submarkets in alternative propulsion technologies and environmentally friendly infrastructure and transport management systems; and the market domains of recycling, sustainable agriculture with organic farming and green services with a focus on sustainable finance. In this profile, the highest shares are taken by the domains of energy efficiency, environmentally friendly energies and energy storage and water management. All these green lead markets combined amounted to a market volume of €285 billion in 2011; this comes close to the automobile sector, Germany's lead industry, with its 351 billion volume. Yet the future expansion of these new green markets on a global scale is not only determined by the economic factors of private sector supply and demand, but also by government support concerning the actual use and consumption of green technologies and products (Kahlenborn *et al.* 2013).

Policies in support of the greening of innovation activities are subject to the interventions of diverse economic and social interests, which may support or hamper an innovation-based low carbon transition. Environmental policies may be viewed as one of the main drivers of innovation in low carbon technologies, as they create a need for abatement solutions while providing market opportunities to innovative firms. Also, the diffusion and adoption of these new technologies benefit from implemented environmental policies, as demonstrated most convincingly in the German case of policy support to renewables (Johnstone *et al.* 2010). However, industrial interest coalitions that involve firms, business associations and labour unions, may have concerns with the costs associated with a low carbon transition. Their apprehension revolves around seeing these costs as posing a danger to industrial competitiveness. This can hinder further advances in emissions reduction, although these advances could have provided dynamic incentives for further innovations. As the German production model seems to favour incremental change along established technological trajectories over the setting up of new trajectories, the matter of static versus dynamic competitiveness also alludes to the quality of innovation at large. The introduction of hybrid motors and electric motor vehicles is a case in point. Key inventions underlying these technologies have been established in Germany, yet German automobile producers have been reluctant in recent years to push for corresponding innovations. In this context, emissions-related interventions by the German government on behalf of the automobile industry proved to be counter-productive. They may have been in the short-term interest of an industry that is focused on fuel-based engines, yet they preclude incentives for long-term innovations in non-fossil fuel technologies (Ruhkamp and Rossbach 2013; Lamparter *et al.* 2013).

The international dimension of these issues is exemplified by the prevailing difficulties with solar energy. Major German firms have been rethinking their subsidised activities in photovoltaics, in part due to competitive pressures from subsidised foreign competitors, in particular China and Korea. A case in point is the decline of Saxony's 'Solar Valley', with its low carbon technology cluster (Schultz 2012). Then again, one can examine the current revival of coal power plants in the new low-emission technology environment, which has been created based on well established industrial capabilities and promoted by large enterprises such as Siemens, which is a key player in German private sector R&D (Fuchs and Wassermann 2013; Pahle 2010). With this revival of coal as an energy source, some of Germany's big energy suppliers, such as E.on, see their envisioned expansion of low-emission gas power plants (which had been singled out as future substitutes for nuclear power plants) as endangered. Other suppliers, like RWE with its extensive activities in coal, tend to benefit from these developments. American exports of coal and gas have pushed international prices for coal into an even steeper decline than those for gas, which provides further incentives for the continued use of coal (Steltzner 2013).

In other words, both national and international policy actors, with their particular strategies, take centre stage in the making and shaping of a low carbon economy. Following the analytical framework of the varieties of capitalism approach, the analysis now turns to the influence of associational governance, which complements regulatory governmental influences in Germany. Concerns with the degradation of the environment and the challenges of climate change are well represented, yet are also persistently contested. This happens through coordination efforts by both business associations and labour unions, with their particular interests, as the forces that determine the actual dynamism of the low carbon transition (Mikler 2009, 2011).

Policy actors and strategies in the German transition towards a low carbon economy

