Energy Research & Social Science 76 (2021) 102058

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Friends or foes? Exploring the performance of incumbent energy providers and the expansion of renewable energy in five European countries

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A R T I C L E I N F O

Keywords:
European incumbents
Stock-market performance
Energy markets efficiency
Sustainability
Low carbon transition
Photovoltaic energy

A B S T R A C T

Societies at large are increasingly accepting the need for a transition to a lower-carbon energy system. How this transition is conducted and its final results, however, are matters of concern. In fact, there is already some available evidence based on qualitative and case-study research showing that, in some cases, costly and uncertain technologies are being promoted instead of cheaper small-scale alternatives.

This research intends to shed some quantitative light on this issue by looking at the stock market performance of electric utilities in the major European economies and their behavior in the face of increasing renewable energy deployments. The main result is that their performance has not worsened due to those deployments, except for the photovoltaic energy, which shows a consistent and negative impact across all countries, with Spain's remarkable exception. This is due to this energy source's characteristics, particularly its scalability, unabated cost declines, and technical simplicity, paving the way for decentralized and distributed energy markets instead of the current unique and centralized distribution system. The paper also discusses the shortcomings of the creative-destruction paradigm when applied in this context, showing that even an active 'exnovation' policy might not be enough to ensure this outcome. An active political stance supporting the appropriate kind of regulation to enable the right environment for these efficient developments to be realized is therefore required.

1. Introduction.

The transition to a low or neutral carbon energy system has been mainly considered until recently as a cost minimization problem; see, e.g., [1–4]. The urgency underlined in [5] and the deep cost reduction in two key renewable energy (RE) technologies, namely onshore wind, and solar PV, are making it increasingly feasible and unavoidable [6,7]. After initial attempts to question the transition [6–9], the incumbent fossil energy industry may be switching to a strategy of reshaping it in favor of costly and risky technologies that may prevent the transition to a more efficient and sustainable system [10]. Case studies are pointing to this possibility, at least regarding some European countries [11–14]. This study's primary purpose is to contribute to that research field by applying a quantitative methodology [15,16]. The research intends first to test statistically to what extent incumbent utilities oppose, or lead, the deployment of RE. The main European electricity markets have been considered for this purpose, and the stock market performance has been selected as the main economic indicator to be explained. A second and related question is which REs, if any, are more suited to fulfill the ambitious program stated, e.g., in [17,18] for REs in general.

The paper is organized as follows: Section 2 details the literature context of the research; Section 3 briefly describes the data and methodology and presents a summary of the main empirical results of the research, discussed with more detail in Section 4; Section 5 concludes by outlining policy measures and future lines of research. Appendix A discusses some related economic issues, Appendix B presents the data and methodology, and detailed empirical results are gathered in Appendix C.

2. Literature context.

Several aspects related to the transition and the potential role of small-scale RE technologies and distributed energy systems to address them are discussed next. The empirical results presented in Sections 3

Abbreviations: CCS, Carbon Capture and Storage; CSP, Concentrated Solar Power; EV, Electric vehicles; LR, Learning Rate; PV, photovoltaic; RE, Renewable Energy.

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https://doi.org/10.1016/j.erss.2021.102058
Received 25 September 2020; Received in revised form 22 March 2021; Accepted 25 March 2021

and 4 focus mainly on them as well.

2.1. The economic approach to the transition

The main focus of transitional studies for the whole world to a low carbon economy as recently as in [1,2,3,4] has been on economic issues, even dealing with the subsequent reduction of Greenhouse gases as a more or less direct side effect. Country studies have similarly been tackled as a purely techno-economic problem, e.g., [19]. The goal of these studies has been to propose a so-called Roadmap, backcasting from some specified target in the future, usually the year 2050, guaranteeing the supply from intermittent RE sources, and simultaneously minimizing the implied investment costs in the new technologies. Because the Learning Rate (LR) effects of RE, particularly solar photovoltaic (PV) and onshore wind, have been consistently high, cost concerns have subsided [6,7]. As underlined in [5], the urgency of the required transformation has also been shown to decrease relevant cost measures, like the Levelised cost of energy with fast RE deployments [20].

From the policy point of view, the economic approach has overwhelmingly supported carbon taxes as the best policy measure to achieve decarbonisation through the workings of competitive markets; see, e.g. [21] and significantly [22]. The phase-out of fossil fuel subsidies has also been proposed as a complementary pricing measure, rather than regulatory and direct niche RE support policies, allowing consumers and firms to adjust through a gradual implementation [23]. Global subsidies are estimated to be 5%-6% of world GDP, counting environmental, health, and climate-related costs, consumption subsidies in oil-producing countries being the bulk of that remaining estimated amount. Production subsidies are a small fraction of that total and more challenging to estimate. Nevertheless, the EU, e.g., estimates that they amount to just 0.4 of its combined GDP, although a large and increasing share in support of natural gas [24].

These policy measures require efficient, competitive markets to work as assumed, which may not always hold in practice according to [25]; see also [26,27], and Appendix A. They imply gradual and slow adjustments, and their socially regressive nature has been largely neglected with some exceptions, e.g. [28,29]. Contrarily, green industrial policies supporting niche developments, mainly in the wind and solar PV energies, explain the large cost declines and increasing deployments in both cases [30].

2.2. Political and social aspects

Beyond carbon taxes and fossil fuel subsidies, the implementation of the transition and particularly its political and social implications have been largely disregarded till recently, especially in the economic literature. Exceptions are, e.g. [31,32]: [31] propose a *meta*-theoretical framework embodying three perspectives that enhances political science given that policy is becoming prominent in shaping energy transitions. [32], in turn, implement the multi-level perspective to analyse energy transitions deriving specific lessons: a) implement dynamic policy mixes, b) focus on demand besides supply technologies, c) manage phase-outs to avoid intense political resistance.

The following several interrelated issues have become relevant: first, the fossil conglomerate initially opposed the transition and channeled funds to think-tanks that questioned its urgency [6,8], feasibility [6,9], sowed doubts [8], and curtailed funds for climate research [33]; more recently, the economic costs of the early maturity of fossil investments are being emphasized - the stranded assets issue, e.g. [7]. Another recent example is the promotion of hydrogen as a green gas omitting the risks and uncertainties involved [13]. Second, the social implications of the transition, particularly the implied job losses and whole decline of regions, are being highlighted; this has happened acutely in the coal industry's decline, caused mainly for cost reasons [34]. But the transition also opens opportunities for economic change. Specifically, a fairer new system may be put in place, allowing for a more competitive and, as a result, efficient market; see [35], Appendix A, and [36,37] for the current economic context. However, these two goals can only be achieved under a sufficiently politically transparent framework and therefore demand and highlight the need for a robust political stance beforehand.

The incumbent fossil industry has finally acknowledged the climate change derived risks [8] and switched its strategy to become leader of the transition [10,38,39]. The technologies they advance are, however, subject to some caveats since, a) either do not directly fight carbon emissions, like weather engineering and flood adaptation, or that, b) promote energies and technologies requiring large investments unaffordable to small investors [11], like nuclear power [39] and Carbon Capture and Storage (CCS). However, both are nowadays jeopardized because of their high costs and risk concerns: cost overruns above two times the initial projected cost in nuclear investments are the norm [40], the technical feasibility of large scale CCS is uncertain [41], and neither of them is on track to meet low-cost competitive targets because of 'design complexity' [42]. Nevertheless, [43] argue that nuclear energy can provide flexibility to an otherwise RE system, and [44] that CCS may contribute to decarbonization coupled with biomass and natural gas energy sources. But new ones have been put forward, e.g., offshore wind [45], which is even touted as an investment opportunity for oil firms with drilling sea rigs, and electric vehicles (EV). However, there is enough space for onshore wind [46], which is besides cheaper [47], and EV may be a form of entrenching injustices and inefficiencies of the previous energy system if not deployed adequately [48]. The overselling of hydrogen as a green gas would be another example [13].

Notwithstanding these caveats, [49] remark that the decentralization of energy systems brought by distributed energies and local grids may present business opportunities for utilities as providers of services, thereby opening ways for partnerships between incumbents and newcomers.

2.3. Transition sustainability

A new, although different type of risk highlighted by [50], is that the pronounced cost declines, particularly in the PV and wind energies brought about by consistent and robust LRs, might yield a new wave of growth as has always happened in the past with the discovery of energies sources. Supporters of the Green-Growth and New Green Deal agendas expect that to be the case. Nevertheless, there are increasing signs that the current trends of the world economy are not sustainable. Even if the climate problem was adequately dealt with, there are impending multiple and interrelated boundaries, like water supply, minerals availability, and nature degradation, among others [46,51]. Sustainability should be another primary goal of the transition, implying social justice as underlined, e.g., in [52], and acknowledging the earth limits [46,50]. This is another reason why the transition presents an opportunity to reach a more competitive and market-efficient economy, as underlined, e.g., by [36]. A more open economic system might help discuss the earth's physical limits, preventing, therefore, the risk of successive ecological crises - see, e.g. [39].

