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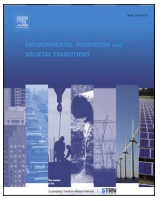

A comparative and dynamic analysis of political party positions on energy technologies

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1. Introduction

Accelerating and deepening sociotechnical transitions through public policy is a main lever for addressing sustainability challenges such as climate change (Geels et al., 2017; Markard et al., 2020, 2012). The crucial role of policies and policy mixes for such transitions are widely acknowledged and increasingly well-documented (Kivimaa and Kern, 2016; Rogge and Reichardt, 2016; Schmidt and Sewerin, 2019; van den Bergh, 2013; Weber and Rohracher, 2012). The *politics* underlying these policies remain, however, less well understood, and there have been multiple calls for addressing this gap (Hess, 2014; Meadowcroft, 2011; Roberts et al., 2018; Smith and Stirling, 2010). Responding to these calls, transitions scholars have integrated politics into major transitions frameworks, such as the Multi-Level-Perspective (Geels, 2014) and transition management approaches (Kern and Howlett, 2009). Others have borrowed concepts from disciplines such as political science to conceptualize the interactions of policies, technological change, and politics (Edmondson et al., 2019; Egli et al., 2020; Hoppmann et al., 2014; Kern and Rogge, 2018; Markard et al., 2016; Rosenbloom et al., 2019; Schmid et al., 2020b), for example by focusing on *technological learning* (Goyal and Howlett, 2020). A subset of this burgeoning literature on the politics of sociotechnical transitions has recently turned to the roles of *actors and agency* in response to the dominance of structural explanations in the transitions literature (Avelino et al., 2016; Duygan et al., 2019; Kivimaa et al., 2019; Sovacool et al., 2020; Wittmayer et al., 2017). Collectively, these contributions have improved our understanding of politics, actors, and agency in sociotechnical transitions.

Yet, so far these studies have not considered a political actor key for sociotechnical transitions, namely *political parties*. There is a dearth of systematic research on the role of political parties in transitions. More specifically, there is a lack of research on how political parties position themselves toward sociotechnical transitions, how these positions change over time, and how transitions, in turn, co-evolve with party positions. This lack of sector and technology-specific analyses of political party positions is problematic for two reasons. First, as we know from the innovation and transitions literature, accounting for such sector and technology-sensitive differences is necessary for meaningful analyses and effective policy recommendations (Azar and Sandén, 2011; Huenteler et al., 2016; Zeppini and van den Bergh, 2011). Second, we know from political science literature that, in democracies, political parties fulfill a variety of important functions (Benoit and Laver, 2006; Ware, 1996). Parties are considered to be key designers of public policy as they are fundamental in structuring legislative processes, ensuring voting cohesion among legislators and developing positions for both legislative and executive authorities (Strøm, 2000). Further, political parties aggregate and communicate political preferences of constituencies such as voters and interest groups (Lindberg et al., 2008; Lipset and Rokkan, 1967). In other words, political parties reduce the transaction costs associated with collective decision-making in both the legislative (horizontal coordination) and electoral arenas (vertical aggregation) (Aldrich, 1995; Luna et al., 2020). Given these functions, parties are central in sustainability transitions, which require overcoming collective action problems at a large scale and rapid speed (Geels et al., 2017).

A systematic and dynamic assessment of political party positions on technologies is hence necessary for improving our

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understanding of the politics of sociotechnical transitions. Given the urgent need for accelerated policy change to address time-sensitive sustainability challenges (Kivimaa et al., 2020; Roberts et al., 2018), the rate and directionality of party position *change* is particularly relevant. While recent transitions literature suggests that actors may change their positions as a result of learning processes (van Mierlo and Beers, 2020) – including technological learning based on (changing) technology characteristics (Goyal and Howlett, 2020) – it remains unclear if and how political parties engage in such learning and subsequently change positions related to socio-technical transitions. With an empirical focus on the energy sector – a key sector for addressing sustainability challenges such as climate change – we address these gaps with the following research questions: How do political parties change their positions on energy technologies and policy instruments targeting these technologies? How does party position change co-evolve with technological change?

To answer these questions, we take an exploratory approach and examine party position changes in a longitudinal and comparative case study of Germany, France, and the United Kingdom (UK) from 1980 to 2017. This diverse case selection approach with both within and cross-case variation is suitable for an inductive and exploratory research design (Seawright and Gerring, 2008). Methodologically, the paper proceeds in two steps. First, we map party position changes related to energy technologies and policy instruments targeting these technologies based on a novel dataset that included all major parties in the three countries over a period of four decades. This dataset complements the established Party Manifesto Project (Volkens et al., 2019) with technology- and policy-specific codes on renewable energy technologies (RET), nuclear technology (NT), and fossil fuel-based technologies (FFT). Besides offering pro- and contra-positions on energy technologies and related instruments, this dataset also allows us to capture the salience of positions in party manifestos. Our analyses reveal, for the first time, the party politics underlying the different transition pathways in Germany, France, and the United Kingdom identified by previous transitions research (e.g. Geels et al., 2016). Second, we qualitatively analyzed the collected data to examine the co-evolution of party positions and technological change,[1] with a focus on technological learning by parties (Goyal and Howlett, 2020). We find that political parties engage in a learning process based on changing *issue characteristics* of different technologies, and inductively identify two mechanisms through which technological learning happens. Our findings also suggest that factors such as party and party system characteristics and path dependence related to energy systems constrain these learning mechanisms. Based on the results of our exploratory analysis, we discuss the relevance of our findings for the politics of sociotechnical transitions and transition pathways, and provide avenues for future research.

2. Political parties as key political actors in sociotechnical transitions

2.1. Politics and agency in sociotechnical transitions

Sociotechnical transitions are inherently political processes because they entail both winners and losers of technological change in a process of *creative destruction* (Acemoglu and Robinson, 2006; Dasgupta, 2018; Meadowcroft, 2011; Mokyr, 1998). While the energy transition from fossil fuel-based to renewable energy technologies creates winners in the form of new entrants in niche markets, it also threatens incumbent actors on the regime level and hence provokes *political* resistance (Geels, 2014; Sovacool et al., 2020).

Criticism about the lacking attention to *politics* (Meadowcroft, 2011) has led to a growing number of studies on politics and power in transitions (Ahlborg, 2017; Avelino et al., 2016; Avelino and Rotmans, 2011; Brisbois, 2019; Fesenfeld et al., 2020; Geels, 2014; Kern, 2011; Leipprand et al., 2020; Lockwood, 2016; Normann, 2015; Raven et al., 2016; Rosenbloom et al., 2016; Smith and Stirling, 2010; Sovacool and Brisbois, 2019). To analyze how politics shape sociotechnical transitions, scholars often draw on political science and public policy literature (Kern and Rogge, 2018), such as discourse analysis approaches (Rosenbloom et al., 2016), policy network theory (Normann, 2017), or the Advocacy Coalition Framework (Markard et al., 2016). Studies building on policy feedback theory have highlighted that technological change underlying sociotechnical transitions also feeds back into and co-evolves with politics (Edmondson et al., 2019; Rosenbloom et al., 2019; Schmid et al., 2020b; Schmidt and Sewerin, 2017). A subset of this literature on the politics of transitions is focused on the role of *actors and agency* in sustainability transitions (Farla et al., 2012; Fuenfschilling and Truffer, 2016; Scherrer et al., 2020; Wittmayer et al., 2017). Various roles and types of actors have been analyzed, such as business actors (Meckling, 2019), social movements (Hess, 2018), activist communities (Seyfang and Smith, 2007), intermediary actors (Kivimaa et al., 2019; Rohracher, 2009), technology users (Rohracher, 2003), and political activities of niche and regime actors (Geels, 2014; Smink et al., 2015; Turnheim and Sovacool, 2019).

While results from these studies have provided valuable insights into the agency and politics of transitions, there is a paucity of research on a key actor type, namely *political parties*. For instance, political parties are not mentioned in two reviews on the role of actors and elite power in sustainability transitions (Fischer and Newig, 2016; Sovacool and Brisbois, 2019). Similarly, political parties are only tangentially referred to in three recent research agendas on politics in transitions (Köhler et al., 2019; Lockwood et al., 2017; Roberts et al., 2018). In a special issue on actors in transitions by Farla et al. (2012), not a single study explicitly examines political parties. The few studies which analyze political party positions related to sociotechnical transitions either look at single jurisdictions (Schmidt et al., 2019), single points in time (Thonig et al., 2020), focus on specific party types such as Conservative parties (Hess and Renner, 2019) or analyze the party politics of generic climate policy without accounting for sector and technology-specific party positions (Carter et al., 2018; Ćetković and Hagemann, 2020). Other scholars have provided a dynamic account of electoral politics of energy transitions; however, these were based on stylized models without empirical data on real-world party positions (Aklin and

[1] Here, we define technological change as invention, innovation, and diffusion of new technologies (Abernathy and Utterback, 1978).

Urpelainen, 2013; Dumas et al., 2016).

The lack of sector and technology-specific analyses of political party positions is problematic for two reasons. First, in the innovation and transitions literature, scholars highlight the importance of such sector-specific and technology-sensitive analyses (Azar and Sandén, 2011; Huenteler et al., 2016; Zeppini and van den Bergh, 2011). Technology characteristics such as maturity, design and manufacturing complexity or need for costumization are fundamentally influencing politics because they shape the incentives for political actors to allocate resources and support a given technology (Breetz et al., 2018; Malhotra and Schmidt, 2020; Schmid et al., 2020a; Schmidt and Huenteler, 2016; Schmidt and Sewerin, 2017; Wilson et al., 2020). Second, political parties have a crucial role with respect to the steering of technological change and sociotechnical transitions (Langhelle et al., 2019). In democracies, political parties are often the origin of, or at least substantially influence, policy mixes targeted at innovation and technological change (Simmons, 2016). Kivimaa and Kern (2016, p. 211) have proposed that such policy mixes contain a wide range of *creative* and *destructive* policies which are defined as "combinations of policy instruments which interact explicitly or implicitly in fostering […] innovations and disrupting dominant (high-energy) regimes" (see also caption of Fig. A.3 in the appendix for more details). Implementing these "motors of creative destruction" is often, however, constrained by political challenges because "[c]hoices among alternative technological pathways involve [political] struggles among rival commercial groups […]. And politics and governments are inevitably preoccupied with managing the distributional fall out, […]" (Meadowcroft, 2011, p. 71). Hence, the (changes in) positions of political parties toward sociotechnical transitions are key for the *political feasibility* of ambitious policy instruments, and thus transition pathways more general (Jewell and Cherp, 2020).

2.2. Party politics

From political science literature we know that, in democracies, political parties fulfill several functions relevant for sociotechnical transitions (Benoit and Laver, 2006; Ware, 1996). As mentioned above, parties are key designers of public policy as they are fundamental in structuring legislative processes, ensuring voting cohesion by members of parliament and developing positions for both legislative and executive authorities (Strøm, 2000). Empirically, party positions have been found to be reflected in subsequent policy change (Borghetto and Belchior, 2020; Brouard et al., 2018; Garritzmann and Seng, 2020). Further, political parties aggregate and communicate political preferences of constituencies such as voters and interest groups (Lindberg et al., 2008; Lipset and Rokkan, 1967). Parties constitute a "transmission belt" between these societal preferences and the policymaking process (Lindberg et al., 2008). In other words, political parties reduce the transaction costs associated with collective decision-making in both the legislative and electoral arenas (Aldrich, 1995). While the function of parties in the legislative arena refers to a *horizontal coordinative capacity*, the channeling and representation of societal interests in the electoral arena points to their *vertical aggregative capacity* (Luna et al., 2020).

