A global-scale study on decision making in renewable energy policy: Internal and external factors driving the adoption of Feed-in Tariffs and Renewable Portfolio Standards

Abstract

To accelerate the clean energy transition, it is necessary to better understand the global policy dynamics and motivations behind clean energy policy adoptions and diffusion. This paper examines the differential roles of internal and external diffusion factors on decisions to adopt renewable energy policies, i.e., feed-in tariffs (FIT) and renewable portfolio standards (RPS), employing a unique blend of cluster analysis and event history analysis. Cluster analysis uncovers a dichotomy in adopting countries. Firstly, early adopters emerge as high-income, democratic countries, mostly energy importers with high CO2 emissions, with OECD and EU membership. Conversely, the second cluster consists of adopters from middle-income, non-OECD, and non-EU nations with lower CO2 emissions. Strikingly, these clusters align with UNFCCC party classifications, underscoring the pivotal role of international agreements. Event history analysis suggests that especially environmental pressure, but also democratic governance and economic development are important when adopting renewable energy policies. Interestingly, environmental endowments seem to be less important. These findings lead to an important question: Are the requisite policy tools readily available to navigate diverse socio-economic, political, and environmental landscapes, and are they deployed in a timely fashion? Beyond these findings, the study also shows that policy diffusion especially through normative emulation and social learning – operationalized as political globalization, OECD member and following regional neighbors – are important for policy adoption, suggesting the importance of such tools for promoting policies. Moreover, distinctive factors come into play when examining the adoption of FIT versus RPS policies, emphasizing the need for nuanced policy approaches.

Keywords

renewable energy policy, policy adoption, policy diffusion, policy decision making, global-scale, cluster analysis, environmental factors

1 Introduction

Challenges facing the energy sector including climate change, energy security and affordability call for the transformation of our current fossil-fuel based energy system to a cleaner, more secure, and renewable energy system. If action is timely, this could enable us to keep global average temperatures to below 2°C above pre-industrial levels (United Nations , 2015), prevent high risk planetary-scale changes and alleviate problems related to dependence on non-domestic energy resources and geopolitical tensions.

Renewable energy policy support mechanisms have thus far played an inseparable part in supporting renewable energy technology innovation and deployment and will continue to play an essential role in transforming our currently locked-in energy system (e.g., Grubb *et al.*, 2021; Peñasco *et al.*, 2021). Among all energy policies, Feed-in Tariffs (FIT) and Renewable Portfolio Standards (RPS) are the two most widely adopted renewable power generation policies with increasing numbers of adoption over the past decades as shown in Figure 1. They have profoundly contributed to the expansion of renewable energy generation capacity across the world (e.g., Barbose, 2019; Gan *et al.*, 2007; García-Álvarez *et al.*, 2017; Grubb *et al.*, 2021; Peñasco *et al.*, 2021; REN21, 2017).

[Figure 1]

In terms of the policy mechanism of the two policies, on one hand, FIT relies on price regulation by guaranteeing renewable energy generators with a specified tariff for the energy they produce (e.g., USD per kWh) for a fixed number of years, usually about 10-20 years (REN21, 2017). FIT is often employed alongside a regulation that allows renewable energy generators to connect and sell power to the grid. The exact policy design features of FIT such as tariff rates and length of contracts, however, vary across technologies, generators, and countries.

Arguably, the earliest form of a FIT scheme was adopted by the United States in 1978 under *the Public Utility Regulatory Policies Act (PURPA)* (Couture *et al.*, 2010; GovTrack.us, 2020; Haas *et al.*, 2008; Lipp, 2007; REN21, 2017; 2018). Under PURPA, utilities were required to purchase power from small renewables production and cogeneration facilities, through long-term contracts (in some states), at a cost that can be avoided by utilities for providing that same electrical generation (GovTrack.us, 2020; Hirsh, 1999). While prices calculated as such were generally lower under PURPA (and varied across states) compared to the more ambitious FIT tariff rates, its policy design closely resembles that of current more evolved FIT schemes.

In terms of its impact, FIT has been instrumental in reducing risk for investors and increasing bankability of projects by offering long-term contracts and thus increasing renewable energy generation capacity and bringing down technology costs (IRENA *et al.,* 2018). It has also played an important role in opening up the renewables market to independent and non-traditional generators (Hirsh, 1999; Lipp, 2007). However, many governments have experienced difficulties in setting tariffs rates that are efficient. It has also led to shifting risk to consumers by increasing electricity prices for consumers and to utility companies by supporting consumers to produce their own electricity (Baldwin *et al.*, 2019).

