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The politics of low-carbon energy transitions – tracking and explaining change in German energy advocacy coalitions

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Abstract

The de-carbonization of the energy sector through a socio-technical transition is key to avoid dangerous levels of climate change. Of course such transition is not a mere technological challenge but highly political. Substantial policy change is necessary to open the regime and enable new technological and organizational solutions to flourish. In the transitions literature, the politics of socio-technical transitions have received more attention lately (Meadowcroft 2011; Kern and Rogge 2017). However, the link between political science theories and transitions theories is not firmly established. Here, we aim to strengthen this link by combining two literature streams from political science and relate them to transitions research. In order to analyze what causes policy change and policy stickiness, the Advocacy Coalitions Framework (ACF) has proven to be a valuable conceptual framework (in the field of energy and beyond). However, we argue that existing ACF research underemphasizes the external context of policy subsystems, in particular the socio-technical system and its changes. Our paper addresses this research gap, asserting that combining the AFC with elements of recent literature on policy feedback can help better explain temporal dynamics of actor and belief constellations in the energy-subsystem and, consequently, policy change. We therefore combine (1) external factors inherent in the ACF with (2) feedback effects based on policy-induced technological change in the energy sector. Policy feedback literature is compatible with the ACF, since both share the central assumption that significant changes in policy-subsystems require perturbations in socio-economic conditions and technology. The paper explores the validity of these claims with an empirical analysis of policy-induced technological feedback effects on the evolution of advocacy coalitions and beliefs in the German energy sub-system. Methodologically, the article identifies these dynamics based on Discourse Network Analysis (Leifeld 2016) of German parliamentary debates and newspaper articles from 1983 to 2013. We find strong indications that change in core beliefs of main stakeholders (particularly the Social Democrats) were largely enabled through policy-induced technological feedback, thus leading to even more ambitious policy change. As this change happened already during the 1990s – so rather early in international comparison – Germany could establish itself as one of the early movers in the global energy transition.

1. Introduction

The energy sector is the largest contributor to anthropogenic greenhouse gas (GHG) emissions (Mulugetta et al. 2014). In order to avoid dangerous levels of climate change, GHG-emitting technologies and practices have to be phased-out and replaced by low- or non-emitting technologies (Geels et al. 2017). Considering the urgency of the problem, it is surprising that the *politics* behind this necessary technological change (TC) in the energy sector have not been empirically analyzed systematically (Cherp et al. 2018), despite longstanding calls to focus on these politics (Meadowcroft 2011). Only few studies rigorously apply established policy theories to the topic of energy transitions (Kern and Rogge 2017), although classical policy theories, such as the Advocacy Coalition Framework (ACF) offer a rich toolset to analyse policy change and its underlying politics (Jenkins-Smith et al. 2014). The ACF explains major policy change primarily through events external to the subsystem, such as changes in public opinion, other policy subsystems, or socioeconomic conditions and *technology* (Markard, Suter, and Ingold 2016; Nohrstedt 2011; Sabatier 1988; Weible, Sabatier, and McQueen 2009). ACF studies provide valuable insights into policy change and evolution of advocacy coalitions in various sectors and across geographic boundaries (Pierce et al. 2017; C. Weible, Sabatier, and Jenkins-Smith 2011). However, there are two gaps in ACF literature: (1) The *mechanisms* linking external events to policy change are less well understood (Nohrstedt and Weible 2010; C. Weible, Sabatier, and McQueen 2009). Here, Policy Feedback Theory (PFT) literature might provide helpful complementary insights. PFT studies have helped better understand feedback effects of policies on a multitude of actors in different fields (Béland 2010). A prominent categorization of feedback effects differentiates between interpretive and resource effects (Pierson 1993). (2) Although technological change (TC) figures prominently in the original ACF framework developed by Sabatier (Sabatier 1988), this factor deserves systematic attention. Recently, Schmidt and Sewerin (2017) have argued that TC is an important factor in analyzing agency in politics.

In this paper, we address these two gaps by analyzing feedback effects of policy-induced technological change on the evolution of advocacy coalitions and their technology-related beliefs. The contribution of the paper is twofold. First, drawing on PFT literature, we discuss policy change with a focus on the mechanisms underlying such change. Second, using the case of the German energy transition, we empirically analyze policy-induced technological change as important, yet understudied, factor of policy change. We aim at answering the following research question: *How does policy-induced technological change affect the evolution of advocacy coalitions?*

In order to answer this question, we analyze the technology-related beliefs of actors in the German energy subsystem from 1983-2013, with special emphasis on the three legislative periods 1983-1987, 1998-2002 and 2009-2013. We proceed in two steps. First, we conduct a Discourse Network Analysis

(DNA) (Leifeld 2016) of the evolution of advocacy coalitions in the German energy subsystem. Second, we use process-tracing to investigate the mechanisms linking TC to this coalition evolution. We find that, besides factors such as nuclear disasters and shifts in public opinion, the evolution of German energy politics was driven by interpretive and resource feedbacks of technological change on actors' beliefs and coalitions. We show that the advocacy coalitions supporting fossil fuels and nuclear energy became less central in the subsystem, while the RET advocacy coalition increased in size and actor diversity. We propose a conceptual framework for understanding the evolution of energy politics as a function of policy-induced technological change (Schmidt and Sewerin 2017) and its interpretive and resource feedback effects (Pierson 1993) on advocacy coalitions (Jenkins-Smith et al. 2014). Our proposed framework builds on the well-established ACF and the emerging PFT literature, stressing the role of technological change as a driver of actor beliefs and coalitions.

The paper is structured as follows: Section 2 presents our theoretical argument based on the ACF and PFT literature. The research case and method are outlined in Sections 3 and 4. Section 5 presents the results of both DNA and process-tracing. We conclude with a discussion of the analysis, suggestions for future research and a summary of the main contributions.

2. Explaining the evolution of advocacy coalitions combining the Advocacy Coalition Framework and Policy Feedback Theory

The Advocacy Coalition Framework (ACF) is one of the most well-established frameworks in the field of policy studies (Sabatier 1988; Weible, Sabatier, and Jenkins-Smith 2011). In this framework, policy subsystems are the primary unit of analysis for understanding dynamic, long-term policy processes. Subsystems operate within a broader environment defined by stable and dynamic parameters and external events, as well as long-term coalition opportunity structures, short-term constraints and resources of actors, and other policy subsystem events (Weible, Sabatier, and McQueen 2009). Subsystems are conceptualized as coalitions of actors (advocacy coalitions) that seek to influence subsystem affairs and are defined by their shared policy beliefs and coordination patterns (Weible, Sabatier, and McQueen 2009). In other words, advocacy coalitions emerge because actors vary in their belief systems and seek to translate their beliefs into actual policies. Thus, a change in core aspects of policies indicates a major change in the beliefs of a subsystem's actors (Sabatier and Weible 2007). The ACF distinguishes between three levels in the belief system. First, deep core beliefs are fundamentally normative values and ontological axioms. They are not policy specific and can be applicable to multiple policy subsystems. Second, policy core beliefs are bound by scope and topic to the policy subsystem and thus have territorial and topical components. Third, secondary beliefs deal with a subset of the policy subsystem or the specific instrumental means for achieving outcomes (Jenkins-Smith et al. 2014, 191). These beliefs are subject to change over time, varying in how easily they evolve. While deep core beliefs are very hard to change, policy core beliefs are more flexible. Secondary beliefs change the fastest. As these beliefs "constitute the principal glue holding a coalition together" (Sabatier 1988, 117), assessing the evolution of subsystems requires the analysis of these beliefs. ACF hypotheses on advocacy coalitions and their beliefs focus on stability of coalitions, emphasizing the difficulty to change actors' policy core beliefs (Jenkins-Smith et al. 2014). In order to assess dynamics in coalition evolution, studies use traditional ACF hypotheses on policy change (Jenkins-Smith, St. Clair, and Woods 1991; Pierce 2011). The ACF explains policy change through a combination of four mechanisms (Nohrstedt and Olofsson 2016; Pierce et al. 2017). First, processes of policy learning can cause belief changes. Policy-oriented learning is defined as "relatively enduring alternations of thought or behavioral intentions that result from experience and/or new information and that are concerned with the attainment or revision of policy objectives" (Sabatier and Jenkins-Smith 1999, 123). It is argued that policy-oriented learning only affects secondary beliefs, explaining minor policy change only (C. Weible, Sabatier, and McQueen 2009). Second, beliefs can evolve through negotiated agreement between actors within the subsystem. Third, beliefs can shift because of perturbations internal to the subsystem, such as major electoral shifts. Finally, belief shifts occur because of perturbations external to the subsystem. The ACF argues that major policy change occurs through such perturbations external to the subsystem (Sabatier and Weible 2007), e.g. public opinion, policy outputs from other subsystems or changes in socioeconomic conditions and technology (P. Sabatier 1988; Wellstead 2017). These mechanisms have been applied in several studies, including climate policy (Ingold and Varone 2012), fracking policy (Ingold, Fischer, and Cairney 2017), offshore oil and gas developments (Jenkins-Smith, St. Clair, and Woods 1991), hydraulic fracturing (Weible and Heikkila 2016), pollution policy (Smith 2000), transport policy (Henry 2011), changes in energy policy (Markard, Suter, and Ingold 2016; Rinscheid 2015). While these studies offer important insights in the evolution of advocacy coalitions and policy change, the literature discusses two gaps: (1) the need to better describe causal mechanisms by which the external context influences policy subsystems, and (2) the integration of long-term dynamic external factors, such as technological change, in the explanation of policy change.

First, existing ACF research underemphasizes the *mechanisms* by which the external context influences policy subsystems (Henry et al. 2014; Howlett, McConnell, and Perl 2017; John 2003), leaving actual processes of policy change as a black box (Albright 2011; Leifeld 2013b; Nohrstedt 2010). Weible et al. (2009) argue that the steps between an external perturbation and major policy change need to be investigated more thoroughly. The transition from one stable advocacy coalition structure to a new stable structure has not been sufficiently analyzed (Leifeld 2013b). The ACF does not clearly specify how or under what conditions a dominant coalition alters the "policy core aspects" of a governmental program – or its underlying policy core beliefs —the definition of major policy change (Nohrstedt 2008; P. Sabatier and Jenkins-Smith 1999).

Second, although ACF literature conceptually highlights the importance of external events, *dynamic long-term* factors of policy change, especially technological change, remain understudied. Most literature analyzing external events puts its emphasis on the impact of single events and crises to policy change (Nohrstedt and Weible 2010), such as nuclear disasters (Nohrstedt 2008). However, as Jones and Jenkins-Smith (2009) have argued, a range of dynamic long-term macro-level features, such as public opinion and policymaking venues, play also an important role in shaping policy processes. In the ACF, an important hypothesis to explain policy change includes these external dynamics: "Significant perturbations external to the subsystem (e.g., changes in socioeconomic conditions, public opinion, system-wide governing coalitions, or policy outputs from other subsystems) are a necessary, but not sufficient, cause of change in the policy core attributes of a governmental program" (C. Weible, Sabatier, and McQueen 2009, 113). For understanding policy change in the subsystem, the first of these perturbations, e.g. changes in socioeconomic conditions, is an important factor. The ACF argues that such changes in socio-economic conditions and technology can substantially affect a subsystem, either by undermining the causal assumptions of present policies or by significantly altering the political support of various advocacy coalitions (P. Sabatier 1988). As Sabatier (1988, 134) argued, "changes in relevant socio-economic conditions (…) can dramatically alter the composition and the resources of various coalitions and, in turn, public policy within the subsystem." The ACF gives technical information an important role for understanding subsystem affairs and belief evolution (Jenkins-Smith et al. 2014). However, only few studies analyze the role of technological change for changes in subsystems (Markard, Suter, and Ingold 2016).