Given these important functions of political parties, understanding how parties position themselves toward and how much attention they allocate to policy issues is central to understand transition policy, and policy output more generally. Thus, the main goal of party politics literature is to describe and explain (changes in) party *positions* as well as their *salience*[2] (Adams and Somer-Topcu, 2009; Walgrave and Nuytemans, 2009). In this literature, several explanations for changes in party positions and their salience have accumulated over the last few decades (for a review see Fagerholm, 2016). For the purpose of this paper, we focus on an explanation deemed particularly useful in the context of sociotechnical transitions: *learning* processes by political parties based on *issue characteristics*.[3]

The evaluation of issue characteristics and related incentives for political parties has been shown to be a primary driver of party positions and their relative salience (Abou-Chadi et al., 2020; Green-Pedersen, 2019). Here, we define issue characteristics as features of energy technologies, such as their relative costs, maturity, complexity, deployment, associated jobs and economic activity. Recent contributions in transitions literature also highlight the relevance of learning processes based on issue characteristics in the context of technological change (Boon and Bakker, 2016; Goyal and Howlett, 2020; van Mierlo and Beers, 2020). Learning in transitions can occur along multiple dimensions including technical, market, cultural, infrastructure, production, policy, and societal and environmental aspects (Schot and Geels, 2008). In this paper, we focus on learning pertaining to technology and its issue characteristics, i.e. technological learning (Goyal and Howlett, 2020). Collective actors, such as political parties, are argued to be key players in facilitating societal learning, and "the absence of or lack of alignment amongst one or more of these collective actors can hinder learning and act as a barrier to the transition process" (Goyal and Howlett, 2020, p. 318). Absence of alignment among political parties may result, amongst others, from the lack of objective and commonly shared criteria to assess issue characteristics of technologies (Hoppmann et al., 2020). Particularly in the early stages of a technology life-cycle, collective actors face considerable uncertainty and complexity (Tushman and Rosenkopf, 1992), which are especially high in the energy sector (Grubler et al., 2016). Hence, party positions on technologies are the result of "puzzling and powering" (Lindblom, 1959) rather than the product of purely rational technological learning and subsequent decision-making (Winner, 1980). As a result, parties enter in conflicts over policy goals linked to technologies and the means or instruments to achieve them (Meadowcroft, 2009; Schmidt et al., 2019). In this view, party positions on technologies

[2] Here, we define salience as the relative importance attached to an issue relative to other issues (Wlezien, 2005). Given that decision-makers in the policymaking process – in our case political parties – operate with limited available time and resources, not all policy issues can receive appropriate attention. Thus, issue salience influences decision-makers' prioritization and their subsequent actions (Jones and Baumgartner, 2005).

[3] Of course, other factors such as societal cleavages (Lipset and Rokkan, 1967), party-voter links (Bartolini and Mair, 1990), and party-industry ties (Allern and Bale, 2012) also influence party position changes. While we acknowledge these factors, discussing and empirically analyzing them would go beyond the scope of this paper.

are unlikely to be homogenous and are not only driven by related issue characteristics (Smith and Marx, 1994), but moderated by a set of party and party system characteristics and subject to path dependence (Arthur, 1989).

From party politics literature, we know that *party characteristics* constrain and moderate how parties learn based on changing issue characteristics. For instance, opposition parties have more degrees of freedom in changing positions compared to governing parties constrained by coalition agreements and election promises (Wagner, 2012). Scholars also differentiate between incumbent and niche parties: Compared to incumbent parties, niche or challenger parties are considered to be more flexible in their programmatic choices and they have incentives to focus on new policy issues (Adams and Merrill, 2006). Left-right ideological positions of political parties are additional longstanding factors moderating learning and position change (Gabel and Huber, 2000). For instance, center-right to right parties are less progressive on climate policy than parties on the left end of the spectrum (Båtstrand, 2015; Carter et al., 2018; Ćetković and Hagemann, 2020; Geddes et al., 2020; Hess and Renner, 2019; Lockwood, 2018). The above discussion suggests that – in line with framing and discourse theory (Chong and Druckman, 2007; Leipold and Winkel, 2017; Slothuus and De Vreese, 2010) – political parties *strategically* build on changing issue characteristics to support their positions on technologies. Uncertainty linked to socio-technical change and transition pathways creates the possibility for parties to engage in strategic behavior aimed at influencing other parties' positions and thus shape the overall political agenda of the party system. Yet, whether parties may achieve to influence the overall agenda also depends on the number, strength, and roles of political parties in a respective party system (Sartori, 1976). *Party system characteristics* can influence how parties relate to each other in terms of position and salience change on a given policy issue. Political parties may choose accommodative, adversarial, or dismissive strategies to react to other parties' changes in position (Meguid, 2005). Overall, this implies that party positions often evolve in relation to one another within the boundaries of a "party system agenda" (Green-Pedersen, 2019), which may constrain learning processes of individual parties. Finally, path dependence related to existing energy systems and related infrastructure and materiality may constrain the extent to which parties oppose incumbent technologies or are willing to engage in learning on new technologies that are early in their lifecycle (Arthur, 1989; Seto et al., 2016; Unruh, 2000).

2.3. Combining transitions and party politics literature

These insights from the party politics literature complement those of the transitions literature and provide a novel theoretical background for analyzing the co-evolution of party positions and technological change. In a nutshell, the argument is that political parties change their *positions* on energy technologies and related policy instruments as a result of *technological learning*. We argue that technological learning happens based on parties' perception of changing *issue characteristics* of technologies, such as related co-benefits or costs. Importantly, party politics literature suggests that whether and how political parties react to changing issue characteristics and engage in technological learning is moderated by *party characteristics*, such as ideology. In addition, the number of parties, as well as their relative strength and interactions, i.e. *party system characteristics*, may also shape how parties change their technology-related positions. Finally, given the central role of political parties in policy processes, changing party positions (at least of governing parties) are likely to be reflected in the implementation of *policy instruments*. Such *policy output*, in turn, influences innovation and diffusion of technologies, thus closing the *feedback loop* among party politics, policy output, and technological change. Note that this paper focuses on the co-evolution of party positions and (policy-induced) technological change and treats related policy processes and their output as black box.

3. Case selection

In an exploratory approach, we examine party position change on *energy technologies* and *policy instruments targeting these technologies* in *Germany, France*, and the *United Kingdom* (UK) from 1980 to 2017. We selected these cases for three reasons. First, the energy sector is a suitable policy area for examining party positions related to technology because it is a large and complex sociotechnical system characterized by path dependence, inertia, and interdependence with public policy (Geels et al., 2017). The so-called "carbon lock-in" makes it difficult for renewable energy technologies to diffuse in the market without the support of public policy (Seto et al., 2016). At the same time, the energy sector is one of the most regulated sectors of the economy due to its relevance as well as several externalities and system failures (Gillingham and Sweeney, 2012). Hence, over the last four decades, sociotechnical change in this sector was largely policy-induced (Kern and Howlett, 2009; Nemet, 2009; Rogge and Reichardt, 2016). Table A1 in the appendix provides an overview on key energy policies in these three countries (Cointe, 2015; Kern et al., 2014; Lauber and Jacobsson, 2016; Lockwood et al., 2019; Renn and Marshall, 2016; Schmid et al., 2020b).

Second, we selected these countries because they are similar in terms of broad socioeconomic variables but demonstrate relevant variation. Germany, France, and the UK are all advanced liberal democracies with comparable levels of economic development and (in the study period) common membership in the European Union. At the same time, the countries vary on two dimensions pertinent to this study: the type of party system and the structure of the energy system and its dynamics in terms of transition pathways (Geels et al., 2016). Regarding party systems (see Ware, 1996), Germany is a classic case of proportional representation with a multi-party system that includes influential niche parties, such as the Greens. France is considered a multi-party system; however, it has relatively weak niche parties due to the majoritarian representation system. The UK is often described as a two-and-a-half party system due to the

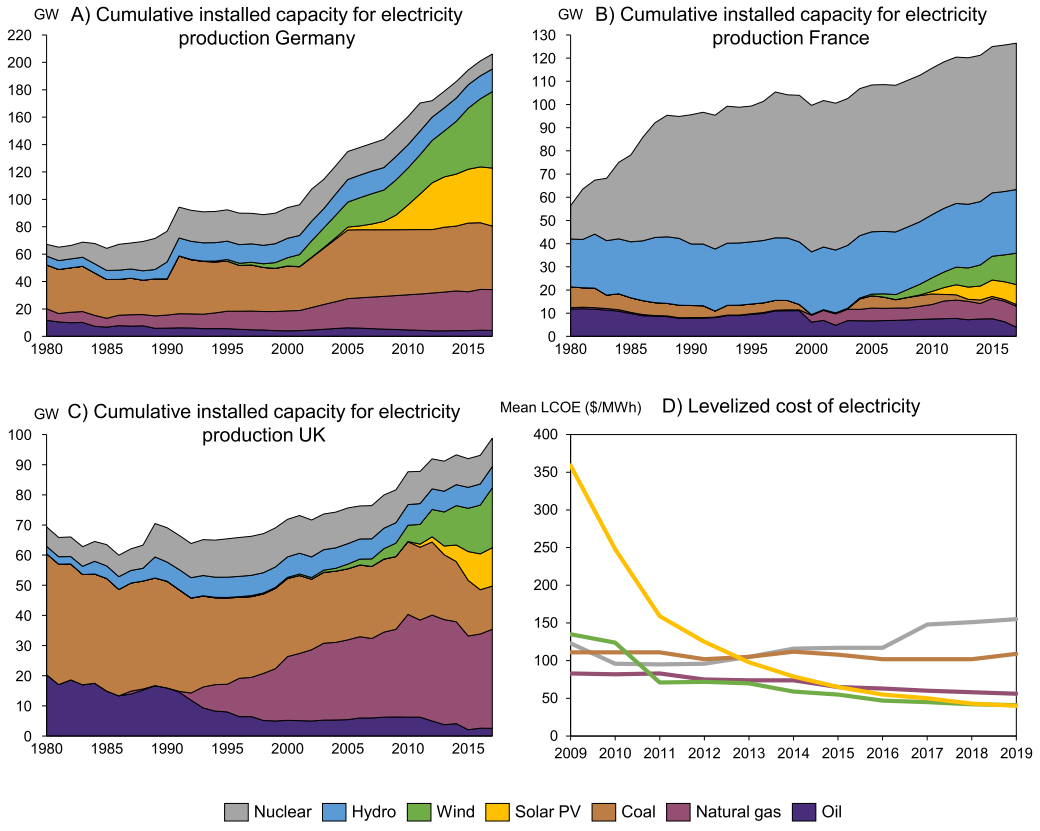

Fig. 1. Technological change in the energy sector. A)-C): Cumulative installed net capacity of electricity-producing technologies and energy carriers (in% of total installed capacity). Source: International Energy Agency (IEA, 2017). D) Proxy for cost development of different energy technologies: Levelized cost of electricity (LCOE). Unsubsidized LCOE analysis reflecting the average of the high and low LCOE for each respective technology in each year in the United States 2009 - 2019. Including sensitivities for subsidies, fuel prices and costs of capital. Other costs, such as grid-related or regulation-related costs are not included. Source: Lazard (2019).

presence of a weak federal niche party and the dominance of two major parties. Fig. A.1 in the annex shows the share of parliamentary seats of individual parties over time, as well as their participation in government. Regarding energy systems, the three countries have significantly different resource endowments, energy system structures, and dynamics over time. Fig. 1 (A to C) shows the share of cumulative installed capacity of electricity-generating technologies.

