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Two ways to success expansion of renewable energies in comparison between Germany's federal states

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ABSTRACT

Expansion of renewable energies is a central pillar of the German energy transition towards a non-nuclear renewable system. The expansion rate is co-determined to a significant degree at the level of the federal states, and varies considerably from state to state. Apart from the existence of natural energy resources and general economic conditions, do parties in government play an important role for the development at the state level? We consider potentially influential factors in a fuzzy-set Qualitative Comparative Analysis (fsQCA) focusing on the expansion of renewable electricity production in all 16 federal German states from 2004 to 2014. As a result, two promising ways for accelerated expansion of renewable electricity production can be identified. On the one hand, a group of economically less developed states have succeeded in promoting expansion and uses it as part of an economic modernization strategy. Within the economically more developed states, however, the party-political composition of the state governments (Green party's involvement) plays a significant role. These results also have implications for other (federal) countries beyond Germany, pointing to tailor-made policy strategies that consider these specific circumstances.

1. Introduction

Increasing the share of renewables in the energy mix[1] is one of the central pillars of the German energy transition toward a "non-nuclear renewable system" (Eichelbrönner and Henssen, 1997, p. 468). This undertaking entails high conversion costs (temporary subsidies for renewable energy sources), as well as significant measures for adaptation (extension of electricity networks, Wurster and Köhler, 2016, p. 285). Even though Germany has already advanced relatively far along this path in an international comparison (Cox and Dekanozishvili, 2015, p. 167), significant regional disparities are evident between individual federal states. There is much variation when considering per capita expansion of electricity production from renewable energy sources for the period from 2004 to 2014 (see Fig. 1). In addition to the differences between the federal states, Fig. 1 also draws attention to temporal variation in the expansion dynamics within individual states. The outcome not only varies between the federal states' present status of electricity production from renewable energy sources but there are also significant shifts in the federal states' rankings over time (and, accordingly, over periods of government in the states).[2] Whereas some states, like Brandenburg, Mecklenburg-West Pomerania, and Lower Saxony were able to improve their position over time, others, like Bavaria, experienced a relative decline.

These divergent trends in policy outcome require an explanation, especially because they indicate that, in addition to state-specific, time-invariant determinants (general economic and geographical conditions), time-variant effects over different periods of government might be responsible for developments in renewable electricity supply in the individual federal states. Measures that different government coalitions take (policy output) may have an important impact. Thus, we concentrate on the following research question, which seem relevant for a deeper understanding of the German energy transition toward more renewable energies:

> What (party-) political factors, in addition to the existence of natural energy resources and general economic conditions, have significantly influenced increases in electricity production from renewable energy sources within German states?

The answer to this question appears not only important from a theoretical perspective (supplements to the growing comparative policy

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[1] Up to the year 2025, approximately 40–45% of the electricity consumed in Germany must be produced from renewable energy sources; up to the year 2035, this share is to reach 55–60% (Bundesministerium für Wirtschaft und Energie, 2016b).

[2] Besides the expansion of renewable electricity production, we tested the expansion of electricity generating capacity in the federal states as a potential outcome. While the variation is almost identical, we ultimately decided for the expansion of electricity production, as this indicator is available for more years.

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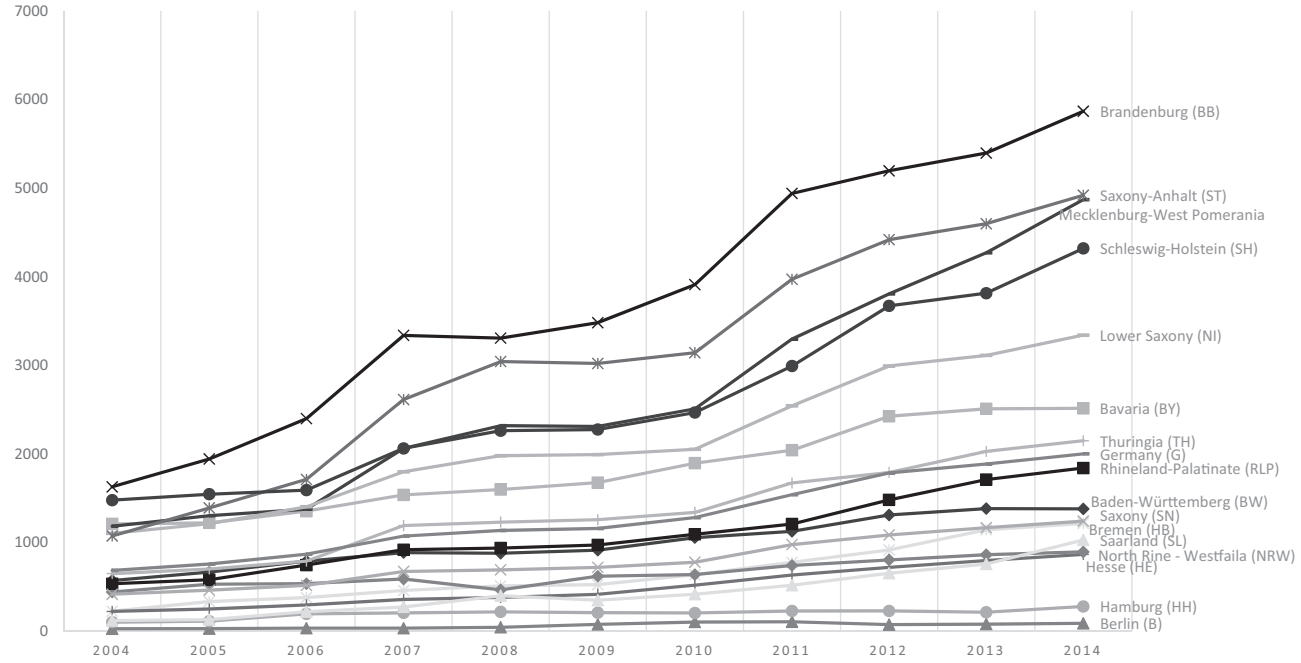

Fig. 1. Expansion of per capita electricity generation from renewable energy sources in a comparison between federal states (in kWh).

analysis literature at the level of the federal states: Schneider and Wehling, 2006; Hildebrandt and Wolf, 2008, 2016;; Bräuninger and Debus, 2012; Hörisch and Wurster, 2017), but is also relevant, from a practical perspective, for understanding the conditions of successful renewable energy expansion (see on this also Goetzke and Rave, 2016, Andreas et al., 2017).