To overcome these gaps in the ACF literature, we argue for combining ACF with policy-feedback theory (PFT). The first gap described above can thus be overcome by using causal mechanisms from policy-feedback theory (PFT) to complement ACFs description of policy change. The second gap can be overcome by conceptualizing external factors not as singular and subsystem-independent events but instead as policy-induced events, i.e. outcomes caused by subsystem-internal decisions. Such policy-induced events are at the heart of PFT thinking, effectively establishing an evolutionary understanding of the interaction of policy outcome and subsequent politics (John 2003).

Policy feedback is a temporal concept that points to the fact that over time, policy can shape politics (Beland 2010). In other words, "new policies create a new politics" (Pierson 1993, 595). Policy feedback theory provides us with a more detailed theory on mechanisms of policy change through its distinction between interpretive and resource effects of policies on politics (Pierson 1993). These two mechanisms resonate with the ACFs distinction between cognitive policy-learning and real world changes (P. Sabatier 1988, 134). First, studies investigating interpretive effects view policies as sources of information and meaning, affecting the cognitive evaluation of policies (Pierson 1993). Thereby, interpretive effects can create and change visions and expectations of actors. In the ACF, such interpretive mechanisms are discussed as policy-oriented learning. Policy-oriented learning involves perceptions concerning external dynamics, and increased knowledge of the state of problem parameters and the factors affecting them. The framework assumes that such learning is instrumental, serving to further their policy objectives (Sabatier 1988). Second, resource effects of policies are defined as effects that provide means and incentives for political activity of actors, hence influencing the relative material power of actors (Pierson 1993). New policies can also create new actors that become part of advocacy coalitions (Patashnik 2008). In the ACF, these resource effects are discussed in the context of external shocks. After such as shock, a redistribution of resources may occur, shifting the power among coalitions in a subsystem and mobilizing minority coalitions (Nohrstedt 2008, 2011). These resources may include financial or political and scientific/technical resources, leadership, public opinion, and access to authority (Nohrstedt and Weible 2010; P. Sabatier and Weible 2007). Both feedback effects, interpretive and resource, can result in attitudinal responses of actors, affecting their beliefs and positions in advocacy coalitions (Mettler and SoRelle 2014). Importantly, these effects can be positive and negative (Jacobs and Weaver 2015; Jordan and Matt 2014). Such a perspective could help to better explain how coalitions form and maintain themselves over time (Schlager 1995).

Interestingly, and perhaps because most feedback-centered research is done in the field of social policy (Kern and Rogge 2017), technological change as driver of politics is rarely considered systematically in this literature (T. S. Schmidt, Sewerin, and Bateson 2017). Engaging more systematically with the potential feedback effects of technological change seems highly relevant: Technological change has a huge influence on creating socio-economic winners and losers, which relates back to the two main feedback mechanisms, interpretive and resource, and the ACF mechanism of change through external events and dynamics. Such a perspective allows us to complement the basic PFT paradigm that new policies create new politics: we would argue that new policies create new technologies which create new politics. This should be particularly relevant in the case of energy transitions where the basic idea is to shift from incumbent carbon-intensive energy technologies to low-carbon technologies (Raven et al. 2016). For instance, there is a consensus that policies enabled major TC in the RET sector (Hoppmann et al. 2013; Sagar and van der Zwaan 2006). Policies influence TC through mainly through research and development funding, subsidies or regulation (Taylor, Rubin, and Hounshell 2005), thus creating favorable market conditions for the diffusion of new energy technologies (Smith and Raven 2012). Crucially, this policy-induced feedback in the energy sector can lead to both resource and interpretive effects: Providing resources can influence activities and strategies of actors stimulating changes in the energy subsystem to the benefit of specific energy technologies (Foxon, Hammond, and Pearson 2010). Experience with policy-induced TC can influence cognitive perception and attitudes concerning competing energy technologies and their respective (dis-)advantages, such as costs or environmental impact.

In this paper, building on ACF's external mechanism of policy change, we discuss policy-induced technological change and its feedbacks as main driver of the evolution of advocacy coalitions. Figure 1 gives an overview of our conceptual framework.

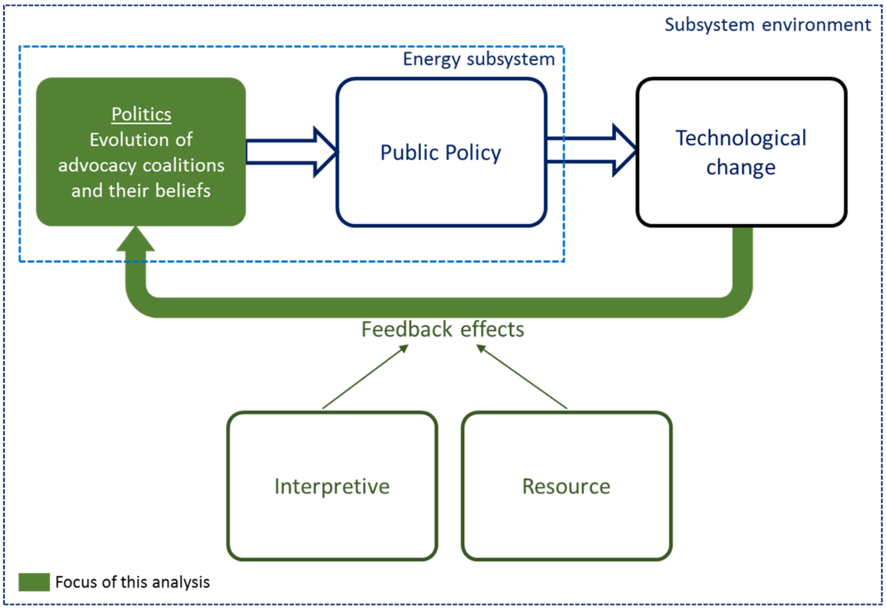

Figure 1: Schematic overview of theoretical argument

Based on Schmidt and Sewerin (2017)

As proposed by the ACF framework, we analyze politics as the evolution of advocacy coalitions and their beliefs over time. Empirically, we restrict our analysis to the German energy subsystem and its actors. In our analysis, we focus on the evolution of advocacy coalitions and their beliefs (highlighted in green in Figure 1). Second, addressing calls for better integration of TC into the explanation of policy change (Schmidt and Sewerin 2017); we focus on feedback effects of TC as main factor explaining evolution of the energy subsystem. Third, since we are interested in technological change as main driver of the evolution of advocacy coalitions, we focus on the change in technology-related beliefs of subsystem actors. We argue that beliefs around energy technologies correspond best to policy-core beliefs, as they are neither deep-core beliefs based on ontological axioms, nor minor secondary beliefs. Instead, beliefs on energy technologies are bound by scope and topic to the energy policy subsystem. Finally, our analysis conceptually relies on the external mechanism of policy change and policy learning proposed by the ACF. In order to analyze the mechanisms of these feedback effects, we draw on PFT literature and its distinction between interpretive and resource feedback effects.

3. Case selection

In our study, we analyze the evolution of advocacy coalitions in the *German energy sector*. We selected the energy sector, because it has seen major technological changes in the last three decades (Edenhofer et al. 2011). Second, technological change in this sector is mostly policy-induced, making an analysis of the politics behind these changes interesting and necessary (Meadowcroft 2011). Third, analyzing the evolution of the energy sector is highly relevant, as it is a major contributor to Greenhouse Gas Emissions (Mulugetta et al. 2014). Thus, in order to avoid dangerous levels of climate change, GHG-emitting technologies and practices have to be phased-out and replaced by low- or non-emitting technologies (Geels et al. 2017). To gain more insights into the feedback mechanisms of policy-induced technological change on advocacy coalitions, we study the evolution of German energy politics in three periods from 1983-1987, 1998-2002 and 2009-2013. Even though Germany's leadership in climate and energy politics is diminishing in favor of countries like China or India (Bals et al. 2013), it is still one of the frontrunners of the global energy transition towards low-carbon energy systems and enabled major advances in renewable energy technology (Hake et al. 2015; Jacobsson and Lauber 2006; Lauber and Jacobsson 2016). Furthermore, its long and exceptional history of conflictual political energy debates (Renn and Marshall 2016) makes it an interesting case for longitudinal analyses. Besides these empirical considerations, Germany is also an interesting case from a theoretical perspective: while most parameters in Germany's energy subsystem's environment remain relatively stable, the factor of interest – changes in socioeconomic conditions and technology – is very dynamic. It is thus a typical case in Seawright and Gerring's (2008) case selection rationale.

Theoretically, ACF distinguishes between the subsystem and its environment. This environment is composed of (1) relatively stable parameters and structures and (2) external system events (see Figure 6.1 in Jenkins-Smith et al. 2014, 194). First, more stable parameters consist of the basic institutional, social and cultural structures in which a subsystem is embedded. Long-term coalition opportunity structures are products of these relatively stable parameters. Second, the external subsystem environment is also composed of external system events, such as single disastrous events, public opinion, changes in other policy subsystems, or socioeconomic conditions and technological change. In the ACF framework, these dynamic conditions take a center stage in explaining policy change, through their effects on actor beliefs and resources. As discussed in the previous section, the dynamic conditions leading to policy change are understudied in the ACF. In the following, we first discuss stable parameters of the German case, followed by a discussion of the dynamic external system events. As discussed in section 2, we argue that TC is an important, yet understudied, external system event. In section 3.2., we provide more information on these changes in socio-economic conditions related to TC.

3.1. The environment of Germany's energy subsystem

Throughout all three periods, Germany's basic constitutional structure remained a consensual and parliamentary democracy (M. Schmidt 2009). Corporatism characterized the relationship between political elites and civil society actors in the policy process. Although the reunification of West and East Germany certainly affected the energy subsystem's environment, the basic constitutional structure and fundamental sociocultural values did not lead to major changes relevant for the energy policy subsystem (Illing 2016). Only the distribution of natural resources evolved through the integration of East German lignite mines (Renn and Marshall 2016), arguably reinforcing the coal advocacy coalition in the energy subsystem. In addition, the long-term coalition opportunity structures were rather stable. The degree of consensus needed for major policy change was always high, with coalition governments and corporatist relations to societal actors in the subsystem in all three periods (M. Schmidt 2009). The arrival of the Greens and the Left party in 1983 and 1998 indicate a stable level of openness of the political system (Dryzek et al. 2003).