Germany's electricity mix was historically dominated by coal and nuclear power, but with strongly increasing capacity of RET and decreasing capacity in NT. France's profile is distinct in that NT represents a large share of installed capacity, and fossil fuel-based electricity generation only plays a minor role due to the low resource endowment in fossil fuels. At the same time, the transition to (non-hydro) RET has been slow in France. In the UK, similar to Germany, electricity generation has been dominated by coal and nuclear power, with a "dash for gas" starting in the 1990s and a growing deployment of RET in the 2010s, combined with a decrease in the installed capacity of coal.

Third, we chose to examine the years 1980 through 2017 because this period captures significant changes in the energy sector.[4] Besides changes in the installed capacity discussed above, Fig. 1(D) depicts changes in the levelized cost of electricity (LCOE). Costs developed differently across technologies: RET such as solar photovoltaic have displayed strong cost decreases. At the same time, FFT and NT have experienced stagnating or even increasing costs. These differences in technological change – in installed capacity and cost development illustrated here, but also in terms of job provision – alter the issue characteristics of a given technology. Overall, the diverse case selection with within-case and cross-case variation on theoretically relevant dimensions is suitable for the exploratory research design used in this paper (Seawright and Gerring, 2008).

4. Method and data

Methodologically, the paper proceeds in two steps. First, we map party position and salience change on energy technologies and related policy instruments based on a novel dataset including all major parties in Germany, France, and the UK from 1980 to 2017.

[4] We abstained from examining the years 2017 to 2020 because no federal election happened in this period in Germany or France.

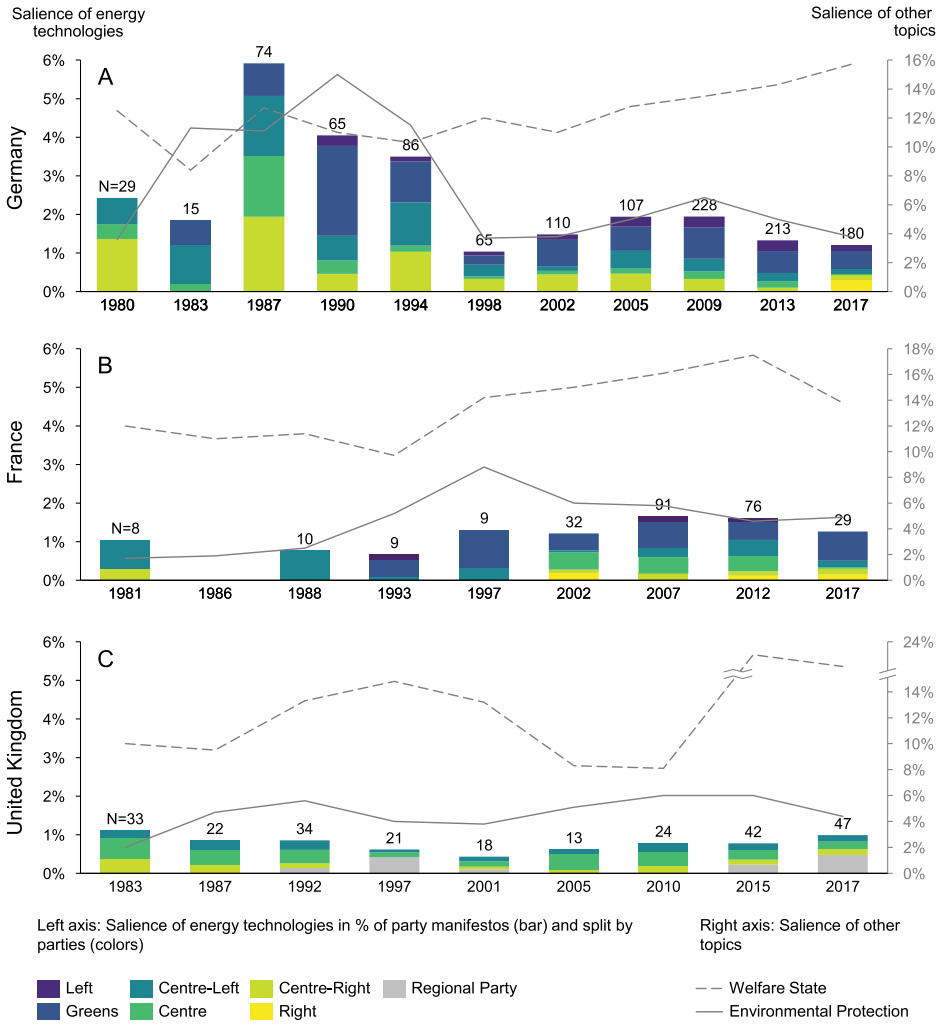

Fig. 2. Salience of energy technologies in party manifestos by party family in Germany (A), France (B), and the United Kingdom (C) from 1980 to 2017 and in comparison to other topics. Salience measured as the share of quasi-sentences in a party manifesto (number (N) of coded sentences on energy technologies indicated above bars). Colors indicate the share of individual parties (see legend). Data on salience of Welfare State [variable ID: welfare] and Environmental Protection [variable ID: 501] taken from the Manifesto Project (Volkens et al., 2019), and depicted on a secondary axis (right) at a different scale.

Major parties are defined as those that either participated in government or that have won at least 5% of the parliamentary seats in at least one election of the analyzed period (see Fig. 1.A in the annex). The exclusion of smaller parties can be justified on two grounds: Often, they do not exist over a long period, and they are insignificant for political issue competition and the policymaking process.

We collected the data in line with the methodology of the established Party Manifesto Project by manually hand-coding the quasi-sentences of each manifesto according to an iteratively developed coding book (Volkens et al., 2019). Party manifestos are an appropriate data source because they are published regularly, endorsed officially, and representative of the key signals to voters before elections. Manifestos may reveal party positions even more clearly than policy outputs, which are often the result of inter-party compromises (McDonald et al., 2004). We complemented the Party Manifesto Project dataset with technology-specific codes on RET, NT, and FFT. We aggregated different FFT (lignite, hard coal, natural gas, oil) because there were only rare cases in our dataset in which political parties had contrasting positions on different FFT, and often parties alluded to fossil fuels in the aggregate. The same rationale held for RET (onshore and offshore wind, solar PV, biomass, geothermal). We coded sentences in manifestos according to their substantive pro- or contra-positions on energy technologies. Controlling for the length of party manifestos (number of sentences) allowed us to measure the salience allotted to these positions. Following the established methodology in party politics literature (Adams and Somer-Topcu, 2009), we calculate the salience of an issue as the share of sentences related to this issue (in%) compared to

Table 1
Characteristics of the empirical corpus. Abbreviations of political parties: Germany: Social Democratic Party Germany (SPD), Free Democratic Party (FDP), Christian Democratic Union / Christian Social Union (CDU/CSU), Alternative for Germany (AfD). France: Communist Party France (PCF), France Insoumise (FI), Europe Ecology Les Verts (EELV), Socialist Party (PS), Union for French Democracy (UDF), Democratic Movement (MoDem), The Republic Forward (LREM), Rally for the Republic (RPR), Union for a Popular Movement (UMP), The Republicans (LR). UK: Liberal Democrats (Lib Dems), Conservative Party (Tories), Scottish National Party (SNP). *In total 13 separate parties (over time), but which can be attributed to the 6 categories.

∑ Number of analyzed party manifestos	136
Germany	*50*
France	*46*
United Kingdom	*40*
∑ Number of major parties (government participation or > 5% of parliamentary seats in one election in the study period)	23
Germany	*6*
Die Linke (Left), Die Grünen (Greens), SPD (center-Left), FDP (center), CDU/CSU (center-Right), AfD (Right)	*13**
France	*4*
PCF/ FdG / FI (Left), Les Verts/ EELV (Greens), PS (center-Left), UDF/MoDem/LREM (center), RPR/UMP/LR (center-Right), FN/RN (Right)	
United Kingdom	
SNP (Regional), Labour Party (center-Left), Lib Dems (center), Tories (center-Right)	
∑ Number of coded statements in party manifestos	1690
Germany	*1172*
France	*264*
United Kingdom	*254*

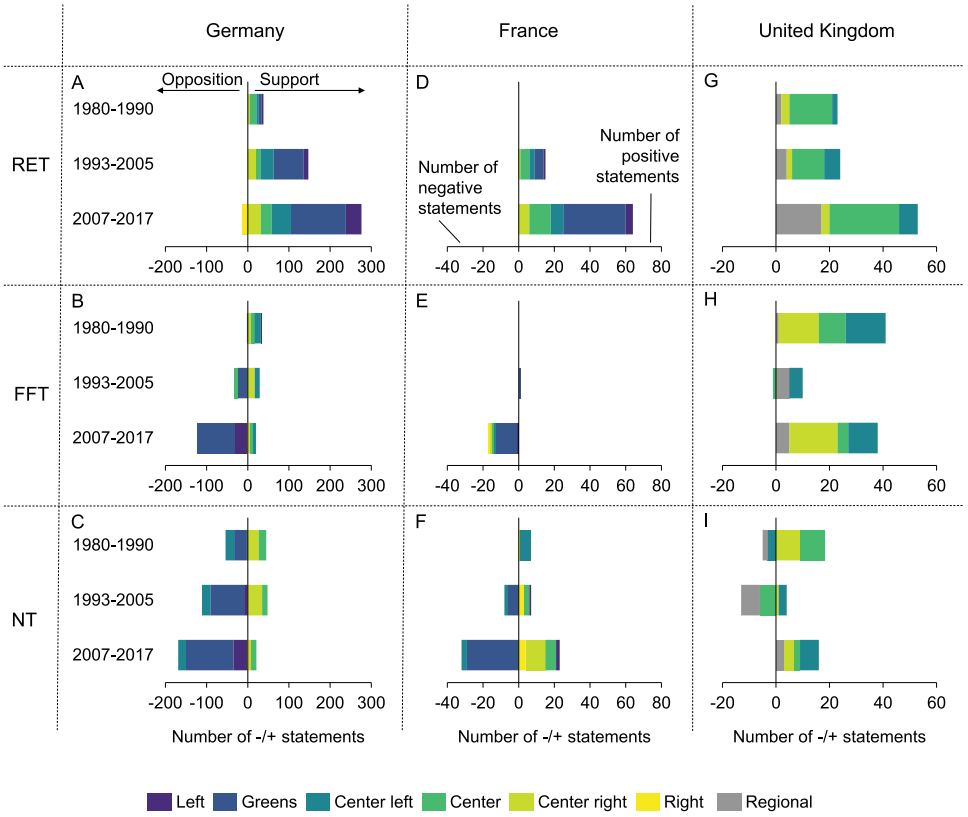

Fig. 3. Positions of political parties on energy technologies in Germany (A-C), France (D-F) and the United Kingdom (G-H) from 1980 to 2017. The stacked columns show the total number of negative (left of Y axis) and positive (right of Y axis) statements on renewable energy technologies (RET), fossil fuel-based technologies (FFT), and nuclear technology (NT), aggregated on three periods. Note that the scales in the three countries are different due to variation in salience (see Fig. 2). The three periods (1980–1990, 1993–2005, 2007–2017) reflect the following legislative periods in the three countries (see Fig. 2): Germany (four periods between 1980 and 1990, four periods 1994–2005, three periods 2009–2017), France (three periods between 1981 and 1988, 1993–2003, and 2007–2017, respectively), United Kingdom (three periods between 1983 and 1992, 1997–2005, and 2010–2017, respectively). Colors (see legend) show the share of individual parties in the overall statements. Visualization based on the coding of quasi-sentences allocated to the individual technology groups per party manifesto (see Table A.2 in the annex).