The German economy's prominent position in the field of carbon emissions reduction, and the expansion of energy emanating from renewables during the 2000s, is reflected in public opinion that considers climate change to be a policy priority that requires continued action (UBA 2010a). This is consistent with a long-standing pattern of policy-making and public discourse on climate change, part of an evolving environmentally oriented policy agenda from the 1970s. The oil and energy crisis of 1973 provided the first impetus for economic-political concerns about the resource efficiency and sustainability of established energy systems to come to the fore in the industrialised world. The debate on substituting renewable energy sources for fossil fuels evolved together with the rejection of nuclear energy. Indeed, public opposition to nuclear power became a political factor, with demonstrations against the building of new nuclear power plants in Whyl in 1975 and Brokdorf in 1976, further fuelled by the nuclear accident in Harrisburg in the United States in 1979. In the 1980s these protests continued with efforts focused on preventing the construction of nuclear reprocessing plants in Wackersdorf and Gorleben. The foundation of the Green Party in 1980 provided this broad-based environmental movement with a strategic platform, one that would criticise the use of nuclear energy as a mode of energy supply as prone to major uncertainties. This new social movement combined anti-nuclear sentiments and the push for resource sustainability with a critique of large-scale energy systems and their lack of democratic control. Energy from renewables, in contrast, was hailed as a decentralised, democratic small-scale alternative. This position was further instigated by the Chernobyl accident in the Soviet Union in 1986. Crucially, these debates would parallel campaigns for nuclear disarmament as organised by the peace movement. In this context, a specificity of the German situation derived from the fact that nuclear power did not play the same strategic role in national prestige as it did in countries such as the United Kingdom and France. There were never nuclear weapons under German sovereign command, which gave nuclear power a different political standing, making its use more accessible to economic reasoning in cost-benefit terms. Even after the end of the East–West confrontation, anti-nuclear protests continued, with demonstrations against the transportation of nuclear waste continuing throughout the 1990s and 2000s (Klein 2012). One might add that the Green Party played a key role in transmitting civil society protests to parliamentary and governmental operations. This was also due to Germany's political system, with elections based on proportional representation that promoted the entry of the Green Party as a regional and national force in various coalition governments with both Social Democrats and Conservatives, at times also including the Liberals (Bailey 2007).

Set in this context, German debates on environmental policy in the late 1980s approached a gradual restructuring of the energy mix, by expanding the share of renewable energy sources. A first step towards supportive legal regulation of energy from renewables, was realised with a heavily contested first law on feeding in renewables, *Strom-Einspeise-Gesetz StrEG*. It was introduced by the Liberal–Conservative Kohl government in 1990, four years after the Chernobyl nuclear disaster in Ukraine. In its basic orientation, it took up an initiative of the European Commission, which had been pushing for an expansion of renewable energy. Originally, most policy actors did not expect it to generate major economic and technological effects, but this law provided the institutional background for the introduction of the feed-in-tariff system, providing a building block in the transition of the energy system. In particular, it provided economic incentives for the supply of onshore wind, which would soon be accompanied by regional industrial policies in support of northern German coastal regions, framed by the competitive success of Germany's well positioned wind turbine builders (Jacobsson and Lauber 2006).

The act on renewable energy, *Erneuerbare Eneregien-Gesetz (EEG)*, was introduced in 2000 by the red–green Schröder government. It continued with the established approach of using feed-in tariffs as a means of promoting renewable energy. Crucially, it formulated a legal framework for obliging grid operators to prioritise feeding in electricity from renewable energy technologies, based on a minimum payment for electricity. Its design catered to specific technologies, in particular onshore wind, solar photovoltaic and geothermal, while outlining a long-term, 20-year time horizon in its financial and legal support architecture. The advocacy coalition of this act included a broad array of societal forces, involving environmental organisations, labour unions and even industry associations from within the German manufacturing sector. This effort at promoting renewables was soon followed by the *Atomkonsens*, a formal consensual agreement between government and business with regard to the phase-out of nuclear energy in 2002. This fulfilled a demand for which German environmentalist groups, the Green Party and the left flank of the Social Democrats had spent several decades struggling. Crucially, despite the fact that the nuclear industry was challenging this phase-out in both legal and political terms, it was still possible to find some common ground in a public agreement. Indeed, nuclear power had faced serious troubles in economic terms for some time, not least due to the high cost of risk management with regard to waste disposal. Thus, even before the red–green government pushed forward with a plan to phase out nuclear energy by legal means in 2002, the sector had been under constant criticism from various political and business-related angles (Jacobsson and Lauber 2006).