2.4. The renewable energy solution

According to [17,18] and even more so [53], REs are a kind of panacea that can solve almost every problem facing humankind: specifically, they argue that REs promote decentralization of power, and more generally, would ease progress in the implementation of all the United Nations sustainable development goals [54]. RE's benefits could spill over to the economic and social orders, becoming means for participatory development [55] thereby as well. However, energy transformations can lead to clashes with the incumbency and even political unrest and revolutions in some cases [50]. Less dramatically, and according to [38,40,57,58], and notably [56], if the RE transition is conducted under the auspices of the fossil industry, that could impair the

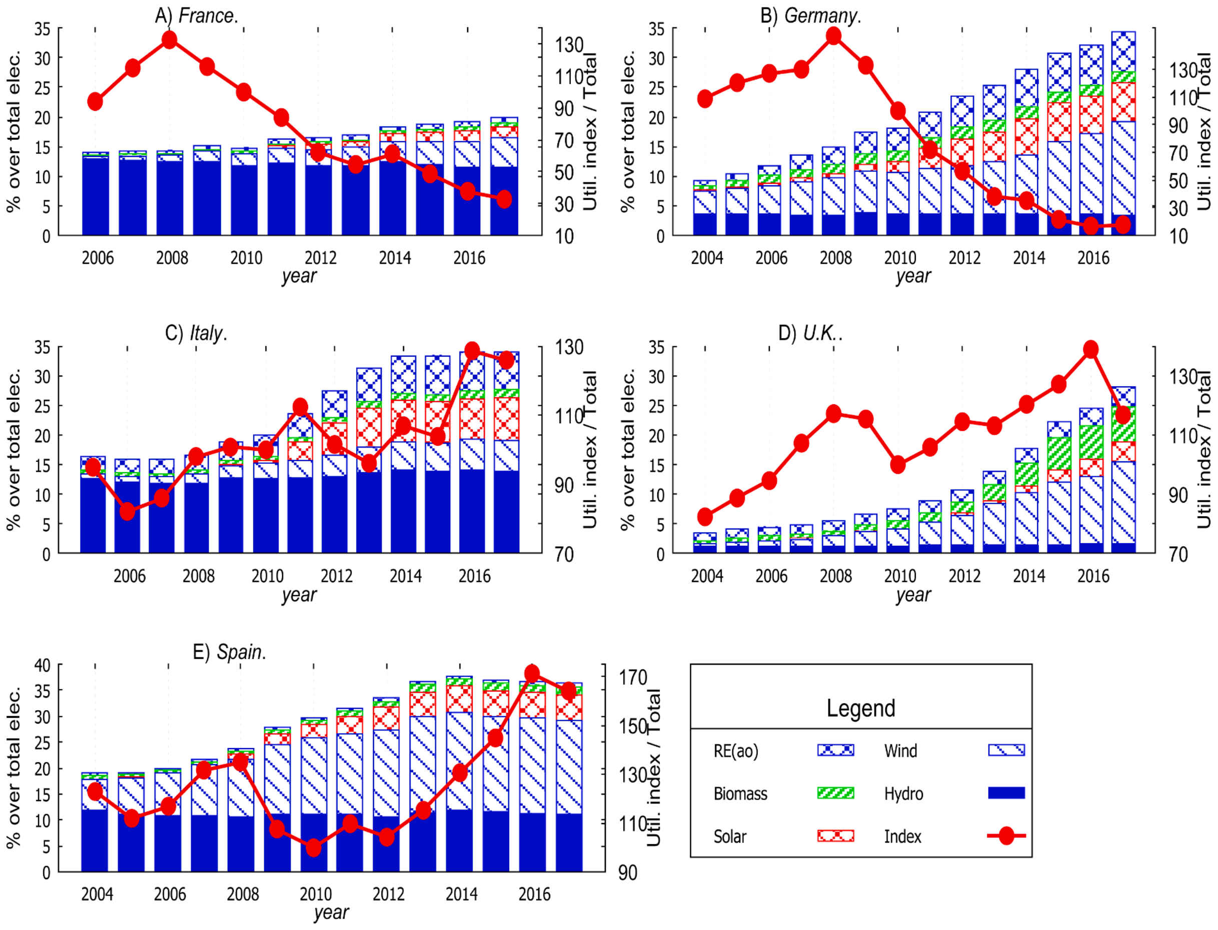

Fig. 1. Renewable Energies & Utilities stock market indices. (*Source: Eurostat and authors' calculations. See Appendix B.1,2 for details*).

solution of some long-term problem – e.g., limited competition and sustainability.

Some research based on qualitative studies [58], and econometric regression studies [59], has concluded that increased policy inclusiveness and transparency lead to more significant deployment of REs, but the converse may not occur. There is primarily qualitative case-study empirical evidence on this possibility, and one purpose of this study is to make a quantitative contribution to that question - [15,16] also remark the need for more quantitative studies in social sciences.

2.5. Econometric studies on renewable energies

As for econometric studies, most of them deal with, a) whether REs increase final consumer prices and lead to decreased investment and installed electricity generating capacity, b) the translation to prices of carbon taxes and emission permits, c) RE learning rates and their reliability[1]. According to [60], e.g., REs have caused decreased investments and generation capacity, and ultimately higher electricity prices in European markets because of the uncertainty introduced. [60] propose carbon taxes to tackle climate change instead of support for renewables. [25], in turn, show that utilities pass on to consumers the full cost of carbon emission permits, a result fully compatible with the highly concentrated structure of electricity markets, and that would counter the feasibility of a transition based on this policy measure - demand is too inelastic and unlikely to decrease significantly; see as well Appendix A. [61] also show that the increased electricity prices in Germany in 2013 would have been higher without the RE deployment. As for LR studies, given the unabated decreasing cost trend of the two leading RE technologies, solar PV and onshore wind [62], the research questions regarding their stability and uncertain estimates have been broadly settled. Finally, there is no significant published research relating to RE deployment and the utilities stock market performance.

3. Methods and results

3.1. Data and methods

Data for RE installed capacity is available annually for the period *t*= *(2001–2017),* and all European countries, classified into =*(* Hydropower, Wind, Solar, Biofuel (solid), RE(all other)) - see Appendix B. Electricity generated by every type of RE has been scaled - i.e., divided over - by the total electricity generated in every country, to set apart general trends affecting general generation and consumption. Stock market quotes for the utilities considered have been annualized accordingly, averaging over appropriate monthly observations - only listed utilities in their respective national stock markets are considered since this is a synthetic proxy measure for their business performance. From individual utility data, stock market utility indices for every country have been calculated and scaled by the general stock market

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[1] After having implemented a standard methodology in literature surveys, no significant published research relating RE deployment and the utilities stock market performance has been found. Several combinations of the main following words have been searched: econometric(s), electricity, renewable(s), utilitie(s), stock market, price(s), index, and others suggested by the search engines used, i.e., Google scholar and Worldwide Science; other search engines produced similar or no results. Energy journals in the main editorials have also been searched - Elsevier, Taylor &Francis, etc .