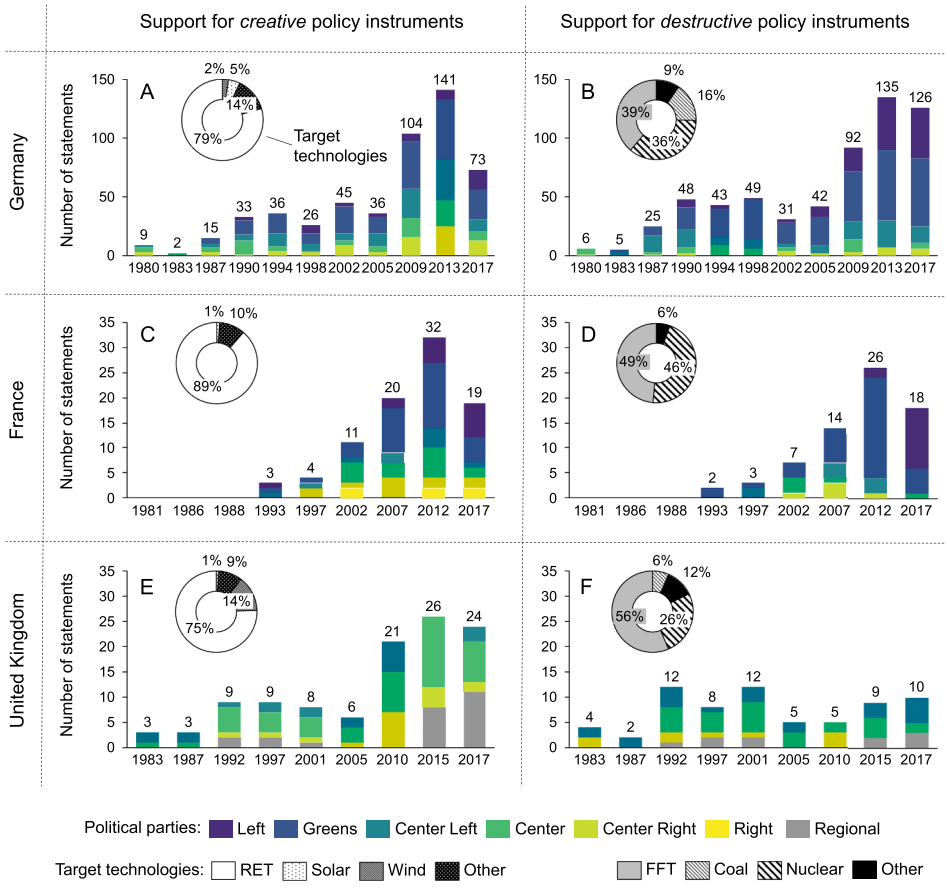

Fig. 4. Positions of political parties on creative and destructive policy instruments in Germany (A, B), France (C, D) and the United Kingdom (E, F) from 1980 to 2017. The stacked columns show the total number of supportive statements on creative and destructive policy instruments targeting the energy sector. Visualization based on coding of party manifestos in line with the policy instrument typology developed by Kivimaa and Kern 2016. Colors (see legend) show the share of individual parties in the overall statements. Visualization based on the coding of quasi-sentences allocated to the individual technology groups per party manifesto (see Table A.2 in the annex). The doughnut charts show the targeted technology (groups) of these statements on policy instruments, aggregated across all parties and years per country and for creative and destructive policy instruments (see also 2nd legend).

the total content-related sentences per manifesto (see also Volkens et al., 2019). We also collected data on political party support for policy instruments targeting these technologies. To do so, we followed the established typology by Kivimaa and Kern (2016) which distinguishes between *creative* and *destructive* policy instruments (see Section 2.1.). Where possible, we also coded what technology (group) the political party aims at targeting with a given policy instrument. Fig. 2.A in the appendix depicts the coding scheme and decision tree used for the coding.

Next, following grounded theory, we qualitatively analyzed the data to examine the co-evolution of party positions and technological change, and specifically learning by parties therein. Grounded theory is a case study methodology that is based on an iterative coding process in which the researcher develops abstract categories both inductively from systematic data collection, in-depth case knowledge, and deductively from theory (Eisenhardt, 1989; Sovacool et al., 2018). Based on this method, we detected two mechanisms on technological learning by political parties, based on the 1690 coded statements and informed by previous literature on the interaction between technology and politics (Edmondson et al., 2019; Schmid et al., 2020b). In the second step of the analysis, based on qualitative judgment, we selected statements to illustrate these mechanisms.

We labeled political parties according to the left-right spectrum based on the PartyFacts project (see Döring and Regel, 2019). We categorized parties as Left, Center-Left, Center, Center-Right, and Right. For visualization purposes, we labeled Greens and the Scottish National Party (SNP) separately. Although the naming and organizational structure of French parties changed over time, it was possible to sort them into a coherent continuum (see Guinaudeau and Persico, 2013). Table 1 contains details about the empirical

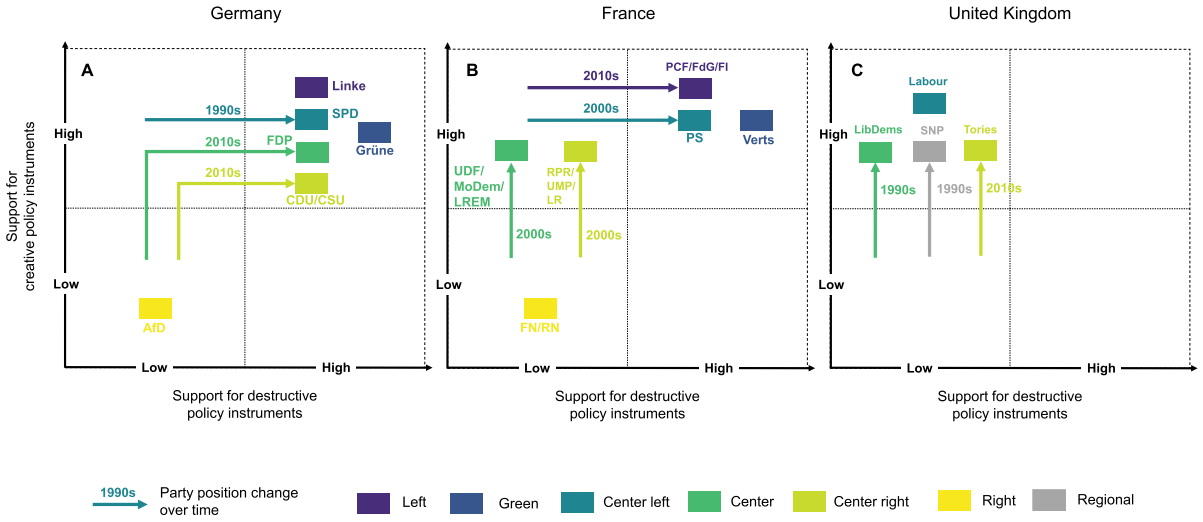

Fig. 5. Stylized overview of party position change on creative and destructive policy instruments in Germany (A), France (B), and the United Kingdom (C) from 1980 to 2017. Arrows represent simplified position change over time, colors party type (see legend). Stylized overview based on analyses in Figs. 2, 3 and 4.

corpus and the abbreviations for parties used in this paper (see caption). Table A.2 in the annex shows the collected frequencies per country, party, year, and technology.

5. Results

5.1. *Mapping political party position change on energy technologies and related policy instruments*

In a first step, we mapped changes in political party positions and their salience. Fig. 2 (A-C) depicts the changes in salience allocated to energy technologies in each election year (bars), split by party family (colors) from 1980 to 2017. The gray lines indicate salience levels of other policy issues from the Manifesto Project. In light of our first research question, four observations can be made. First, salience levels varied across countries. While energy technologies accounted for, on average, 2.4% of party manifesto text in Germany, they accounted for only 1.1% in France and 0.7% in the UK. Yet, salience levels changed over time. Most notably, German parties allocated considerably more salience to energy technologies from 1987 to 1994. While salience levels increased in France beginning in 1993, energy technologies were completely absent from party agendas in the election year of 1986. In the UK, salience decreased continually from 1983 to 2001 and then increased again through 2017.

Third, salience levels differed between party families. In Germany, except for the years 1980 and 1987, parties from the center-left to left dominated the party system agenda on energy technologies. This was also true in France where the Green party accounted for the most salience relating to energy technologies starting in 1993. In the UK, center and regional parties emphasized energy technologies more than others. Fourth, the salience of energy was considerably lower than that of generic policy issues such as environmental protection and the welfare state, which are indicated with lines on the secondary axis with different scales.

Next, we zoomed in on pro and contra positions on technology groups. Fig. 3 depicts party position change on technology groups (RET, FFT, and NT) for all relevant political parties in Germany, France, and the United Kingdom. Note that to facilitate interpretation we aggregated positions on three time periods (see caption for details). Three main observations can be made.

On the level of technology groups, we observe an increasing support for RET in all countries (Fig. 3A, D, G). This support is primarily driven by center to left parties, with a slight uptake in support by center right parties in the 2nd and 3rd periods. Notably, with the exception of opposition by the right party AfD in Germany, renewable energy technologies are not subject to political partisanship. A different picture emerges for FFT (B, E, H), where we observe an increasing partisanship in Germany, opposition in France, and homogenous support in the UK. In Germany and France, opposition against FFT is driven by left and green parties and especially salient in the latest period. Regarding NT (C, F, I), we notice an increasing polarization in France between opposed center-left to left parties and supportive center to right parties, and a decreasing polarization in Germany. In contrast, after partisanship in the first and second period, British political parties engaged in a U-turn towards cross-party support for NT in the latest period.

Next, we zoom in the data even further and examine whether these broad patterns of support for and opposition to energy technologies are also reflected in party positions on *policy instruments* targeting these technologies. Fig. 4 depicts changes in party support

Table 2
Exemplary quotes on a mechanism of technological learning: Changes in the perceived co-benefits and costs of technologies. Sources in brackets (party manifestos of legislative elections), ID for reference in text in square brackets.

Country	Exemplary quotes
Germany	*"Germany's electricity prices inevitably continue to increase with each additional wind and solar power plant and network expansion."* (AfD, 2017) [1]
	"The expansion of renewable energies has shifted considerable economic activity and value creation back to rural areas." (CDU/CSU, 2017) [2]
	"German hard coal is a non-competitive energy source. Coal subsidies are economically irresponsible." (FDP, 2002) [3]
	"In the long term, renewable energies from wind power (offshore and onshore) and solar energy are the most cost-effective form of energy generation." (SPD, 2017) [4]
	"The use of nuclear energy is too risky." (SPD, 2009) [5]
	"More than 250,000 people work in the renewable energy sector, more than in the coal industry." (Grüne, 2009) [6]
	"Today, Germany is the global market and technology leader in wind power and photovoltaics." (Grüne, 2005) [7]
	"New technological developments - such as hydrogen technology and other forms of renewable energies - offer the opportunity to make East Germany an important location for environmentally friendly energy generation." (Die Linke, 2017) [8]
France	*"Nuclear power equipment allows our country to be more independent from ups and downs of oil prices."* (PS, 1988) [13]
	"Maintaining our energy independence and good performance in terms of CO_2 emissions requires conserving nuclear energy in the medium term." (FN, 2012) [14]
	"We will keep a significant share of nuclear energy production, which does not emit greenhouse gasses. Neither Fessenheim nor any other power plant will close, except for safety and security considerations." (LR, 2017) [15]
	"Nuclear is an effective response to climate change, provided that the necessary research and development is carried out to find a solution to the waste issue." (MoDem, 2002) [16]
United Kingdom	*"Since 1983 productivity in the coal industry has risen by over 50 percent. Coal will continue to meet much of the steadily rising demand for electricity."* (Tories, 1987) [9]
	"Wind power is hopelessly inefficient and wind farms rely heavily on reserve back-up from conventional power sources." (UKIP, 2017) [10]
	"Scotland has a wealth of onshore and offshore renewable energy potential which, if unlocked, can support thousands more jobs and further economic growth." (SNP, 2017) [11]
	"Electricity generated by new nuclear plants will be sold for more than twice the current retail price. SNP MPs will hold the UK government to account over its support." (SNP, 2005) [12]

for *creative* policy instruments (A, C, E) and *destructive* policy instruments (B, D, F) in the three countries, based on the instrument typology by Kivimaa and Kern (2016). In addition, the doughnut charts in Fig. 4 show the share of technologies political parties intend to target with these instruments.