The analysis proceeds as follows. The next section is dedicated to the specific structures and developments in the federal states' energy sectors. It then identifies the special challenges associated with the German energy transition, and discusses possible determinants of the expansion dynamics of renewable energies in the electricity sector at the state level based on policy analysis theories. This focus on the characteristics of the energy sector, economic components, and (party-) political factors is presented and then bundled in research hypotheses. This is followed in Section 3 by a detailed description of the methodological approach, before the data used and operationalization of the conditions are discussed in Section 4. Section 5 then analyzes various configurations of success in a *fuzzy-set Qualitative Comparative Analysis* (fsQCA) that considers the expansion dynamics of renewable electricity production in all 16 federal states in the period from 2004 to 2014.[3] A conclusion (Section 6) summarizes the results, and points out further research perspectives and important policy implications.

2. Accounting for variation in the expansion of renewable electricity production

2.1. Electricity sectors in the German federal states

As an exceptional economic area (Jochum and Pfaffenberger, 2006, p. 21) the energy sector is characterized by natural monopolies, a line-bound infrastructure, and high hurdles for storage of material requiring transport (Wurster and Köhler, 2016, p. 284f.). In Germany, the electricity sector was long characterized by significant market restrictions (this changed after EU induced liberalizing policies in the late 1990s), high institutional stability (interwoven division of responsibilities between the federal, state, and municipal governments) and continuity of key actors (dominance of semi-public, supra-regional, affiliated energy companies and municipal utilities). In addition, the sector proved very stable and saw mainly incremental changes in the energy mixture generated from different sources. The post-war dominance of domestic coal was superseded successively by oil and natural gas from abroad, while electricity produced from nuclear power also gained importance from the 1970s onward (Wurster, 2010, p. 275 et seq.). Whereas the diversification strategy initiated in the 1970s in the wake of the oil price shocks clearly lost momentum in the 1980s, the electricity feed-in law (StrEG) adopted at the beginning of the 1990s served as the first important legal basis for promoting renewable energies at the federal level. The ensuing rapid expansion of renewable energies was intended to fundamentally change Germany's electricity sector (increase in decentralized production, emergence of new electricity providers) and, thus, constituted a real structural breakthrough.

It became clear at an early stage that, in addition to the central government, the federal states play an important role in promoting renewable electricity generation. Accordingly, it was initially federal states that encouraged expansion of renewable energy through their own programs, years before the adoption of the electricity feed-in law.[4] In addition to the possibility of influencing federal legislation via the upper house of the German parliament,[5] the federal states possess independent regulatory competencies and instruments to influence the development of renewable energy in their territories.[6] Their importance for the development of renewable energies in Germany is underlined by the fact that they provide about one-third of total state research funding in this area (Bundesministerium für Wirtschaft und Energie, 2016a).

[3] See for a similar methodical approach at the level of European member states Andreas et al. (2017).

[4] In 1987, North Rhine-Westphalia took the initiative with its "program for rational use of energy and inexhaustible energy sources", which included broad-based promotion of energy efficiency, energy saving, and use of renewable energy sources, and served as orientation for further state programs in subsequent years (Mez et al., 2007, p. 99).

[5] This results from the competing legislative responsibilities between the federal and state governments in this policy field (Wurster and Köhler, 2016). Thus, in negotiations, the federal states repeatedly succeeded in enforcing their own interests via the upper house. As an example, see the amendments to the Renewable Energy Sources Act (EEG; Dagger, 2009, p. 189–205 and 289 f.).

[6] Accordingly, the federal states are able to adopt state-specific energy laws and employ numerous instruments for implementing energy policy (laws concerning planning, regional development, approvals, etc.).

The success story of renewable energy expansion in Germany from the beginning of the 1990s is remarkable also from an international perspective, and not only resulted from efforts at the central level[7] but also benefited from the commitment at the level of the federal states. For example, all federal states have committed themselves since the mid-2000s to promote the expansion of renewable electricity generation (Mez et al., 2007, p. 129–135). However, there are differences between the federal states, both in terms of the general ambition to expand and in priorities regarding individual energy sources. So there are still many (and in part also new) state regulations (like for example the 10-H-Regelung acts passed by the Bavarian State Parliament that requires the distance between a wind turbine and the nearest residence to be at least 10 times its height) that hinders expansion and impede initiatives especially on the regional level (Galvin, 2018, p. 273).

Accordingly, the targets defined for achieving shares of renewable energy with respect to total energy consumption vary considerably, between 20% (Saarland until 2020) and over 300% (Schleswig-Holstein by 2025, Agentur für Erneuerbare Energien, 2015). While expansion of wind energy is of central importance to states such as Mecklenburg–West Pomerania, Lower Saxony and Rhineland–Palatinate, promotion of biomass and photovoltaics plays an important role for states such as Baden–Württemberg and Bavaria (Wurster and Köhler, 2016, p. 292 et seq.).

2.2. Explanatory conditions at the level of the federal states

Thus, the state level plays a key role in implementing the energy transition and expanding renewable energies in Germany. At the same time, the dynamics of expansion vary considerably between the federal states and over the periods of government. This is also true for the regional level, “since decisions taken purely on a national scale may clash with local aspirations” (Galvin, 2018, p. 270).

The systematic expansion of renewable energies, together with the associated, fundamental restructuring of Germany's energy system, constitutes an extremely complex undertaking that initially gives rise to high costs and uncertainties. The direct expansion of renewable energy capacity from solar, wind, water, and biogas[8] goes hand-in-hand with investment risks and produces not only winners but also losers.[9] The transition to a "non-nuclear renewable system" also poses completely new challenges to an energy infrastructure suddenly aimed at decentralization (expansion of regional and supra-regional energy networks).[10] In addition to avoiding supply bottlenecks and grid instabilities, it is necessary to overcome significant organizational and technical problems that initially require high financial investments (Stram, 2016). However, these (short-term) disadvantages and challenges are potentially balanced by (long-term) benefits, like environmental sustainability, as well as tangible economic profit. In the medium- to long-term, the expansion of renewable energies in a federal state allows increased independence from external energy sources, lowering of energy costs, development of a modern industrial infrastructure, and establishment of new energy branches (*first-mover advantage*). In this process, it is also possible to boost local economic development and obtain profits from energy exports.

The energy transition poses great political, social, and economic challenges, the success of which is linked to certain conditions and requirements at the state level. Several different factors are potentially relevant to account for the success of renewable energy expansion. We therefore consider explanatory factors from different theoretical approaches. These range from socio-economic factors, power-resources of different actors to effects connected to party difference theory (Hibbs, 1977).[11] In this sense, we generally assume that neither a single factor nor, necessarily, a single combination of factors is crucial for the expansion dynamics of renewable energy at the state level. Rather, different combinations of factors or conditions might explain the success or failure of expansion (a situation of so-called equifinality). Methodologically, the discussed explanatory factors usually resemble INUS conditions, that means conditions which are neither individually necessary nor sufficient for the outcome, but instead work as an essential part of a sufficient combination of conditions (Mahoney and Goertz, 2006, p. 24–25). These conditions are thus necessary only for the combination, not on their own for the outcome. Based on theoretical considerations, it is possible to formulate four hypotheses whose empirical content is to be examined subsequently, with the help of an fsQCA.