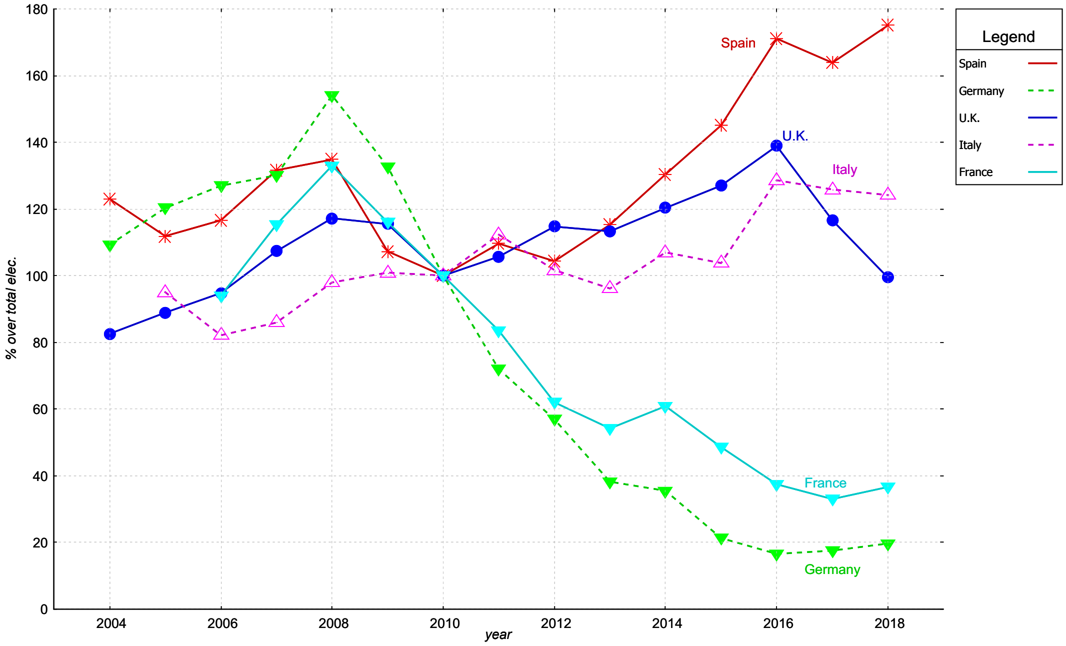

Fig. 2. European Utilities stock market indices. (*Source: Stock market quotes and authors' calculations. See Appendix B.1,2 for details*).

index in the corresponding country: this is done to set apart the index behavior from other more general aspects of the whole economy.

With these variables, regression models have finally been set up and run, explaining the relative utility indices' behavior in every country considered by the relative percentages of RE electricity generated of every type in the country considered. Individual and combined estimations have been implemented - the more technical points concerning the algebraic handling of all variables and the types of regression applied are left to Appendix B.

3.2. *Trends in main European markets*

The empirical study has focused on the electricity market in Europe. The main five countries, amounting to 70% of the combined EU 29 GDP in 2019, and 75% of the EU 19 – without the UK -, have been considered. Although this may limit the reach of the conclusions, it should be noted that REs have been deployed mainly in Europe and China, and data for China is not so readily available. Besides, RE has been distributed mostly through the electricity market, notwithstanding some biofuel developments in the car market, particularly in Brazil.

The global trends for the economies and markets considered are presented and discussed in two figures first, and the specific details for every RE type and country have been analyzed with the help of regression analysis afterwards. Fig. 1 displays the timeline breakdown of RE in the European countries analyzed as % over total electricity generated and compares it to the utilities stock market indices - note that indices are referred to the right-hand side scale and REs to the left. A downside trend in Germany and France, sharper after the 2008 crisis, coupled with an upward trend in total RE generation, notably in Germany, is the main message in Fig. 1.A, B. Although the increasing RE trend in Italy, Spain, and particularly in the UK is clearly seen, utilities seem to have performed well, notably in Spain, and contrary to France and Germany. It is worth remarking as well that in the two countries where RE reaches the highest % rate of electricity generation, above 35% in 2017, the utilities show a remarkable opposite stock market behavior - a result discussed in Section 4.

The utilities stock market performance is further portrayed in Fig. 2, showing two distinct groups, France and Germany, on the one hand, Italy and the UK on the other, and an outright outlier, Spain. The two extreme cases are Germany and Spain: this is even more remarkable since the contribution of REs are similar in both countries and the highest in Europe in the period considered. It also reflects the fact that the RE deployment has followed opposite and extreme pathways in both countries: whereas the energy transition has favored large scale RE technologies in Spain [14], like large onshore wind parks, large hydroelectric dams, and solar CSP, Germany has allowed new entrants deploying small scale technologies [11].

Table 1

Single estimation: Summary results (averaged, qualitative).

	Germany	France	Spain	Italy	UK
Hydro	—	L,(+),*	—	—	—
Wind	L,(-),**	M,(+),*	—	M,(+),**	L,(+),**
Solar	H,(-),***	H,(-),***	—	L,(-),*	L,(-),*
Biomass	L,(+),*	M,(+),*	—	—	—
RE(ao)	M,(+),**	H,(-),*	—	—	—
R^2	97%	91%	—	72%	75%

Notes:

1) Impact size: H, High (>30), M, Medium, (30–10) L, Low (10 >)

2) Impact sign: (+) positive, (-) negative.

3) *, **, ***: slightly significant (10%), significant (5%), highly significant (1%).

These being the global trends, it remains to analyze the impact of specific energy sources conducted next in Sections 3.3, 3.4, and 3.5. The main results are organized following the regression types presented in Appendix B.3. Only global averages according to the regression type are reported, while a detailed account is left to Appendix C. This has been done partly because, depending on the approach, results may vary; see Appendix C. Also, given the relatively short time span of available data, performing analysis from several points of view might help extract better whatever information may be embedded in the data. As will be seen next, this approach has yielded some worthwhile results.

3.3. *Single country estimation*

Table 1 reports the results of estimating individual models for every country with all REs as explanatories and selecting the most relevant - averages from Tables B.1,2 in Appendix C. The results obtained according to the usual statistical yardsticks - i.e., goodness of fit, and significance and sign of the estimated parameter coefficients -, after

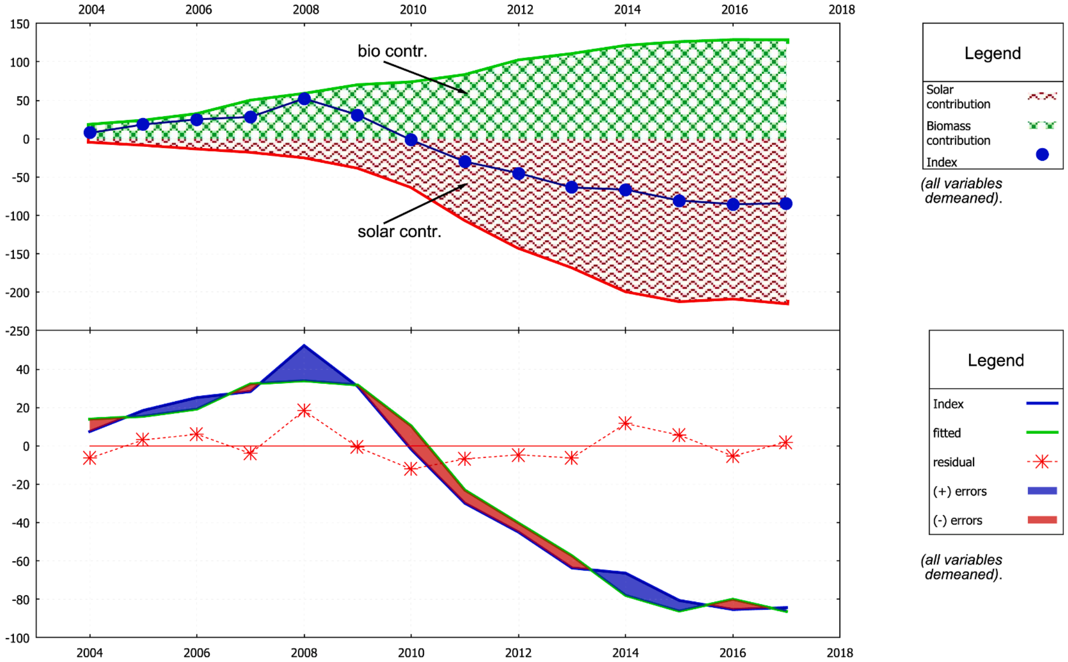

Fig. 3. Germany: Fit and decomposition. (*Source: Authors' calculations. See* Table C.3 *in Appendix C*).