On the other hand, RPS is based on quantity regulation as it places a quota obligation on entities, in most cases on electric utility companies but in some cases also on energy generators or consumers, to generate, sell or use a certain percentage of their electricity from renewable energy sources (REN21, 2017). As in the case of FIT, policy design features such as the targeted renewable share, compulsoriness (mandatory or voluntary; only mandatory RPS adoptions are analyzed here), stringency and enforcement vary by country. RPS has been important in helping to enforce and achieve gradually increasing national targets. It is often coupled with tradable green certificates (TGCs), making RPS generally a more market-based tool that can encourage competition and lead to cost-efficiency (Gan *et al*., 2007; IRENA *et al.,* 2018). However, it involves monitoring compliance and penalizing shortfall that requires certain government capacity. These considerations exemplify the type of choices that decision makers must make when choosing among policy tools. It is therefore important to understand the complexity around policy tool choices as future challenges and technologies continue to emerge.

In terms of the geographical dispersion of adoptions, the United States and many European countries were among the earliest adopters of the two policies discussed. However, countries from other regions and with different characteristics including India and Sri Lanka also belong to earliest adopters. Furthermore, a diverse group of countries – Armenia, Australia, Algeria, Brazil, Indonesia and Japan – adopted one of the two renewable power generating policies during the largest wave of adoptions between 2000 and 2010. Interestingly, these adoption patterns and their timings do not seem to follow major international agreements or other explanatory variables such as socio-economic characteristics and international engagements.

This raises the question of which factors and to what extent they influenced countries to adopt renewable power generating policies.

Despite the widespread adoption of FIT and RPS, most renewable energy and climate change policy adoption studies have focused on a limited set of countries such as the EU (Knill *et al.,* 2012; Zhou *et al.*, 2019) and OECD member states (Biesebender & Tosun, 2014), American states (Matisoff & Edwards, 2014; Yi & Feiock, 2012), developed (Knill *et al.*, 2008; Tobin, 2017) or developing countries (Stadelmann & Castro, 2014). Despite the global aspect of climate change and energy security, global studies have only recently started to emerge (Alves *et al.*, 2019; Baldwin *et al.*, 2019; Bergero *et al.*, 2021). They have generally turned to the use of novel analytical methods such as directed dyadic analysis (Baldwin *et al.*, 2019) and qualitative comparative analysis (Bergero *et al.*, 2021). Yet, there is no previous research using event history analysis (EHA) as a well-established methodology to study and confirm findings on policy adoption and diffusion at the global scale. Furthermore, while these studies hypothesize some interesting factors as driving the adoption of renewables policies, such as electric sector conditions and coercive relationships (Baldwin *et al.*, 2019), they heavily focus on external factors and leave out some important (internal) aspects such as environmental factors. Nevertheless, environmental pressures and environmental endowments are expected to play an important role in decisions to adopt renewable energy policies as can be exemplified by PURPA that was adopted as part of a comprehensive energy policy to tackle the energy crisis related to the 1973 oil embargo (Hirsh, 1999) or other similar crises that often accelerate policy change (e.g., Minstrom & Vergari, 1996).

As factors influencing adoption and diffusion of policies can come from within a country or from the outside (Berry & Berry, 1990; Berry & Berry, 2018; Linder & Peters, 1989; Walker, 1969), I examine the differential roles of internal and external (diffusion) factors on decisions to adopt two of the most widely used renewable power generation policies – FIT and RPS – as a group and separately over the past 40 years at a global scale, with an increased focus on environmental pressures and endowments. Including all countries in the analysis adds an important dimension to this study as emerging Asian economies like India and China generate more than half of the global greenhouse gas (GHG) emissions with expected future increases in their energy demand (BP, 2017). I employ EHA as a well-established methodology to study policy adoption and diffusion. I also use cluster analysis as an exploratory tool that has not yet been applied in this context previously as it can group similar countries based on a set of variables and reveal interesting patterns and temporal dynamics in terms of policy adoption and diffusion and thus complement the results of EHA.