While the grand coalition of Conservatives and Social Democrats did not alter these regulations after taking power in 2005, the Liberal–Conservative Merkel government overturned the earlier phase-out procedure following the 2009 election. Crucially, this did not mean that nuclear energy was reinstated as a future component of Germany's energy system. Rather, it meant a rearticulating of the phase-out process, for the red–green phase-out strategy was

viewed as unrealistic. In particular, as a business friendly move, the lifetimes of nuclear power plants were extended by eight or 14 years – depending on when they were built. This was accompanied by a new energy concept that put forward the ambitious goals of achieving a of 35 per cent share of renewable electricity by 2020, and 80 per cent by 2050. Mounting energy costs and questions of energy security were provided as key arguments for this move. Yet these plans for slowing down the nuclear phase-out were reversed after the Fukushima nuclear accident in March 2011. Indeed, after this accident, German public opinion shifted massively against nuclear power. The Green Party won elections in the Christian Democratic heartland of Baden-Württemberg, which is a major region in terms of modern manufacturing industries and technological innovation, while simultaneously being a regional champion in environmental affairs. The Fukushima disaster led to the swift adaptation of policy proposals by the Merkel government, which decided to accelerate the phase-out of nuclear power, reversing its 2010 decision to increase the lifespan of nuclear power plants. After a moratorium including the shutdown of eight of the older nuclear plants, and general security checks at all of the nuclear power plants, the German parliament voted for a definitive nuclear phase-out by 2022, in line with the original red-green initiative of the late 1990s (Klein 2012).

This most recent effort concerning the phase-out of nuclear energy should be operated in tandem with a phasing in of clean energy. This incorporates renewable energy as the new cornerstone of the energy supply, replacing the current prominent role of emissions-intensive coal. Both the phase-out of nuclear energy and fossil fuels in the generation of electricity, and the phase-in of energy from renewable energy sources, primarily onshore wind and solar photovoltaics, constitute the so-called energy turn, *Energiewende*. *Energiewende* is a historically unique societal project, which strives for a multi-decade effort at transforming the national energy system. To achieve this transformation the Liberal–Conservative government put forward a detailed set of goals. Next to the complete phase-out of nuclear energy by 2022, the share of renewables for electricity generation should be increased to at least 38 per cent by 2020, 50 per cent by 2030, 67 per cent by 2040 and 80 per cent by 2050. This is to be paralleled by increases of the share of renewables in final energy consumption to 30 per cent by 2030 and 60 per cent by 2050. As a consequence, GHG emissions as compared to 1990 levels should be reduced by 40 per cent by 2020, 55 per cent by 2030, 70 per cent by 2040 and up to 95 per cent by 2050. Furthermore, energy efficiency is meant to be optimised. Energy consumption from buildings should be reduced by 20 per cent in 2020 and by 50 per cent in 2050. Also, energy consumption from transportation should be reduced by 10 per cent in 2020 and by 25 per cent in 2050. This shift to a new energy supply and use structure should proceed in line with a strategic decarbonisation of the supply of electricity, substituting gas for nuclear power during the energy transition (IEA 2013b; BMU 2012). Crucially, this set of quantitative goals has come together with a further transformation of the structural features of the energy system. This is particularly evident with regard to the increasing role of decentralised, small-scale energy providers that accompany the large-scale operations of the oligopolistic energy companies. The second 'grand coalition' government of Christian Democrats and Social Democrats that came to power in 2013 did not modify these objectives. However, it entered further bargaining processes with regard to the speed of the transition. Thus, the 2014 amendments to the law on renewable energies confirmed its basic orientation (Hirschhausen 2014).

The combination of phasing out nuclear power and shifting energy use towards decarbonisation has been the subject of comprehensive policy efforts in market regulation and governmental subsidisation. Major investment incentives have been set up in the domains of wind, photovoltaics, biomass and hydropower, combined with feed-in tariffs that have contributed to an ever more complex system of price control. In effect, however, the protectionism that has essentially resulted from these price regulations and subsidies may end up reducing incentives for competitive strategies in German firms entering new markets. Moreover, and more visible in the short-term, is the problem of the social distribution of the energy transition's economic costs among public sector, private business and households. This is the subject of price-setting for energy supply and use as regulated in the law on renewable energies, *EEG*. This law was put into legislation for the first time in the 2000s, as a cornerstone of the German institutional framework for low carbon energy transition, and has been subject to a multitude of amendments and adaptations. German electricity users pay a specific charge, based on a feed-in tariff that is used for funding renewable energy generation, with the aim of supporting its diffusion. In a positive light, this law on renewable energies and its mechanism of feed-in tariffs has contributed to the international acclaim of the high predictability and positive performance of German policies in support of renewable energy sources (Butler and Neuhoff 2008).

