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The impact of subsidy retraction on European renewable energy investments

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ABSTRACT

Over the past few decades, renewable energy has received considerable public support through subsidies. However, its reliance on governments inherently induces policy uncertainty through the possibility of retroactive policy changes, i.e., ex post subsidy adjustments, which, in turn, impact private investors' appetite for renewable energy investments. We empirically investigate the effect of retroactive policy changes on investment decisions by considering common support mechanisms in the EU for the period 2000–2017. To quantify the impact, we estimate a regression model utilizing a difference-in-difference approach, which allows us to identify the impact stemming from retroactive policy changes. The results show that a retroactive subsidy change decreases the investment rate by approximately 45% for PV and 16% for *onshore* wind. Hence, our results indicate that once the seed of mistrust is sown, it is likely to have a lasting impact. Consequently, our results suggest that a stable policy environment with credible policy commitments is crucial for incentivizing investments made by private firms. We find that that sudden unexpected policy changes deter further investment activity in affected countries suggesting that a stable policy environment is crucial to incentivize investments by private firms. This effect was greater for solar investments than *onshore* wind.

1. Introduction

The increasing awareness of the potential consequences of climate change has led to international commitments to reducing greenhouse gas emissions. In the European Union, specific targets under the EU2030 climate and energy framework are being pursued to cut emissions 'substantially' by 2050 (European Commission, 2012). Increasing the share of renewable energy production in the overall energy mix is recognized as a critical step in reaching these goals. However, following the deregulation of the European electricity market, investments in renewable energy (RE) production have largely been made by private companies, meaning that investment decisions are constrained by profitability concerns (Abadie and Chamorro, 2014).

In recent years, the cost of renewable energy production has declined, and different technologies are approaching retail grid parity (IRENA, 2018). Along with national economic constraints and the changing political climate, this parity has prompted several European governments to decrease their support levels. Some policy changes have also had retroactive effects, that is, unexpected reductions in the profitability of existing projects (Boomsma and Linnerud, 2015). For example, RE subsidies fuelled an investment boom in the Czech Republic. Combined with the added financial strain due to the European debt crisis, the government suddenly introduced a solar tax of 26%. This change not only curtailed the attractiveness of investments in new projects but also greatly affected the profitability of existing production and thus limited further investments. In another example from Spain in 2012, an unforeseen and retroactive subsidy revision made some producers resort to legal proceedings. This effectively created a precedent in which investors have to consider the risk of retroactive policy changes when making investment decisions (The Economist, 2013).

Even though renewable technologies are approaching retail grid parity, the empirical evidence suggests that cost reductions are largely offset by increased exposure to policy and revenue risk (Karneyeva and Wüstenhagen, 2017). For example, Statkraft, a large European RE producer, emphasizes the importance of a stable policy framework by explicitly taking uncertainty into account during its investment decisions (Statkraft AS, 2018). Furthermore, evidence from the United Kingdom demonstrates how policy risk can have immediate and

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nationwide consequences for the investment rate. New investments in green energy declined by more than 50% from 2016 to 2017 as a result of government policy changes (The Guardian, 2018).

In this study, we aim to contribute to the understanding of how damaging policy uncertainty can be in terms of offsetting the investment incentives created by subsidies. The problem is widespread, but for concreteness, we shall focus on policy uncertainty in terms of the retroactive retractions or substantial negative revisions of existing subsidy schemes. We construct a panel dataset of 26 European countries over 18 years and consider the most common support mechanisms employed in Europe during this period, namely, feed-in tariffs (FITs) and feed-in premiums (FIPs).[1] We employ a difference-in-difference (DD) method which allows us to both identify and quantify the impact of retroactive policy interventions on future investments, and we find that retroactive changes in these subsidy schemes greatly reduce the investment rate for both *onshore* wind and PV investments. Interestingly, the result of a retroactive policy intervention impacts the investment rate in PV to a greater extent compared to *onshore* wind. The implications of these new insights are important considering that many countries implement subsidy schemes without taking into account how their perceived credibility from earlier support schemes might offset the effectiveness of the considered scheme. Furthermore, our results show that governments should consider how private firms act in light of policy uncertainty to effectively stimulate further investments.

We proceed by positioning ourselves and highlight how we extend the current literature in Section 2. Section 3 introduces the dataset and discusses the relevant factors for RE investments. The model is introduced in Section 4, together with a discussion about possible identification problems regarding policy uncertainty. The results are presented and discussed in Section 5. Finally, Section 6 concludes the paper by offering policy insights.