2 Theory of decision making: Policy adoption and diffusion and hypothesis formulation

Decision makers have been faced with a difficult choice among the types of policies that are the most suitable for their countries and most effective in supporting the expansion of renewable energy, encouraging clean energy technology innovation, and boosting domestic industrial development. While government action is more often incremental than not, decision makers have had to take non-incremental action and adopt new policy tools to deal with the myriad of energy-related challenges (Berry & Berry, 2018; Hall, 1993; Lindblom, 1959; Walker, 1969). In this context, policy adoption is referred to as the year in which a policy tool is adopted by a country for the first time.

Policy tool choices do not only depend on the attributes of policy tools but also on the country context in which they are chosen and outside influence (Berry & Berry, 1990; Linder & Peters, 1989; Walker, 1969). In this paper, two groups of factors following the literature, namely, 1) internal factors, and 2) external (diffusion) factors, and the extent to which they can be associated with decisions to implement renewable power generating policies is tested.

2.1 *Internal factors*

Socio-economic and political factors within a country have been shown to play an important role in policy adoption processes, including environmental and renewable energy policies (Berry & Berry, 2018; Dolšak, 2009; Edquist, 2005; Zhou *et al*., 2019). However, environmental factors also need to be considered as they define problem severity and influence decisions in the renewable energy sphere (Matisoff, 2008; Zhou *et al.*, 2019). In this paper, four groups of internal factors are considered, i.e., economic development, political system, environmental pressure, and environmental endowments.

2.1.1 Economic development

Economic development is one of the apparent factors to be considered for a variety of reasons (e.g., Börzel, 2002; Dolšak, 2009; Jänicke, 2005; Matisoff, 2008; Tobin, 2017). Firstly, citizens of highly developed industrialized countries have the capacity to pay more attention to environmentalism and pressure policy makers to adhere to stringent environmental policies

(Dolšak, 2009; Jänicke, 2005). Secondly, policies often require major expenditures making the availability of economic resources of a country essential for adoption (Berry & Berry, 2018). Both FIT and RPS are capitally and technically intensive, so it is reasonable to assume that countries with higher levels of economic resources may be apt to take part in policy experimentation and invest in the policy at early stages. For example, RPS requires monitoring and a system for penalizing noncompliance, which are often stronger in developed and democratic countries (Dahl, 1971; IRENA *et al.,* 2018). Lastly, the high upfront costs of renewable energy technologies suggest the need for relatively wealthy buyers – whether that is at the household, developer, or local government level.

Hypothesis 1: Countries with higher economic development are more likely to adopt renewable energy policies.

2.1.2 Political system

Scholars suggest that there exists a link between political institutions and environmental protection (Congleton, 1992; Fredriksson, 1997; Matisoff, 2008). Dealing with environmental and climate change issues is expected to be more important for countries with democratic political systems than for non-democratic ones (Congleton, 1992). In democratic regimes political actors benefit more from the provision of environmental quality based on the preferences of voters as opposed to authoritarian governments wherein political actors do not gain any advantage from it (Stadelmann & Castro, 2014). Furthermore, higher levels of civil liberties are more likely to lead to higher access to information, e.g., on climate change, which in turn makes citizens more likely to support government intervention and even pressure policy makers to adopt renewable energy policies (Dolšak, 2009; Lyon & Yin, 2010; Matisoff, 2008).

Hypothesis 2: Countries with more democratic political systems are more likely to adopt renewable energy policies.

2.1.3 Environmental pressure

Environmental pressure with a negative impact on the environment such as industrialization, economic and population growth make governments more likely to adopt renewable energy policies (Congleton, 1992; Dolšak, 2009; Matisoff, 2008; Stadelmann & Castro, 2014), especially as environmental problems have been gradually receiving more attention since the 1960s.

GHG emissions resulting from human activities have been leading to rising average global temperatures that have already surpassed 1°C compared to pre-industrial levels (IPCC, 2018). Thus, countries with higher emissions, usually developed and industrializing countries, are more likely to adopt energy policies that support renewable energy development and generation to offset their emissions. This is further exacerbated as reducing GHG emissions also creates domestic benefits such as reducing air pollution – the two being tightly linked by the shared source of fossil fuel combustion – which is known to be high on the policy agenda of developing and coal dependent countries (Dolšak, 2009; Marques et al., 2010). Countries with high GHG emissions also receive lots of pressure to cut their emissions from various sources – including international agreements and actors (e.g., Paris Agreement, Kyoto Protocol) and emerging global norms.