In assessing the actual costs of these wide-ranging transformative endeavours, it is useful to first account for the social costs of nuclear energy and coal, that is, the major energy sources that are set to be replaced in the *Energiewende*. The social costs of nuclear energy primarily relate to the risk of nuclear accidents, costs which make nuclear the most expensive source of electricity. The social costs of coal reflect issues such as environmental degradation and health problems from pollution. These stunningly high social costs can be compared with a mechanism of social cost degression to learning effects that result from the use of solar photovoltaic and onshore wind, among others. Therefore, the calculation of costs and benefits needs to account for cost factors beyond the immediate cost concerns of firms, households and the public sector (Hirschhausen 2014).

Still, the coincidence of Germany phasing out nuclear energy and pushing renewable energy sources at the same time, has caused a set of problematic short-term effects. These may affect the overall legitimation of the political project for a low carbon transition. First of all, German electricity imports

increased significantly to compensate for the loss in generation capacity that resulted from the first wave of nuclear power plant closures. This effect points directly to the matter of energy security in an increasingly uncertain international political environment, with Russia becoming a much less reliable partner for energy imports. Most relevant for the emissions reduction strategy, however, is the current trend of increasing GHG and carbon emissions. This is a result of the phase-out of nuclear power and the increased use of fossil fuel fired power plants. Paradoxically, then, and quite contrary to the goals of climate change mitigation, the elimination of nuclear energy from the German energy mix is set to promote a revival of emissions-intensive coal as an energy source (Klein 2012).

In effect, the aforementioned additional costs for energy consumption associated with this transition to renewable energy may hit both the industrial sector and private households. Indeed, due to the higher than market price of electricity, the net costs of the promotion of renewable energy in Germany have amounted to an estimated €125 billion since 2000. Households carry one-third of the financial surcharge in support of electricity from renewables, which has been further increasing in recent years. In technological terms, solar photovoltaic holds the largest cost share, with 43 per cent of the total costs of renewable energy sources, while comprising only 6 per cent of German electricity generation. The impact on consumers has been straightforward; electricity prices more than doubled between 2000 and 2015 and household prices for electricity were among the highest in the European Union, almost double the price paid in neighbouring France. Also, industry prices are among the highest across Europe (BMWi 2016; BDEW 2016).

The additional costs for business are especially subject to extended debates and lobbying efforts. These are usually based on arguments concerning a distortion of national competitive conditions, which is most pronounced in international markets that matter a lot for export-biased German manufacturing industry. This international dimension to the exemptions that have been granted for certain industries also hints at the contested compatibility of this national regulation with supranational institutional frameworks, in particular with the institutional setting of the European Union. The European Commission has repeatedly stated that it is set to counter Germany's renewable energy law for an alleged breach of EU competition regulations (IEA 2013b). Indeed, the impact of price distortions due to feed-in tariffs on the international competitiveness of domestic manufacturing industries has become a leitmotif for industry associations such as the Federation of German Industries (BDI). This is paralleled by infrastructural debates that highlight aspects of energy security. These include the fact that nuclear energy, which is being phased out, still provides almost 15 per cent of gross electricity generation, while electricity grid expansion and the risk of power grid instability remain largely unresolved problems (Borshchevska 2016). In fact, these uncertainties related to the energy transition have put the stock price performance of Germany's major utilities under stress. These issues have come together with the matter of competitiveness in the expansion of renewables. In particular, mounting costs for the operation of renewable energy technologies and international competition, in particular from East Asia, pose problems that are accompanied by the unsolved matter of energy storage and demand management (Geels *et al.* 2016).