For the expansion of renewable energies, the technical potential available in a federal state for generating electricity from renewable sources (wind, solar, hydroelectric power, and biogas) should play a central role as a fundamental factor specific to the policy sector. Depending on the state, this potential varies. Wind energy potential is very high in the north of Germany while in the south solar radiation is of particular importance. However, in all federal states (except in the city states) the wind energy potential is higher than the potential from other renewable energies. As no federal state has yet fully exhausted its potential in renewable energy sources (except for hydroelectric power, in some cases), it plays an important role for the expansion, in two respects: First, availability of potential allows certain energy paths to be taken, while sometimes even completely excluding others. Second, a large expansion potential is likely to increase the financial and economic incentives for rapid expansion, due to the resultant achievement in economies of scale.[12] Successful expansion can, be expected whenever there are especially high expansion potentials in a federal state. At the same time, one can even presume that no significant expansion is possible without appropriate potential.

H1: A large overall potential to produce electricity from renewable sources is an INUS, or perhaps even a necessary condition for the significant expansion of renewable energies in a federal state.

[7] Principal milestones include the "100- and 250-megawatt wind program" for promoting wind energy, the electricity feed-in law (StrEG), which was passed in 1991 (Becher et al., 1997, p. 252) and triggered a veritable wind energy boom in the 1990s (Ohlhorst, 2006, p. 107 f.), the "100,000-roofs photovoltaic program", launched in 1999 and replaced in 2004 by the preliminary photovoltaic law, and, in particular, the Renewable Energy Sources Act (EEG) from 2000. No later than the EEG, which arranged long-term feed-in tariffs for renewable energy sources decoupled from market prices, Germany rose to become a pioneer nation in promoting renewable energies.

[8] Unlike other studies that focus on only one renewable energy source (Goetzke and Rave, 2016) we focus on all four major forms of renewable electricity generation, as the German states excel in different fields. To make sure that the comparison is fair, however, we control for the states' potential to produce renewable electricity. This provides a holistic view of renewable energy development in Germany; however, in doing so, individual aspects and policy developments for single renewable sources (wind, solar, etc.) cannot be covered in detail.

[9] These include existing operators of conventional power plants. Residents can also be negatively affected, depending on the renewable energy source (shadow flicker and landscape spoiling by wind turbines, etc.).

[10] So it is all the more problematic if centralization processes like for instance recent changes in the nationally regulated pricing structure for renewable energies have negative impacts one regional development (Galvin, 2018, p. 273).

[11] Theoretical approaches that deal in greater measure with influential factors of an international, political, and institutional nature are not considered, and neither aspects of political heritage or political path dependence. This can be explained from the specifics of the still relatively young "renewable energy" policy field and the focus of this analysis on the state level (similar general institutional conditions at the national and European levels, *most similar system design*).

[12] Despite the undoubtedly great importance of natural occurrences, political decisions on actual utilization of existing energy resources are controversial (see the decline in coal mining in Germany). This was due not to a lack national coal reserves—which are still abundant—but to excessively high mining costs and requirements for greater environmental and climate protection. Though the purely technically available or exploitable potential for generating electricity from wind energy, hydroelectric power, photovoltaics, and biogas is, therefore, an important factor, it should be noted that not all potentials are economically usable just like that, and also that conflicting objectives including those concerning protection of the environment, animals, and landscapes, can result in politically induced restrictions.

In view of the enormous economic importance of a low-cost, dependable energy supply for the domestic economies of the individual federal states, socioeconomic explanatory factors are also likely to play an important role in the expansion of renewable energy. The state's economic structure, in particular, the proportions of the primary, secondary, and tertiary sectors in the overall economy, should be of decisive importance here. Other things being equal, an economic structure with a heavy share of industry should tend to result in higher energy consumption and, thus, greater demand for stable, low-cost energy (presence of many energy-intensive sectors), compared with a developed service economy, which is likely to require fewer energy resources (de-materialization).[13] Moreover, states with developed industries have generally undergone an establishment of long-term, integrative structures between the production sector and energy suppliers, typically based on large-scale industrial (fossil or nuclear) power-plant infrastructure. These established industrial conglomerates constitute a significant hurdle for a transition to a decentralized energy supply from renewable energy sources. Namely, the economic actors involved in this structure and profiting from it are likely to use their significant financial, social, and political power resources (for different power resources, see, for example, Korpi, 1983) to try to delay a transformation to renewable energy, which they associate with uncertainties and high costs. Even though existing industrial capacities make it easier, in principle, to produce and utilize new energy technologies, a consolidated industrial structure (based on fossil and nuclear energy sources) can, thus, also hinder the emergence and establishment of new industries in the renewable energy sector.

H2: A low share of industry in economic structure is an INUS condition for significant expansion of renewable energies in a federal state.

In addition to economic structure, the financial strength and associated economic prosperity of a federal state are likely to influence expansion. Two arguments in favor of a mainly beneficial effect of high prosperity can be mentioned. First, a federal state possessing high financial strength is likely to be more capable of supporting the expansion of renewable energy through various funding initiatives, be it in the form of supporting research or via direct subsidies for developing production capacities and energy infrastructure. Furthermore, businesses and citizens in a rich federal state should also possess sufficient private capital for promoting expansion.[14]

H3:. High financial strength and associated economic prosperity are an INUS condition for significant expansion of renewable energies in a federal state.

Finally, the development of renewable energy in a federal state is likely to be influenced by (party-) political determinants in addition to economic ones. The party difference hypothesis assumes that the colors of political parties influence their policy decisions and that incumbent political parties can make a significant difference to policy outcomes (Hibbs, 1977; Rose, 1984; Budge and Keman, 1990, p. 132). However, this influence is not immediately given, but mediated through programs, laws and measures (policy output), which are initiated by a government. Corresponding party effects can be demonstrated in numerous studies, also controlling for further potentially influential factors (Wenzelburger and Zohlnhöfer, 2015). With regard to energy policy, the literature on party differences suggests that Green parties should be particularly interested in an expansion of renewable energies. This does not mean that other parties have not included environmental issues into their programs. Instead, we have seen party-political contagion effects since the 1980s (Schmidt, 2016). However, for no other party this policy area is as important as for the Greens. Traditionally, issues such as nuclear phase-out, climate protection, and development of renewable energy sources have been among Green parties' core topics (high *issue* salience). According to the political cleavage model (Lipset and Rokkan, 1967, p. 1–64), which differentiates between socio-economic and socio-cultural dimensions (Niedermayer, 2013, p. 265–288), a Green party can basically be localized as part of the left spectrum, while representing progressive policy with regard to the socio-cultural and ecological dimension (Hough, 2011). This assumption is upheld by a comparison of Green-party programs with regard to energy policy at the state level (Wurster and Köhler, 2016; Wurster, 2017). This suggests that Green parties are likely to support an expansion of renewable energies at least programmatically (see Goetzke and Rave, 2016). However, renewable energies were greatly expanded at the state level in recent years in general, although the Greens were part of only a few cabinets. This indicates that, in addition to party effects (Green party in the state government, ideally with control over the energy portfolio), further factors might play an important role. In particular, specific interests pursued for "reasons of state", regardless of the state government's party-political coloring ("new territorialism", Turner, 2011, p. 49).