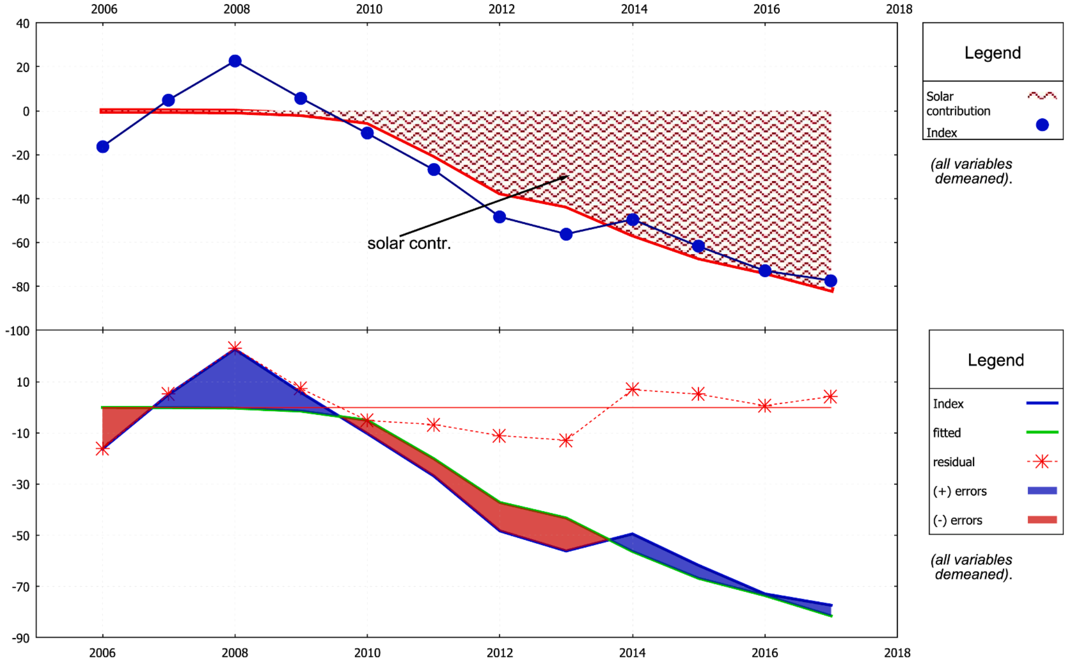

Fig. 4. France: Fit and decomposition. (*Source: Authors' calculations. See* Table C.4. *in Appendix C*).

some statistical modeling for all countries implementing the methodologies explained in Appendix B.3 were statistically acceptable, notably for Germany and France - see Tables B.3,4 in Appendix C for a detailed account.

The most salient result is the negative impact of solar energy, highly significant in Germany and France, and less so in Italy and the UK. Wind energy is significant and negative in Germany and positive in the remaining countries. This is likely a reflection of the German energy transition pathway, where the role of new entrants in the market deploying small-scale RE technologies has been more relevant than in the remaining countries [11,14,63]. As for biomass and RE(ao), their sign, size, and significance vary too much across estimation methods. There is no sensible statistical model of any kind for Spain, either restricted or unrestricted.

The main fitting results for Germany are portrayed in Fig. 3: the lower graph depicts the original Index variable (blue), the regression fitted line (green), and their difference, i.e., the fitting errors (dotted, red line); the upper graph displays the contribution of the explanatory variables (solar, biomass) to the Index along time - see also Appendix C, d) for details. Fig. 4 displays the equivalent graphs for France. For Italy and the UK the results are less clear-cut, and the Spanish case, finally, yielded no meaningful statistical results as noted before.

Table 2
SURE estimation: Summary results (averaged, qualitative).

	Germany	France	Spain	Italy	UK.
Hydro	—	—	—	—	—
Wind	—	—	—	M,(+),***	L,(+),**
Solar	H,(-),***	H,(-),***	—	L,(-),**	L,(-),*
Biomass	—	—	—	—	—
RE(ao)	M,(+),**	—	—	M,(-),*	—
R^2	97%	90%		71%	68%

Notes: See notes to table 1.

Table 3
Panel estimation: Summary results (averaged, qualitative).

	I	II	III
Hydro	H,(+),***	—	M,(+),***
Wind	—	L,(-),***	—
Solar	L,(-),**	H,(-),***	—
Biomass	L,(+),**	H,(-),**	L,(+),***
RE(oa)	M,(-),**	M,(+),***	—
R^2	75%	92%	69%

Notes: I: All countries; II: Germany and France; III: Italy and UK.(see also notes to Table 1)

3.4. *System estimation*

Results implementing the system estimation methodology presented in Appendix B.3 are reported next in Table 2 - all countries, but with different coefficients for each of them. A more detailed account is given in Tables B.5,6,7 in Appendix C.

As before, the only consistent result across countries and REs is the negative and broadly significant solar impact. Wind energy is significant and positive in Italy and the UK, and the remaining energies become mostly insignificant. Results for Spain are again not statistically significant.

3.5. *Panel estimation*

Table 3 finally reports the average results implementing the panel methodology - see Appendix B.3. -, which broadly amounts to imposing equal coefficients for all energy types across countries. Detailed results for every case analyzed are reported in tables B.8,9,10 in Appendix C.

The impact of solar PV is negative and significant broadly as before. Wind is significant but with a low impact for Germany and France. Hydro turns out to be positive, sizeable, and highly significant, especially for the second group - Italy and the UK. Results for biomass and other REs are significant in some cases but hard to interpret and not consistent with previous results presented in Tables 1 and 3. As discussed in Appendix B.3., the upside of the panel approach is that it significantly increases the sample size, which in some cases may be unavoidable; yet, this imposes strong restrictions that may lead to results somewhat more challenging to interpret.

4. Summary and discussion

The first set of results worth remarking is the lack of a constant sign and statistical significance for all technologies on the utilities stock-market performance except the PV, although wind energy has a positive impact generally, and hydro in some cases. A second, and perhaps the main result of the research, is the negative and statistically significant impact of PV energy, large in Germany and France, moderate in Italy and the UK, and insignificant in Spain. This result, besides, is quite robust and independent of the estimation methodology implemented. The third and last point that should be underlined is the lack of results for the Spanish case, coupled with the incumbent utilities' extraordinary performance compared to the remaining European cases and even to the general Spanish economy. They are discussed next.

That the transition can and in fact is being achieved under or inside the incumbent fossil energy system is a potential risk that has been pointed out by several authors as discussed in Sections 2.2.3, and is further underscored by the first set of results: in short, it might be

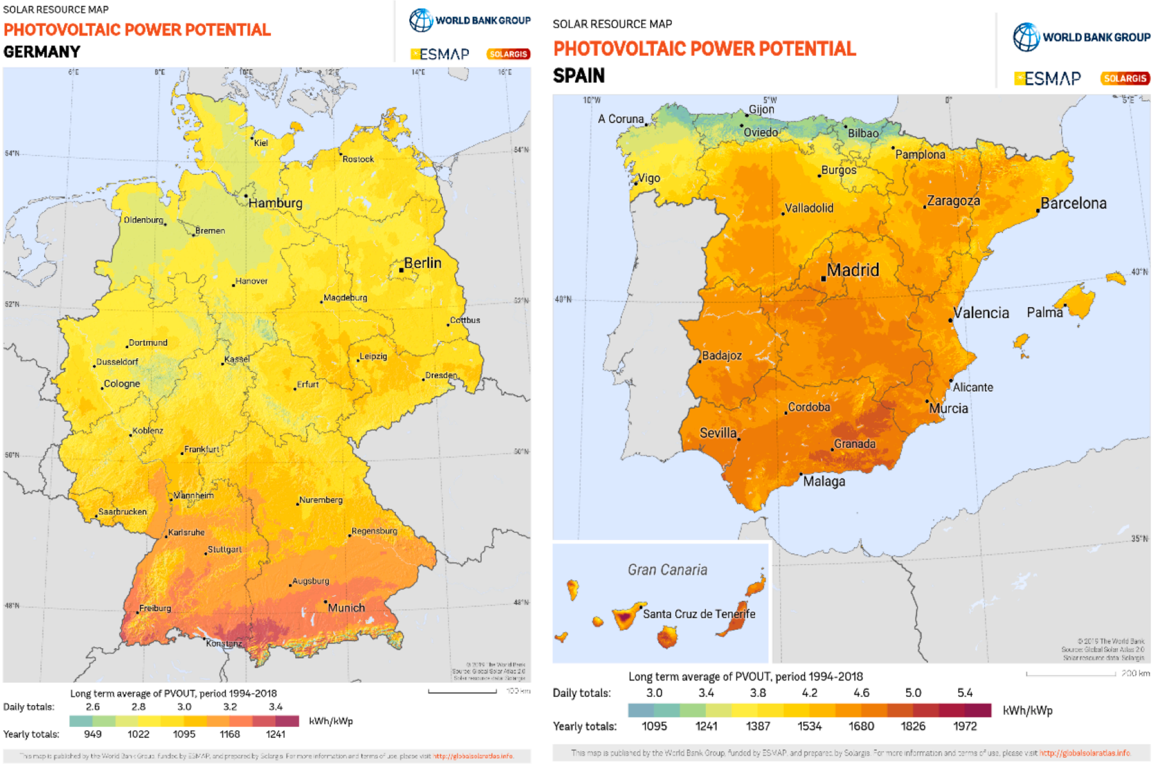

Fig. 5. Solar irradiance: Germany vs. Spain.

Table 4
Germany vs. Spain: relative PV deployment.