2. Literature review

Traditionally, price, volume and balancing risk have been considered important factors in determining policy design (Mitchell et al., 2006); however, recent contributions emphasize the stability of the support system itself, i.e., policy uncertainty, as an important determinant for RE investments (Lüthi and Wüstenhagen, 2012; Chassot et al., 2014). Although policy uncertainty is intangible and difficult to quantify, Baker et al. (2016) demonstrate that by using analyses of keywords in newspapers they are able to construct an index that measures uncertainty related to major political events. Unfortunately, an RE-specific newspaper index does not exist to the best of our knowledge, and the limited number of articles on this topic make it difficult to capture the major policy events affecting RE. Nevertheless, there exist several promising alternative techniques to they newspaper approach that allow us to better understand policy uncertainty. One stream of the literature uses theoretical models to investigate government commitment to existing policies and a firm's best response to an uncertain policy, whereas another stream utilizes empirical techniques to quantify or describe RE investments in light of policy uncertainty, either through stated preference approaches or regression analysis.

The first stream of the literature seeks to understand how policy uncertainty interacts with investment incentives using theoretical models. The seminal contribution of Kydland and Prescott (1977) shows how investments today are made with the anticipation of policy adjustments in the future. Kydland and Prescott (1977) therefore advocate a rule-based policy approach to alleviate concerns about ex post policy optimization. Blackman and Zeckhauser (1992) study the interaction between a regulator and a utility, where once an investment is undertaken, it is vulnerable to appropriation by the regulator. They find that it is advantageous for the regulator to repay at least the investment cost, which ensures sufficient trust to allow for future investments. A strand of this literature illustrates how government commitment may be necessary to induce investments in energy and environmental technologies. Laffont and Tirole (1996) introduce a framework to examine the impact of the government's ex post discretion in setting pollution permits on the ex ante incentives for innovation. A time-inconsistency problem arises in the following sense: once clean technology is invented, the government has an incentive to issue a large number of permits and reduce the spot price of pollution permits as much as possible. This policy will force the owner of the clean technology to reduce its price to zero, which is also socially optimal ex post. Knowing the behaviour of the government, the innovator will not invest in the creation of new technology, which is socially inefficient. Hence, the government's ability to reach ambitious climate goals crucially depends on the level of subsidy commitment.

Rather recently, a new strand of theoretical literature addresses the impact of policy uncertainty on the firm's investment decision via real options. Real options theory is frequently used since it facilitates the modelling of dynamic decision making under uncertainty. Blyth et al. (2007) were among the first to study the effect of policy uncertainty on investment in RE. They study an option to invest in coal- and gas-fired power plants with carbon capture and storage (CCS) technologies. Their results indicate that climate policy uncertainty creates a risk premium for power generation investments; however, the option to retrofit an investment with CCS acts as a hedge against policy uncertainty. Boomsma et al. (2012) investigate the effect of different subsidy schemes on investment in RE. They find that the implications of the uncertainty associated with each support scheme can be crucial for both the time of the investment and the size of a project. More specifically, in their case study, FIT leads to earlier investment in the Nordic market, while a market-based support system encourages greater capacity. In the same line of work, Boomsma and Linnerud (2015) find that an expected subsidy retraction increases the rate of investment if it is applied to new projects, while it slows down investment if it has a retroactive effect; i.e., existing projects will be also impacted by policy changes. In contrast, Adkins and Paxson (2016) conclude that an unexpected retroactive withdrawal of a subsidy motivates earlier investment since the firm seeks to capture existing subsidies compared to the case without subsidies. The implications of an FIT for RE investment are further explored in Ritzenhofen and Spinler (2016), who show that under a sufficiently attractive FIT regime, future policy regime changes have a negligible impact on current investment projects. In contrast, investment is deferred or even withdrawn when a regulatory shift exposing investors to price uncertainty is likely.

Chronopoulos et al. (2016) study the optimal timing and size of stepwise investment decisions in a renewable energy project under the risk of sudden and permanent subsidy retraction. The results show that greater policy uncertainty increases the incentive to invest but lowers the installed capacity. Similarly, Dalby et al. (2018) study how investment in a green energy project is affected by the risk of an adverse subsidy adjustment with retroactive effects. In this study, the investor is assumed to have a subjective belief of the time until subsidy revision. The paper examines how updating this belief over time through Bayesian learning influences the investment decision. Dalby et al. (2018) show that the investment threshold increases as the perceived expected time until a policy change decreases. Their results indicate that investors will prefer a lower FIT level, which is expected to be provided for a longer time horizon, to a high subsidy level with a high risk of retraction. Although real options theory is well suited for enhancing our understanding of and the interconnection between important determinants of RE investment, this strand of theoretical literature seldom tests its assumptions or implications empirically.