H4: Green party control of a state's energy policy is an INUS condition for significant expansion of renewable energies in a federal state.

In addition to these four influential factors, there are further potentially interesting variables that we did not consider relevant for this study. First, social acceptance of renewable energies in Germany is exceptionally high, both generally and in one's "own backyard"; while more than 92% of German citizens generally supported expansion in 2012, 67% even approved of expansion in their immediate vicinity (Agentur für Erneuerbare Energien, 2017). Interestingly, there is hardly any variance between federal states in this regard, so separate consideration as an explanatory factor does not appear necessary.[15] Second, just like social acceptance, political and institutional factors at the state level, such as the system of government, can be considered largely identical and, thus, 'controlled'. At the federal level, the Renewable Energy Sources Act (EEG) is equally important for all states and, therefore, constitutes a scope condition for the results of this investigation but does not need to be included separately in the empirical analysis. Even as the EEG has been adapted and changed over time (learning and adaption process, Huenteler et al., 2012, p. 7), we concluded that these changes amounted mostly to a difference in degree and not in kind both between earlier versions and regarding its effect on single states during the period of investigation. The EEG is, thus, of crucial importance as a scope condition for this analysis, but its influence does not vary to a relevant extent among the *Länder*. Finally, large endowments with fossil energy sources could influence decisions to invest in renewables, but they do not seem relevant here. On the one hand, they do not compete directly with renewables, as income from feed-in tariffs will always be an additional revenue. On the other hand, the states with high coal and, especially, lignite endowments feature both successful (Brandenburg, Thuringia, Saxony, Saxony–Anhalt) and less successful performers in renewable electricity production (North Rhine–Westphalia, Saarland), underlining the lack of relevance of this variable.

[13] However, energy-intensive sectors (metal-processing industry, chemical industry, etc.) have appeared to make great efforts to reduce energy consumption, which constitutes a particularly large cost factor for them.

[14] Accordingly, the proportion of citizens possessing photovoltaic facilities (or a share in them) in the rich states of Baden–Württemberg and Bavaria in 2011 was twice the national average, while the proportion in the poor states of Saxony–Anhalt and Mecklenburg–West Pomerania reached only one third of the national average (Agentur für Erneuerbare Energien, 2017).

[15] While expansion is approved by at least 87% nationwide, acceptance in one's neighborhood varies between 61% in Brandenburg and 75% in Bavaria (Agentur für Erneuerbare Energien, 2016).

3. Method: fuzzy-set qualitative comparative analysis

The following analysis accounts for the differing developments in renewable energy production in Germany's federal states. For several reasons, QCA is an ideal choice for this endeavor. Firstly, QCA is suitable for dealing with a medium number of cases, which is too complex for analysis with other qualitative comparative methods, yet offers too few cases for statistical research. Furthermore, the set theoretic logic of QCA is highly compatible with the theoretically formulated expectations; the individual explanatory factors probably act in combination and are alone not sufficient for the outcome (Schneider and Wagemann, 2012, p. 12). At the same time, it is conceivable for different combinations to lead to the same outcome, thus representing instances of equifinality (Ragin, 2008, p. 63). Both expectations can be tested empirically in a QCA.[16] Finally, the fact that we are dealing mostly with numerical data allows for the application of the fuzzy-set variant of QCA and thus to benefit from more fine-grained membership scores in the analysis.

4. Data

As there is only room for a brief summary here, the research design and the data, including a detailed explanation of the operationalization and calibration decisions, are discussed at length in the online Appendix to this article. Units of analysis for comparison are not the federal states, but are cabinets of the state governments which are labelled with the official abbreviations and numbered in order of occurrence. This makes it possible to account for variances in their party-political composition. Each cabinet holding office for more than one year and either based on a new parliamentary majority or consisting of new coalition partners is considered as a new case. The cases are labelled with states' official abbreviations, and numbered in order of occurrence; for example, the first cabinet in North-Rhine Westphalia in the period of investigation in labelled NRW1. This results in a total of 51 cases for the investigated period from 2004 to 2014.[17] The timeframe covers the maximum period since the establishment of the crucial EEG for which complete data are available. The federal states and their abbreviations are again summarized in Table 1.

The outcome is determined as the average annual per capita increases in renewable electricity production during a cabinet's term. Full members in the set "Significant expansion of renewable electricity generation" exhibit a growth of at least 160 kWh. All cases exhibiting an average per capita expansion of more than 150 KWh (but less than 160 KWh) are still partially members of the set "Significant expansion of renewable electricity generation" (0.67). All cases exhibiting more than 50 kWh, i.e. over the next relatively clear threshold are still partially non-members of the set, while all states exhibiting even lower expansion are fully non-members of the set.

As the outcome investigates changes in installed renewable energy capacity for electricity generation, states' potential must be taken into account correspondingly in the form of expansion possibilities in this area. Potential is, therefore, considered as the general technical possibility of electricity generation (independent of the year) in kWh per capita in the areas of wind energy (onshore), hydroelectric power, photovoltaics, and biogas. In 2014, these four energy sources accounted for approximately 86% of electricity supply from renewable energies, making them by far the most relevant potentials for renewable electricity generation.[18] Among the states with high potential are the sparsely populated and/or coastal states of Brandenburg, Mecklenburg–West Pomerania, Schleswig–Holstein and Lower Saxony, in addition to Bavaria, with its high potential in terms of biogas, hydroelectric power, and, in particular, photovoltaics. Clear non-members are the city states, which exhibit a relatively low potential for renewable energy per capita, especially due to their high population density.