Various scholars have also shown that increasing population size is positively associated with the likelihood of renewable energy policy adoptions (Holzinger *et al.*, 2008; Stadelmann & Castro, 2014). Growing population has unquestionably contributed to increasing the pressure on the environment in the form of resource depletion, environmental pollution, and degradation (Panayotou, 2000).

Energy security has always been the highest priority of governments as industrialization and economic growth are highly dependent on energy. This attitude has further been strengthened by energy shortages and energy price hikes that have been occurring due to mismanagement of finances, market manipulation and geo-political tensions. Therefore, developing domestic renewable energy alternatives can help maintain security of supply in countries that highly rely on the import of energy from other countries (Marques *et al.*, 2010). However, the opposite is expected to be true for countries that are exporters as they bear a substantial burden of renewable energy policies, which are likely to reduce the demand for their energy exports (Dolšak, 2009). Furthermore, industrial lobbying in these countries may also be greater negatively impacting renewable energy policy.

Hypothesis 3: Countries experiencing higher environmental pressure – including high levels of CO_2 emissions, large population, and energy dependence – are more likely to adopt renewable energy policies.

2.1.4 Environmental endowments

Similarly, unique environmental endowments of countries are likely to have an impact on their energy policies as well as the type of technologies they support (Jenner *et al*., 2012; Lyon & Yin, 2010; Matisoff, 2008). Larger renewable energy endowments such as more wind and sun allow countries to pursue renewable energy policy with more confidence as it indicates more cost-effective renewable energy generation (e.g., in the case of adopting FIT) and lower compliance costs for entities required to generate or use certain amount of electricity from renewables (i.e., RPS).

Hypothesis 4: Countries with larger renewable energy endowments – including wind and solar potential – are more likely to adopt renewable energy policies.

2.2 External (diffusion) factors

The meaning of problems and policy tools and their perception is influenced by national and international agents outside of the country, which biases the decisions of policy makers and shapes their policy tool choices (Berry & Berry, 1990; Linder & Peters, 1989). In addition, decision makers also tend to simplify the decision-making process by considering solutions used elsewhere when faced with personal, informational and time constraints (Simon, 1957).

There are several mechanisms of policy diffusion – the process by which policies are 'communicated through certain channels over time among the members of a social system' (Rogers, 1983, p. 5) – including normative emulation, social learning, economic competition, and coercion (Dobbin *et al.*, 2007; Shipan & Volden, 2008; Berry & Berry, 2018). These mechanisms eventually lead to following policy tool choices of other governments, although via different channels (Berry & Berry, 2018). In the next section, each mechanism is considered in terms of its influence on renewable power generation policy adoption.

2.2.1 Normative emulation and social learning

Perceptions of problem scenarios shape decision makers' policy choices. Consequently, policy focus and tool preferences shift as societal interpretations of issues and norms evolve over time (Dobbin et al., 2007). Normative emulation describes the phenomenon of policy diffusion due to changes in ideologies and norms. Countries often copy successful counterparts' policy tools to simplify complex decision-making processes (Berry & Berry, 2018; Linder & Peters, 1989). Emulation is closely tied to social learning, while the latter relies on accumulation of knowledge and evidence about policy tools used elsewhere over time leading to changing beliefs and perceptions (Dobbin *et al.*, 2007).As social constructs shift, national and international agents begin supporting and advocating for new norms. Intergovernmental organizations (IGOs) fulfill a facilitative function primarily influencing the speed at which information and policies flow between its members (Oberthür & Tänzer, 2002). For example, OECD member states have access to a 'unique forum and knowledge hub for data and analysis, exchange of experiences, best-practice sharing, and advice on public policies and global standard-setting' (OECD, 2019). Its specialized body – International Energy Agency (IEA) – specifically deals with energy matters and has a mission to 'recommend[] policies that enhance the reliability, affordability and sustainability of energy' (IEA, 2021). Thus, particularly emulation and learning could be enhanced by membership in OECD because of communication between different structures at different meetings and forums and policy advice. Furthermore, IGOs influence signatories to various agreements that require the adoption of best practices and the support of new norms and thus increasing political globalizations can lead to diffusion of policies.