As opposed to the stable parameters, external system events in the German case were very dynamic. Clearly, single events, such as nuclear disasters have affected the German energy subsystem (Renn and Marshall 2016). The Chernobyl and Fukushima accident have reinforced already existing doubts about the role of nuclear energy in the energy subsystem, primarily in pivotal political parties in the first (Social Democrats) and third period (Conservatives). Related to these events, public opinion played a major role in shaping beliefs towards energy technologies. For instance, the Greens arrived in the German parliament with the support of a grass-roots movement against nuclear energy (Dryzek et al. 2003). Several studies mention the central role of wide public support for RETs as an important factor for the success of the German energy transition (Wüstenhagen, Wolsink, and Bürer 2007). Changes in other policy subsystems also played a role in the energy subsystem. Nuclear energy policy always related to foreign affairs, e.g. through the relationship with France and the EU in EURATOM (Illing 2016). The EU integration started through the set-up of the European Coal and Steel Community. From the 1980s on, environmental concerns around pollution and climate change influenced actor's beliefs on energy technologies beyond the more traditional themes of costs or energy security.

3.2. Changes in socio-economic conditions and technology

Crucially, changing socio-economic conditions and technology affected the German energy subsystem, especially between the three periods, 1983-1987, 1998-2002 and 2009-2013. Over these decades, the relative importance of fossil fuels (including mainly lignite and hard coal, but also gas and oil), nuclear energy and RETs (solar, wind, biomass, geothermal and hydro) changed significantly. Figure 2 depicts the evolution of the share in the electricity production of fossil fuels, nuclear and RETs from 1980 to 2015. The share of fossil fuels declines from the beginning of the 1980s, with sharp decreases in the period from 1980 to 1985, and between 2010 and 2015. After an increase between 1980 and 2000, the share of nuclear energy starts decreasing in the year 2003. The share of RETs (including hydro) remains stable until the end of the 1990s, however it increases strongly after the year 2000, especially from 2005 onwards.

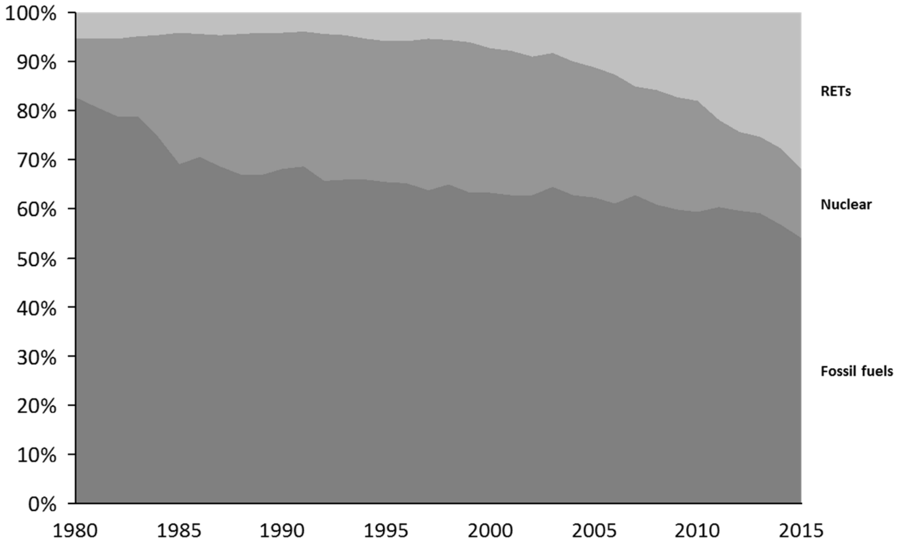

Figure 2: Electricity production per energy source (in % of total), Source: IEA, Worldbank

Interestingly, the growth in RET was accompanied by a redistribution of ownership of electricity production. While conventional energy, such as hard coal and lignite, was dominated by the "Big Four" (RWE, EON, Vattenfall, EnBW), the RET ownership structure is much more diverse (Bayer 2014; Steffen 2018). In 2012, private citizens and farmers owned 46% of the total electricity production from RETs, while the "Big Four" only owned 5%. Project developer and industry actors owned 14% of electricity production each, banks 13%. Regional/municipal utilities and other actors owned the remaining 8%.

Besides the share in electricity production and the ownership structure, also costs of energy technologies developed over time. Figure 3 depicts the learning curves of solar PV in Germany (a.) and nuclear energy in Western countries (b.). Figure 3a shows a strong decrease in the module price of solar PV with increasing cumulative production (logarithmic axes). The price decreased by ca. 90% between 1990 and 2010. The cost development looks different in the case of nuclear. Figure 3b shows that for both the French and US nuclear power plants, costs more than quadrupled between 1980 and 1999. These costs should be comparable to those of German nuclear power plants.

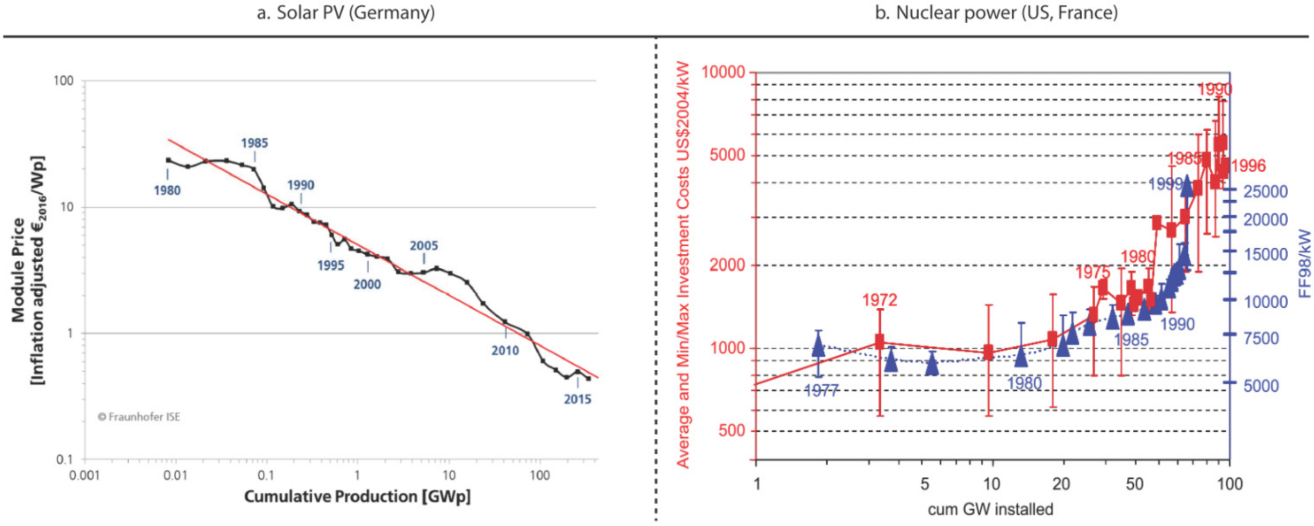

Figure 3: Learning curve of solar PV in Germany (Wirth 2018) *and nuclear energy in the US and France* (Grubler 2010)

Research and development is another important indicator for technological change in the energy sector. Figure 4 shows the increase of number in patents on different RETs in Germany from 2000 to 2016. The number of patents increased by 967% between 2001 and 2009, and by another 75% between 2009 and 2016.

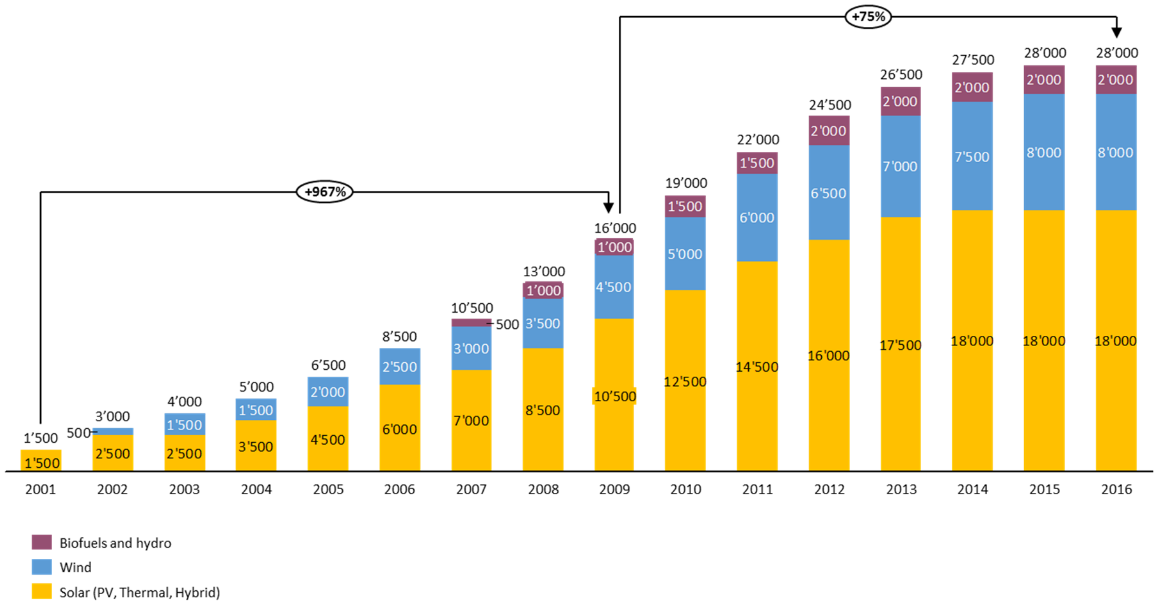

Figure 4: Number of patents on RETs in Germany, Source: IRENA (2018)

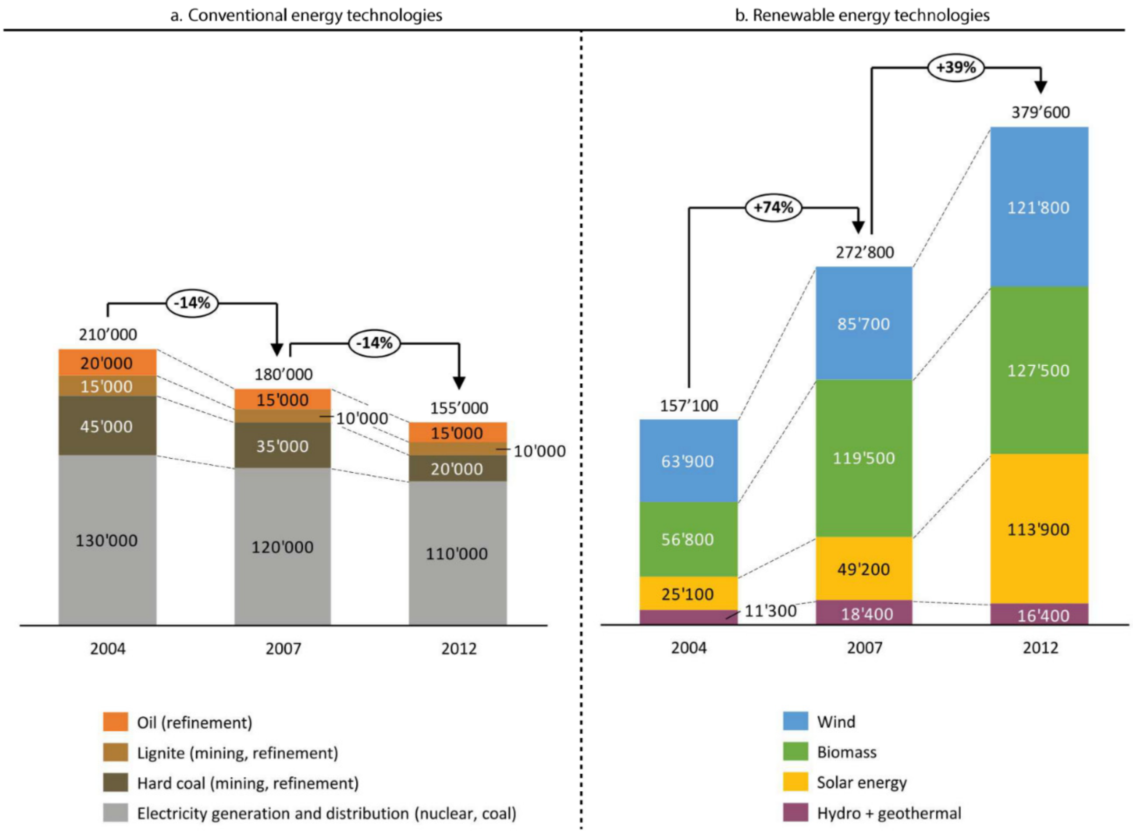

Figure 5: Employment in the conventional sector (Dehnen, Mattes, and Traber 2015) *and the RET sector* (O'Sollivan, Lehr, and Edler 2014)