A second stream of literature seeks to empirically establish and understand the importance of policy design and uncertainty through stated preference approaches. Stated preference approaches leverage questionnaires to illicit how decision makers value different investment

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[1] FIT: fixed and guaranteed price over the whole period. FIP: premium payment in addition to the market price.

factors. Using a stated preference approach with 63 European PV project developers in 2008, Lüthi and Wüstenhagen (2012) quantify the importance of different types of policy risk. Based on relative importance, the results show that the *duration of the administrative process* (25.6%), *the level of FITs* (24.4%), *existence of a cap* (18.7%), *number of PV policy changes* (17.7%) and *duration of FITs* (13.6%) were recognized as the most critical factors. Chassot et al. (2014) utilize a similar technique to investigate investors' perceptions of regulatory risk and the influence on the investment decision. Their research demonstrates that high regulatory risk reduces the probability of investment. Recently, Botta (2019) examined how policy-induced uncertainty affects the cost of capital of renewable energy power plants via a stated preference approach. He focuses on renewable energy auctions and on the Brexit negotiation to investigate how uncertainty regarding future business conditions might impact the cost of capital. The results indicate that an improved auction design can substantially reduce the cost of capital, however, the impact of policy uncertainty is hard to establish. Although the abovementioned contributions establish a negative relationship between policy risk and RE investment, the aggregate impact on RE investments is not clear.

Hence, to investigate the aggregate impact of different factors on RE investments, a branch of the empirical research utilizes panel data. Among the existing contributions, Walls et al. (2007) consider the decision to build new electric power generation projects in a changing and uncertain regulatory environment and estimate the likelihood of abandoning a planned project in North America. They find that private firms are far less likely to make necessary investments when the regulatory environment is uncertain. Additionally, Eyraud et al. (2011) take an econometric approach, using a fixed-effects model, to determine the main macroeconomic drivers of investment in renewable energy sources. The results show that income level, cost of capital and oil price are significant variables. Furthermore, when holding other factors constant, the investment rate in countries adopting an FIT scheme far exceeds the rate in countries that do not provide any government incentives. In a different setting, Linnerud et al. (2014) analyse policy uncertainty by considering panel data on small run-of-the-river hydropower plants. They find that professional investors act according to real options theory, meaning that they delay the investment decision when facing an uncertain future subsidy scheme.

A further indication of the importance of stable policy environments is provided by Karneyeva and Wüstenhagen (2017). They conduct a case study of the PV markets in Germany, Italy and Switzerland and investigate the effects of declining subsidy amounts on markets approaching grid parity. The authors emphasize that while the cost of PV modules declined by 75% between 2009 and 2014, the consequent removal of subsidies has resulted in a net reduction in investments in the European solar market. Correspondingly, the paper argues that stable policy environments provide the basis for promoting further investments in PV.

By considering different support schemes across Europe, García-Álvarez et al. (2018) are able to quantify the impact of subsidy schemes on the investment rate in RE. They use a pooled OLS regression for European countries with data from 2000-2014, evaluating FITs, FIPs and quota obligation schemes[2] and their design elements. They find that a variable indicating whether a subsidy in the form of either FIT or FIP is currently provided has a statistically significant impact on installed PV capacity. Although both tariff size and the duration of the scheme also show a positive correlation with investment rates, these effects are not significant. García-Álvarez et al. (2018) conclude that policy makers should create a stable and predictable policy environment to increase investment security and stimulate investment.

Similar to Eyraud et al. (2011), we use a fixed effects model to study the determinants of green energy investments. However, where Eyraud et al. (2011) investigate macroeconomic drivers, our analysis focuses on the effect of policy uncertainty. Additionally, we include time fixed effects to account for unobservable covariates that change over time. For example, the investment cost is expected to decline over time, yet it is difficult to discern its true value; however, as long as the investment cost declines with the same rate across countries, the impact is controlled via time dummies. Finally, in contrast to both Eyraud et al. (2011) and García-Álvarez et al. (2018), we use a DD approach to identify the causal impact of unexpected subsidy revisions on the investment rate. Hence, we are able to quantify the effect of retroactively implemented policy changes. This was identified as an important future research direction by García-Álvarez et al. (2018) and is particularly important given that the empirical literature suggests that the impact of technological progress has in recent years "largely been offset by increased exposure to policy and revenue risk" (Karneyeva and Wüstenhagen, 2017). Furthermore, although the aforementioned literature offers crucial insights into investments under different support schemes, it does not explicitly seek to quantify the impact of policy shocks. Our paper contributes to the literature in the following four ways.