The federal states' economic structure was determined on the basis of the manufacturing sector's share of gross added value during a particular cabinet's term. Generally used for the strength of a state's industry, this indicator varies on average between 10.5% in Berlin and 31.96% in Baden–Württemberg during the period under investigation. Here, the EU average of 20% for highly industrialized member states serves as the threshold for membership in "Low share of industry".[19]

A federal state's prosperity is established on the basis of the transfer payments received as part of the 'Länderfinanzausgleich', the federal system of transfer payments between states. As transfer claims are derived from the miscellaneous tax revenues of the federal states, these are also an indicator of their affluence. Even if the federal states' finances are greatly balanced by transfers, there are still notable differences here, thereby likely making it significantly easier for some rich federal states, and, especially, their economies and private individuals, to invest in renewable energy, compared to poorer federal states. Data from the Federal Ministry of Finance for the period from 2004 to 2014 show marked differences between the states. Value-added tax compensation, financial equalization for states and federal supplementary allocations as a "balance of the federal transfer system" (Hildebrandt, 2016), are taken into account here); consult the Appendix for details of this system). All net contributors, as well as minor net recipients, during the investigation period count as members of the set "Rich federal states", while only significant net recipients count as non-members.

Finally, party effects are measured in terms of expansion of renewable energies on the basis of "Green-party involvement in government" (Wurster, 2013), which should have a greater effect if Green-party ministers are directly responsible for energy (1.00) and still be relevant if they are at least part of the cabinet (0.67). The direct method of calibration which offers the most fine-grained membership scores

Table 1
Abbreviations of German federal states' names.

State	Abbreviation
Baden-Württemberg	BW
Bavaria	BY
Berlin	BE
Brandenburg	BB
Bremen	HB
Hamburg	HH
Hesse	HE
Mecklenburg-West Pomerania	MV
Lower Saxony	NI
North Rhine-Westphalia	NRW
Rhineland Palatinate	RP
Saarland	SL
Saxony	SN
Saxony-Anhalt	ST
Schleswig-Holstein	SH
Thuringia	TH

[16] The method searches for combinations of causal conditions linked systematically to an outcome. It allows for combinations of multiple conditions as an explanation for an outcome (*conjunctural causation*), as well as the possibility that multiple combinations can lead to the same outcome (*multiple conjunctural causation*). QCA is, therefore, very suitable for identifying possible paths leading to expansion of renewable energies. Here, it is also possible to differentiate between necessary and sufficient conditions for expansion.

[17] We expect a government's influence to extend beyond the actual term of office, because decisions already made continue to have an effect, and a new cabinet needs time to plan its own measures. To take this offset into account, the influence of the cases has been considered, with a slight time shift: During calculations of case conditions, the year in which a government takes office is still fully attributed to the previous government. Robustness was also tested for a time lag of two years, which did not substantially alter the results (see the section on robustness checks in the Appendix).

[18] The only energy source not taken into account here, and comprising the next most important proportion, is the use of solid biogenic fuels for generating electricity, which accounted for seven percent of electricity supply from renewables in 2014.

[19] The set was calibrated inversely so that the theoretical expectation for all sets positively influences the outcome in the case of membership.

was used for all sets, except for the party effects.

5. Fuzzy-set QCA: ways to success

The first step in every QCA is the analysis of necessary conditions. Every condition and its complement (i.e., its negation) are tested for possible necessity for the outcome. Necessity means that we would always expect to find the condition when we see the outcome. Consistency of necessity offers a numerical expression for this relationship between a condition and the outcome: thus, the higher the consistency value, the fewer instances of the outcome exist which do not also feature the presence of the condition under scrutiny, and thus contradict the claim of necessity. For successful expansion of renewable electricity production, no consistent results are obtained for necessity: The highest consistency values are found for "High potential" (0.78) and, interestingly, for the absence of "Green-party involvement in government" (0.82). Still, both are clearly below the usually applied threshold of 0.9 (and thus H1 fails here with regard to necessity). The threshold is exceeded only during the analysis of necessity for the absence of the outcome: Here, absence of “high potential” reaches a very high value of 0.902, and is, therefore, almost a necessary condition for the absence of successful expansion.

The next step is the analysis of sufficiency. To test for sufficient combinations, the data matrix created for analysis is calibrated (i.e. turning cases’ values on conditions into set membership scores) and thereby converted into a *truth table*. The truth table differs from the data matrix as it is not a list of cases’ values on the conditions under scrutiny, but rather a list of all logically possible combinations of these conditions. Mathematically, this means that every truth table contains 2^k rows, with k as the number of conditions used. While we thus know the number or rows and combinations in advance, calibration tells us to which line of the truth table a case belongs. In this analysis, there are $2^4 = 16$ possible combinations of the four conditions. The truth table (Table 2) shows that 14 of these logically possible combinations are covered by the 51 cases. Only two rows therefore remain without cases (*logical remainders*, that is combinations which are logically possible, but not found empirically), but these can still be considered in the further analysis as will be explained below.

Sufficient combinations of conditions for further reduction are selected on the basis of consistency values. It is thus not only interesting which case belongs to which row of the truth table, but also whether or not the cases in a row feature the same outcome. For example, if a row includes cases with both successful expansion of renewable energy production and without, the combination of conditions of this row does not lead convincingly (i.e. consistently) to either successful or non-successful expansion and is thus a very inconsistent statement for both results.

In our analysis, high consistency values appear in five of the 16 rows. Above the dashed line in Table 2, all combinations reach values of 0.885 or more, while covering only one case that is a non-member in the outcome (TH2). Accordingly, the clear majority (17) of successful cases of interest here are members of consistent combinations, and only four of them (NI1, NI2, BY2, and SL4) cannot be taken into account in the analysis due to low consistency (that means membership in rows with mixed values on the outcome). Furthermore, the consistency of combinations for the outcome is underpinned by high PRI values, controlling whether a combination of conditions is potentially also sufficient for the absence of the outcome, thus explaining also the opposite and therefore a *false positive* result (Schneider and Wagemann, 2012). The relatively low PRI value of 0.776 in the fifth row does not pose a major problem either, as a comparison of the combination with the *truth table* for absence of the outcome shows that the row is not simultaneously also sufficient for this result (see the Appendix for more details).

The combinations of conditions identified as consistent can now be further reduced. Practically, this means to match rows that differ only in one condition. This condition can then be dropped as redundant, as we see the outcome both with these conditions present and without. The goal of minimization is the maximum reduction of conditions following this logic. All parts of the analysis are conducted using the R-packages "QCA" (Duşa, 2007) and "Set methods" (Medzihorsky et al., 2017); the results are summarized in Table 3. Three different results are normally produced in a QCA: The *complex solution* is produced by minimizing the *truth table's* rows, which are covered with empirical cases. The *intermediate solution* then also consider combinations not covered by cases (the above-mentioned logical remainders). These combinations are included by using theoretical expectations as a basis for deciding whether they lead to the outcome (*easy counterfactuals*). Finally, the *parsimonious solution* considers these combinations, but the decision concerning their membership in the outcome is made solely with regard to the combinations' minimization potential (and thus a rather technical process). Table 3 shows the commonly interpreted *intermediate solution*, with a total of three sufficient paths to the outcome. The results are presented according to the notation of Ragin and Fiss (2008) and Fiss (2011), using black dots ("•") to indicate the presence of a condition and crossed dots ("⊗") to indicate absence, while empty cells mean redundancy of a condition in a path. Due to the small number of *remainders*, the result of the *parsimonious solution* is identical to that of the *intermediate solution*.