The strong increase in innovation in the RET sector also affected employment in the RET sector (Figure 5, b.). While employment in conventional energy generation, as well as mining and refinement in the coal and oil industry decreased by 14% from 2004 to 2007 and 2007 to 2012 (Figure 5, a.), employment in RETs increases by 74% and 39% in the same periods. While one should be careful when comparing these numbers – 5a. and 5b. rely on different data sources -, these numbers indicate an opposite employment trend for conventional energy technologies and RETs. The main cause for the negative trend in the conventional energy sector is the falling employment in hard coal and lignite mining. In the hard coal industry, more than 60000 miners worked in 2000, in 2017 there are fewer than 8000 and in 2018 the last mine will be closed (Wörlen, Keppler, and Holzhausen 2017). Interestingly, the negative employment effect of the nuclear phase out is not very strong, as the sector offers relatively few jobs, and as most working force remains employed for activities accompanying the phase out (Dehnen, Mattes, and Traber 2015).

The evolution of electricity production, costs, patents and jobs indicate that the relative importance and competitiveness of fossil fuels, nuclear and RETs evolved between 1983 and 2013. As the energy sector was a highly regulated sector (Meadowcroft 2011), policies are the main factor inducing these technological developments (Sagar and van der Zwaan 2006). In the end of the 1990s, the market liberalization through the German Act on Energy Management affected all energy technologies, as the monopolies of the big energy companies had been broken (Lauber and Jacobsson 2016). Before this reform, the monopolistic energy companies had no obligation for general connection and supply of third-party electricity (Illing 2016). While the market liberalization affected was not targeted at single energy technologies, most policies were technology-specific. First, fossil fuel policies focused mainly on the regulation and promotion of hard coal and lignite. In the 1980s, regulations aimed at decreasing the impact of coal production on the environment, especially addressing the issue of *Waldsterben* (Renn and Marshall 2016). Besides regulations, subsidies for hard coal and lignite were high and only declined in the early 2000s (Pahle 2010). As expensive German hard-coal could not compete with other energy sources, the government launched a gradual hard-coal phase-out already in the 1980s, protecting the hard coal industry through subsidies up to 327 billion Euros between 1983 and 2014 (Renn and Marshall 2016). Lignite was not included in the phase-out plan, as it was more cost-competitive and regarded as a national energy reserve (Illing 2016). Second, nuclear energy was introduced in the 1970s with significant state subsidies, both for research and development and deployment. In 2002, after major conflicts around nuclear policy, the German government and the "Big Four" power utilities agreed a nuclear phase-out, limiting the lifetime of power plants to 32 years on average (Renn and Marshall 2016). In October 2010, the conservative-liberal government amended the Atomic Energy Act with the goal to again extend the lifetime of nuclear power plants. However, after the Fukushima accident in 2011, the same government enacted the 13th amendment to the Atomic act, implementing a nuclear phase-out by 2022 and closing seven power plants immediately (Huenteler, Schmidt, and Kanie 2012). Third, first RET-supportive policies were implemented in the early 1980s, when the government started subsidizing solar panels and heat pumps (Hake et al. 2015). In 1988, research and development programs were introduced, involving market creation for 100 MW of wind power and 1.000 solar roofs, later extended to 100.000 solar roofs (Jacobsson and Lauber 2006). In 1990, a first feed-in-law introduced a duty for utilities to pay a minimum price and accept third-party renewable energy in the grid (Illing 2016). Between 1990 and 1999, wind power generation increased by a factor of 78 (from 71 to 5.528 GWh) and solar power by a factor of 42 (from 1 to 42 GWh) (Jacobsson and Bergek 2004). The subsequent feed-in law in 2000 introduced fixed feed-in tariffs for electricity from renewable sources, now decoupled from current electricity prices and a lot higher than under the previous policy (Jacobsson and Lauber 2006). In 2010, the conservative-liberal government introduced the Energy Concept, setting the goal of 35% and 80% of renewable power generation in 2020 and 2050 (Lauber and Jacobsson 2016). To conclude, policy-induced technological change represents a major dynamic factor in the environment of the German energy subsystem.

4. Methods

To investigate whether policy-induced TC affects the evolution of advocacy coalitions, we proceed in two steps: First, we apply Discourse Network Analysis (DNA) to measure belief change of advocacy coalitions. In a second step, we complement this quantitative analysis with case-study methodology in the form of process-tracing. This mixed-methods research design allows us to substantiate whether policy-feedback in the form of resource and interpretive effects are the causal mechanism linking TC and belief change.

As argued in the ACF framework and discussed in sections 3.1 and 3.2, the combination of relatively stable parameters and more dynamic factors creates constraints and resources of subsystem actors. These constraints and resources, in turn, affect actor's beliefs and their positions in competing advocacy coalitions. Discourse Network Analysis (DNA) is particularly suited to measure belief change of advocacy coalitions (Leifeld 2013, 2016). It is a combination of category-based content analysis and social network analysis. Based on coding of text, the method allows linking actors (such as firms, associations, NGOs etc.) to concepts (such as arguments for or against energy technologies). The results of such an analysis is a two-mode network representing the topology of a subsystem, consisting of beliefs and actors sharing these beliefs. Figure 7 in the annex gives an overview on the model. For a detailed description of the method, see Leifeld (2016). With such an actor-technology network, we are then able to apply network tools, e.g. visualizing the evolution of networks over time, and indicating the relative centrality of actors and concepts in the network. For the analysis of advocacy coalitions, we will transform the two-node actor-technology networks into one-mode actor networks, e.g. showing networks of actors forming ties based on their shared technology-related beliefs.

Based on policy documents and scientific literature on German energy politics, we selected three periods that cover crucial periods of fundamental (re-)orientation of the German energy sector: the 10^{th} (1983-1987), 14^{th} (1998-2002) and 17^{th} (2009-2013) legislative period. During these periods, competition between fossil fuel technologies, nuclear energy and renewable energy technologies was particularly salient in the German energy subsystem. Interestingly, these periods set the scene for discussions on general support for and opposition to, as well as benefits and disadvantages of energy technologies. They revolved around the following questions: which energy technologies should play an important role in the future and why technology A (instead of B)? Unit of analysis is the affiliation of an actor to a positive or negative statement on an energy technology. Since we want to compare competing energy technologies and their advocacy coalitions, our analysis includes all major energy technologies important for the German subsystem: fossil fuels (mainly hard coal and lignite, but also comprising gas and oil), nuclear energy and renewable energy technologies (mainly solar PV and onshore/offshore wind, but also comprising biomass, geothermal energy and hydro). Concerning actors, we include policymakers, since they are primary responsible of energy policies (Renn and Marshall 2016). Due to the strong corporatist element in the German energy subsystem (Jänicke and Jacob 2004), we also include other societal actors such as unions and NGOs, energy technology industry, energy producer/utilities, and research institutes.

For data collection and analysis, we follow the steps as described by Leifeld (2013a). Analysis of newspaper articles allows us to identify all relevant actors in each period and their technology-related beliefs. As data source, we chose the Frankfurter Allgemeine Zeitung (FAZ) archive, since it is the only nation-wide German quality newspaper with an electronic archive dating back to the 1980s. In order to define the population of newspaper articles, we used the FAZ-internal selection tool. We restricted newspaper articles to general energy policy topics in both the economy and politics section of the newspaper. In a next step, we excluded several key words and chose the periods as indicated above (see Table 5 in the appendix for more detailed information). With this filter method, we obtained a total of 3387 newspaper articles for all three periods. After data collection, we started the coding process. We developed the codebook through an iterative process, both inductive and deductive, based on existing literature and pre-analysis of newspaper articles. For a draft of the codebook, see Table 4 in the appendix. A single researcher encoded the articles, and a second researcher double-checked the coding. This four-eye-principle ensures the validity and reliability of the coding (Eisenhardt 1989). Besides the control coding by a second person, we employed a full-text search based on regular expressions to find potentially missing statements. The time intensive iterative development of the codebook, discussions with the control coder and additional measures mentioned above increase the reliability and validity of the coding (Leifeld 2013a).

After quantitatively assessing the development of advocacy coalitions and their beliefs over time through DNA, we seek to trace mechanism linking TC and these developments. As a distinct case-study methodology, process-tracing attempts to identify the intervening causal process between an independent variable (or variables) and the outcome of the dependent variable (Collier 2011). Crucially, this method can also be used for building theories of causal mechanisms (Beach 2016). As discussed in Section 2, we argue that the two policy-feedback effects established in the literature can complement ACF theory and its understanding of external subsystem events. According to Beach and Pedersen (2016), theory-building process-tracing is an iterative process that seeks to build mid-range generalizable theoretical explanation describing causal mechanisms from empirical evidence. Thus, it allows for generalizing outside of the individual case to a broader context.

5. The evolution of the advocacy coalitions and their beliefs in the German energy subsystem

Our empirical analysis of the German energy subsystem focuses on three periods, from 1983-1987, 1998-2002, 2009-2013. For each of these periods, we identify the relevant changes in advocacy coalitions in the German energy subsystem. First, we discuss the evolution of advocacy coalitions through discourse network analysis. In a second step, we complement these descriptive network analyses with process tracing of belief shifts of selected actors.

5.1 Discourse network analysis

Figure 6 presents the advocacy coalitions of each period. Nodes represent subsystem actors, such as political parties, firms, utilities, NGOs, unions or research institutes. Since subsystems are affected by any actor directly or indirectly influencing subsystem affairs, we included all actors that voiced their beliefs about energy technologies in the newspaper articles[1]. To analyze this actor diversity, simplifying assumptions must be made to describe and analyze the subsystem (Jenkins-Smith et al. 2014, 191). According to the ACF, an effective approach is to organize actors into advocacy coalitions based on shared beliefs. In our analysis, we follow this advice by focusing on policy-core beliefs of actors that relate to energy technologies. In the three networks in Figure 6, two nodes are connected if both support or reject the same energy technology, grouped into the following categories: fossil fuels, nuclear, efficiency and RET. In order to increase the visibility of advocacy coalitions, we ran a grouping algorithm[2]. The color of nodes indicate the affiliation to one of the three advocacy coalitions: fossil fuels, nuclear or renewables. Nodes that are assigned to the same coalition have more shared technology-related beliefs than nodes in another coalition (shared beliefs with other coalitions' actors are still possible). Finally, the bars on the left of each network indicate the relative centrality of these technology-related beliefs in the respective networks[3].