These conflicts of interest are further reflected within the political system, most obviously in persistent intra-governmental rivalries that echo the conflicting orientations of vested interests in the industrial sector. For instance, in the former Conservative–Liberal government, the Conservative Minister of Environmental Affairs pushed for price increases in carbon emission licences in order to set further incentives for emission reduction, whereas the Liberal Minister of Economy and Technology would block these initiatives due to concerns about the additional costs that could arise for German industry. In the more recent grand coalition government of Conservatives and Social Democrats, these conflicts persist, even though both the economic and environmental affairs ministries are headed by Social Democrats. In fact, the Minister of Economic Affairs underlines the need for the continued use of coal to prevent major price shocks for German industry and private households. Doing this directly rejects further governmental interventions regarding the utilisation of specific power plants, while the Minister of Environmental Affairs insists on the elimination of the most emission-intensive coal-fuelled power plants. The pro-coal coalition among Social Democrats and Conservatives has seemed to hold (Meiritz 2014), and may even persist beyond the September 2017 federal elections .

In view of these bargaining processes and wide-ranging conflicts over interests and ideas, the German style of environmental policy has been outlined as a regulatory state with a strong legal basis. This is accompanied by inter-party bargaining involving regional interests in a federal multi-level system, with corporatist patterns of interest mediation between government, private sector and civil society. All of this is located within culturally rooted concerns with environmental affairs. The ensuing policy style resembles a pattern of 'regulated self-regulation'. This is because business actors take part in sector-specific and allegedly voluntary agreements, with self-commitments that are moderated by government, and also allow for the inclusion of interest groups from civil society (Bailey 2007). Examining the actual mixture of governance structures that operates in the 'energy turn' of Germany's coordinated capitalism, yields an institutional pattern that involves market mechanisms, regulations and private sector governance. All these mechanisms are contested with regard to their functional efficacy in the transition towards a low carbon regime.

Market instruments include participation in the European Union's carbon emissions trading scheme since it began in 2005, which built on Germany's preceding liberalisation of electricity and gas markets starting in the late 1990s. Yet this market-based scheme has suffered from an over-allocation of allowances, which has lowered the carbon price in a manner that obstructed further

encouragements for a significant reduction in emissions. New caps on emissions defined at the EU level, and set to be progressively reduced, should hopefully contribute to more effective market operations. In fact, the most crucial problem with this emissions trading system relates to the fact that national success in emissions reduction leads to a release of emission certificates, which means that emissions might increase in other European countries. Thus, in the context of tradable emission certificates, the overall effectiveness of national efforts in emissions reduction might be called into question (Andor *et al.* 2017).

Policy-driven regulations include aspects such as technological and emissions standards, as well as politically moulded price regulations. A critical element of these market regulations is the system of feed-in tariffs that is used to promote electricity from renewables. As outlined above, this German feed-in tariff system implies that electricity generated from renewable energy sources has preferential access to the grid, priced on the basis of feed-in tariffs that outline technology-specific pricing above market rates over a 20-year period. This system has actually become an international role model, despite its disadvantages with regard to the distortion of price signals and corresponding disincentives for the suppliers of electricity from renewables (Andor *et al.* 2017). Indeed, the latter problem currently informs the tendency towards a market-oriented shift in regulations to support renewables. Auctions have recently been introduced to augment the feed-in tariff system, with a more competitive and potentially cost-reducing mechanism. First rounds were held for solar photovoltaic in 2016, while further auctions are also planned for onshore wind (FS-UNEP Centre 2017).

Private sector governance includes the operations of industry associations and voluntary agreements among private sector firms, as applied to carbon emissions in the automobile industry for example. The latter may be singled out as a characteristic of the relational mode of coordination in the German variety of capitalism. Indeed, when addressing these voluntary agreements on emissions reduction, one could even speak of a German brand of eco-corporatism. This is illustrated by the major roles played by BDI and the German federal government in the promotion of industrial commitments to emissions reduction (DIW *et al.* 2001). An initial Climate Change Self-Commitment was signed in 1995 as a largely symbolic gesture, followed by more ambitious agreements in 1996 and 2000 that would involve various energy-intensive sectors and related industry associations in undertaking a reduction in carbon emissions. However, the impact of these private sector and associational forms of governance in driving the low carbon economy transition is subject to ongoing analysis. In fact, self-commitments were soon replaced by fiscal efforts for an ecological tax reform, that would resemble policy-driven regulations. In 1999, initial steps were taken by introducing a so-called eco tax on the consumption of fossil fuels, originally excluding coal due to its political relevance to the electorate. Manufacturing firms were initially granted 80 per cent in tax reduction, a concession that was later downgraded to 40 per cent (Bailey 2007). In the longer run, thus, it seems that the German model of industrial self-regulation has not been successful in markedly reducing carbon emissions in its own right. Nonetheless, it may be argued that it facilitated the introduction of market-oriented instruments in climate change policy, as implied in the negotiations on the implementation of the EU emissions trading scheme. In this manner, the regulatory drive of associational governance may have paradoxically contributed to a further marketisation of the instruments of climate change mitigation (Klein 2012).