The first path corresponds strongly to the theoretical expectations,

Table 2
Truth table with four conditions for the outcome "successful expansion of renewable electricity generation".

G	I	P	R	OUT	*N*	Consistency	PRI	Cases
1	1	1	1	1	2	1	1	**SH1,SH4**
1	0	1	1	1	2	0.962	0.915	**NI3,RLP3**
0	1	1	1	1	2	0.947	0.881	**SH2,SH3**
0	1	1	0	1	8	0.939	0.918	**BB1,BB2,BB3,MV1,MV2,MV3,ST1,ST2**
0	0	1	0	1	4	0.885	0.776	**ST3,TH1**,*TH2*,**TH3**
1	1	0	0	0	1	0.680	0.212	*HB2*
0	0	0	0	0	4	0.645	0.413	*HB1,SL1,SL2*,**SL4**
1	0	0	0	0	2	0.633	0.208	*HB3,SL3*
0	0	1	1	0	7	0.628	0.336	*BY1*,**BY2**,*BY3*,**NI1,NI2**,*RLP1,RLP2*
0	1	0	0	0	6	0.459	0.232	*B1,B2,B3,SN1,SN2,SN3*
1	0	0	1	0	4	0.447	0.177	*BW3,NRW1,NRW3,NRW4*
1	1	0	1	0	1	0.439	0.178	*HH3*
0	0	0	1	0	3	0.410	0.094	*BW1,BW2,NRW2*
0	1	0	1	0	5	0.325	0.088	*HE1,HE2,HH1,HH2,HH4*
1	0	1	0	?	0	–	–	–
1	1	1	0	?	0	–	–	–

Note: The letters are abbreviations for the sets "Rich federal state" (R), "Strong Green-party influence" (G), "Weak industry" (I) and "High potential" (P). Cases in italics are non-members in the outcome.

Table 3
Sufficient combinations for successful expansion of renewable electricity generation.

	Sufficient combinations		
	Path 1	Path 2	Path 3
Green-party involvement in governance	●		
Rich federal state		⊗	
Low share of industry			●
High potential	●	●	●
Consistency	0.979	0.918	0.942
PRI	0.965	0.885	0.920
Raw coverage	0.137	0.565	0.566
Unique coverage	0.034	0.087	0.060
Cases/unique members	SH1	MV1	MV1
	SH4	MV2	MV2
	NI3	MV3	MV3
	RLP3	BB1	BB1
		BB2	BB2
		BB3	BB3
		ST1	ST1
		ST2	ST2
		ST3	SH1
		TH1	**SH2**
		TH2	**SH3**
		TH3	SH4
Total consistency		0.921	
Total PRI		0.889	
Total coverage		0.706	

Note: The combinations show the intermediate solution. Black circles indicate presence of a condition, crossed circles indicate its absence. Intermediate solutions and parsimonious solutions are identical in this analysis. Cases in bold type are *uniquely covered*, those in italics are contradictions.

revealing a combination of Green-party involvement in government and high potential as sufficient for successful expansion. This path covers two Red–Green cabinets from Schleswig–Holstein, one from Lower Saxony, and one from Rhineland–Palatinate. The second path consists of non-membership in "Rich federal state" and membership in "High potential", and unites all cases from Mecklenburg–West Pomerania, Brandenburg, Saxony–Anhalt and Thuringia. Even though these states experienced no Green-party involvement in government at any point during the period under investigation, the states nonetheless feature some of the most successful cabinets. Interestingly, "Rich federal state" works contrary to the theoretical expectation here; in these cases, wealth is not relevant for investment in renewable energies, but, rather, non-membership in "Rich federal state" is part of a combination leading to expansion. Despite the contradictory membership of TH2 in the combination (no member in the outcome), its consistency remains very high (0.918). Finally, the third path corresponds again in greater measure to theoretical expectations and brings together "Low share of industry" and "High potential". However, this path overlaps to a high degree with path two. It explains all cases from Mecklenburg–West Pomerania and Brandenburg, in addition to the first two cabinets from Saxony–Anhalt. In addition, all cases from Schleswig–Holstein are members here. In general, it is interesting to note that potential, though not a necessary condition for successful expansion, is nonetheless as an INUS condition a crucial part of all three combinations leading to the outcome. The consistencies of the individual combinations are visualized in plots in Fig. 2. How empirically sound are these combinations, and what conclusions can be drawn from them?

Overall, the analysis reveals two central patterns: The first shows a theoretically expected "green" path leading to successful expansion based on party-political determinants. The combination of Green-party involvement in government and potential for renewables explains four of 21 successful cases, although only two are exclusive members (NI3, RLP3). The role of Green parties in utilizing expansion potential at the state level is, thus, empirically present, but requires a differentiated consideration. Interestingly, absence of Green-party involvement in a state's government is also assigned a very high value (0.82) as a necessary condition for successful expansion. Can Green-party involvement in government, therefore, also be, under certain circumstances, detrimental to renewable electricity production? The high value for necessity results mainly from the weak role of the Greens in the eastern federal states, which, at the same time, both possess and utilize especially great expansion potential. However, it is implausible to assume that absence of the Greens in these states contributes to expansion; moreover, the more important observation that their complete absence from east German state governments (and often even from state parliaments) during the investigated period simply provides no case for minimizing this condition, which is also why it is not dropped as an INUS condition until the *intermediate solution*. To make a relevant statement on the role of Green parties, it is, therefore, more important to consider more closely the cases where Greens were involved in government and that also had potential. Did the Green parties make the decisive difference in favor of greater expansion in these cases? In Lower Saxony, they appear to be the least relevant; though NI3 is explained by path 3, the *truth table* shows that the other cases in Lower Saxony without Green-party involvement in government were equally successful. Green-party involvement in government in Lower Saxony, therefore, made no difference. Similarly, in Schleswig–Holstein, existing potential is exploited under state governments of all colors, and cases SH1 and SH4 are explained not only by the "green" path 1, but also by path 3. In contrast to Lower Saxony, however, in Schleswig–Holstein, a state government with Green-party involvement (SH1) has at least initiated greater expansion, thus introducing a path dependence in favor of renewable electricity generation. A central role in trend reversal towards greater expansion is played by the Greens in Rhineland–Palatinate; here, the Red–Green state government differs clearly from its social–liberal and social democrat predecessors. During the term of the Green party's Eveline Lemke as Minister for Economics, Climate Protection, Energy, and Regional Planning, the state decided and implemented much more ambitious expansion goals for renewable energy compared to the preceding governments. Up to the year 2030, total demand for electricity in the state of Rhineland–Palatinate is to be covered by renewable energy sources, with wind energy responsible for about two-thirds of total electricity generation. For this, electricity generation from wind power must be increased five-fold by 2020, compared with the level in 2010 (Ministerium für Wirtschaft, 2012, p. 4). With the adoption of a Climate Protection Act (2014), for the first time binding targets were codified (Wurster and Köhler, 2016, p. 292). The fundamental revision of the State Development Program and of the Wind Energy Circular as well as the newly issued Wind Atlas Rhineland-Palatinate (Ministerium für Wirtschaft, 2012, p. 14) increased the planning capacities of municipalities and thus enabled a rapid expansion of wind energy. This made it possible to nearly double electricity production from renewable energies during one legislative period. Also possibly serving as evidence of the redirection of Rhineland–Palatinate's energy policy by the Green party, motivated significantly by partisan programming, is the fact that, after the state parliament election in 2016, when the Green party suffered massive losses (sharp drop in the share of votes from 15.4% to 5.3%), many commentators identified excessive focus on the expansion of wind power, neglecting other structural policy objectives, as the core allegation of voters against the Green party's energy and economic policy (for example Fietz, 2016).