In the first network (a.), fossil fuels and nuclear energy are both pre-dominant energy technologies in the subsystem, occupying 42% and 46% of the relative centrality of the advocacy coalitions' beliefs.

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[1] In order to increase visibility of the network evolution, we excluded all nodes with frequency < 2 in networks a. and b. In period c., all nodes are included because we do not have sufficient data for this period, yet. Furthermore, we ran a link sparsification algorithm (quadrilateral Simmelian) that deleted weak links between nodes and increased visibility of the network structure (threshold = 0.6) (Nocaj, Ortmann, and Brandes 2015). A spring-embedder algorithm that increases visibility of the network assigns the relative position of each node. For the visualization, we use *visone* (Brandes and Wagner 2004).

[2] We calculated these groups based on an analysis of the network's modularity using the Louvain algorithm (Blondel et al. 2008). The algorithm detects communities as groups of nodes within a network that are more densely connected to one another than to other nodes. Importantly, affiliation to an advocacy coalition does not exclude shared beliefs with actors in other advocacy coalition. However, this method allows us to aggregate the network complexity into more meaningful groups.

[3] The relative centrality of beliefs is measured in % of the total belief centrality of the inversed one-mode belief network, in which arguments on attitudes form the nodes, which are connected if they are shared by actors. We calculated the centrality with the complete networks (including actors with frequency < 1).

RETs and efficiency are minor technologies, with only 7% and 5% of the relative belief centrality. The network structure mirrors this belief distribution in favor of fossil fuels and nuclear. Most actors in the energy subsystem coalesce in two allied advocacy coalitions around fossil fuels (mostly coal) and nuclear energy. Resourceful actors, such as major utilities (RWE), ministries (Umweltbundesamt), unions (Deutscher Gewerkschaftsbund) or political parties (SPD) support lignite and hard coal. The advocacy coalition around nuclear energy is also powerful, formed by central actors such as the union of German electricity utilities (Vereinigung Deutscher Elektriztitätswerke), Siemens, the German government (Bundesregierung), unions (Gewerkschaft öffentliche Dienste, Transport und Verkehr) and the Conservative party (CDU). A third, smaller advocacy coalition forms around RETs. It consists of fewer actors, mostly environmental organizations and political parties (regional and federal) and it is more isolated and less dense than the other two advocacy coalitions. Important actors within this coalition are the Green party, the Öko-Institut (research institute) or Friends of the Earth Germany (BUND, environmental organization). Between the first and the second period (b.), beliefs on energy technologies and their respective advocacy coalitions changed. The bar on the left of the network indicates that fossil fuels are the most central energy technology, occupying 40% of the relative centrality of beliefs. The high centrality of fossil fuel beliefs can be attributed to the relative non-conflictual debates around coal, especially compared to nuclear; support of coal was spread across a variety of actors in all advocacy coalitions. Nuclear energy decreases in centrality to 31%, efficiency remains stable at 6%, and RETs increase to 25%. Again, the network structure mirrors this belief distribution. The RET advocacy coalition becomes stronger, both in terms of size and actor diversity. At the same time, the strong alliance and reciprocal support between the nuclear and fossil fuel advocacy coalitions starts to dissolve. However, there were still powerful actors supporting nuclear energy, such as the union of electricity producers, the Conservative party, Siemens, and several regional ministries (primarily in Bavaria and Baden-Württemberg). The fossil fuel coalition occupied a middle position between the nuclear and RET coalitions. Although resourceful actors such as industry associations (Verband der Industriellen Energie- und Kraftwirtschaft e.V.) or the municipal utilities (Verband kommunaler Unternehmen) were in favor of fossil fuel-based technologies, major actors shifted towards the RET-coalition. Besides these shifts, new actors joined the RET-coalition, increasing its actor diversity and size. Most notably, industry actors, such as firms (SaG Solarstrom, NaturEnergie AG), or industry associations (Verband Deutscher Maschinen- und Anlagenbau e.V.) joined the coalition. Importantly, because of the election of the red-green government, in place from 1998-2002, federal ministries and both governing parties now supported the development of RETs. Similarly interesting is the shift of the social democrats from the fossil fuel advocacy coalition, with strong links to the nuclear coalition, to the RET coalition. In general, the distance and small number of links between the RET and nuclear coalition represents the conflict between these coalitions around the nuclear phase out, enacted by the government in 2002. This tripartite structure of the German energy subsystem evolved significantly between the second and third period. As the bar in c. shows, RETs were now the most central technology-belief in the subsystem (40%), with fossil fuels and nuclear losing a lot of support (from 40% to 21%, and 31% to 22%). Support for efficiency remained stable at a low level. The RET coalition now formed an equally coherent and strong actor cluster as the fossil fuel and nuclear coalitions in the first period (a.). The coalition now included not only early-movers, such as the Greens and BUND, or companies joining the subsystem (such as SaG Solarstrom in the second, or Vestas in the third period), but also incumbents. Major actors, such as the Conservative party, several ministries, the municipal utilities, industry associations and companies (e.g. Siemens) now supported RETs. The nuclear and fossil fuel coalitions now consisted mostly of incumbent utilities, such as EON and RWE, and regional sections of political parties, primarily in *Länder* affected by the negative consequences of nuclear phase-out or decline in coal production (Conservatives and Social Democrats in North Rhine-Westphalia, respectively).

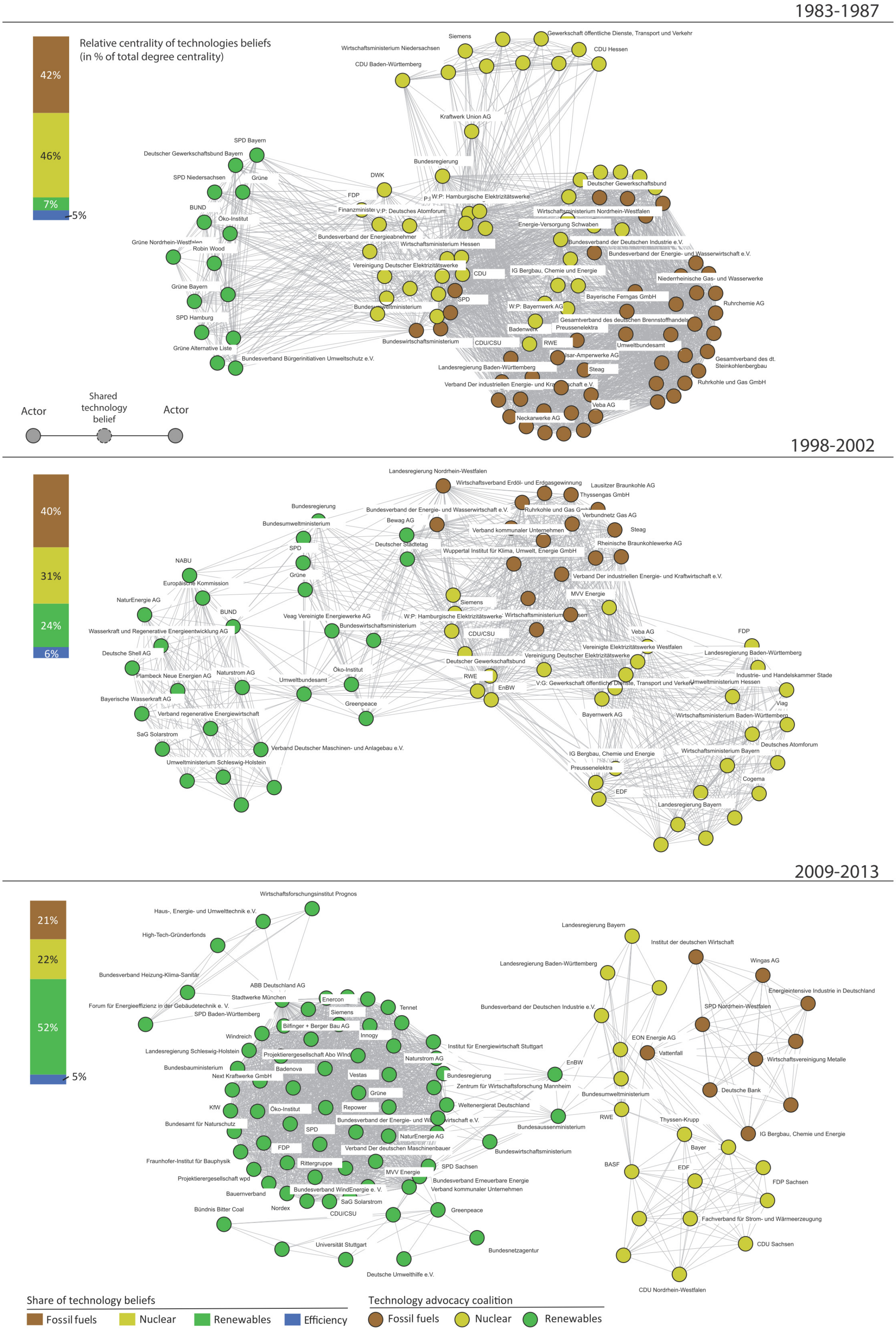

Figure 6: Evolution of advocacy coalitions in the German energy subsystem from 1983-2013

Number of coded statements per period (first to last) = 940, 693, and 295

5.2 Process-tracing of causal mechanisms behind the evolution of advocacy coalitions

Over the three periods, the dominance of the incumbent energy technologies, fossil fuels and nuclear, decreased to the benefit of RETs. The RET advocacy coalition evolved from a minority to a dominant coalition, gaining in size and actor diversity. These belief shifts and coalition evolutions correlate with the dynamics in the subsystem environment, especially with those related to policy-induced technological change. In the following, we use process tracing to provide evidence of causality between policy-induced technological change and the evolution of the German energy subsystem. For this qualitative analysis, we chose two actors that exhibit an interesting technology-related belief evolution and played pivotal roles in the energy subsystem: the Social Democratic Party (SPD) and the Conservatives (CDU/CSU). Both parties shifted to the RET coalition, from the fossil fuel coalition in the second period (SPD), and the nuclear coalition in the third period (CDU/CSU). The analysis is based on newspaper articles and protocols of debates in the German parliament. Table 1 and Table 2 show quotes from German politicians voiced during debates in the parliament. References to single documents are indicated in brackets, referring to Table 3 in the appendix.