Three main observations emerge from this figure. In general, we observe increasing support for creative instruments in all three countries (A, C, E), especially from the beginning of the 2010s. In all three countries, center to left parties appear to be early drivers of support, with center right and right parties supporting such instruments with a time lag and on lower salience levels. Similar patterns can be detected for destructive policy instruments (B, D, F). In Germany and France, support for these instruments increases over time, and is primarily driven by center-left to left parties. Overall, support by center to right parties for destructive instruments is even weaker than for creative instruments. In the United Kingdom, support for destructive instruments is stagnant over time. Finally, the targeted technologies and level of technology-specificity differ between the three countries. In all three countries, support for creative instruments remains mostly on technology group-level (RET) without further specification on which renewable energy technologies (e.g. solar photovoltaic) should be targeted (at least 75% of all statements). More technology-specific statements often reflect national capabilities and resource endowments, e.g. French parties highlighting the role of tidal power, or British parties referring to offshore wind as important target technology. For destructive policy instruments, support is more technology-specific, targeting NT or coal (e.g. in Germany).

Abstracting from the findings of the three steps above, Fig. 5 shows a *stylized* overview on how the party politics of the three countries (A-C) evolved over time for creative and destructive policy instruments and related target technologies. We observe that on the level of the party system agenda, the three countries differ significantly. Following early movers such as the green party, German political parties collectively moved to high support for both creative and destructive policy instruments (A). This relative consensus was the result of decade-long highly salient political battles around NT, and more recently coal (see Fig. 2), accompanied by increasing cross-party support for RET (see Fig. 3). Amongst others, these party politics in Germany resulted in the implementation and stickiness of key energy policies such as the feed-in tariff in 2000, the final nuclear phase-out in 2011, and the coal phase-out plan finalized in 2019 (see Table A.1 in the appendix).

In France (B), while support for creative policy instruments and RET also increased over time (although with a time lag and at lower salience levels than in Germany), there is a clear and unresolved partisanship along the left-right spectrum on the support for destructive policy instruments. Given the low salience of FFT (see Fig. 3), this partisanship primarily resulted from conflicting positions on NT which accounts for the majority of electricity generation in France (see Fig. 1). These party politics, in turn, translated into a relatively late introduction of stringent creative policies for RET, and fluctuating nuclear phase-out targets and policies depending on which parties form the French government. In the United Kingdom (C), support for creative policy instruments targeting RET increased over time with a relative consensus among political parties. Yet, support for destructive instruments remained on low levels for all parties (see Fig. 4). Here, patterns for FFT and NT are diverse. While British parties consistently supported FFT, especially gas, NT came back into favor after a period of opposition by the center and regional party (see Fig. 3). These party politics led to rather stringent

Table 3
Exemplary quotes on a mechanism of technological learning: Changes in the menu of policy options. Sources in brackets (party manifestos of legislative elections), ID for reference in text in square brackets.

Country	Exemplary quotes
Germany	*"To ensure that electricity will always be available at any place and at any time, we are supporting the expansion of the power grids and the development of new storage technologies."* (CDU/CSU, 2013) [19]
	"We see nuclear energy as a bridge technology, because today climate-friendly and inexpensive alternatives are not yet sufficiently available." (CDU/CSU, 2009) [20]
	"We have set ourselves ambitious goals in the area of expanding renewable energies (20 percent by 2020)." (CDU/CSU, 2009) [21]
	"We should achieve at least 12.5% renewable energies in German electricity consumption." (CDU/CSU, 2005) [22]
	"We want to double the share of renewable energies in electricity supply by 2010." (CDU/CSU, 1998) [23]
	"Wind and solar energy and other renewables can increasingly contribute to our energy supply." (CDU/CSU, 1987) [24]
	"Shale gas fracking is an opportunity that can contribute to the success of the energy transition." (FDP, 2013) [25]
	"Gas should be used as a temporary solution to compensate for fluctuations in energy supply." (Grüne, 2013) [26]
	"Converters for solar panels and silicon solar cells are now technically mature." (Grüne, 1994) [27]
France	*"We will promote the rise of renewable energies by supporting the creation and development of industrial activity in this sector."* (PS, 2012) [32]
	"The potential of solar energy, biomass, and wind turbines is considerable." (PS, 2012) [33]
	"We will massively develop the French renewable energy sectors thanks to intelligent protectionism, economic patriotism, public and private investment and deploying EDF." (FN, 2017) [34]
	"Apart from hydropower, so-called "green" energies are not realistic today as such: For example, it would be necessary to install 275,000 wind turbines, or 5 billion square meters of photovoltaic panels (an average department) to produce the electricity necessary for France." (FN, 2012) [35]
	"We will strengthen the development of renewable energy in line with our commitment to produce more than 20% renewable energy by 2025." (LR, 2017) [36]
United Kingdom	*"We believe that shale energy has the potential to do the same thing in Britain, and could play a crucial role in rebalancing our economy. We will therefore develop the shale industry in Britain."* (Tories, 2017) [28]
	"We will support investment in energy storage and smart grid technology to enable this higher reliance on renewables." (Lib Dems, 2015) [29]
	"Set a target for 40 percent of UK electricity to come from clean, non-carbon-emitting sources by 2020, rising to 100 percent by 2050." (Lib Dems, 2010) [30]
	"The Liberal Democrats will make sure that at least 20 percent of the UK's electricity comes from a full range of renewable sources by the year 2020." (Lib Dems, 2005) [31]

creative policies targeting RET without *directly* threatening the regime around NT and FFT through targeted destructive policy instruments (in the analyzed time period).

On an abstract level, what distinguishes the party politics of the three countries, amongst others, is the relative role of niche parties in driving agenda change, and how incumbent parties react to these stimuli. For instance, while we observe *accommodative* strategies by incumbent parties in Germany, French center to center-right parties have rather adopted an *adversarial* strategy on the question of NT. Yet, these cross-country differences suggest that dynamics in party politics may also be tied to the co-evolution with technological change and transition pathways more broadly, which unfolded quite differently in the three countries (see Fig. 1). In the following, we examine this interaction between party politics and technological change.

5.2. Exploring the co-evolution of party positions and (policy-induced) technological change and the role of technological learning therein

In a second step, we explored whether and how party positions on energy technologies co-evolved with technological change, with a particular focus on *technological learning* by political parties. We inductively discovered two mechanisms through which political parties learned on issue characteristics of energy technologies and consequently updated their party agendas: i) the perceived co-benefits and costs of a given technology; and ii) changes in the scope of the menu of available policy options. We highlight the role of moderating factors in this learning process.

First, political party positions co-evolved with changing *relative co-benefits and costs* of technologies. Parties updated their agendas in a learning process, moderated by their ideological orientation and size (see Table 2, individual quotes referenced in the text with [statement ID]). In Germany, the exponential growth of RET and associated economic benefits were accompanied by an increasing support for these technologies by left to center-left parties [statement ID 3, 4, 6, 7], and, with some time lag, the center-right party [2]. With the ongoing diffusion of RET, political parties learned on their co-benefits, such as job creation in rural areas or gains in international competitiveness of the national energy industry. The arrival of a right party in the German party system challenged the broad consensus regarding the benefits of RET, as the AfD strongly emphasized costs and landscape effects related to wind power [1]. Party opposition to technologies such as hard coal and nuclear power increased over time because of learning on their costs and risks [3, 5]. In the case of NT, learning was catalyzed by nuclear accidents that underscored the high risks associated with this technology. Yet, position shifts on nuclear power also resulted from more gradual learning on the high costs related to the technology. We observed similar trends in France, where the center-left and green parties started to emphasize the costs and risks linked to this technology in more recent years. However, beyond this increasing opposition, for a long time, the perceived benefits of NT were a non-partisan issue in the French party system with supportive statements on energy independence and climate change mitigation across the left-right spectrum [13, 14, 15, 16]. In the UK, while parties had temporarily opposed NT on grounds of perceived costs and risks [12], we

observed a U-turn in favor of increasing support for the technology in the 2010s (see also Fig. 3 above). British niche parties were among the first to highlight the co-benefits of RET in terms of jobs and economic growth [11].

Second, these changes in the relative costs and benefits of technologies resulted in extending or limiting the *menu of available policy options* (Jacobs and Weaver, 2015) for technologies (see Table 3, individual quotes referenced in the text with [statement ID]). Political parties selectively built upon these changes in the menu of policy options to underline their positions on technologies.

In all three countries, niche parties such as the German Greens, British Lib Dems, and French UDF first updated their manifestos after learning about the increasing technical maturity of solar PV [27, 31]. In the following years, the growing technical and economic feasibility of RET co-evolved with the ambition levels of target setting beyond these early movers to incumbent parties. For example, the German CDU/CSU increased their ambition steadily over the decades, evolving from an undefined commitment for RET in 1987 to a specific target of 12.5% renewables in 2005 [21–24]. Similar trends can be observed in the UK [29, 30] and France [32, 33, 36], where also the right party FN learned about the increasing feasibility of RET and consequently supported this technology [34, 35]. Hence, in what can be called a learning process, parties adapted their agendas in line with the increasing technical maturity and falling costs which increased the menu of policy options available, e.g. by enabling more ambitious deployment targets. The increasing deployment of RET also resulted in required further technological developments, which was reflected in the parties' agendas. For instance, in the 2010s, parties in Germany and the UK emphasized the need for grid expansion and deployment of energy storage technologies because of RET localization and fluctuation [19, 29]. Besides RET, parties' agendas also reflected developments in FFT. For instance, innovations in fracking technology enabled the exploitation of shale gas, which center-right to right parties in Germany and the UK perceived as an opportunity [25, 28]. Of course, these menu effects can also have a negative directionality. For instance, the nuclear phase-out in Germany led to a subsequent decrease in the salience of positions on NT (see Fig. 4), as this technology was effectively removed from the menu of policy options.

Our findings also suggest that technological learning by political parties is subject to constraints and moderating factors. First, party ideology and size moderate these learning mechanisms. As mentioned above, niche parties such as the Greens in Germany and France or the Liberal Democrats in the United Kingdom have embraced some technological developments faster and earlier than their incumbent counter-parts. Also, political parties selectively refer to co-benefits and risks in line with factors unrelated to the technology characteristics, including political ideology or different problem definitions (e.g. whether climate change is perceived as an immediate threat). For instance, right parties support incumbent technologies like coal and NT and strategically put forward co-benefits associated with these technologies, such as energy security arguments. The relative strength of such niche parties can, consequently, shape the level of consensus or partisanship in the overall party system agenda. Hence, how open a political system is toward smaller niche parties may influence the openness to technological learning of the political system as such. The important role of the green party in Germany in driving support for RET and related creative policy instruments underlines the relevance of party system characteristics. Due to the proportional voting system, amongst others, the green party could make a much earlier entry into the party system than in France and gain higher voting shares. Also, more consensus-based party politics, due to frequent coalition agreements, may explain the more accommodative strategies in Germany compared to France.