The actual design and implementation of these policy strategies and governance structures is subject to the interventions of distinct coalitions of actors. In broad terms, advocacy coalitions in the renewable energy policy area include actors from business firms, industry and employer associations, unions, civil society organisations, political parties and government. While most decisions are made on the level of the federal state and nationwide organisations, the regional level also needs to be taken into account in Germany's federal system. The regional states, *Länder*, are particularly relevant in the support of wind and solar thermal energy, for they play a key role in spatial planning. In terms of the representation of distinct interests and related ideologies, however, one can distinguish between business and ecological concerns – and related advocacy coalitions (Dagger 2009). Business concerns tend to focus on the profitability of renewables. Major players in that domain are the major energy suppliers of E.on, RWE, Vattenfall Europe and EnBW. The related industry association is the Bundesverband der Energie- und Wasserwirtschaft (BDEW). Unions also take part in this advocacy coalition as they articulate the interests of the workforce in the concerned firms and industries. Importantly, the corresponding union in mining, chemicals and energy, the Industriegewerkschaft Bergbau, Chemie, Energie (IG BCE), stands out as an advocate of more conventional energy sources, such as coal. This coalition is well represented in government, in particular in the Ministry for Economy and Technology, BMWi. In political terms, the liberal FDP party has been this faction's most outspoken representative, along with large segments of the conservative CDU and also by certain Social Democrats, who have been politically strong in the traditional heavy industry region of the Ruhr area (Reiche 2004).

Ecological concerns stand for the equal funding of all renewables. They tend to strive for a fundamental transformation towards renewables as quickly as possible, and they are in favour of feed-in tariffs to accomplish that transformation. Industry associations involve the following organisations: Bundesverband Erneuerbare Energie (BEE), Bundesverband Solarwirtschaft (BSW-Solar), Bundesverband Windenergie (BWE), Verband Deutscher Maschinen- und Anlagenbau (VDMA). Unions in this coalition include IG Metall, which is prominent in Germany's competitive industries, such as automobiles and machine tools. Yet the union of the integrated service sector, ver.di, and the union of agrarian and environmental industries, IG Bauen-Agrar-Umwelt, also promote a proactive attitude towards renewables.

The related organisation in government is the Ministry for Environmental Affairs, the Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU). Also, the interest association of German farmers needs to be taken into account, as organised in the Bauernverband (DBV). It is well represented in the federal Ministry for Agrarian Affairs, the Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (BMELV). Corresponding political camps are more difficult to detect. The Green Party stands out in this regard, yet parts of SPD, CDU/CSU and the former Communists of the Linke also take part in these endeavours.

Examples of this kind of ecological alliance building are manifold. Quite prominently, a working group on the trade of emission licences has been set up by organs of the federal state, including the BMU, accompanied by major firms, industry associations and even organisations from the environmental movement. In this manner, the Arbeitsgruppe Emissionshandel zur Bekämpfung des Treibhauseffekts (AGE) has been instrumental in sorting out workable regulations for the trade of emissions licences (BMU und AGE 2012). Also, industry unions are a part of key consultations with government and business, as documented by diverse declarations on resource efficiency, environmental innovation and emissions trade, involving IG Metall along with BMU (BMU and IGM 2006; 2008). Representatives from IG BCE have also been invited to join the Council for Sustainable Development, which is a consultative platform for environmental affairs established by the government in 2001. Industry-specific dialogues on environmental issues between labour unions and employer associations are also common, such as that between IG Metall and the German association of aluminium industries (IGM und GDA 2009).