The Social Democratic Party (SPD) played a pivotal role in German energy politics. In the first period, the party's support for nuclear decreased, while support for coal was high and for renewables increasing. At the beginning of the 1980s, the SPD was still pro-nuclear. In 1983, they did not respond to calls of the Greens for a law phasing out nuclear in the short term (1). However, even before the Chernobyl nuclear accident, beliefs started to shift within the SPD, mainly due to concerns on the competition between nuclear and coal (4)(6)(8). As Volker Hauff, a Member of Parliament (MP) of the SPD put it during a debate in 1986, "*There is no doubt that, if you like it or not, both in the lignite and in the hard coal there is sometimes a predatory competition between nuclear energy and coal*" (48). Also in 1986, Johannes Rau, then Prime Minister of North Rhine-Westphalia, complained about the loss of thousands of jobs due to the decreasing electricity production from coal due to the increase of the share of nuclear energy (48). These statements indicate a negative feedback effect of the policy-induced deployment of nuclear energy on the coal advocacy coalition. This feedback effect is both a resource and an interpretive effect, as it brings about "real world changes" (P. Sabatier 1988, 136), and leads to policy learning of policymakers, based on the cognitive perception of these socio-economic and technological developments. Since nuclear energy was already framed as competition to coal, the Chernobyl disaster only activated already pre-existing doubts about nuclear energy (2)(3). The cognitive perception of technological failure related to the abandonment of the fast breeder reactor design, and the increasing awareness about nuclear risks represent negative interpretive feedback effects of the policy-induced development of nuclear technology. Josef Vosen (MP) described the fast breeder reactor as "*a failed research project*", leading him to the conclusion that Germany should "*stop with this fast breeder*" (47). Additionally, the SPD increasingly supported the idea of an energy transition towards renewable energy technologies (5)(7). However, these negative feedback effects around nuclear benefitted coal more than RETs, as coal-based technologies were seen as the only realistic option to replace nuclear and resonated well with the coal-based constituencies of the SPD. RETs were only seen as part of the solution in the very long term (8). Klaus Lennartz (MP) described the SPD's perception of RETs, taking the example of wind energy, with the following words: "*It will never be the case that wind energy will replace any of the existing primary energy sources. (…) The utopia of a wind-supplied Germany, which is at the heart of your* [the Greens'] *proposal, will always remain a utopia"* (47).

In the second period, the SPD's support for nuclear has collapsed, as they entered in a coalition with the Greens and organized the nuclear phase out (10). This phase-out was only possible due to belief shifts within the SPD, a process starting already in the first period. Interestingly, the argument of the SPD relied not only on the risk of nuclear power plants, but on the perception of the economic uncompetitiveness of nuclear energy, or as Werner Müller (Federal Minister of Economy) put it in 2001: "*Why should we not build a nuclear power plant anymore? It is not about ideological reasons. It is no longer economically viable and in a competitive economy – as it was introduced in the electricity sector - it will not be profitable for a long time, for many reasons"* (49). Thus, between the first and second period there were negative interpretive feedback effects linked to the cost development of nuclear. As a replacement of nuclear energy technologies, the SPD supported mainly the further deployment of Combined Heat and Power (CHP) systems (12) and coal power plants (9). A special focus was the protection municipal utilities' CHP infrastructure, threatened by increasing competition between energy technologies. The SPD feared a "*large-scale loss of jobs*" in this sector (41). While fossil-fuel based solutions were seen as major replacement of nuclear energy technologies, the SPD also supported the development of renewable energy technologies (11)(13), as Rainer Brinkmann, Member of Parliament (MP) said, "we want to boost renewable energies, energy efficiency and energy saving (…)" (51). A major policy output based on the governments support for renewables was the Renewable Energy Act, implementing the feed-in-tariff for several renewable energy technologies. Already in this second period, the SPD referred to the job creation in the RET sector, "*it is assumed that in the last years 20000 jobs have been created in this technology sector*" (Ulrike Mehl, MP in 2001 (41)).

In the third period, the SPD's focus was on the further deployment of renewable energy technologies and the development of national industries around these technologies (14). MPs referred repeatedly to the creation of jobs as a reason for the further development of RETs: "*300000 new jobs have meanwhile been created thanks to the development of renewable energies in Germany*" (Sigmar Gabriel, MP in 2011 (44)), indicating the impact of the resource feedback of policy-induced technological change, in this case the RET feed-in-tariff of 2000. As Ulrich Kelber (MP) put it in 2013: "*Pushing out nuclear energy, billions of euros in investments and 400 000 jobs in Germany are all factors tied to the Renewable Energy Act*" (39). While still important, coal was less prevalent in the SPD's discourse. The SPD strongly criticized the government's plan to extend the time horizon of the nuclear phase-out (15). The main argument against nuclear energy was its detrimental effects on the deployment of renewable energy technologies. In contrast, in the 1980s, the main argument against nuclear was based on its competition to coal-based energy technologies. Interestingly, interpretive feedback effects on costs now also concerned coal: "*Those who believe that the old energy policy of "coal and nuclear energy" is cheaper, and who say that renewable energies are more expensive, are liars."* (Matthias Miersch, MP in 2010 (46)).

Historically, the CDU/CSU was an important supporter of nuclear energy. After the Chernobyl accident, the party emphasized the security of German nuclear power plants and rejected any plans on a nuclear phase-out (16). The party repeatedly referred to the years of experience with nuclear energy in order to stress the safety of the technology: "*Nuclear energy is the most secure form of power generation. There are 300 nuclear power plants all over the world. We have gathered 30 years of excellent experience in this field"* (Alexander Warrikoff in 1984 (34)). In addition, the support for the development of the nuclear breeder reactor design was high (23). Additional important arguments in favor of nuclear energy relied on the creation of "150 000 jobs" (Alexander Warrikoff in 1984 (34)) in the nuclear sector. While CDU/CSU emphasized that both coal and nuclear need to be parts of the German energy future (24) (26), nuclear – not coal - should have priority (18) (25). In contrast to the SPD, the party also emphasized the negative economic consequences, such as job losses in the nuclear industry, (19) and the increase in environmental damages through coal plant emissions in case of a nuclear phase out (17). Interestingly, opposed to the SPD, the Conservatives used cost arguments in favor of nuclear and against coal: "*Don't you know that the adoption of nuclear energy in base load will have in the future a cost advantage towards domestic coal? Moreover, do you know that nuclear energy has some environmental advantages?"* (Josef Bugl, MP in 1985 (35)). The party was not opposed to RETs, however it argued that RETs could not be a solution to replace any other energy technology. In order to support this argument, they relied on experiences with research and development projects, such as GROWIAN (see quote Friedrich Zimmermann in 1986 (36)).

In the second period, the CDU/CSU strongly opposed the nuclear phase-out planned by the Red-Green government. Main arguments were that a phase-out would increase electricity costs (27), lead to job losses (28) (32) (33), and cause higher emissions due to increase in coal-based power generation (30). Gunnar Uldall (MP) argued in 2000, that "*40 000 employees work for the nuclear energy industry. However, it is not just about them. If we lose the ability to compete, 150 000 jobs in the steel, non-*

ferrous metals, chemistry, paper, glass and cement sectors will be endangered. These are the economic impacts we have to deal with if we opt out too quickly" (41). The party supported an energy concept based primarily on nuclear and CHP (29), with a small role attributed also to renewables (31). However, the chances of RETs to integrate into the market were estimated low (20), and the CDU/CSU called into question the economic benefits of RETs in terms of international competitiveness and job creation: "*It is also not credible to play with numbers in the renewables sector, when it comes to jobs. Here the projections overturn: some reach 200 000, other 500 000 jobs. However, there is no reliable computation*" (Christian Ruck, MP in 2001 (43)). When the feed-in law for RETs was implemented in 2000, the CDU/CSU voted against the law (21).

In the third period, although the costs of the policy support for RET were widely criticized in the party (22), the fundamental opposition to RET vanished. The CDU/CSU now repeatedly argued in favor of RETs, highlighting its positive resource feedback effect: "*To this day, 350 000 jobs have been created through the energy transition. There will be more, because through the transition of the energy supply we promote domestic value chains*" (Norbert Röttgen, Federal Minister of Environment in 2011 (44)). Nuclear power was seen as bridging technology until RETs reached enough installed capacity to replace it (33). However, after Fukushima, the Conservative-liberal government led by the CDU/CSU passed a law accelerating the nuclear phase-out. More importantly, the government implemented the "energy concept" in 2010, aimed at increasing the share of RETs and improving energy efficiency. MPs of the party now referred to the positive cost development of RETs and their rising share in the electricity production as an argument in favor of this technology: "*Over a period of ten years, there was a multiplication of the ratio of renewable energies. Now we want to reach a further doubling or a triplication. Ten years ago, the share of renewable energies did not reach 17 percent of electric power. This percentage has considerably increased"* (Norbert Röttgen, Minister of Environment in 2011 (45)).

From the analysis of both parties' beliefs on energy technologies, two conclusions can be drawn. First, positive and negative interpretive feedback mechanisms were at work for all energy technologies. Concerning nuclear energy, and to a minor degree also coal, negative interpretive feedback effects based the perception of costs, technological risks and environmental harm led to falling support in both parties. The opposite is true for RETs, where unexpected cost decreases and increases in deployment of RETs led to shifts in the policy-core beliefs of policymakers in both parties. Second, positive and negative resource feedback effects of technological change were at work in all periods and in both parties. Policymakers' referred repeatedly to the provision of jobs of energy technologies, if phased-in, and the loss of jobs due to phase-out.

	Period	Exemplary quote	Person	Source
Interpretive	80	*Let us stop the development of the fast breeder. We save billions if we do not use this breeder-technology in Germany. This technology is a failed research project.*	Josef Vosen (MP)	(47)
		There is no doubt that, if you like it or not, both in the lignite and in the hard coal sector, there is a harsh competition between nuclear energy and coal. Just look at the numbers.	Volker Hauff (MP)	(48)
		It will never be the case that wind energy will replace any of the existing primary energy sources. (…) The utopia of a wind-supplied Germany, which is at the heart of your proposal, will always remain a utopia.	Klaus Lennartz (MP)	(47)
	90	*Why should we not build a nuclear power plant anymore? It is not about ideological reasons. It is no longer economically viable and in a competitive economy – as it was introduced in the electricity sector - it will not be profitable for a long time, for many reasons.*	Werner Müller (Minister of Economy)	(49)
		The 100 000-Roofs-Program for the photovoltaic industry brought a big boost for this technology. With this policy, we want to lower the prices of electricity generated by photovoltaic panels and develop a long-term perspective for panel manufactures.	Horst Kubatschka (MP)	(50)
		We want to boost renewable energies, energy efficiency and energy saving and implement the exit from a dangerous, non-controllable and hazardous power generation at the same time.	Rainer Brinkmann (MP)	(51)
	00	*Those who believe that the old energy policy of "coal and nuclear energy" is cheaper, and who say that renewable energies are more expensive, are liars.*	Matthias Miersch (MP)	(46)
		People want to get out of nuclear energy fast and to enter the era of renewable energies quickly: it is undeniable.	Rolf Hempelmann (MP)	(52)
		We face the days when the sun does not shine and the wind does not blow with many problems concerning the security of supply and the stability of the grid.	Sigmar Gabriel (MP)	(53)
Resource	80	*Opting out of the nuclear energy program will of course have an impact on the job market, Mr Lenzer. However, you should also know that nuclear energy is the most capital-intensive technology and that it requires the least employees.*	Bernd Reuter (MP)	(54)
		The Federal Government is of course aware that they accept that thousands of jobs in coalmines and supply industries will be lost, in areas, which are already affected by unemployment and structural problems.	Reimut Jochimsen (Minister Economy NRW)	(55)
		The coalmine Zollverein in Essen with 4000 employees will run out at the end of the year. The simple reason for it is that RWE produces less electricity from lignite; instead, the utility connects the nuclear power plant of Mülheim-Kaerlich to the grid.	Johannes Rau (Prime Minister NRW)	(48)
	90	*In the law, we present a security mechanism for Combined-Heat-and-Power of municipal utilities, which is threatened by your legislation. Your policy would lead to a large-scale loss of jobs in some power plant sectors and in several cities.*	Ernst Schwanhold (MP)	(41)
		Just one last word concerning jobs. The subject has already been mentioned here a couple of times. We should maybe underline renewable technologies will lead to the creation of new jobs. It is assumed that in the last years 20 000 jobs have been created in this technology sector.	Ulrike Mehl (MP)	(41)
		However, that one always thinks that the new technologies only lead to the loss of old jobs, without referring to the new jobs created at big scale, especially in the small and medium sized firms, if we subsidize decentralized energy technologies, such as renewable energies, that is not good. In total, we expect the creation of 1.2 million new jobs.	Hermann Scheer (MP)	(41)
	00	*In the last years and months, I have been traveling through the industry heartland Baden-Württemberg, visiting many firms. Of these firms, none would like to build nuclear power plants with great pleasure. However, many firms are eager to produce high-performative wind turbines and photovoltaic panels, and export these technologies in the whole world. That is the chance for the future of the industry location Baden-Württemberg.*	Nils Schmid (Minister of Finance BW)	(45)
		300 000 new jobs have meanwhile been created thanks to the development of renewable energies in Germany.	Sigmar Gabriel (MP)	(44)
		Pushing out nuclear energy, billions of dollars in investments and 400 000 jobs in Germany are all factors tied to the Renewable Energy Act.	Ulrich Kelber (MP)	(39)