Third, beyond party and party system characteristics, path dependence in transition pathways constrains technological learning by political parties. Lock-in into infrastructure around technologies can slow down or even hinder that changing menus of policy options are strategically exploited by political parties (see Table A.4 in the appendix, individual quotes referenced in the text with [statement ID]). Statements on the need for continued support for FFT (especially coal) and NT were often based on their pre-existing dominant roles in energy systems, rather than on specific arguments regarding their benefits and/or costs. For instance, in the 1980s and 1990s, center-left parties in Germany and the UK defended coal technology against NT on such grounds [49, 53]. More recently, mostly right parties emphasized the need to protect FFT against competition by other technologies because of the historic role of this technology group [54]. Similarly, in France, and later in Germany and the UK, parties defended NT based on its relevance for the energy sector [45, 52, 55].

6. Discussion

In this paper, we took an exploratory approach to examine the co-evolution of party politics and technological change. Our analysis proceeded in two steps. In a first step, we mapped the changes in party positions and salience levels. We found that the energy sector is a less salient issue compared to more generic policy issues such as environmental protection or social welfare. Further analyses revealed differences in party positions on technologies and related instruments. We observe that on the level of the party system, the three countries differ significantly. With time lags, German political parties moved to high support for both creative and destructive policy instruments, targeting RET, NT, and coal. In France, while support for creative policy instruments and RET also increased over time, there is a clear and unresolved partisanship along the left-right spectrum on the support for destructive policy instruments targeting NT. In the United Kingdom, support for creative policy instruments targeting RET increased over time with a relative consensus among political parties. Yet, support for destructive instruments remained on low levels for all parties, with a U-turn and increasing support for NT in the most recent period analyzed.

In a second step, we qualitatively analyzed the collected data to explore the co-evolution of party positions and technological change. We showed that political parties are learning based on changing issue characteristics of technologies. We inductively substantiate two mechanisms through which technological learning happens. First, political parties are learning based on changes in the

relative co-benefits and costs associated with technologies (Schmidt et al., 2019). We find that the increasingly supportive positions on RET across all countries was often underpinned by arguments on their growing co-benefits in terms of job creation or international competitiveness of the energy industry. Second, these changes in the perceived co-benefits and costs, in turn, extended or limited the *menu of policy options* (Jacobs and Weaver, 2015). We find that as RET became increasingly economically and technically feasible these technologies therefore expanded the menu available to political parties. At the same time, the menu of policy options also decreased because of technology declines or phase-outs (Rosenbloom and Rinscheid, 2020). As a case in point, the German nuclear phase-out led to a subsequent decrease in the salience of NT in party agendas. Yet, evidence also suggested that party and party systems characteristics and general path dependence related to the energy system moderated these mechanisms. For instance, the timing of emphasized benefits and costs associated with technologies depended on the party family, with some niche parties embracing co-benefits earlier than center-right incumbent parties. The extent and speed to which political parties adapted to changes in the menu of policy options also depended on pre-existing infrastructure and resource endowments. For instance, for a long time, past investments in infrastructure and capabilities around NT made it politically unattractive for French parties to oppose this technology.

Overall, our study has shed light on the party politics of sociotechnical transitions, a phenomenon that has not received much scholarly attention, so far. Our findings suggest that parties may have different roles in transitions. For instance, niche and challenger parties, such as the Greens or Liberal Democrats, often act as *policy entrepreneurs* (Green-Pedersen, 2019). Early on, they adopted supportive positions on both RET and related policy instruments, even in light of the substantial uncertainty linked to technologies' future performance and co-benefits. As a reaction to this stimulus by policy entrepreneurs, with a significant time lag, incumbent parties in Germany and the United Kingdom followed these parties in an *accommodative strategy* (Meguid, 2005). Essentially, party positions in these countries co-evolved within the limits of a commonly shared party system agenda (Abou-Chadi et al., 2020; Green-Pedersen, 2019). Importantly, though, incumbent parties differed in the speed to which they adapted their positions, with center-left parties doing so faster than center-right parties. In France, the incumbent center-right party has taken an *adversarial* approach which has led to a polarized party system agenda.

Given that political parties constitute a "transmission belt" between societal and economic preferences and the political sphere (Lindberg et al., 2008), analyzing their positions can help understand past and ongoing transition processes. Through their horizontal coordinative capacity (Luna et al., 2020), political parties are a key player in the policymaking process and thus the implementation of creative and destructive policies targeted at technologies (Kivimaa and Kern 2016). Hence, our findings on political party positions complement recent transition studies. For instance, the detected country differences in party politics reflect earlier findings on transition pathways of the countries. In a landmark study, Geels et al. (2016) have shown that Germany's energy transition is on a substitution pathway, in which niche and regime technologies initially develop separately and are carried by different actors. This pathway is facilitated through supportive policies for market creation and niche protection and simultaneous regime destabilization through destructive policy instruments (Kivimaa and Kern, 2016). Conversely, the United Kingdom is on a transformation pathway which consists of gradual reorientation of the existing regime through adjustments by incumbent actors who, in turn, form an integral part of the transition to RET (Geels et al., 2016). France's sociotechnical transition, less well covered in the literature, can arguably be located somewhere in between a substitution and a transformation pathway. Given the rather strong partisanship around regime destabilization in France, the pathway may be strongly influenced by political majorities, e.g. leaning toward substitution in presence of center left to left governments. Yet, changing party politics may also re-shape the transition pathways in Germany and the United Kingdom, given that technology deployment is a continuous site of struggle (Smith and Raven, 2012) and, consequently, transitions are likely to be non-linear and permanently subject to modifications (Geels et al., 2016), partially because of changes in party politics. For instance, more recent developments in the United Kingdom, not covered in this study, show increased support for targeted destructive policies among British political parties, enabling a coal phase-out pledge (Brauers et al., 2020).

As shown by previous studies, the co-evolution of policy and technological change is at the heart of these pathway dynamics (Edmondson et al., 2019; Foxon, 2011; Rosenbloom et al., 2019; Schmid et al., 2020b). Our analyses complement these earlier insights which have not specifically analyzed political parties. Our findings show that political parties adapted their positions on technologies in a learning process (Goyal and Howlett, 2020) that is based on changing issue characteristics of technologies. Such learning by political parties suggests that policymakers may intentionally foster long-term political party support for RET by improving their underlying issue characteristics, such as costs, through the establishment of creative policies and protective spaces (Lockwood, 2016). In other words, by inducing technological change, policymakers may trigger a virtuous feedback loop in which niche technologies are increasingly supported by political parties, which may subsequently lead to more ambitious and stringent policy outputs (Levin et al., 2012; Rosenbloom et al., 2019). While this line of argument is central to the emerging literature on the co-evolution and feedback among policy, technology, and politics (Edmondson et al., 2019; Foxon, 2011; Meckling et al., 2015; Schmid et al., 2020b), the role of political parties in such loops has not yet been discussed explicitly. This study may serve a first building block for such an endeavor.

Yet, a virtuous feedback loop is not a guaranteed outcome, given that parties *strategically* draw on technological developments in order to support their arguments on energy technologies, in what could be called an active framing strategy (Chong and Druckman, 2007; Hoppmann et al., 2020; Leipold and Winkel, 2017). Hence, the "readiness" to learn is moderated by party characteristics such as ideology or party size. More generally, transitions research highlights that struggles between political actors are also influenced by institutional settings (Fuenfschilling and Truffer, 2016; Wood et al., 2020), or "static landscape characteristics" which constrain actor behavior (Geels and Schot, 2007). In the context of party politics, such landscape characteristics are certainly relevant and manifold

(see theory Section 2.2), and may help explain some of the cross-country variation observed in our study (see Fig. 5). For example, the role of smaller parties as policy entrepreneurs suggests that party systems more permeable to such parties (e.g. through proportional voting systems) may be more adaptive and flexible in supporting niche technologies compared to rigid two-party systems. In other words, conditional on either an accommodative strategy by incumbent parties or government participation of these challenger parties, political systems more hospitable to smaller parties may have a "comparative political advantage" in the development of niche technologies and the acceleration of technological change (Breetz et al., 2018; Wood et al., 2020).

7. Conclusion and avenues for future research

Given their coordinative and aggregative functions, political parties are central in sustainability transitions, which require overcoming collective action problems at a large scale and rapid speed (Geels et al., 2017). Parties are crucial for the implementation of creative and destructive policy instruments, and hence are key drivers of the "motors of creative destruction" (Kivimaa and Kern, 2016). This paper provides a systematic analysis of the party politics underlying transition pathways in Germany, France, and the United Kingdom. Our paper makes three important contributions. First, to the best of our knowledge, this is the first study that systematically maps political party positions on energy technologies and related policy instruments across all relevant parties in the three countries. Our sector-specific focus on technologies provides a more granular approach compared to party politics research, which is typically focused on more generic policy issues such as climate policy (Båtstrand, 2015; Carter et al., 2018; Ćetković and Hagemann, 2020; Farstad, 2018). Second, our paper also contributes to the growing literature on politics, actors, and agency in sociotechnical transitions as it represents a response to the calls for more research in this vein (Köhler et al., 2019; Lockwood et al., 2017; Meadowcroft, 2009; Roberts et al., 2018; Rosenbloom et al., 2019; Sovacool and Brisbois, 2019; Wittmayer et al., 2017). Third, our analyses shed light on a specific actor, political parties, in the co-evolution of party politics and technological change, and technological learning by parties therein (Edmondson et al., 2019; Foxon, 2011; Goyal and Howlett, 2020; Meckling et al., 2015; Schmid et al., 2020b).

While we believe that our exploratory study is conceptually relevant and empirically well-founded, we wish to highlight limitations that also provide guidance for future research. First, given the exploratory nature of this study, we cannot account for alternative factors that may shape the co-evolution of party politics and technological change. Alternative explanations such as party-industry ties or public opinion have been shown to influence party positions in other issue areas and should be relevant in sociotechnical transitions, too. Future research could tackle these questions with a more quantitative research design that allows to assess the relative weight of different drivers of party position change. Such research could build on our findings for developing hypotheses related to energy technologies and political parties. Second, while our empirical focus was fine-grained compared to much of the extant party politics research, we know from policy design and innovation literature that the even more detailed settings and calibrations of policies, and corresponding technology characteristics, matter for policy outcomes (Haelg et al., 2020, 2018; Howlett, 2014; Malhotra and Schmidt, 2020). While party manifestos do not allow for such analyses, future research should identify other ways to zoom into the party politics of designing policy mixes, for example by conducting expert interviews. Moreover, engaging in-depth analyses of individual cases, future research should analyze party positions on technology and sub-technology level and hence zoom into the aggregated technology groups used in this paper. Research should also focus on how exactly political parties make use of changing issue characteristics of technologies in their strategic framing of policy options, and how such framing interacts with the mechanisms detected here (see Hoppmann et al., 2020). Given the trade-off between analytical granularity and comparability across cases and time, this paper could not pursue such questions. Finally, although insights from party politics literature suggest that party positions influence subsequent policy outputs and changes, whether and how this is the case in socio-technical transitions remains an open empirical question. Future research could build on this study by assessing the links among party position changes, salience levels, and policy mixes targeted at technologies. Such a research agenda could also inform policy advice and help build forward-looking strategies for more ambitious sustainability transitions policy (Rosenbloom et al., 2020). For instance, research may shed light on the distribution of party support for different policy instruments, and thus inform societal actors on how to prioritize lobbying activities. In sum, the interaction between political parties and sociotechnical transitions is a surprisingly under-studied area that, in our view, deserves more attention and has the potential to provide novel and relevant insights for addressing sustainability challenges.

Declaration of Competing Interest

None.