	Surface	MW (2019)	MW/Surface
Germany	357	45,000	126.05
Spain	506	8,700	17.19

Notes: Surface in thousand square km.

summarized by concluding that RE technologies are not necessarily a threat to the incumbent fossil system, and what is more, that it is investing in large scale RE technologies, co-opting the transition to a large extent in the European electricity system, at least in the countries considered. This result has been documented with alternative analytical approaches, e.g., for Germany, the UK, and Spain [14], for the UK [63], and for other countries not directly considered in this study, e.g., Finland [64]. The German case is more nuanced and significantly different from the others, as Fig. 2 suggests and the empirical results in Section 3 have confirmed: as explained analytically in detail in [11], this is the result of the transition pathway implemented that allowed new entrants to deploy small scale RE technologies. However, as shown in [11], a second period was characterized by a strong fightback from utilities, that downscaled policy support for small-scale RE technologies, supported capacity markets policies, and even opened prospects for coal. By contrast, the UK transition has been primarily conducted by incumbents deploying large-scale centralized RE like offshore wind parks and nuclear energy. Even an accelerated transition might not be a threat, provided they can finance the stranded assets through subsidies and appropriate political lobbying. That might solve the climate emergency, only to lead us to the next ecological crisis if earth limits are not acknowledged, and will not solve eventual economic inefficiencies and other justice-related issues.

The second result, nevertheless, is far more encouraging: the PV energy, because of its inherent scalability, technical simplicity, ease of deployment, and above all, low cost achieved through a high and persistent LR, embodies all favorable properties that, according to [17,65] and notably [53], can be ascribed to REs. Other technologies like biogas, hydro, and mainly onshore wind, may also be implemented on a small scale. Still, vested interests in the energy sector have outcompeted it, deploying increasingly large turbines that require significant upfront capital investments only affordable to big firms. Cost studies, particularly LR statistical research, have consistently shown deployment as the overarching explanatory factor behind the historically observed cost decreases. Yet, no equivalent result has been found for turbine size [66]. On the contrary, the PV technology can be deployed with minimum capital requirements, making it likely the most accessible to consumers and small investors among the renewable energies and explains its considerable and relentless deployment growth; see, e.g. [67]. Other REs and storage technologies will be needed as well, but many solutions are readily available; see, e.g. [68]. That it has been substantially deployed in Germany explains the lackluster performance of electricity incumbents and the distributed ownership of energy supply facilities [69,70]. Perhaps this is also why it has been deeply contested in many countries, especially where the incumbents are closely linked to political power through lobbying and revolving doors, a case in point being precisely Spain [58]. It should be remarked, in this regard, that some authors have even suggested special taxes to prevent the widespread use of EV batteries linked to PV prosumers and distributed minigrids [71] to shield the incumbent's market share. This leads to the discussion of the last research result.

The lack of significant statistical results for Spain is a counterexample against the widely optimistic hypothesis about REs put forth, e.g., in [65]. Being the European country with the highest RE electricity generated in the period considered - see Fig. 1 in Section 3 -, and yet the country where incumbent utilities have performed best - see Fig. 2, Section 3 -, it is the opposite case to Germany, which exemplifies the overall benefits of REs, and is the result of a distributed ownership of RE investments [11,53,69]. This is further analyzed in Fig. 5 and Table 4. Solar irradiance is shown to be much higher in Spain, roughly twice that of Germany on average: accounting for the larger Spanish surface implies that the equivalent installed capacity applying German parameters should be close to 127 GW - $(506/357) \times 45 \times 2 \cong 127$ -, a stark contrast with the 8.7 actually deployed in 2019, i.e., almost 15 times lower.

This is a confirmation of the dangers of the transition as noted by several researchers - see, e.g., [10,38,39,48] -, and in particular, that there is no guarantee that it will yield necessarily a more efficient, economic and political, and a more just system unless carefully monitored and conducted.

Remarkably, solar energy's impact is negative and highly significant in all countries except Spain. This results from an energy policy that has subsidized a particular solar technology, such as the CSP, that requires sizeable up-front investments not affordable therefore to small investors. It has also proved to be expensive and with low LRs compared to PV and wind: in fact, the latest available kWh cost estimate for CSP is 0.182 USD, almost three times the equivalent of 0.068 USD PV cost [62]. The fact that the leading firm investing in that technology does not belong to the traditional incumbency only strengthens the case against the risk that the transition is being monitored and conducted by traditional 'élites' [10,38]. In contrast, the far more promising and currently cheap PV alternative was, for all practical purposes and in the period considered, legally banished to shelter incumbents, mainly fossil energy providers, from competition. This could be seen as an example of the failure of the creative-destruction paradigm, which, in this case, is prevented from operating by law manipulation from vested interests.

Another example is reported in [72], although, in this case, the paradigm fails because of a lack of institutional coordination in implementing the necessary policy measures. These two cases lend support to the proposal of 'exnovation', a term introduced by [73] to describe the policy of actively retiring unwanted technologies, rather than waiting till they become outcompeted by the market. An example of this policy could be precisely the phase-out of nuclear energy in Germany and complementary phase-out policies implemented in the German 'Energiewende' [74]. This is not to imply that the German incumbents lack lobbying power, as remarked, e.g., by [10], but rather to underline the stark contrast with most other European countries. In particular, the Spanish experience again shows that even this 'exnovation' policy may not be enough since most coal-based electricity generation was forced to end before 1990. Again, this points to the dangers of a transition monitored and conducted by the economic incumbency, be it directly in the energy sector or more generally. Another related example is the UK's incumbency's destructive-recreation, supporting nuclear energy and shale gas to answer climate concerns [75].

Although there may be barriers of several kinds to the low-carbon transition [76], the immediate and final policy implication may be that, somewhat contrary to the financial sector, the right policy would be to avoid lobbying incumbent pressures that prevent niche technologies from entering the market once they become competitive, through the implementation of the proper policy measures: i.e., to avoid over regulations that virtually forbid the deployment of efficient and competitive new renewable energies, particularly at small scale, as has occurred in Spain till recently at least. And this applies particularly to small-scale energies like PV, small onshore wind, small hydro, biogas, and mini-grids that allow decentralizing the energy supply. But this can only be achieved by an active policy program, as stressed, e.g., in [16].

5. Conclusions

Three related empirical results have been found in this research: first, no renewable energy apart from the photovoltaic has a consistently negative impact on the performance of utilities, and in some cases, like wind, it is frequently positive; second, the photovoltaic energy has a negative effect in all countries analyzed, except in Spain; third, no significant result has been found for Spain, where the stock market performance of the utilities has been remarkably better than in all other European countries considered.

The first policy implication of these findings is a quantitative confirmation that renewable energies are not necessarily a threat to incumbent energy utilities and that the creative-destruction narrative does not apply, except perhaps in the German case. The photovoltaic energy, however, is shown to be the most difficult to monitor by the incumbents, being, therefore, the most accessible technology from the economic point of view: a second policy implication, therefore, is that this could be the primary technology of choice to open the energy system to consumers and small investors. Finally, the Spanish case shows that even with favorable physical and technological environments, the deployment of niche technologies that become competitive is not guaranteed, underscoring the need for a politically controlled transition to prevent economic inefficiencies. Greater government awareness of interested parties' lobbying power and more value placed on independent expertise would be advisable [13]. Policy should focus on well-known niche technologies rather than on uncertain and currently costly alternatives. Increasing the transparency of the energy planning and policymaking processes would also enhance public trust and accountability [18]. In a complementary policy approach implemented by the EU commission to increase competition in electricity markets, steps are being taken at the EU regulatory framework level, supporting active prosumers and energy communities. Although this presents a clear opportunity, overcoming regulatory barriers transposing EU law will be necessary [77].

From the methodological viewpoint, these results might be somewhat nuanced by the moderately short samples available. Nevertheless, a wide variety of methods have been implemented to make up for that shortcoming, all results pointing finally in similar directions. Although the country's combined size is a significant percentage of the total EU GDP, they are a relatively small group, and covering additional cases is a clear direction for future research. Further work along this line should consider similarly disaggregated analysis at the firm level. Extending the sample to more recent years and considering complementary firm performance measures besides stock market prices could also shed more light on the results reported.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements.

The comments and suggestions made by four anonymous referees, the journal editor-in-chief, J.L. Calvo (Uned), and the participants at the Cologne 2020 15th Sdewes conference (on-line), have improved the paper significantly. None of them is responsible for any possible remaining error whatsoever.

Appendix A. Competition and efficiency in economic Theory.

Efficiency in economic analysis is characterized as a situation where there is no way to make everyone better off: it can easily be shown that the monopolistic market - one product, one producer, many consumers -, does not meet this requirement; [35] chap. 2, [26] chap. 13, [27] chap. 10. The opposite extreme is the purely competitive market - one single standardized product, many producers and consumers: it can be shown to be Pareto efficient and is the building block of the general Walrasian economic equilibrium, Pareto efficient as well; [35] chap. 5. This result is known as the first theorem of welfare economics [27] chap. 17.