Table 1: Statements on energy technology of SPD members

	Period	Exemplary quote	Person	Source
Interpretive	80	*Nuclear energy is the most secure form of power generation. There are 300 nuclear power plants all over the world. We have gathered 30 years of excellent experience in this field.*	Alexander Warrikoff (MP)	(34)
		Don't you know that the adoption of nuclear energy in base load will have in the future a cost advantage towards domestic coal? Moreover, do you know that nuclear energy has some environmental advantages?	Josef Bugl (MP)	(35)
		Who wants to phase out nuclear energy now cannot hide behind solutions such as wind or solar energy. Research has been carried out since 1973. The destiny of GROWIAN, the biggest wind turbine of all time, is well known.	Friedrich Zimmermann (Minister of Interior)	(36)
	90	*In Germany, you know that power generation from nuclear sources was a factor of international competitiveness. You also know, that the phase-out will lead to higher electricity prices, which will lead to decreasing competitiveness in the sector of electricity-intensive production.*	Dagmar Wöhrl (MP)	(37)
		The question is how to replace nuclear energy. It cannot be solar energy. We want to develop solar energy, but you cannot simply replace nuclear energy.	Klaus W. Lippold (MP)	(38)
		The replacement of nuclear energy in the base load through renewable energies is absurd.	Kurt-Dieter Grill (MP)	(38)
	00	*Fukushima has changed my attitude towards nuclear energy.*	Angela Merkel (Chanc.)	(39)
		Over a period of ten years, there was a multiplication of the ratio of renewable energies. Now we want to reach a further doubling or a triplication. Ten years ago, the share of renewable energies did not reach 17 percent of electric power. This percentage has considerably increased. The technological-industrial and economical bulkiness we have today are a sign that we have a big chance.	Norbert Röttgen (Minister of Environment)	(39)
		I strongly believe that the increasing competition and the decentralization of the power supply will have a positive impact on energy prices.	Horst Seehofer (Prime Minister Bavaria)	(40)
Resource	80	*In the sector of nuclear industry, including its supply industry, there are 150 000 jobs, jobs that are among the safest and involve highly qualified labor. You would destroy these jobs with a nuclear phase out.*	Alexander Warrikoff (MP)	(34)
	90	*40 000 employees work for the nuclear energy industry. However, it is not just about them. If we lose the ability to compete, 150 000 jobs in the steel, non-ferrous metals, chemistry, paper, glass and cement sectors will be endangered. These are the economic impacts we have to deal with if we opt out too quickly.*	Gunnar Uldall (MP)	(41)
		This nuclear phase-out works at the expenses of climate protection, of training capacity and professions, as well as at the expenses of the German technological progress.	Angela Merkel (MP)	(42)
		It is also not credible to play with numbers in the renewables sector, when it comes to jobs. Here the projections overturn: some reach 200 000, other 500 000 jobs. However, there is no reliable computation.	Christian Ruck (MP)	(43)
	00	*We go through this transformation of the energy sector because we are convinced that this will lead to modernization, innovation, to the development of new markets and that it will lead to the creation of new jobs, to the consolidation of competitiveness and to securing the future.*	Norbert Röttgen (Minister of Environment)	(44)
		To this day, 350 000 jobs have been created through the energy transition. There will be more, because through the transition of the energy supply we promote domestic value chains.	Norbert Röttgen (Minister of Environment)	(45)
		We have transformed the energy transition into a motor for employment. In the last three years, we have created 100 000 jobs in the sector of renewable energies. In the area of energy efficiency, 340 000 jobs – mainly craftwork – were secured and created. Moreover, that was not at the expenses of industries.	Thomas Bareis (MP)	(46)

Table 2: Statements on energy technologies of CDU/CSU members

6. Discussion

This paper analyzed the mechanisms by which change occurs in advocacy coalitions and their beliefs. Our argument was based on ACF's hypothesis that fundamental belief change occurs through external subsystem events. Drawing on literature of policy feedback, we showed that these external events, understood as technological change, play an important role in shaping technology-related beliefs and subsequently advocacy coalitions. Using a case study on the German energy subsystem from 1983-2013, we show that the evolution of advocacy coalitions in the German energy subsystem can be explained through policy-induced technological change. While extensive work has been done on policies aiming at accelerating energy transitions, the politics behind these policies, and feedback effects of technological change on these politics, have only rarely been studied.

To explain these politics, we proposed a conceptual framework to explain evolution of advocacy coalition in policy subsystems. To do so, we combined theoretical arguments from ACF and PFT to substantiate causal mechanisms linking changes in socio-economic conditions with belief changes in advocacy coalitions. This enabled us to overcome two gaps in the literature: The first relates to how external perturbations and policy change are linked, the second to how dynamic long-term factors affect the evolution of advocacy coalitions. Our study thus contributes to the existing literature by improving our understanding of causal mechanisms behind policy change and by identifying policy-induced technological change as important driver of changes in the policy subsystem.

Empirically, we observe that these changes are the result of a combination of positive and negative feedback effects. The analysis also supports the theoretical distinction between resource and interpretive effects. Evidence showed that policy-induced technological change explains why actors changed their technology-related beliefs. On the subsystem level, this resulted in realignment of advocacy coalitions around technologies. This realignment occurred over a long time, indicating an incremental rather than punctuated pattern of subsystem dynamics. We believe that our conceptual framework is conducive to picking up these dynamics. They might have been concealed in a classical ACF framework that might have related them to singular, external events.

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Appendix

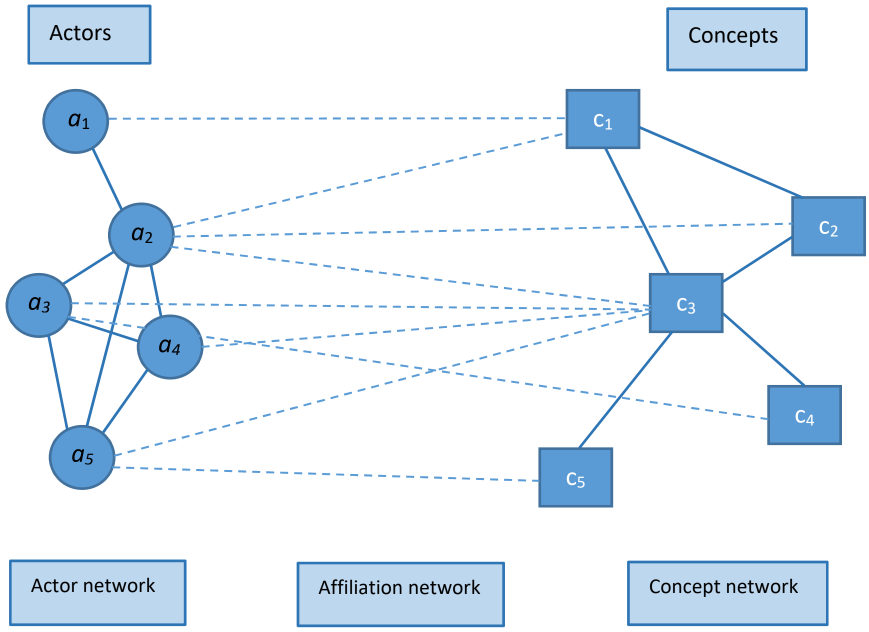

Figure 7: Model of discourse network analysis

Source: (Leifeld 2016a)

Newspaper	Date	Identification
(1)	31.08.1984	NN-FAZ-Artikel-840831_FAZ_0006_6_0003
(2)	06.03.1985	NN-FAZ-Artikel-850306_FAZ_0004_4_0004
(3)	13.05.1985	Klaus_Broichhausen-FAZ-Artikel-850513_FAZ_0013_13_0003
(4)	10.05.1986	NN-FAZ-Artikel-860510_FAZ_0001_1_0001
(5)	28.05.1986	NN-FAZ-Artikel-860528_FAZ_0001_1_0001
(6)	11.08.1986	NN-FAZ-Artikel-860811_FAZ_0001_1_0007
(7)	12.08.1986	NN-FAZ-Artikel-860812_FAZ_0001_1_0006
(8)	01.09.1986	NN-FAZ-Artikel-860901_FAZ_0004_4_0004
(9)	12.01.1999	Hohenthal_Carl_Graf-FAZ-Artikel-F19990112HALATO-100
(10)	20.01.1999	Schwenn_Kerstin-FAZ-Artikel-F19990120ENNKONS100
(11)	04.06.1999	Hohenthal_Carl_Graf-FAZ-Artikel-FR11999060488849
(12)	29.09.1999	Hohenthal_Carl_Graf-FAZ-Artikel-FR119990929177632
(13)	26.02.2000	Hohenthal_Carl_Graf-FAZ-Artikel-FR220000226345060
(14)	18.08.2010	Sattar_Majid-FAZ-Artikel-FD2201008182806540
(15)	21.02.2013	Mihm_Andreas-FAZ-Artikel-FD2201302213797833
(16)	13.05.1986	NN-FAZ-Artikel-860513_FAZ_0001_1_0008
(17)	13.05.1986	NN-FAZ-Artikel-860513_FAZ_0001_1_0008
(18)	08.07.1999	Hohenthal_Carl_Graf-FAZ-Artikel-FD319990708107626
(19)	26.11.1999	Hohenthal_Carl_Graf-FAZ-Artikel-FR219991126242783
(20)	26.02.2000	Hohenthal_Carl_Graf-FAZ-Artikel-FR220000226345060
(21)	26.02.2000	Hohenthal_Carl_Graf-FAZ-Artikel-FR220000226345060
(22)	21.02.2013	Mihm_Andreas-FAZ-Artikel-FD2201302213797833
(23)	23.03.1984	NN-FAZ-Artikel-840323_FAZ_0006_6_0001
(24)	02.01.1986	NN-FAZ-Artikel-860102_FAZ_0013_13_0014
(25)	23.05.1986	NN-FAZ-Artikel-860523_FAZ_0004_4_0003
(26)	21.11.1986	NN-FAZ-Artikel-861121_FAZ_0013_13_0004
(27)	14.01.1999	Hohenthal_Carl_Graf-FAZ-Artikel-F19990114HALMWE-100
(28)	30.01.1999	Hohenthal_Carl_Graf-FAZ-Artikel-F19990130RAD3DOK
(29)	30.01.1999	Hohenthal_Carl_Graf-FAZ-Artikel-F19990130RAD3DOK
(30)	29.05.1999	Hohenthal_Carl_Graf-FAZ-Artikel-FR21999052986259
(31)	17.12.1999	Hohenthal_Carl_Graf-FAZ-Artikel-FR119991217266873
(32)	07.05.1999	Hohenthal_Carl_Graf-FAZ-Artikel-FD21999050776093
(33)	11.08.2010	Mihm_Andreas-FAZ-Artikel-FD2201008112798691