- We contribute to the literature by utilizing a DD approach that enables us to establish a clear link between retroactive policy adjustments and investments in RE.
- Furthermore, the model allows us to quantify the average investment reduction due to an unstable policy environment, and we can thus confirm the impact of policy uncertainty documented through stated preference techniques.
- Additionally, by quantifying the effect of setting precedence for ex post alterations, we provide policy makers with a tool to weigh the costs of discretion against commitment.
- Finally, representing policy uncertainty as unexpected sudden change in existing policy schemes is in partly motivated by the real options literature, and consequently, our significant results lend support to the appropriateness of these theoretical contributions.

3. Data

The following section describes the dataset and variables used to model the investment rate in solar and wind electricity generation. A summary of the different data sources is given in Appendix A. The sample includes time-series data from 27 of the 28 EU member countries[3] for the time period 2000–2017. The data are split into solar PV and *onshore* wind power,[4] while other renewable sources are omitted.

Fig. 1 illustrates the added capacity in MW for solar and wind. There was a considerable boom in solar investment before the European debt crisis in the period 2010–2014. Although the investment rate for solar power fell substantially during the European debt crisis, a similar change was not evident for onshore-wind investments. Furthermore, both RE sources follow a long-term upward sloping trend, which makes the data non-stationary. Hence, we will use the log-difference of total capacity as the dependent variable to reflect the percentage change in capacity.

Note that there is a potential disparity between the investment rate and capacity change since the change in installed capacity, in contrast to new investments, can be negative. If, for example, a large plant is taken

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[2] Quota obligation: electricity suppliers must meet a certain renewable share that they cover by purchasing green certificates from renewable energy producers. The prices of the green certificates are determined by supply and demand.

[3] Only Cyprus is excluded, mainly due to limited renewable production and a lack of subsidy schemes, as well as a lack of data availability.

[4] *Offshore* wind is excluded from the dataset, despite being in line with other renewable sources in terms of investments after 2013 (BNEF, 2018). However, as considerable and wide-ranging offshore wind investments have materialized only in recent years, there are apparent limits to the number of available observations in time.

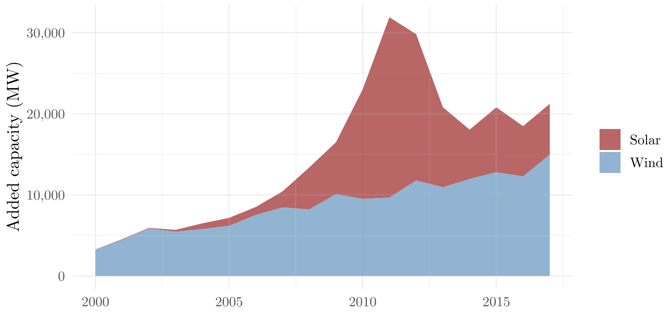

Fig. 1. Total added wind and solar capacity for the 27 European countries considered.

out of production, this will significantly impact the net capacity addition in that year. However, according to a publication from Wind Europe in 2017, only 640 MW of wind power was decommissioned. With reported installations of 15.6 GW, the ratio of withdrawn capacity to added capacity amounted to only 4.1% (WindEurope, 2018). For solar radiation, the average lifetime of a PV module is 30 years, and a large part of the current capacity was installed within the last two decades (IRENA, 2018). Therefore, we assume that annual decommissions are negligible relative to added capacity. In the following we use *capacity change* and *investment rate* interchangeably.

Fig. 2 illustrates average FIT and FIP levels for solar (left) and wind (right) given that a country had a support system in place for a given year. FIT consists of guaranteed payments over the project lifetime, meaning that company profitability is disengaged from electricity price fluctuations. Thus, FIT provides a high degree of certainty about future cash flows (see Couture and Gagnon (2010) for more details). Furthermore, FIT amounts often vary across different plant sizes. We choose FITs for large plants since this contributes to the majority of added capacity IRENA (2018). In contrast, FIP implies that producers are exposed to market risk since they receive a premium on top of the market price. Note that subsidy levels have been decreasing for both FIP and FIT in Fig. 2, and recently, Financial Times (2020) has even suggested that current projects are initiated with nearly no support. The dip in average FIP for wind (right panel) is mainly caused by the withdrawal of lucrative Spanish subsidies. Historically, the support levels provided for solar power production have been higher than those provided for power production from *onshore* wind. This finding is expected since wind power is considered a more mature technology.