Monopoly producers make a profit above the competitive equilibrium, achieved by restricting production and increasing cost and prices, compared to an equivalent market under a competitive framework. This is why they cannot last unless there are restrictions to free entry. It is in this precise sense that open markets allowing free entry and involving many producers and consumers, prevent the exercise of market power and are considered competitive and efficient. Large monopolistic producers are likely to capture regulators in their favor through the exercise of lobbying power [78], and translate consumption related taxes to consumers with inelastic demands as is frequently the case for energy products; [35] chap. 7.6, [26] chap. 7, [27] chap. 5.B.

A variety of frameworks arising in practice, less extreme than pure monopoly, are encompassed by oligopolistic and monopolistic competition. They imply some degree of competitive behavior and are more efficient than pure monopoly likewise; [35] chap. 2, [26] chap. 14, [27] chaps. 10 and 11. Electricity markets in Europe fall in this broad category, particularly after the EU's policy measures to increase competition. Nevertheless, most national markets are still operated by a few companies, although there may be significant differences between countries.

Appendix B. Data, variables, and regression models.

B.1. RE and stock market data.

The official price quotes' stock market performance has been selected as the performance yardstick for the utilities analyzed because publicly traded companies typically are required to comply with rigorous accountancy standards. Small and midsized businesses often follow more simplified standards like Ebitda, widely used in mergers and acquisitions in over-the-counter markets. Ebitda is a company's earnings before interest, taxes, depreciation, and amortization, intended as a proxy for its profitability. Therefore, while a negative Ebitda points to fundamental problems with profitability, a positive one does not necessarily mean that the business generates cash. This is why it is not considered part of the Generally Accepted Accounting Principles by many official institutions, notably the US Securities and Exchange Commission [79]. The stock market price, additionally, a) reflects how the full market values the firm, not just the company's managers and accountants who calculate Ebitda, and, b) takes account of expectations, notably, future expected profits and losses, whereas Ebitda is only a measure of the performance in a given year.

The main electric utilities as listed in their respective stock market indices have been selected, consequently. Finally, it should also be noted that most of them offer products and services in several countries through subsidiaries but are listed in the market of their respective country of origin. Therefore, the stock market quote of the parent company in their respective markets has been selected. The main stock market indices in every country considered have been selected: DAX30 (Germany), CAC40 (France), FTSE100 (UK), IBEX35 (Spain), FTSEMIB (Italy). The electricity utilities listed in their respective stock market are: (Germany) E.on, Rwe-st-a, Mvv-energie; (France) Gdf-suez, Edf, Veolia-environ; (Italy) Enel, Terna-rete-elettrica; (Spain) Iberdrola, Endesa, gas-natural-sdg; (UK) Scottish-southern-energy, National-grid [80].

Renewable electricity data has been taken from Eurostat sources. RE data is classified by Eurostat as follows: Hydro, Wind, Solar, Biofuel(s) - solid -, RE(ao) - all other renewables, including liquid biofuels, renewable municipal waste, geothermal, and tide, wave &ocean. [81].

The initial handling of the raw data has been conducted with *Fortran95* programs written specifically for this research. Subsequent econometric calculations have been run with batch programs written in the *hansl* language [82] that runs in *gretl* - both open-source, allowing, therefore, independent checking. Programs for all figures have been written in the free, open-source language *gnuplot* [83]. Details of the specific econometric procedures can be found in [82] and [84].

B.2. Variables and definitions.

The stock quote for a given utility is denoted by $Q^{m,p}_{i,r,t}$, where i = (Germany, France, Spain, U.K., Italy), r refers to a specific utility, t=(2001, 2017) denotes a given year, m refers to the specific month, and p to the position, or stock market quote p=(open, high, low, close) - e.g., $Q^{4,2}_{1,2,2017}$, refers to the highest market share value of utility 2 for Germany in April 2017. Since data for RE installed capacity is only available annually, stock quotes are annualized accordingly, averaging over all months and quotes, i.e.,

$$Q_{i,r,t} = \left(\sum_{p=1}^{4} \sum_{m=1}^{12} Q^{m,p}_{i,r,t} \right) \Big/ 48 \tag{B.1}$$

and aggregated total market value, $U_{i,r,t}$, is immediately obtained by multiplying it by the number of shares outstanding at that date. Utility indices for all countries are derived from here as,

$$UI_{i,t} = \left\{ \left(\sum_{r}^{n_i} U_{i,r,t} \right) \Big/ \left(\sum_{r}^{n_i} U_{i,r,2010} \right) \right\} \times 100 \tag{B.2}$$

where n_i is the number of electricity utilities considered in the i^{th} country. Note also that $UI_{i,2010} = 100, for\ all\ i$. An equivalent notation is implemented for stock market indices so that, $Ia^{m,p}_{i,t}$ is the p^{th} position index quote for country i^{th}, in month m of year t. Annual global stock market indices values for all countries are derived straightforwardly averaging over all quotes and months, i.e.,

$$Ia_{i,t} = \left(\sum_{p=1}^{4} \sum_{m=1}^{12} Ia^{m,p}_{i,t} \right) \Big/ 48 \tag{B.3}$$

and rescaling, $I_{i,t} = (Ia_{i,t}/Ia_{i,2010}) \times 100$, so that $I_{i,2010} = 100, for\ all\ i$. Finally, the utility index relative to the general Index is given as, $UIp_{i,t} = (UI_{i,t}/I_{i,t}) \times 100$, for all five countries and seventeen dates: these are the explained variables considered in the estimation results - note that $UIp_{i,2010} = 100$ for all i, as well. This has been done to insulate the general impact on the stock market from all remaining macroeconomic variables and otherwise.

Data for RE installed capacity is only available annually, and the notation is defined similarly as before, i.e.: $RE_{i,r,t}$ is the total amount of RE generated in country i, of type r=*(Hydropower, Wind, Solar, Biofuel (solid), RE(all other))* in the year t=*(2001–2017)*. Total electricity generated in every country and year is denoted alike as $TE_{i,t}$. $RE_{i,r,t}$is now scaled relative to total electricity as follows,

$$REp_{i,r,t} = (RE_{i,r,t}/TE_{i,t}) \times 100 \tag{B.4}$$

so that, $REp_{i,r,t}$ is the percentage of total electricity generated by the r^{th} RE source in year t and country i^{th}. Wind energy is almost entirely onshore, and solar is mainly PV, except in Spain, where it is mainly Concentrated Solar Power (CSP). These are the explanatory variables in the estimated models.

A list with the main Symbols is given next:

$Ia^{m,p}_{i,t}$, Stock-market index quote.
$Ia_{i,t}$, Stock-market Index (annual, overall).
$I_{i,t}$, rescaled stock-market Index ($I_{i,2010} = 100$).
$RE_{i,r,t}$, Renewable electricity.
$REp_{i,r,t}$, Renewable over total electricity.
$REp^{w}_{i,r,t}$, $REp_{i,r,t}$ Weighted by country contribution to overall electricity.
$TE_{i,t}$, Total electricity from all sources - renewable and otherwise.
$TEp_{i,t}$, $TE_{i,t}$ as a proportion of all-countries total electricity.
$UI_{i,t}$, Utility index.
$U_{i,j,t}$, Utility annual average market quote.
$U^{m,p}_{i,j,t}$, Utility market quote.
$UIp_{i,t}$, Relative utility index to overall Index.
$UIp^{w}_{i,t}$, $UIp_{i,t}$ weighted by country contribution to overall electricity.

Note. Subindices: i^{th} refers to country, j^{th} to utility, r^{th} to a renewable energy type, t to year; Superindices: m^{th} refers to a month, p^{th} to the position (open, high, low, close).

B.3. Regression models.

Single country estimations have been conducted first. The RE utility index relative to the overall market index, $UIp_{i,t}$, has been run on the percentage of electricity generation of all energy types, $REp_{i,r,t}$, i.e.,

Table C1
Unrestricted single estimation.