Plenary protocol: Name and date

(34) Plenarprotokoll 10/98 (08.11.1984)
(35) Plenarprotokoll 10/72 (25.05.1984)
(36) Plenarprotokoll 10/215 (14.05.1986)
(37) Plenarprotokoll 14/153 (16.02.2001)
(38) Plenarprotokoll 14/95 (23.03.2000)
(39) Plenarprotokoll 17/114 (09.06.2011)
(40) Plenarprotokoll 884 (17.06.2011)
(41) Plenarprotokoll 14/79 (16.03.1999)
(42) Plenarprotokoll 14/111 (29.06.2000)
(43) Plenarprotokoll 14/209 (14.12.2001)
(44) Plenarprotokoll 17/68 (28.10.2010)
(45) Plenarprotokoll 17/117 (30.06.2011)
(46) Plenarprotokoll 17/229 (15.03.2013)
(47) Plenarprotokoll 10/171 (07.11.1985)
(48) Plenarprotokoll 10/236 (03.10.1986)
(49) Plenarprotokoll 14/16 (21.01.1999)
(50) Plenarprotokoll 14/153 (16.02.2001)
(51) Plenarprotokoll 14/98 (06.04.2000)
(52) Plenarprotokoll 17/106 (15.04.2011)
(53) Plenarprotokoll 17/228 (14.03.2013)
(54) Plenarprotokoll 10/255 (10.12.1986)
(55) Plenarprotokoll 571 (28.11.1986)

Table 3: Newspaper articles and parliamentary protocols

Meta-categories	Categories	Code	Description
Arguments on energy technologies	Energy security	Non-renewable energy source fossil fuels	Fossil fuel resources are not renewable, e.g. they are available only up to a limited amount
		Energy autonomy nuclear	Deployment of nuclear power increases German energy autonomy (also: since it reduces dependence on oil and gas)
		Energy autonomy nuclear (N)	Deployment of nuclear power does not increase German energy autonomy (since uranium needs to be imported)
		Nuclear energy imports nuclear	German nuclear phase out would lead to increasing imports from nuclear power plants abroad (e.g. France)
		Renewable energy source nuclear (N)	Uranium supply is not unlimited, thus not a renewable energy source
		Supply security nuclear	Nuclear power increases supply security for industries and households due to its steady production
		Grid stability renewables	Deployment of renewable energy technologies does not necessarily make the energy grid unstable, rather stable energy supply is possible
		Grid stability renewables (N)	Increasing use of renewable energy technologies lead to increasing grid instability due to high supply volatility
		National autonomy renewables	Higher deployment of renewable energy technologies such as wind and solar lead to increasing national energy autonomy
		Supply security renewables (N)	Renewable energy technologies such as wind and solar are not capable of providing enough energy for the German energy system to function (without nuclear and/or fossil fuels)
	Energy cost	Energy costs hard coal	Hard coal is a cheap energy source
		Energy costs hard coal (N)	Hard coal is becoming increasingly expensive / it is too expensive compared to other energy sources
		Energy costs lignite	Lignite is a cheap energy source
		Energy costs nuclear (N)	Nuclear energy is not a cheap energy source
		Energy costs nuclear	Nuclear energy as cheap energy resource
		Over-capacity nuclear	Generally, there is over-capacity in the system, this is why nuclear does not need to be extended – without major consequences for energy pricing
		Over-capacity nuclear (N)	Generally, there is no over-capacity (and energy demand will even grow in the future). Thus, nuclear energy is necessary in order to keep prices low
		High investment nuclear	Nuclear energy is as cost-intensive and highly subsidized technology, as such it is not profitable
		High investment nuclear (N)	Investment costs for nuclear energy are not high, also compared to other technologies
		Energy costs renewables	Renewable energy (also if only single energy technologies such as solar or wind) is the cheapest solution for the future energy system
		Energy costs renewables (N)	Renewable energy (also if only single energy technologies such as solar or wind) is expensive
		Switching costs renewables (N)	The switch from nuclear energy and fossil fuels to renewable energy technologies is not linked with too high switching costs
	Environment	Environment CHP	Combined Heat and Power (CHP) can be a solution when it comes to climate change mitigation
		Environment CHP (N)	Combined Heat and Power (CHP) is not a solution for decreasing emissions and combatting climate change
		Environment coal	Clean coal (no specification for lignite / hard coal) is possible and it can be – after modernization - in line with environmental standards and climate change goals
		Environment coal (N)	Clean coal (no specification for lignite / hard coal) is not possible – it causes too much emissions and pollution
		Environment nuclear	Nuclear energy is CO_2-neutral and thus a solution for combatting climate change
		Environment nuclear (N)	Nuclear energy is not a solution for combatting climate change
		Nuclear risk (N)	Nuclear risk is too high to justify use of nuclear power, includes radiation, waste and other nuclear hazard
		Nuclear risk	Nuclear risk is not too high, German security standards are very strict and can ensure a safe deployment of nuclear energy
		Environment renewables	Renewable energy has benefits for the environment since it reduces CO_2 emissions by replacing fossil fuels in the energy production
	Energy industry	Employment nuclear	Nuclear energy is providing jobs (directly and indirectly), phase-out of this technology would cost many of them
		Employment nuclear (N)	Nuclear energy is not providing many jobs compared to other energy technologies (e.g. such as wind and solar)
		Industry policy nuclear	Nuclear energy technology is important for Germany because it ensures leadership in nuclear industry policy and future technological development
		Outdated technology nuclear	Nuclear is the wrong technology choice since nuclear power plants will not provide industrial advantages in the future
		Outdated technology nuclear (N)	Nuclear is the right technology for future challenges and it will be part of a modernized energy system in the future
		International competitiveness nuclear	Nuclear energy technology is an important factor of international competitiveness of Germany as location for business and industry
		Breaking monopolies nuclear (N)	Nuclear phase-out is good for competition between energy technologies and utilities. It decreases the power of oligopoly of nuclear power providers, leading to a more diverse energy sector in Germany
		Employment renewables	Renewable energy technologies (including solar, wind, biomass, hydro, geothermal) have benefits in terms of employment: Renewable energies are creating jobs in Germany
		Employment renewables (N)	Renewable energy technologies (including solar, wind, biomass, hydro, geothermal) are not creating (many) jobs in Germany (especially compared to other energy technologies)
		Industry policy renewables	Growth of renewable energy technologies leads to the development of a new industrial sector in Germany

		International competitiveness renewables	Deployment of renewable energy has benefits in terms of Germany's competitiveness, since it makes Germany a world-leader in green technology
		International competitiveness renewables (N)	Growth of a renewable energy sector does not lead to higher competitiveness of the German industry
		International competitiveness CHP	Combined heat and power has benefits in terms of international competitiveness
		Employment coal	The transition towards coal has benefits in terms of employment: Coal is creating more jobs than other energy technologies
		Employment efficiency	The transition towards higher energy efficiency standards creates jobs
Attitudes on energy technologies	Fossil fuels	Lignite	Lignite as important part of energy mix (if used specifically as Braunkohle)
		Lignite (N)	Lignite needs to be phased out and will not play an important part in the energy mix of the future
		Hard coal	Important role for hard coal (Steinkohle)
		Hard coal (N)	Hard coal needs to be phased out and will not play an important part in the energy mix of the future
		Refined coal	Refined coal as important pillar of the energy system (Kohleveredelung), also: Kohleverflüssigung
		Refined coal (N)	There is no need to deploy technologies based on refined coal, it should not be part of the energy mix of the future
		Oil	Important role for oil
		Oil (N)	Oil should not play an important role in Germany's energy mix
		Gas	Important role for gas: Shale gas (almost not mentioned), mostly natural gas
		Gas (N)	Gas should not play an important role in Germany's energy mix
		CHP	Important role for CHP: Combined heat and power, also included: discussions about district heat; CHP revolved almost exclusively around fossil-fuel based power generation
		CHP (N)	Combined heat and power should not play an important role in Germany's energy mix
	Nuclear	Nuclear	Important role for nuclear energy
		Nuclear (N)	Nuclear energy should be phased out
		Breeder reactor	Important role for the so-called breeder reactor, Schneller Brüter
		Breeder reactor (N)	Breeder reactors should not be deployed at all
	Renewables	Solar	Important role for solar: PV, CSP
		Solar (N)	Solar cannot and will not play an important role in the future energy mix
		Wind	Important role for wind: Offshore and onshore wind energy
		Wind (N)	Wind cannot and will not play an important role in the future energy mix
		Hydro	Hydro energy: also pumped storage power plant
		Biomass	Important role for biomass: All kinds of biomass, however no traditional biomass
		Biomass (N)	Biomass cannot and will not play an important role in the future energy mix
		Geothermal	Geothermal will play a significant role in Germany's future energy mix
		Geothermal (N)	Geothermal will not play a significant role in Germany's future energy mix
		Renewables as replacement	Renewables will be able to replace another primary energy source (mainly used in the context of nuclear energy, as replacement of the base load
		Renewables as replacement (N)	Renewable energy technologies are not able to replace fossil fuel and nuclear energy technologies in the future
		Mix of renewables	If renewable energy technology is not specified, but only mentioned as renewables, or renewable energy technologies
	Mix of technologies	Mix of renewables (N)	Renewables should not play an important role in Germany's energy mix of the future
		Nuclear, fossil and renewables	Mix of coal, gas, oil, nuclear and renewables
		Fossil and renewables	Mix of coal, gas, oil and renewables
	Energy efficiency +Other	Energy efficiency	Important role for energy efficiency: Production, housing, transport efficiency, energy savings
		Energy efficiency as replacement	Energy efficiency will be able to replace another primary energy source (mainly used in the context of nuclear energy)
		Energy efficiency (N)	Energy efficiency cannot and therefore should not play an important role in Germany's energy future
		Energy storage	Renewable energy makes energy storage increasingly necessary, thus it will form an essential part of the future energy system
		Fuel cell	Fuel cell can play an important role in future energy mix

Table 4: Codebook

Criteria	Selection
Scope	FAZ supra-regional only + restricted to Germany
Topics	Economy and politics
Subject area (based on FAZ key word classification)	Energy
Publication periods	01.01.1984 – 31.12.1986; 01.01.1999 – 01.06.2002; 01.07.2010 – 01.09.2011; 01.01.2013 – 01.05.2013
Article type	Only regular newspaper articles, no readers' letter, comments, interviews or book reviews
Excluded key words (based on FAZ key word classification)	Articles tagged with - Nuclear waste disposal - Single nuclear waste transports - Technical details of nuclear power plants - Fuel elements - Single nuclear power plants - Single hydro power plants - Single fossil power plants - Energy law

Table 5: Selection newspaper articles