During the period of 2000–2017, there were significant cost reductions and technological developments in the generation of both solar and wind energy. The left panel of Fig. 3 illustrates the average cost of a PV module and total installed costs[5] (TIC) for wind. Although the proxies illustrated in Fig. 3 are not directly comparable, both measures convey a downward sloping trend. By comparing the left panel of 3 with Fig. 2, there seems to be a positive correlation between lower technology cost and subsidies. Consequently, the impact of subsidies on the investment rate might be obfuscated by decreasing technology costs. Hence, we will include time fixed effects in our model to account for technological improvements. In the right panel, there is a sharp decline in the number of countries employing an FIT scheme during the last ten years, with a distinct increase in the number of FIP schemes during the same period. From a historical high in 2009, the number of FIT schemes has been reduced by half for both technologies. Moreover, the number of FIP schemes has doubled. Furthermore, notice that in 2017, 23 countries out of the 26 considered had an RE support scheme in place. A noticeable trend in European support policies over the considered time period is the transition from guaranteed prices (FIT) to market-based subsidy types (FIP and quota obligation).

4. Model

To isolate the effect of retroactive policy changes from non-retroactive ones, we apply a DD method with country and time fixed effects. DD estimation consists of identifying a specific intervention or treatment and subsequently comparing the difference in outcomes on an unaffected group. In our model, this treatment is the occurrence of retroactive policy changes. The countries in our sample are consequently split into countries that have experienced retroactive policy changes, the treatment group, and those that have not experienced retroactive policy changes, the control group.

A concern with the DD approach is that there is an endogeneity problem since retroactive subsidy retractions and installed capacity could potentially interact; i.e., greater capacity makes retroactive subsidy changes more likely. However, these retroactive interventions seem to be closely linked to the European debt crisis, which can be considered an exogenous shock to RE investments. Furthermore, it is unlikely that investors anticipated these retroactive subsidy changes since we see no evidence that investment activity slowed down prior to the policy events, as also illustrated by several ensuing lawsuits (The Economist, 2013). Additionally, by incorporating country and time fixed effects, we account for systematic differences in terms of policy uncertainty between the countries and across time.

Based on the study of Lüthi and Wüstenhagen (2012), several attributes reflecting the key factors involved in investment risk were identified, one of which was *policy instability*. Moreover, retroactive subsidy retractions were identified by Helm et al. (2003) as one of the main threats to the profitability of RE projects, and as suggested by García-Álvarez et al. (2018), the effect of retroactive changes is included in our model. To measure policy uncertainty, we introduce a variable that takes a value of 1 if a retroactive change has occurred in a given year and all subsequent years. The implicit assumption is that any retroactive change sets a precedent for further policy decisions and increases the perceived risk faced by investors. We consider the following cases to be retroactive: Italy (Karneyeva and Wüstenhagen, 2017), Spain (del Río and Mir-Artigues, 2012), Greece, Bulgaria and the Czech Republic (Boomsma and Linnerud, 2015) and Portugal (Peña et al., 2017), which all occurred in the period between 2010 and 2012.

Next, to quantify the investment rate, we first transform total capacity by taking the log difference for country i at time t, as indicated in (1) for *onshore* wind and solar separately. Hence, $y_{i,t}$ is approximately equal to the percentage change in capacity and reflects an investment rate in the current year for a given country and technology.

$$y_{i,t} = \log\left(Capacity_{i,t}\right) - \log\left(Capacity_{i,t-1}\right) \tag{1}$$

To isolate the effects of retroactive changes on installed capacity, we estimate the regression given by (2).

$$y_{i,t} = \gamma_i + \lambda_t + \beta D_{i,t} + \delta \mathbf{X_{i,t}} + \varepsilon_{i,t} \tag{2}$$

The first term, γ_i, describes time-invariant country effects, whereas the second term, λ_t, captures the changes over time that are common across states, such as investment costs and the oil price. Note that the retroactive policy changes observed across the countries in our sample occur at different points in time. Hence, a staggered DD approach is used; i.e., $D_{i,t}$ takes the value of 1 for all subsequent years in country i after a retroactive policy change has occurred and zero otherwise. The coefficient β can thus be interpreted as an average treatment effect caused by a retroactive subsidy withdrawal. Furthermore, X_{it} represents control variables, and $\varepsilon_{i,t}$ is a random disturbance term with mean zero. Note that when using percentage change in capacity as a proxy for investments, there is an apparent need to account for the time of project development. According to Wayne (2008), there is a two-year period from financing to operation in solar projects. For wind projects, SEIA

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[5] TIC: yearly total price of all installations divided by the annual installed capacity.