Furthermore, scholars highlight that governments often emulate or learn from geographically close governments that have already embraced a particular policy (e.g., Berry & Berry, 1990; Kammerer & Namhata, 2018; Walker, 1969). This is often attributed to proximity-based access to information, shared structural and cultural traits, and heightened competitive dynamics among neighboring entities.

Hypothesis 5: Normative emulation and social learning – via political globalization, OECD membership, and following geographically close governments – positively influence renewable energy policy diffusion.

2.2.2 Coercion

Coercion arises due to power asymmetries between entities when powerful groups, governments, and international organizations manipulate economic costs and benefits in a way that they influence the policy choices of other entities (Dobbin *et al.*, 2007). The IMF or EU are common examples of such entities as they often shape policies of countries that rely on them for trade, security, or financial assistance. In terms of the energy sector, such organizations are increasingly putting more pressure on countries to reduce their GHG emissions through 1) putting unspecific pressure on countries and 2) providing them with special incentives to act and comply with international commitments (Oberthür & Tänzer, 2002).

A series of EU directives on renewable energy production, that have imposed targets for EU member countries and have also signaled the commitments that EU adherent countries have to face, required national governments to adopt renewable energy policies. Countries were first softly pushed to adopt renewable energy targets and later required to adopt binding targets. In 2001, the *EU Directive 2001/77/EC* promoting the production of renewable energy set national indicative targets for energy production from renewable energy technologies from individual member states (EU, 2001). This directive has been superseded in 2009 by the *EU Renewable energy directive 2009/28/EC* which 'set [] national binding targets for all EU countries with the overall aim of making renewable energy sources account by 2020 for 20% of EU energy' (EU, 2009). Concurrently, the EU ratified the Kyoto Protocol in 2002, showcasing its long-term and deep-rooted involvement in energy matters. While not enforcing specific policies (EU, 2001), the EU sets renewable energy targets, thus indirectly shaping policy adoption.

Hypothesis 6: Coercion – via EU membership – positively influences renewable energy policy diffusion.

2.2.3 Economic competition

Countries compete for various economic benefits through implementing policies that are market-friendly, attract global investments and make exports competitive (Dobbin *et al.*, 2007). When one country simplifies, for example, its regulatory requirements that attract investments, its competitors will follow suit to stay competitive, which leads to a cycle of policy diffusion.

In the context of renewable energy, on one hand, countries that adopt policies early on – whether they support renewable energy research, development or deployment – may gain first movers' advantage in accumulating knowledge, building capacity, expanding domestic renewable energy technology industries and achieving economies of scale, which in turn can lead to increasing exports (Zhou *et al.*, 2019). On the other hand, having renewable energy policies in place ameliorates investment risks for developers of renewable energy technologies. For example, medium- and long-term contracts under FIT show the long-term commitment of a government to renewables. FIT along with other national strategies also indicate which technologies are supported by the government and therefore are worth investing in. Similarly, national targets (e.g., under RPS) also deepen the commitment of governments to renewables. Thus, it is expected that countries compete with their economic peers in terms of renewable energy adoptions to strengthen their domestic renewable energy industries and competitiveness.

Hypothesis 7: Economic competition positively influences renewable energy policy diffusion.

3 Data & Method

To examine the factors that lead to renewable power generation policy adoption, I use two methods: 1) cluster analysis and 2) EHA using Cox regression as described in section 4.2 and 4.3, respectively. However, details on the data used are given first.

3.1 Data

The dependent variable represents whether a country adopted renewable power generation policy at national scale for the first time. The dataset is in country-year format, where policy adoption is initially set to 0 for each country and changed to 1 in the year in which a country adopts a policy. Observations of a country after policy adoption are removed from the sample as the country is no longer at risk of adopting the policy again. Generally, data in this format is particular to EHA as it models the duration until adoption as opposed to a dummy indicator that could not account for the differences in times to adoption (Box-Steffensmeier & Jones, 1997).

The resulting main dataset, referred to as the pooled dataset, comprises of 81 national level adoptions and 113 non-adoptions. It is based on FIT and RPS adoptions according to whichever of the two policies was adopted earlier (data from REN21, 2017 & 2018). It is further disaggregated into two additional datasets, where FIT policy adoptions (76) and RPS policy adoptions (19) and non-adoptions are examined separately to better understand differences in policy tool choices (see Appendix A for adoptions by country by year). The period of each dataset includes a five-year pre-specified interval before first policy adoption helping to avoid selection bias and left-censoring problems (Box-Steffensmeier & Jones, 1997).