Furthermore, the expansion of renewables was initially driven by new entrants to the market, involving business firms, citizen cooperatives and professional environmental groups, who combined the environmental and social concerns of a social movement for sustainability in a discourse that would later shape the discussions and practices of the *Energiewende* . Their impact on the expanding sector of renewables was most obvious in onshore wind, biogenic fuel, biogas and solar photovoltaic. Subsequently, business actors would gain in influence as large firms came to enter promising market segments (Geels *et al.* 2016). For instance, the initial introduction and adoption of wind turbines on a small scale was driven by utilities, as well as by farmers and environmental groups who, in the 1980s when Germany's new social movement of ecologically concerned protests gained in influence, combined an ecological programme of sustainable development with anti-nuclear anxieties (Jacobsson and Lauber 2006). Also, in its early stages the photovoltaics industry in Germany seemed to be driven not only by business firms, industry associations and government, but also by civil society and environmentalist social movements. On the regional and local levels, these alliances have driven cluster formations in this industry, and thus contributed to the diffusion of related 'green' technologies (Fuchs and Wassermann 2013).

In effect, the low carbon transition of the German economy proceeds on a hybrid basis with both market and non-market coordination, in a manner that reflects the institutional specificities of the German variety of capitalism, and its ongoing institutional evolution.

Conclusion

Germany follows a distinct trajectory in the transition towards a low carbon economy. The corresponding patterns of industrial and technological specialisation reflect the specificity of the prevailing national production model, as well as the institutional conditions and settings. The production model of the German economy is still biased towards diversified quality production in the manufacturing industries, with the automobile industry as a paradigmatic lead sector. The corresponding German innovation system, with its specialisation in gradual types of technological change, is part of a hybridised coordinated variety of capitalism. This hybrid character of German capitalism is reflected in the policy mix of market-oriented, regulatory and associational approaches to the governance of low carbon transition. The transition towards a low carbon economy relies on these industrial structures and institutional patterns, which provide opportunities for new low carbon innovations, which are particularly relevant in the domain of renewable energy sources. Indeed, German efforts in the expansion of renewable energy have been impressive, including with regard to their innovative impact. However, as a specifically German phenomenon, nuclear energy is set to be phased out in the coming decades. The corresponding transition mechanisms in this *Energiewende* are subject to ongoing controversies regarding the efficacy of market-breaking price regulations and subsidies, versus market-conforming instruments such as auctions. Thus, while the share of renewables in the energy mix is increasing further, the transition towards a low carbon regime of production and innovation also needs to account for the private costs of this process. Accordingly, the German transition towards a coordinated 'green capitalism' remains both economically and politically contested.

6 Norway's low carbon strategy

Internal and external drivers

Jon Birger Skjærseth and Torbjørg Jevnaker

Introduction

Norway's stated objective is to become carbon neutral by the year 2050. This will prove extremely challenging, particularly as fossil fuels continue to dominate the Norwegian economy. Oil and gas contribute 14 per cent of the state's revenues and 40 per cent of total exports. The transformative effect of oil and gas has had significant ramifications for other sectors of the Norwegian economy by opening up huge markets for shipbuilding, engineering, information technology and other business services. It has benefited national manufacturing industries and strengthened the economy through rapidly increasing tax revenues, which are filling up the world's largest sovereign wealth fund. Production of oil and gas is the cause of more than one quarter of Norway's greenhouse gas (GHG) emissions. Leading up to 2050 the Norwegian government will be faced with the dilemma of managing the key national interest of maximising profits from the oil and gas sector on the one hand, while decarbonising the economy on the other. This chapter explores how, why and to what extent Norway has embarked on the transformation towards a low carbon economy, as a response to the global challenge of climate change.

Norway's low carbon strategy and the prospects for change are analysed from two perspectives with different relevances for varieties of capitalism (VoC) theory (Hall and Soskice 2001). The first, a domestic politics perspective, indicates that the key drivers of change in the face of an international challenge can be found at the domestic level, rather than emanating from abroad. As such, Norway's low carbon strategy – its national response to the international challenge of climate change – is expected to be the product of domestic factors. Domestic drivers are essential in VoC theory, which places particular emphasis on relationships between companies and the national institutions in a state's political economy. Differences in national responses to common problems are explained by the state (or government itself), the society, or the relationship between state and society.

The second perspective takes us from domestic politics to the external context, particularly the European Union (EU). The EU's decarbonisation