	Germany	France	Italy	Spain	UK
Hydro	−12.0	23.4	11.7	−18.0	78.0
	(−0.737)	(6.90)	(1.72)	(−0.91)	(−1.11)
Wind	−0.158	33.4	23.2	4.52	−5.87
	(−0.0555)	(3.18)	(2.97)	(0.16)	(−1.11)
Solar	−32.8	−70.6	−2.7	−31.9	−7.79
	(−7.94)	(−5.12)	(−0.87)	(−0.35)	(−1.15)
Biomass	−5.16	31.9	16.7	147	10.6
	(−0.177)	(1.26)	(0.57)	(0.52)	(1.40)
RE(ao)	20.6	−170	−18.8	30.1	23.0
	(1.67)	(−1.58)	(−2.10)	(0.06)	(0.838)
RSS	874	1021	546	3710	981
R^2	0.972	0.917	0.747	0.395	0.666
T	14 (2004/17)	12 (2006/17)	13 (2005/17)	14 (2004/17)	14 (2004/17)
DW	2.06	1.48	1.71	0.92	1.24

Notes:
1) all t-ratios robust (against heteroc. and serial autocorr. of unknown form)
2) UK results in logs.
3) RSS, residual sum of squares.
4) a constant included in all cases.

$$UIp_{i,t} = \sum_{r=1}^{5} \left(\beta_{i,r} \times REp_{i,r,t}\right) + \varepsilon_{i,t} \tag{B.5}$$

where $\beta_{i,r}$ are the coefficients associated with the corresponding RE source, $REp_{i,r,t}$, and $\varepsilon_{i,t}$ are the regression fitting errors. Note that parameter estimates are distinct across countries. Unrestricted and restricted estimations have been run where appropriate.

Single estimations for every country can be combined first in a simple way by accounting for possible correlations of the fitting errors - i.e., Seemingly Unrelated Regressions or SURE estimation; see, e.g. [82,84]. The empirical results show that the five countries can be broadly split into two sets, Germany and France, on the one hand, and Italy and the UK, on the other, Spain being somewhat of an outlier. Estimations have been therefore conducted jointly for all five countries and independently for both groups. As before, restricted and unrestricted estimation have been run.

Panel estimates have also been run, i.e., a single equation for all data, allowing for some country and time-specific variables - mainly cross-sectional dummy variables or stochastic errors across countries and dates; see, e.g., again [82,84]. The single joint equation for all countries in the previous notation becomes,

$$UIp_{i,t} = \sum_{r=1}^{5} \left(\beta_{r} \times REp_{i,r,t}\right) + \varepsilon_{i,t} \tag{B.6}$$

where the individual country coefficients $\beta_{i,r}$ are replaced by common coefficients for all energy types becoming just, β_r. This basic model has been implemented for the whole set of countries and independently to both country sets discussed before. Parameter restrictions can and have been implemented as well, where appropriate.

Estimations relaxing the restriction of common parameters across all countries have also been conducted, weighting all variables by the relative size of its electricity market, i.e.,

$$\begin{aligned} TEp_{i,t} &= TE_{i,t} \Big/ \left(\sum_{i=1}^{5} TE_{i,t}\right) \\ UIp^{w}_{i,t} &= UIp_{i,t} \times TEp_{i,t} \\ REp^{w}_{i,r,t} &= REp_{i,r,t} \times TEp_{i,t} \end{aligned} \tag{B.7}$$

where the super index *w* is added to underline that it is the original variable weighted, and that it replaces the original unweighted variable in (B.6) where appropriate. Lastly, constants have been included in all previous models where applicable.

Appendix C. . Detailed estimation results.

Before presenting and discussing the results reported, a few comments are in order:

a) Significant *p-values* are omitted to simplify reporting and because they are implicit in *t-ratios* (supplied in braces below every estimate). The conventional symbol '*', to point at the significance level where appropriate is avoided, accordingly.
b) The specific value of the estimated coefficients can be better explained through an example - see Appendix B.2. for a specific and detailed definition of all relevant variables: consider, e.g., the impact of hydro in Germany, reported in Table C.1, -12.0; if there is a 1% increase in its share on the total electricity generated, e.g., from 20 to 21%, this implies a 0.12 points decrease in the relative utility index with respect to the whole market index, i.e., the ratio drops 0.12 points - note that the ratios have been scaled by 100 (see equs. B.2,4)).

Table C2
Restricted single estimation.

	Germany	France	Italy	UK.
Hydro	—	—	—	—
Wind	—	—	14.377 (3.315)	0.182 (3.00)
Solar	−32.20 (−10.60)	−42.76 (−7.07)	−4.2479 (−1.871)	−0.027 (−1.111)
Biomass	—	—	—	—
RE(ao)	18.70 (5.46)	—	—	—
AR(1)		0.306		
RSS	894	1189	701	0.0633
R^2	0.972	0.904	0.675	0.752
T	14 (2004/17)	12 (2006/17)	13 (2005/17)	14 (2004/17)
DW	1.967	1.52	1.785	1.625

Notes:
1) *t-ratios* robust (see Table 1)
2) UK results in logs.
3) a constant included in all cases.

Table C3
Germany: Utility index over the global stock market index.

	I	II	III	IV	V
Hydro	−12.0 (−0.338)	−12.0 (−0.638)	—	0.0201 (0.0162)	—
Wind	−0.158 (−0.0509)	−0.158 (−0.0909)	—	−1.35 (−3.39)	−1.35 (−3.32)
Solar	-32.8 (-6.59)	-32.8 (-7.70)	-32.2 (−9.13)	−1.23 (−5.83)	−1.23 (−5.95)
Biomass	−5.16 (−0.190)	−5.16 (−0.253)	—	2.83 (4.40)	2.83 (4.20)
RE(ao)	20.6 (1.82)	20.6 (2.22)	18.7 (4.58)	1.49 (4.63)	1.49 (4.46)
RSS	874	874	894	2613	2620
R^2	0.972	0.972	0.952	0.962	0.962
T	14(2004/17)	14(2004/17)	14(2004/17)	14(2004/17)	14(2004/17)
DW	2.06	2.06	1.97	1.15	1.15

Notes:
1) I: standard OLS.
II: robust t-ratios (see Table 1), OLS.
III: robust t-ratios, selected signif. vars., OLS.
IV: robust t-ratios, variables in logs., OLS.
V: robust t-ratios, selected signif. vars. (logs.), OLS.
2) RSS in cols. IV and V, in the equivalent form to remaining cols. (see text).
3) a constant included in all cases.

c) In all the following tables, 'restricted' means the final equation obtained after a specification search, keeping only statistically significant and economically meaningful coefficients.
d) A regression fit can be decomposed as follows: consider the equation,

$$y_t = \left(\widehat{\beta}_1 \times x_{t,1} + \widehat{\beta}_2 \times x_{t,2} + \cdots\right) + e_t \tag{C.1}$$

where $\widehat{\beta}_i$ are the estimated parameters, e_t is the fitting error, andy_t is the variable explained; the term in curved braces is the global fit, the contribution at time t of the variable x_t is $\left(\widehat{\beta}_1 \times x_{t,1}\right)$, and similarly for the remaining variables.

e) Statistical results in practice are a combination of data and models, and the usefulness of the final result depends on the quality of the data and the soundness of the hypotheses. Since the implementation may follow several alternative pathways, it has been common practice since the introduction of the Bayesian statistical approach to average the results to increase their robustness. This procedure is routinely implemented for simulation and forecasting purposes in economics and other fields like weather forecasting. It is also followed here to summarise the results reported next – see Tables 1, 2, and 3 in Section 3.

C.1. Single country estimation.

The following results have been summarized and briefly discussed in Section 3.3. Some further explanations for the German and French cases and additional technical points are presented next - Tables C.1-4.

Table C4
France: Utility index over the global stock market index.

	I	II	III	IV	V	VI
Hydro	23.4	23.4	—	—	5.63	—
	(1.15)	(6.90)			(8.28)	
Wind	33.4	33.4	—	—	1.34	0.803
	(0.879)	(3.18)			(14.4)	(5.58)
Solar	−70.6	−70.6	−44.0	−42.8	−0.0839	—
	(−2.71)	(−5.12)	(−10.3)	(−7.07)	(−2.25)	
Biomass	31.9	31.9	—	—	0.0451	—
	(0.495)	(1.26)			(0.242)	
RE(ao)	−170	−170	—	—	−5.01	−4.86
	(−0.575)	(−1.58)			(−6.72)	(−9.76)
RSS	1021	1021	1323	1189	278	1616
R^2	0.917	0.917	0.892	0.903	0.977	0.911
T	12(2006/17)	12(2006/17)	12(2006/17)	12(2006/17)	12(2006/17)	12(2006/17)
DW	1.48	1.48	1.23	1.51	1.79	2.8

Notes:
1) I: standard OLS.
II: robust t-ratios (see Table 1), OLS.
III: robust t-ratios, selected signif. vars., OLS.
IV: selected signif. vars., AR(1), PWE.
V: robust t-ratios, variables in logs., OLS.
VI: robust t-ratios, selected signif. vars. (logs.), OLS.
2) RSS in cols. IV and V, in the equivalent form to remaining cols. (see B.3,4).
3) a constant included in all cases.