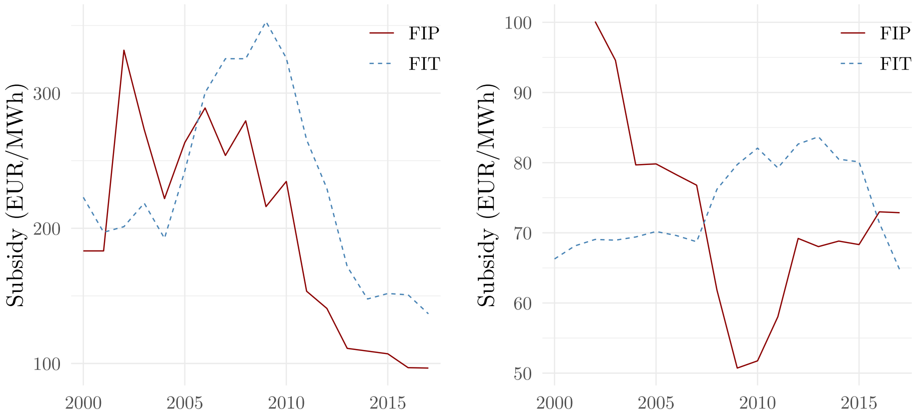

Fig. 2. Average FIT and FIP levels for solar (left) and wind (right).

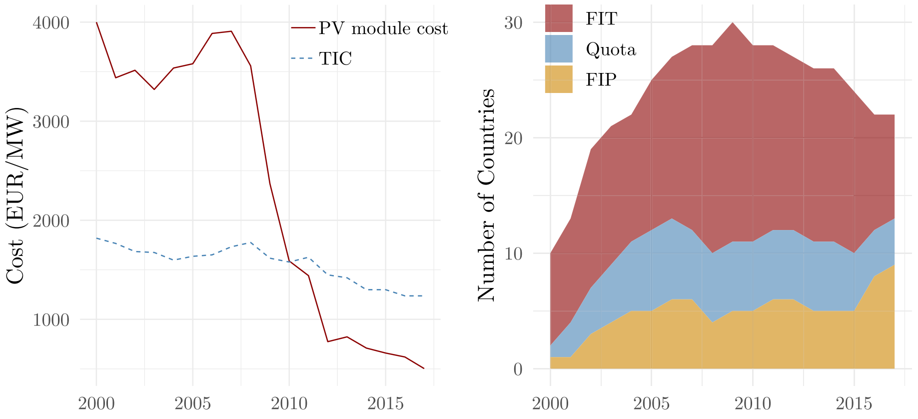

Fig. 3. PV module and total installed costs (left panel) and numbers under different subsidy schemes (right panel).

(2013) suggests a lag of only one year. To investigate the impact of subsidies and policy uncertainty on the investment rate, we therefore lag the explanatory variables by one year for wind projects and two years for solar projects. We further assume constant development times for projects within each technology.

DD estimations with a small number of clusters (countries) can generate severely biased standard errors (Bertrand et al., 2004). This can lead to the serious overestimation of t-statistics and subsequent overconfidence in the estimators. According to Cameron and Miller (2015), this can, however, be mitigated by implementing the wild cluster bootstrap approach with Rademacher weights. We, therefore, run inference using the wild cluster bootstrapping technique included in the *clusterSEs* package in R.

Table 1
Variables used in the regression analysis.

Statistic	N	Mean	St. Dev.	Min.	Max.
Solar - Percentage change	486	0.4	0.6	0	7
Solar - Dummy FIT or FIP	486	0.6	0.5	0	1
Solar - Max (FIT, P + FIP) (EUR/MWh)	486	141.7	167.3	0	650
Wind - Percentage change	486	0.2	0.3	−0.5	3.5
Wind - Dummy FIT or FIP	486	0.6	0.5	0	1
Wind - Max (FIT, P + FIP) (EUR/MWh)	456	79.5	75.7	0.0	397.6
[-1.8ex] GDP per capita (EUR/capita)	486	28,766.9	20,866.0	1,613.9	120,856.9
Electricity price (EUR/MWh)	456	109.0	30.9	45.7	204.7
Risk-free rate	468	4.2	2.4	0.1	21.9

Table 1 presents descriptive statistics of the variables considered in the regression analysis. The variables describing percentage change are calculated according to (1). Note that there is a higher average growth rate for solar (0.4) than for wind (0.2) and that the standard deviation for solar (0.6) is rather high. The high standard deviation is caused by some countries with a heavy investment activity, whereas many countries have had close to zero investment activity. To identify any positive effect stemming from a subsidy scheme, we include a dummy variable that is one if an FIT or FIP is provided in a country for a given year. We also analyse the amounts provided, where we assume that the firm chooses either an FIT or FIP, depending on which subsidy scheme is the most profitable. Intuitively, an essential determinant of profitability in a renewable energy project is the amount of financial government support. Historical evidence supports this view, with the econometric studies of both García-Álvarez et al. (2018) and Eyraud et al. (2011) showing a positive relationship between investments and the existence of a subsidy scheme.