In sum, party-political factors in the context of Green-party influence play a role in the expansion of renewable electricity production, but they tend to be moderate, as a whole. This is derived in particular from the fact that Green parties were hardly ever involved in governments in federal states with a high potential for expansion, and, if they were, the preceding governments, except for one case, already had begun to exploit this potential.[20]

[20] In general, it must also be noted that the influence of the Greens was limited by their infrequent involvement in government during the investigated period. They only participated in 13 of 51 cabinets, being responsible for the energy portfolio in only eight of these cases.

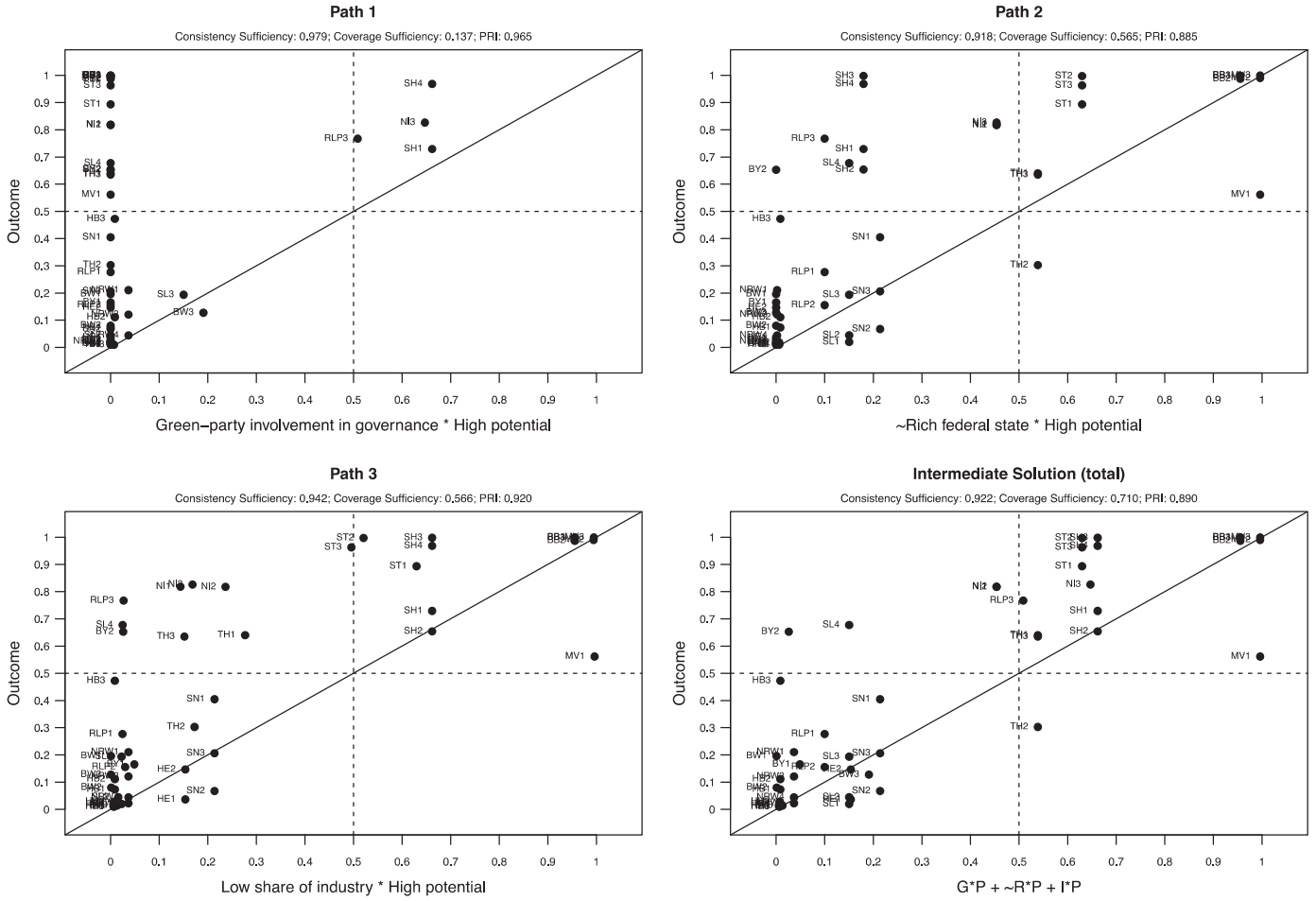

Fig. 2. Plots for sufficient combinations of conditions (intermediate solution).