For countries with federal systems, the year of policy adoption is assumed to be when adopting subnational governments represent at least 50% of the country's population and PURPA is included as an early form of the FIT scheme (as discussed in the Introduction). While I acknowledge the limitations of this assumption such as limited understanding of within-country policy ideas and learning, the number of countries for which this assumption is applied is relatively low – three countries in each dataset (pooled, FIT and RPS). Furthermore, to check the robustness of this assumption, results are compared to policy adoptions coded under two extreme coding assumptions (see Appendix B for a comparison of the three assumptions). The *first adoption assumption* is based on the very first policy adoption in each country whether that is at the national or subnational level to account for the fact that the policy innovation or knowledge of its existence was already available regardless of the level of government by which it was adopted and thus was unlikely to be influenced by external factors. Following the same argument, it also includes the adoption of PURPA. Under the *excluding federal countries assumption*, only national adoptions are coded as adoptions to avoid mismatches in the level of analysis and PURPA is excluded as a national FIT.

The independent variables and their operationalizations are summarized in Table 1 (for descriptive statistics see Appendix C). There are two sets of independent variables: internal and external. Internal factors include economic development, political system, environmental pressure, and endowments. External factors include normative emulation and social learning, coercion, and economic competition.

[Table 1]

3.2 Cluster analysis

While EHA is most frequently used to predict the factors that can be associated with policy adoptions, cluster analysis groups observations in a way that observations in the same group are more alike than the ones in the other groups based on a set of factors (Everitt *et al.*, 2011). I use cluster analysis to descriptively examine the different groups of countries that adopted renewable power generation policies and the factors that distinguish these groups from each other and hence potentially influence renewable power generation policy adoptions to complement the main research method: EHA. The results also enable conclusions on the temporal dimension of policy adoptions and diffusion. The groups identified are used to better understand the empirical data, however they are not coded or included in EHA.

Following Skovgaard *et al.* (2019), I use the *two-step cluster analysis* in SPSS as it allows the specification of binary and categorical variables without treating them as continuous (SPSS, 2001). Furthermore, it automatically determines the number of clusters that exist within the data (SPSS, 2001). The distance measure used is log-likelihood and the clustering criterion used is Bayesian information criterion (BIC). As a cross-sectional subset of the pooled dataset, only adopting countries with data for the year of adoption are used for cluster analysis. Year of policy adoption and regional classification of countries are included as two additional variables but their results are only presented in the Appendix.

3.3 Event history analysis

EHA can be used to predict the probability that a particular type of country will adopt a policy during a particular year (Box-Steffensmeier & Jones, 1997). I use discrete-time EHA, using the *survival package* in R Studio, to estimate the probability of experiencing renewable energy policy adoption as a function of various independent factors supporting the fundamental research question of this study. It is well suited for studying change and it can deal with the problem of right censoring, i.e., when there are countries with no adoption when the observation of data ends, as opposed to standard regression techniques which could produce biased estimates (Berry & Berry, 1990; Box-Steffensmeier & Jones, 1997; Box-Steffensmeier & Jones, 2004).

The variable of interest in a discrete-time EHA is called the hazard rate/probability λ and it is defined as the probability P that a country will experience adoption T during a particular time period t, given that the country is at risk at that time $T \geq t$:

$$\lambda(t) = P(T=t \mid T \geq t) \qquad \text{Eq. 1}$$

In this article, the hazard probability of experiencing adoption as a function of various independent variables (internal and external) is of interest. To get parameter estimates β', I calculate hazard probability conditional on various independent variables X (see Table 1 for the list of these variables):

$$\lambda(t) = P(T=t \mid T \geq t; \alpha, \beta' X) \qquad \text{Eq. 2}$$

where α represents baseline probability, that is, probability of policy adoption when independent variables are equal to zero $\alpha(t) = \log h_0(t)$.

For estimation, I use the Cox regression model with time-varying covariates to examine my hypotheses:

$$\log \lambda(t) = \alpha(t) + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k \qquad \text{Eq. 3}$$

or,

$$\lambda(t) = h_0(t)\ exp(\beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k). \qquad Eq.\ 4$$

The Cox regression model has an advantage that it does not require the baseline probability to be specified, so parameter estimates are independent of the baseline probability (Box-Steffensmeier & Jones, 1997). This means that estimates are not biased as might otherwise be the case with all other standard parametric models that require such specifications (Box-Steffensmeier & Jones, 2004; Jones & Branton, 2005). Given that most of the variables are time-varying by design the proportional hazards assumption does not apply.