Table C5
SURE estimation.

	Germany	France	Italy	Spain	UK
Hydro	−7.31	22.5	13.6	−13.9	109.4
	(−0.30)	(2.74)	(1.9)	(−1.02)	(1.97)
Wind	−0.80	32.6	25.3	−2.83	−6.47
	(−0.38)	(2.36)	(3.84)	(−0.34)	(−1.93)
Solar	−29.4	−80.8	−1.72	−18.0	−10.23
	(−8.06)	(−6.71)	(−0.85)	(−0.71)	(−1.79)
Biomass	−0.21	34.3	0.69	109.0	13.84
	(−0.01)	(1.27)	(0.04)	(1.37)	(2.52)
RE(ao)	16.3	−126.4	−21.3	236.9	13.0
	(2.16)	(−1.05)	(−2.29)	(1.02)	(0.63)
RSS	949	1079	599	4039	1006
R^2	0.97	0.915	0.722	0.355	0.658
T	14 (2004/17)	12 (2006/17)	13 (2005/17)	14 (2004/17)	14 (2004/17)

Notes:
1) system estimation
2) results for every country from the system estimation over the stated period for that specific country.
3) a constant included in all cases.

The two consistent results across specifications are for solar, negative and highly significant, and RE(ao), although this result is less amenable to an explanation, since that category lumps together a motley variety of energies. The log specification may look more satisfactory statistically, but a concern is the relatively large number of parameters – 6 in col. IV, 5 in col. V -, to the short span of the sample, with just 14 observations. Besides, another parameter would be required to account for the autocorrelation implied by the DW.

For comparability, and when the dependent variable is in logs., the sum of squared residuals has been calculated as follows:

$$log(y_t) = \widehat{log(y_t)} + \widehat{\varepsilon}_t$$

$$RSS = \sum_{t=2006}^{2017} \left\{ y_t - exp\left[\widehat{log(y_t)}\right] \right\}^2 \tag{C.2}$$

where y_t is the dependent variable, $\widehat{log(y_t)}$ the fitted value, and $\widehat{\varepsilon}_t$ the fitting error.

The log specification again looks more satisfactory statistically, although 12 observations is too short a sample for the 6 parameters in col. V, whereas the fit worsens significantly in col. VI. Besides, another parameter would be required to account for the autocorrelation implied by the DW. As for REs, the only consistent result is the negative and highly significant solar effect in all cases but the last.

Table C6
SURE estimation.

	unrestricted		*restricted*	
	Germany	France	Germany	France
Hydro	−4.29	13.40	—	—
	(−0.16)	(1.02)		
Wind	0.45	20.47	—	—
	(0.19)	(0.86)		
Solar	−31.6	−67.90	−29.95	−43.87
	(−8.54)	(−3.87)	(−9.33)	(−10.17)
Biomass	−1.01	43.0	—	—
	(−0.05)	(1.01)		
RE(ao)	17.4	−90.56	15.66	—
	(2.09)	(−0.48)	(3.91)	
RSS	888	1068	930	1323
R^2	0.972	0.913	0.970	0.892
T	14 (2004/17)	12 (2006/17)	14 (2004/17)	12 (2006/17)

Notes:
1) system estimation.
2) results for every country from the system estimation over the stated period for that specific country.
3) a constant included in all cases.

Table C7
SURE estimation.

	unrestricted		*restricted*	
	Italy	UK.	Italy	UK.
Hydro	12.27	0.38	—	—
	(1.54)	(0.46)		
Wind	23.49	0.22	14.5	0.16
	(3.28)	(2.33)	(3.06)	(2.05)
Solar	−2.69	−0.03	−4.30	−0.02
	(−1.14)	(−0.77)	(−1.81)	(−0.81)
Biomass	14.84	0.005	—	—
	(0.74)	(0.04)		
RE(ao)	−18.94	−0.30	—	—
	(−1.89)	(−0.54)		
RSS	547	0.062	701	0.060
R^2	0.746	0.757	0.675	0.648
T	13 (2005/17)	14 (2004/17)	13 (2005/17)	14 (2004/17)

Notes:
1) system estimation.
2) results for every country from the system estimation over the stated period for that specific country.
3) UK results in logs.
3) a constant included in all cases.

C.2. System estimation.

A summary table derived from all results reported next has been presented, and the main implications are briefly discussed in Section 3.4. The methodology has been implemented to the whole set of countries and independently to the two groups remarked in Fig. 2 in Section 3. Restricted and unrestricted specifications have also been estimated. Detailed results are reported in Tables C.5-7.

C.3. Panel estimation.

A detailed account of the summary results presented in Section 3.5, after implementing the panel methodology presented in Appendix B.3 is reported next. A variety of models has been estimated for the whole set of countries and for the two groups considered, yielding similar results in all cases, nevertheless - see, e.g. [82,84] for details of the methods. Restricted and unrestricted estimates are reported as in previous sections, and weighted and unweighted estimations have been conducted - see Eqs. (B.7) in Appendix B.3 and Tables C.8-10.

Table C8
Panel estimation: All countries.

	unweighted		*weighted*			
			unrestricted		*restricted*	
	Fixed effects	Random effects	Fixed effects	Random effects	Fixed effects	Random effects
Hydro	48.3	44.8	68.7	63.5	69.8	65.5
	(6.46)	(6.28)	(6.21)	(6.01)	(7.06)	(6.88)
Wind	−2.38	−2.76	−0.48	−0.89	—	—
	(−1.1)	(−1.29)	(−0.23)	(−0.43)		
Solar	−0.73	−0.09	−8.82	−8.11	−9.36	−9.11
	(−0.19)	(−0.02)	(−2.04)	(−1.90)	(−2.61)	(−2.57)
Biomass	12.3	13.0	9.17	9.90	8.42	8.52
	(2.57)	(2.75)	(1.84)	(2.01)	(2.26)	(2.30)
RE(oa)	−20.9	−20.6	−15.3	−15.2	−15.3	−15.1
	(−4.17)	(−4.15)	(−2.77)	(−2.77)	(−2.79)	(−2.78)
RSS	18,902	19,473	806	824	807	829
R^2	0.749	0.702	0.757	0.749	0.757	0.742
T	12 (2006/17)	12(2006/17)	12(2006/17)	12(2006/17)	12(2006/17)	12(2006/17)
n	5	5	5	5	5	5
Sample:n × T	60	60	60	60	60	60
DW	0.953	0.926	1.059	1.061	1.074	1.073

Notes:
1) weighted/unweighted; see equs. (B.7) in Appendix B.3.
2) random-effects Using Nerlove's transformation; 5 cross-sectional units included.

Table C9
Panel estimation: Germany and France (weighted).

	unrestricted		*restricted*	
	Fixed effects	Random effects	Fixed effects	Random effects
Hydro	0.072	−6.82	—	—
	(0.11)	(−1.30)		
Wind	−2.65	−2.95	−2.65	−2.35
	(−3.48)	(−3.07)	(−3.78)	(−3.84)
Solar	−30.2	−30.6	−30.2	−31.8
	(−4.27)	(−4.17)	(−4.41)	(−4.28)
Biomass	−43.1	−44.0	−43.1	−38.0
	(−2.98)	(−2.88)	(−3.13)	(−2.87)
RE(ao)	25.0	26.3	25.0	26.1
	(3.60)	(3.88)	(3.65)	(3.32)
RSS	146	486	146	488
R^2	0.950	0.901	0.950	0.900
T	12 (2006/17)	12 (2006/17)	12 (2006/17)	12 (2006/17)
n	2	2	2	2
Sample:n × T	24	24	24	24
DW	1.748	1.749	1.748	1.752

Notes: See notes to Table C.8.

Table C10
Panel estimation: UK and Italy *(weighted)*.

	unrestricted		*restricted*	
	Fixed effects	Random effects	Fixed effects	Random effects
Hydro	21.6	13.6	11.3	10.4
	(1.59)	(3.50)	(32.1)	(19.7)
Wind	−0.09	−0.30	—	—
	(−0.02)	(−0.07)		
Solar	−0.36	−0.62	—	—
	(−0.25)	(−0.51)		
Biomass	3.34	3.28	2.39	2.49
	(0.37)	(0.37)	(72.3)	(55.7)
RE(ao)	−4.12	0.04	—	—
	(−0.69)	(0.04)		
RSS	47.7	48.2	48.6	49.3
R^2	0.706	0.707	0.701	0.698
T	12 (2006/17)	12 (2006/17)	12 (2006/17)	12 (2006/17)
n	2	2	2	2
Sample:n × T	24	24	24	24
DW	1.473	1.475	1.468	1.474

Notes: See notes to Table C.8.

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