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Appendices

Fig. A.1, Fig. A.2, Fig. A.3
Table A.1, Table A.2, Table A.3, Table A.4

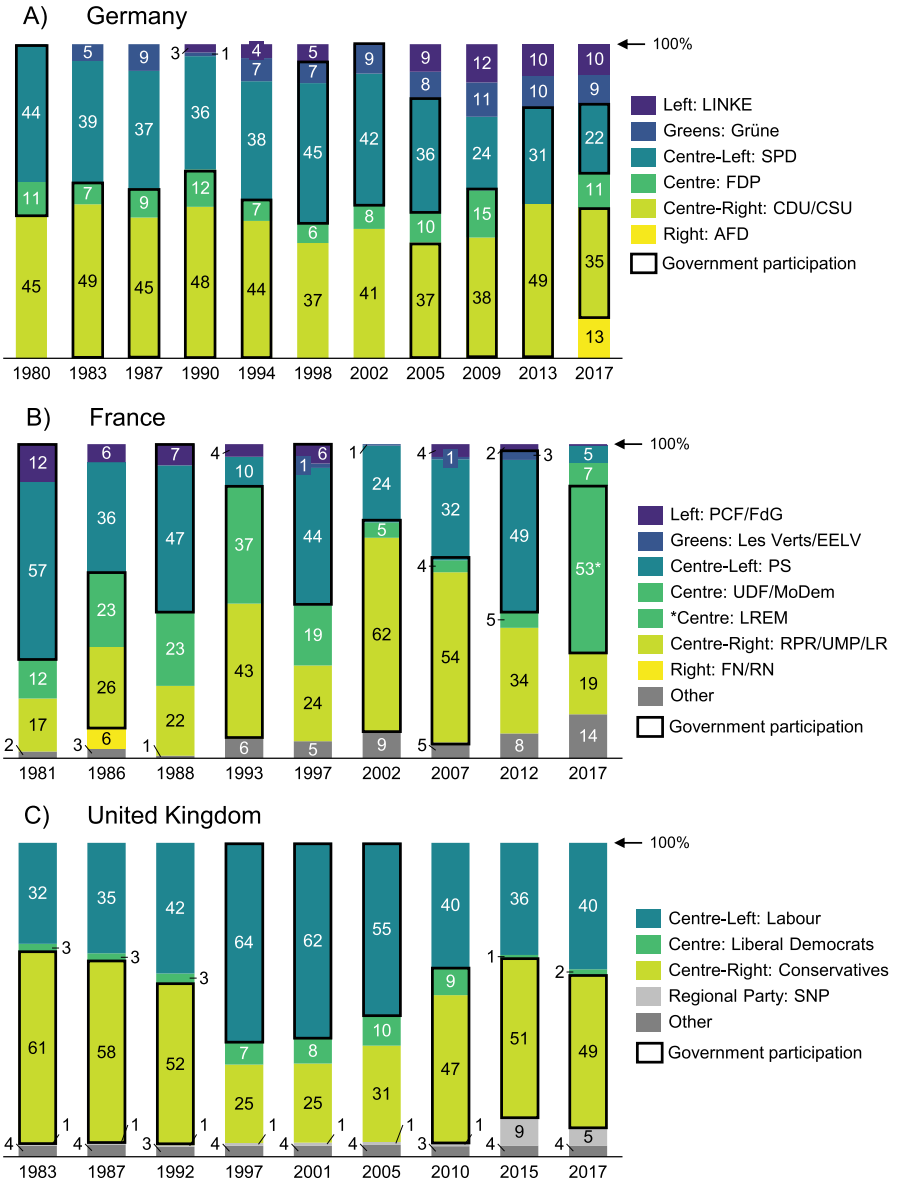

Fig. A.1. Share of parliamentary seats (in%) and government participation of political parties analyzed in this paper. Own illustration based on data from http://www.parlgov.org (see Döring and Regel, 2019).

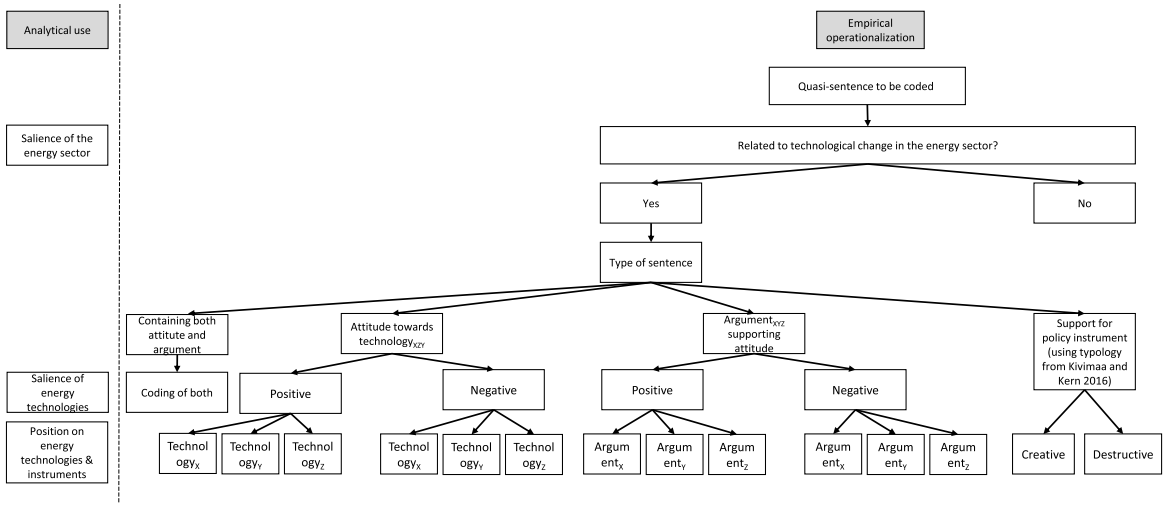

Fig. A.2. Coding scheme. The scheme distinguishes between analytical use (left) of data collected and the operationalization (right) and provides an overview on the coding procedure in chronological order from top to bottom.

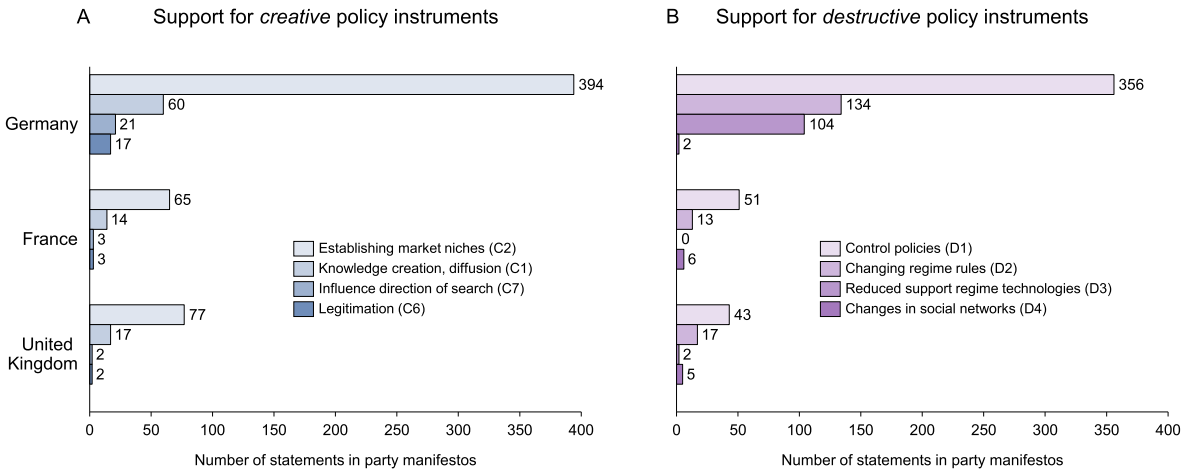

Fig. A.3. Most frequently supported creative policy instruments (A) and destructive policy instruments (B) in Germany, France, and the United Kingdom from 1980 to 2017 (aggregated). Based on coding of party manifestos and the policy instrument typology by Kivimaa and Kern (2016). The authors proposed the following policy instrument typology. Creative policy instruments: Knowledge creation, development and diffusion (C1); establishing market niches/market formation (C2); price-performance improvements (C3); entrepreneurial experimentation (C4); resource mobilization (C5); support from powerful groups/legitimation (C6); influence on the direction of search (C7). Destructive policy instruments: Control policies (D1); significant changes in regime rules (D2); reduced support for dominant regime technologies (D3); changes in social networks, replacement of key actors (D4).

Table A.1
Timeline of selected policy interventions in the energy sector in Germany, France, and the United Kingdom. Own illustration based on (Cointe, 2015; Kern et al., 2014; Lauber and Jacobsson, 2016; Lockwood et al., 2019; Renn and Marshall, 2016; Schmid et al., 2020b).

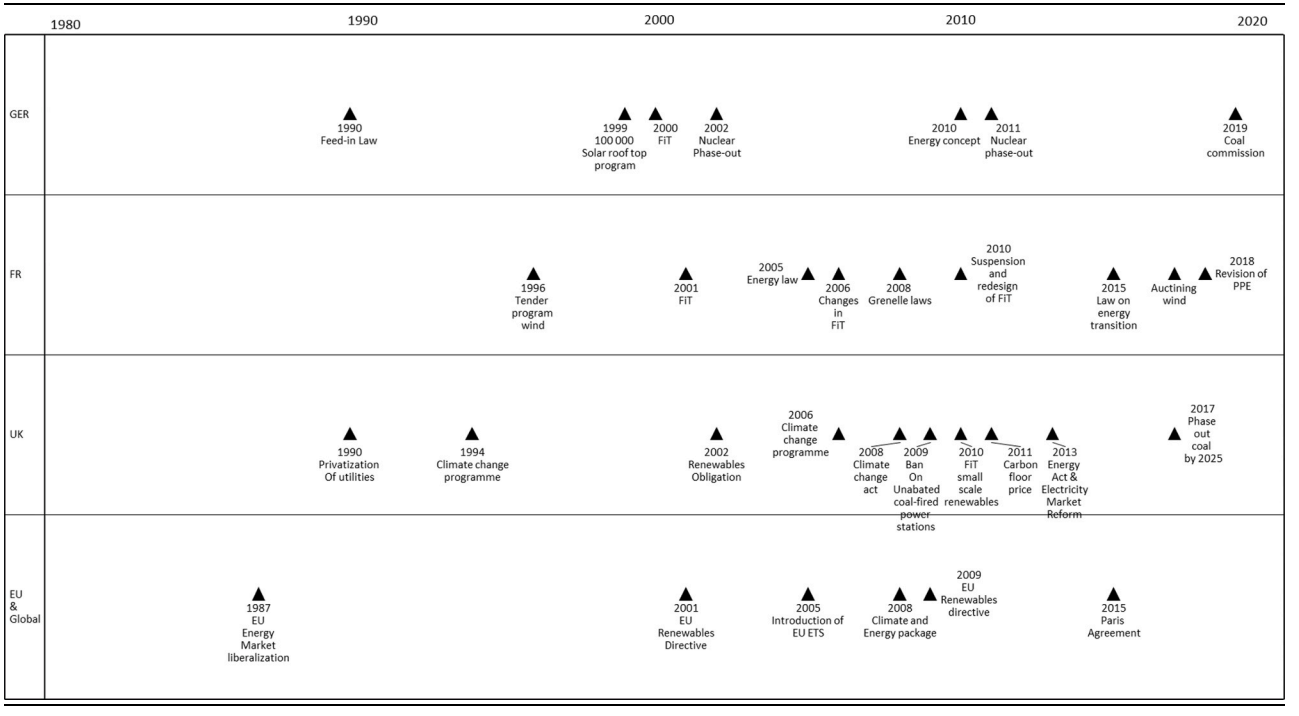

Table A.2
Frequencies of coded sentences on energy technologies per country, party, technology and year. Total sentences equals the total amount of quasi-sentences in a manifesto, including non-energy related topics. Positive or negative sign in front of numbers signifies support or opposition towards a given technology. In the rare case that a party has issued both positive and negative statements, the number indicates the net sum of these statements. Total number of coded sentences across all countries, years, and parties: 1680.