The second and third paths to greater expansion of renewable energies combine high potential with "Low share of industry", or the status of net recipient from federal transfer payments, and can be understood as an expansion strategy based on economic and political calculations ("economic" paths). The industry was originally assigned the role of a veto player trying to avoid a costly transformation of energy production. However, in addition to the absence of such a (negative) influence it also seems plausible that the absence of a strong industrial base and generally weaker economic performance act as a central positive incentive to pursue an economic growth strategy based on utilizing existing potentials of strongly subsidized renewable electricity generation. Two observations support this interpretation: First, both paths share most of the cases (eight of 12), and only Schleswig–Holstein deviates as a member in "Rich federal state". However, as the northernmost federal state is not a major net contributor but, rather, a (slight) net recipient from financial transfers between the states, the reason for Schleswig–Holstein's expansion strategy (and the mechanism acting there) could be similar to that in the other cases covered in path 2.[21]

Furthermore, a comparison with other relevant cases only provides a mixed picture, and, therefore, also tends to point out the importance of an economic growth strategy. A relevant null hypothesis in the case of the argued "economic" expansion strategy would be that expansion is driven solely by potential. Accordingly, states that are non-members in "Low share of industry" and members in "Rich federal state" would have to utilize their expansion potential, just like the poorer states. The *truth table* shows only one relevant row for this comparison, with a total of seven cases. This row contains the two successful cases from Lower Saxony, the two unsuccessful cabinets from Rhineland–Palatinate, in addition to two cabinets with low expansion and one with high expansion from Bavaria. Thus, the result is much more mixed than in the consistent paths two and three: In total, four cases (BY1, BY3, RLP1, and RLP3) show that states with a strong industrial and financial base use their large potential for expansion less successfully than do those exhibiting “Low share of industry” and a lack of financial resources. An outlier is the Christian–liberal coalition in Bavaria, which achieved twice the expansion in renewable electricity generation compared with its predecessor.[22] A real contradiction, by contrast, is Lower Saxony, where the high potential for expansion has been used by all cabinets, despite a strong industry. Compared to Bavaria, however, Lower Saxony is, furthermore, not a net contributor to the

[21] The incentive structures for expansion of renewable energies are particularly favourable in Schleswig–Holstein for two further reasons. Due to its geographical location between the Baltic Sea and North Sea, it offers almost optimal conditions for expansion of wind energy. Furthermore, Schleswig–Holstein's energy system was characterized significantly by nuclear energy until recently. Thus, the phase-out decision puts the state under special pressure to act. How the actual potential for expanding renewable energy in the state is assessed as a whole is made clear by the target that Schleswig–Holstein should remain an electricity exporting state, even after shutdown of the third nuclear power plant in 2021. (Agentur für Erneuerbare Energien, 2015; Landesregierung Schleswig-Holstein, 2015, p. 10).

[22] Regarding Bavaria in general, it should be noted that the non-members are more representative of a stagnation at a high level than of a basic aversion to expansion. In 2014, for example, per capita generation of renewable electricity amounted to 2515.8 kWh, surpassing Thuringia, calibrated here as successful (2149.3 kWh), even if clearly behind leading states, such as Brandenburg (5867.3 kWh), Mecklenburg–West Pomerania (4870.4 kWh) and Schleswig–Holstein (4319.5 kWh). In general, however, the outcome selected here aims to register a state government's dynamics, which were, ultimately, not especially high in BY1 and BY3.

Länderfinanzausgleich, so expansion might be motivated here by the same (economic) reasons as in the cases covered by paths 2 and 3, especially in view of the very large potential. In general, this comparison also points toward the relevance of a strong economic incentive to achieve high expansion dynamics.

6. Conclusion and policy implications

This article compares varying expansion rates of renewable energy production in the German federal states. Our findings generally support studies highlighting the relevance of technical potential for the expansion of renewable energy sources (e.g. Staid and Guikema, 2013, p. 382), which is also in our analysis part of all solution paths.

In addition to this rather foreseeable finding, our result is surprising in two respects: On the one hand, (party)-political factors play a role in successful expansion of renewable electricity production in individual federal states (for similar results regarding wind energy, see Goetzke and Rave, 2016), but less than expected regarding the theoretical assumptions (*H4*). Only in one out of 51 cases does a change to Green party involvement in government seem to have genuinely been the reason for greater expansion. This finding thus only partly sustains other studies' results highlighting a relevant role of Green party support for the expansion of wind energy in Germany (Goetzke and Rave, 2016, 8).

In most other cases, however, governments attach priority to the economic benefits of renewables. The Renewable Energy Sources Act apparently ensures that prosperity is not a prerequisite for costly expansion of this energy form, but, rather, a factor whose absence provides an incentive to exploit existing potentials for renewables and, thus, to profit from guaranteed sponsorship. This strategy to utilize existing potential is very clearly evident in states with a weaker economic base and a low share of industry. By contrast, the readiness to exploit potentials is significantly lower in states with a strong industry and sufficient financial capacity. Therefore, it seems generally plausible that sufficient potential, although an important initial condition for successful expansion (and also existent in 20 of 21 successful cases), is most likely to be utilized, given ideological and, in particular, economic incentives. This result makes sense against the backdrop of findings from earlier studies reporting a positive effect from the installation of renewables on local employment and municipal value added (Heinbach et al., 2014, p. 7). We would thus also conclude that in some states the expansion of renewables "appears to be perceived as a means of securing economic and labour market benefits" (Goetzke and Rave, 2016, p. 12). In more general terms, the finding that also poorer regions can contribute to clean energy transitions also resonates well with findings of continued expansion of renewables in economic crisis torn countries in Europe (Andreas et al., 2017, p. 86), or a positive effect from income equality and thus higher general development on CO2 emission levels (Jorgenson et al., 2017).

The importance of the economic path in our analysis underscores the special importance of political and institutional factors in the form of the Renewable Energy Sources Act as a scope condition for the results. Without the incentive of guaranteed feed-in tariffs for electricity from renewables, the dynamics of expansion would probably be significantly lower in the states. It remains unclear, however, exactly how this incentive works: Do federal states with "Low share of industry" and limited financial capacities have a special incentive for liberal regulation of expansion of renewable electricity generation, thereby attracting more investment than do states with potential but stricter requirements? Or do the strong industrial sectors of states use the power at their disposal to block development of those energy sources that are not as appealing to them, as theoretically presumed at the beginning? These questions concerning the exact effect of the explanatory factors identified for successful expansion in this investigation are to be examined in the future in detailed process tracing analyses that allow for a stronger focus on the activities of actors and employed policy instruments at the state level. At the same time, it is important to ask for the exact policy instruments employed at the state level (policy outcome) and their contribution to the successful expansion of renewable electricity production. What effects do they have looking also on the regional level (see Galvin, 2018)?

The results have also implications for other (federal) countries beyond Germany aiming at the expansion of their renewable electricity production. Financial incentives set at the central level can work to promote the expansion of renewables, especially in poor states, which can use it as part of their economic development and modernization strategy. Offering this kind of support helps to make the expansion of renewables independent from states' affluence and increases the likelihood that existing potential is used. Basing one's strategy only on richer states that can afford expansion seems not to suffice, as their decisions for renewables appear to be more mixed. Tailor made strategies addressing the specific and varying needs at the state level can, thus, be a crucial element to boost expansion, as goals of development and the 'greening' of electricity production can go together.

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Appendix A. Supplementary material

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