Several other factors influence the investment decision in a renewable energy project. For example, the risk-free rate will affect project valuation and financing, while the electricity price will determine the output value under an assumption of market exposure. This is supported by the results of Eyraud et al. (2011), who found variables such as GDP to be statistically significant determinants of investment rates in renewable energy sources. Hence, to account for the impact of factors not directly related to subsidies or policy risk, we include a set of control variables.

5. Results and discussion

To establish the effect of retroactive changes on the investment rate for solar and wind, we initially estimate (2) without any control variables. The results considering the investment rate for solar radiation as the independent variable are given in Table 2, with confidence intervals (CI) and p-value at the 95% confidence level. In Model 1, we include all countries, whereas in Model 2, we run the same analysis for a subselection of ten countries that had the greatest combined wind and solar capacities[6] before the European debt crisis.[7] This is done to alleviate concerns that retroactive changes were mainly made in countries with excessive RE construction activity before the crisis. Note that the p-values indicate that our DD estimators of retroactive changes are significantly different from zero and that the two models provide a consistent estimate of the impact of a retroactive change of approximately −0.45. This implies that a retroactive change is expected to reduce the investment rate by 45% in subsequent years compared to before the subsidy retraction. Hence, setting ambitious climate goals with associated support schemes may be an inefficient way to induce RE adoption when future policy makers are unable or unwilling to follow through on previous promised support schemes.

When we consider the wind investment rate as the dependent variable, we obtain the results presented in Table 3. Here, as before, we run the regression for all countries and the sub-selection of 10 selected countries based on total RE capacity. The results of both models show a significant treatment effect stemming from retroactive changes. However, the magnitude of policy uncertainty on the investment rate for wind is now approximately −0.16, which is considerably lower than that for solar. This result is in accordance with the data shown in Fig. 1, which only indicate a pronounced boom for solar investment. Nevertheless, our results suggest that retroactive changes also impact wind investments significantly. Thus, our results indicate that from a policy making standpoint, the effect of setting a precedence for retroactive policy changes may severely inhibit a country's ability to reach ambitious climate goals.

A reasonable concern about the model specifications so far, is that our previous results on policy uncertainty in fact captures two distinct effects. The first is the effect of a change in revenue for solar and wind projects, whereas the second is the increased policy uncertainty. In other words, the drop in the investment rate is not necessarily due to decreased perceived government credibility but may be caused by lower expected net-present value. Consequently, we include a subsidy dummy and a subsidy amount variable to control for this possibility. Table 4 presents the results when we include these control variables and GDP per capita; however, the estimated magnitude of the DD coefficients remains stable. Under this specification, a retroactive change reduces the investment rate by 47% (14%) for solar (wind). Moreover, the dummy indicating the presence of an FIP or FIT is significant for wind power investment. This provides some evidence of the effect of subsidies documented by García-Álvarez et al. (2017). To reverse the negative results observed, policy makers could facilitate trust in existing policy schemes via a prespecified-state-contingent subsidy scheme (Ulph and Ulph, 2013; Jakob et al., 2014), i.e., support levels that depend on technological progress and consequently make policy adjustments more transparent.

Table 2
Regression results for PV.

	Model 1			Model 2		
	Coeff.	95% CI	P-value	Coeff.	95% CI	P-value
Retroactive change (0/1)	−0.45	[-0.63, -0.26]	(0)	−0.43	[-0.77, -0.09]	(0.026)
R^2	0.02			0.08		
Num. obs.	484			178		

Table 3
Regression results for wind.

	Model 1			Model 2		
	Coeff.	95% CI	P-value	Coeff.	95% CI	P-value
Retroactive change (0/1)	−0.16	[-0.26, -0.05]	(0)	−0.11	[-0.22, -0.01]	(0.039)
R^2	0.01			0.05		
Num. obs.	485			179		

Table 4
Regression results with control variables.

	Solar			Wind		
	Coeff.	95% CI	P-value	Coeff.	95% CI	P-value
Retroactive change (0/1)	−0.47	[-0.7, -0.25]	(0)	−0.14	[-0.29, 0.026]	(0.07)
Subsidy - Dummy	−0.07	[-0.37, 0.23]	(0.639)	0.23	[0.04, 0.41]	(0.005)
Subsidy - Amount	0.001	[-0, 0.002]	(0.268)	−0.001	[-0.002, -0]	(0)
GDP per capita (in 1000)	−0.02	[-0.02, -0.01]	(0)	−0.003	[-0.007, -0.001]	(0.001)
R^2	0.06			0.04		
Num. obs.	484			461		

We run the same regression with electricity price and bond rate as additional control variables in Appendix B. The hypothesis is that the electricity price impacts the need to subsidize the RE industry, which will lead to an omitted variable bias. Similarly, the bond rate is related to the financing cost of the project and thus the need for subsidies. However, the inclusion of these control variables does not change the significance or the overall magnitude of a retroactive policy change.