Germany												
		1980	1983	1987	1990	1994	1998	2002	2005	2009	2013	2017
center-left: spd	fossil fuels	3	7	3	2	3	3	2	4	7	2	−4
	Nuclear	2	1	−16	−8	−6	−6	−3	−5	−9	−4	−6
	Renewables	2	1	0	3	10	7	5	10	16	20	11
	Total statements	7	9	19	12	19	16	10	19	32	26	21
	Total sentences	285	237	281	263	303	998	1610	882	2208	2898	2645
Left: LINKE	Fossil fuels	0	0	0	1	0	0	0	0	−2	−15	−14
	Nuclear	0	0	0	−2	−1	−2	−2	−4	−9	−7	−19
	Renewables	0	0	0	4	1	3	4	3	10	8	20
	Total statements	0	0	0	7	2	5	6	7	21	29	33
	Total sentences	0	0	0	359	289	936	844	573	1664	2472	3939
Left: Greens	Fossil fuels	0	0	3	−5	−8	−5	−4	−7	−30	−29	−25
	Nuclear	0	−4	−12	−15	−20	−13	−22	−27	−44	−43	−28
	Renewables	0	0	3	4	13	10	30	20	43	57	33
	Total statements	0	4	18	24	41	28	56	55	127	129	96
	total sentences		164	492	144	684	2153	1660	1867	3596	5430	3875
center-right: cdu/csu	fossil fuels	4	0	2	3	5	3	7	2	4	3	−1
	Nuclear	8	0	18	1	6	4	15	10	7	0	−2
	Renewables	1	0	3	1	5	3	7	5	18	8	6
	Total statements	13	0	23	5	16	10	29	17	29	11	9
	total sentences	264	137	273	152	276	567	1315	777	2006	2574	1342
center-right: fdp	fossil fuels	6	0	0	2	−2	−2	−4	0	3	5	0
	Nuclear	3	1	9	5	2	2	3	6	7	0	0
	Renewables	0	1	5	10	4	2	2	3	9	13	4
	Total statements	9	2	14	17	8	6	9	9	19	18	4
	Total sentences	645	275	205	687	905	1605	1982	1419	2247	2579	2077
Right: AfD	Fossil fuels	0	0	0	0	0	0	0	0	0	0	1
	Nuclear	0	0	0	0	0	0	0	0	0	0	3
	Renewables	0	0	0	0	0	0	0	0	0	0	−13
	Total statements	0	0	0	0	0	0	0	0	0	0	17
	Total sentences										73	1004

France										
	years	1981	1986	1988	1993	1997	2002	2007	2012	2017
center-left: ps	fossil fuels	2	0	−2	0	0	0	−2	0	0
	Nuclear	3	0	8	0	−3	0	−2	−4	0
	Renewables	0	0	0	2	3	2	6	6	2
	Total statements	5	0	10	2	6	2	10	10	2
	Total sentences	264	164	232	250	286	696	601	428	152
Left: PCF, Front de Gauche	Fossil fuels	0	0	0	0	0	0	0	−2	0
	Nuclear	0	0	0	2	0	0	4	0	0
	Renewables	0	0	0	2	0	0	2	6	0
	Total statements	0	0	0	4	0	0	6	8	0
	Total sentences	84	119	55	294	70	80	600	1494	457
Les Verts/EELV	Fossil fuels				0	1	0	−7	−3	−2
	Nuclear				−2	−1	−3	−11	−16	−2
	Renewables				1	1	3	15	11	9
	Total statements				3	3	6	33	30	13
	total sentences				65	48	266	653	1130	220
center-right: rpr / ump / lr	fossil fuels	0	0	0	0	0	0	−2	0	0
	Nuclear	3	0	0	0	0	0	14	4	4
	Renewables	0	0	0	0	0	2	8	2	2
	Total statements	3	0	0	0	0	2	24	6	6
	Total sentences	224	79	47	127	61	426	1902	944	514
Right: Front National	Fossil fuels					0	0		0	−2
	Nuclear					0	6		4	4
	Renewables					0	0		0	0
	Total statements					0	6		4	6
	Total sentences		670	372.5	372.5	75	624	1225	594	516
Center: UDF/MoDEM	Fossil fuels				0	0	0	0	−2	
	Nuclear				0	0	6	8	4	
	Renewables				0	0	10	10	12	
	Total statements				0	0	16	18	18	
	Total sentences	55	55	55	55	122	694	584	826	904
Center: La Republique en Marche	Fossil fuels									0

(*continued on next page*)

Table A.2 (*continued*)

France										
	years	1981	1986	1988	1993	1997	2002	2007	2012	2017
	Nuclear									0
	Renewables									2
	Total statements									2
	Total sentences									724
United Kingdom										
	years	1983	1987	1992	1997	2001	2005	2010	2015	2017
center-left: labor	fossil fuels	8	2	5	1	3	1	3	5	3
	Nuclear	0	−1	−2	1	1	1	2	1	4
	Renewables	1	1	0	1	3	2	3	1	3
	Total statements	9	4	7	3	7	4	8	7	10
	Total sentences	1455	561	637	830	1494	1068	1133	1009	1328
Regional Party: SNP	Fossil fuels	–	–	1	5	0	–	–	2	3
	Nuclear	–	–	−2	−5	−2	–	–	0	3
	Renewables	–	–	2	3	1	–	–	6	11
	Total statements			5	13	3			8	17
	total sentences			813	651	806			892	787
center-right: conservatives	fossil fuels	5	3	7		0	0	3	5	10
	Nuclear	5	3	1		1	0	2	2	0
	Renewables	0	1	2		1	1	2	1	0
	Total statements	10	7	9		2	1	7	8	10
	total sentences	774	1047	1686	1084	724	344	1112	1588	1496
center: liberal democrats	fossil fuels	7	3	0	0	−1	0	1	5	−2
	Nuclear	4	6	−1	−3	−1	−2	−1	1	2
	Renewables	2	2	12	2	4	6	7	13	6
	Total statements	14	11	13	5	6	8	9	19	10
	Total sentences	741	960	837	842	1149	685	815	1917	1131

Table A.3
Frequencies of coded sentences on creative and destructive instruments per country, party, and year. Instruments coded with same dataset as for energy technology positions (Table A.2), following the instrument typology of Kivimaa and Kern 2016.

Germany												
		1980	1983	1987	1990	1994	1998	2002	2005	2009	2013	2017
center-left: spd	support for creative policy instruments	2	0	3	5	11	6	6	11	25	35	10
	Support for destructive policy instruments	0	3	14	15	7	8	3	7	15	23	14
Left: LINKE	Creative	0	0	0	3	0	7	3	3	7	8	17
	Destructive	0	0	0	7	3	1	3	9	20	45	43
Greens	Creative	0	0	5	12	17	9	23	14	40	51	25
	Destructive	0	2	8	19	24	34	18	24	43	60	58
Center: FDP	Creative	4	2	4	12	4	1	4	5	16	22	8
	Destructive	5	0	2	5	9	6	3	0	11	0	5
Center right: CDU/CSU	Creative	3	0	3	1	4	3	9	3	16	24	13
	Destructive	1	0	1	2	0	0	4	2	3	7	6
Right: AFD	Creative	0	0	0	0	0	0	0	0	0	1	0
	Destructive	0	0	0	0	0	0	0	0	0	0	0

France										
	Years	1981	1986	1988	1993	1997	2002	2007	2012	2017
Center left: Socialistes	Creative	0	0	0	1	1	1	2	4	1
	Destructive	0	0	0	0	2	0	3	3	0
Left : PC, Front de Gauche	Creative	0	0	0	1	0	0	2	5	7
	Destructive	0	0	0	0	0	0	0	2	12
Greens : Les Verts	Creative	0	0	0	1	1	3	9	13	5
	destructive	0	0	0	2	1	3	7	20	5
center-right: rpr / ump / lr	creative	0	0	0	0	2	1	4	2	2
	Destructive	0	0	0	1	1	3	9	13	5
Center : UDF/MoDEM/LREM	Creative	0	0	0	0	0	4	3	6	2
	Destructive	0	0	0	0	0	3	1	0	1
Right: FN	Creative	0	0	0	0	0	2	0	2	2
	Destructive	0	0	0	0	0	0	0	0	0

United Kingdom									
Years	1983	1987	1992	1997	2001	2005	2010	2015	2017

(*continued on next page*)

Table A.3 (*continued*)

United Kingdom										
	Years	1983	1987	1992	1997	2001	2005	2010	2015	2017
Center left: Labour	Creative	2	2	1	2	2	2	6	0	3
	Destructive	2	2	4	1	3	2	0	3	5
Center right: Tories	Creative	0	0	1	1	1	1	7	4	2
	Destructive	2	0	2	1	1	0	3	0	0
Center: LibDems	Creative	1	1	5	4	4	3	8	14	8
	Destructive	0	0	5	4	6	3	2	4	2
Regional: SNP	Creative	0	0	2	2	1	0	0	8	11
	Destructive	0	0	1	2	2	0	0	2	3

Table A.4
Exemplary quotes on path dependence as constraint for technological learning. Sources in brackets (party manifestos of legislative elections), ID for reference in text in square brackets.

Country	Exemplary quotes
Germany	*"We need nuclear energy as a transition technology until renewable energies can generate a sufficient amount of base load-capable electricity or until CO2 capture and storage for coal-fired power plants is available."* (FDP, 2009) [45] *"The Renewable Energy Sources Act, which was adopted by the red-green coalition in 2000, has led to an unprecedented expansion of renewable energies - today their share of electricity consumption is already over 25 percent."* (SPD, 2013) [46] *"We will gradually reduce our dependence on oil."* (CDU/CSU, 1980) [47] *"Domestic coal should come before nuclear energy in heat supply and power generation."* (SPD, 1983) [49] *"New coal-fired power plants, and extending the lifespan of nuclear power plants, are blocking the necessary expansion of renewable energies."* (Grüne, 2009) [50]
France	*"We will reduce the share of nuclear energy in electricity production from 75% to 50% by 2025, by guaranteeing the maximum safety of the installations and by continuing the modernization of our nuclear industry."* (PS, 2012) [57] *"We will reduce the share of nuclear energy by increasing the share of renewable energies in our final energy consumption to 20% in 2020 and to 50% in the longer term."* (PS, 2007) [58] *"We want to phase-out nuclear power by 2031 and the immediate cessation of plutonium and MOX production, reprocessing and transport of nuclear materials."* (Les Verts/EELV, 2012) [59]
United Kingdom	*"Labour will ban fracking because it would lock us into an energy infrastructure based on fossil fuels, long after the point in 2030 when the Committee on Climate Change says gas in the UK must sharply decline."* (Labour, 2017) [51] *"The UK has the world's oldest nuclear industry, and nuclear will continue to be part of the UK energy supply."* (Labour, 2017) [52] *"We will secure the long-term future of the coal industry by reducing imports, stopping the 'dash for gas' and reining back on open-casting."* (Labour, 1992) [53] *"The British coal industry once employed one million miners. Now, all three remaining deep coal mines in Britain are set to close by 2016, at a cost of 2000 jobs, despite having many years of productive life left and regardless of our continuing need for coal. 30 percent of our electricity is still produced from coal and we will be dependent on fossil fuels for many more years to come."* (UKIP, 2017) [54] *"We will support further nuclear projects and protect nuclear workers' Jobs and pensions."* (Labour, 2017) [55] *"In the next Parliament, the interests of the whole country require Britain's massive coal industry, on which we depend for the overwhelming bulk of our electricity generation, to return to economic viability."* (Tories, 1983) [56]

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