6. Conclusions and policy implications

Policy uncertainty has become increasingly relevant, as production from renewable energy sources is approaching retail grid parity, leading policy makers to revise their support schemes. Looking at the case of Europe, our dataset shows that revisions of support schemes have occurred frequently and with a substantial impact, thereby undermining investor confidence. The aim of this paper is, therefore, to investigate and explain the effect of policy uncertainty in the form of unexpected major revisions or reductions in subsidies on investments in renewable energy in the EU. Furthermore, we also seek to quantify the impact of policy revisions to verify the appropriateness of the theoretical contributions and the importance of policy uncertainty uncovered through stated preference techniques.

The implications of this study should be of interest for policy makers, as we quantify how market participants respond to the retroactive policy revisions of support schemes. More specifically, our results indicate that a retroactive subsidy change decreases the investment rate, captured by expected capacity change, by − 45% for PV and −16% for *onshore* wind. This effect is significant at the 95% confidence level for solar and wind investments. Interestingly, the impact of retroactive policy changes on the investment rate is greater for solar than for wind, which might be due to the investment boom in PV before the retroactive changes. For policy makers, these results imply that the effectiveness of subsidy schemes aimed at reaching specific investment targets depends on

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[6] The countries are ESP, DEU, FRA, ITA, GBR, PRT, SWE, NLD, GRC, and POL.

[7] The current country list is based on combined capacities for wind and solar in 2007; however, we ran the same regression based on different cutoff years and obtained similar results.

credible government commitments. Hence, policy interventions should be designed to minimize investors' perceived policy uncertainty. Moreover, our results can be used to weigh the cost of retroactive policy changes against full commitment, which is costly since it eliminates all flexibility.

Another objective of this analysis is to test the implications of theoretic contributions within the real options literature by using empirical techniques. Our results provide empirical evidence for the theoretical findings of Boomsma and Linnerud (2015) and Sendstad and Chronopoulos (2020) that retroactive changes negatively affect annual installed capacity. Additionally, we find some empirical support for the fact that subsidies induce investment, as predicted by the real options literature.

Future research could benefit from including more countries and using annual investments instead of installed capacity. Additionally, future research could investigate the impact of more general policy uncertainty measures on the investment rate. For example, the economic policy uncertainty index by Baker et al. (2016) captures periods of increased economic uncertainty that could potentially impact investment incentives in RE.

CRediT authorship contribution statement

Lars H. Sendstad: Methodology, Visualization, Project administration, Writing – original draft. **Verena Hagspiel:** Reviewing and Editing, Writing – review & editing, Supervision, Validation. **Wilhelm Jebsen Mikkelsen:** Software, Visualization, Writing – original draft. **Ruben Ravndal:** Software, Visualization, Writing – original draft. **Martin Tveitstøl:** Software, Visualization, Writing – original draft.

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.

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Appendices.

A List of variables

The following table lists the variables used in this study and the corresponding definitions and sources.

Table 5
Variable list

Variable	Definition	Source
Annual installed capacity	In MW	IRENA 8
GDP/capita	EUR/capita	IMF9
Gov. bonds	Zero coupon 10 y gov bonds	Eikon databse
Production cost	Solar panel module price, TIC for wind	IRENA (2018)
Electricity prices	In EUR/MWh	Eikon database
FIT/FIP amount	In EUR/MW	IEA10/RES Legal11

B Robustness check

Table 6 includes more control variables for solar and wind investments. Note that, the control variables do not confound the previous results, i.e. providing some support for no omitted variable bias.

Table 6
Regression results with more control variables

	Solar			Wind		
	Coeff.	95% CI	P-value	Coeff.	95% CI	P-value
Retroactive change (0/1)	−0.43	[-0.62, -0.23]	(0)	−0.15	[-0.29, -0.01]	(0.031)
Subsidy - Dummy	−0.11	[-0.33, 0.1]	(0.329)	0.24	[0.05, 0.43]	(0.019)
Subsidy - Amount	0.0008	[0, 0.002]	(0.049)	−0.001	[-0.002, -0.0002]	(0.022)
GDP per capita (in 1000)	−0.01	[-0.03, 0.01]	(0.33)	−0.003	[-0.007 -0]	(0.018)
Electricity price	−0	[-0.008, 0.007]	(0.895)	0.001	[-0.001, 0.003]	(0.177)
Bond rate	0.0003	[-0.06, 0.06]	(0.994)	0.007	[-0.01,0.02]	(0.412)
R^2	0.05			0.05		
Num. obs.	451			449		

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