4 Results & Discussion

Cluster analysis and EHA were used to test the influence of internal and external factors on decisions to adopt renewable power generation policies at a global scale and their extent.

4.1 Cluster analysis

Firstly, cluster analysis was used to descriptively examine the different clusters of countries that adopted renewable power generation policies (pooled dataset) and the factors that distinguish them. This contributed to explaining the temporal dynamics of adoptions. The analysis automatically identified two clusters of countries based on internal and external factors as presented in Table 2 (see Appendix E for more details on the profile of each cluster) with little variation upon testing different combinations of variables for robustness.

The resulting clusters show that there were two distinct periods of policy adoption by two different sets of countries. Cluster 1 (n=25) is on average made up of more economically developed and more democratic countries, mostly energy importers with high CO_2 emissions per capita, and low solar and higher wind potential relative to cluster 2. Cluster 1 countries can furthermore be characterized as early adopters with an average adoption year of 1999±7 (mean±1SD) and mainly from Europe and North America. Cluster 2 (n=44) represents the rest of the adopters with an average policy adoption year of 2006±4, on average less developed and less democratic countries, with a relatively larger population size, higher solar PV potential, and lower CO_2 emissions per capita on average, from various regions of the world. All countries in cluster 1 are OECD members and about 88% are EU members, while no countries are OECD and only 2 countries are EU members in cluster 2. The institutional role of OECD and EU as early movers in renewable energy policy adoptions is thus evident from the clustering. The political globalization index is also higher for cluster 1 compared to cluster 2 (88±9 vs. 77±10 on a scale of 100, respectively). The difference between the two clusters in terms of following regional neighbors and economic competition are small. However, as various combinations of variables were tested for robustness, following regional neighbors becomes relatively more important for cluster 1 when the two additional variables – year of adoption and regional classification – are included. Additional countries from Eastern Europe and Central Asia become part of cluster 1 as being in close proximity to the early adopters from Europe (see Appendix F for geographical representation).

[Table 2]

By plotting the resulting clusters over time, Figure 2 reveals the temporal distribution of renewable energy policy adoptions as they proceeded over time providing more details about policy adoption dynamics at work. Various factors such as environmental pressure including high CO_2 emissions and energy dependence but also shifts in norms in smaller circles such as represented by membership in IGOs (e.g., OECD) and coercion from EU led more developed countries to adopt policies early on. The early 2000s can be characterized as a turbulent period in the EU in terms of increasing concerns and actions related to climate change. Due to the high capital and technical costs of policies such as the ones studied here and the uncertainty around new policies, countries with higher GDP were better positioned to adopt and experiment with these at early stages. As time proceeded and experience with the policies accumulated, less developed countries outside of the influence of OECD and EU followed suit possibly because of shifting norms related to the climate change agenda globally and their aim to build innovative capabilities to boost economic growth and development and compete with developed countries. While using a different methodology, Zhou *et al.* (2019) has offered similar insights in terms of differences in initial spread of renewable energy policy instruments and subsequent policy adoptions.

[Figure 2]

Furthermore, when observing the clustering results, they closely correspond with the classification of parties to the United Nations Framework Convention on Climate Change (UNFCCC) established in 1992. Its aim is to stabilize GHG ‘concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interferences with the climate system’ (United Nations, 1992). On one hand, cluster 1 (early adopters) is made up of Annex II countries and a couple of Central European countries from Annex I. According to the

Convention, both Annex I and II include developed countries that need to adopt national policies, take action to mitigate climate change, and limit anthropogenic GHG emissions. The difference is that Annex II parties are required to also support economies in transition and developing countries by providing financial and technical support (United Nations, 1992). On the other hand, cluster 2 (late adopters) is almost entirely comprised of non-Annex parties that are lower-income and developing countries. These results suggest to some extent that UNFCCC, and likely other international agreements, can provide a useful tool for promoting policies. Furthermore, it is expected that the more stringent the targets and requirements (e.g., Annex II vs. Annex I vs. non-Annex in decreasing order of stringency), the earlier the adoptions happen.

4.2 Event history analysis

Secondly, EHA was used to estimate the influence of various factors on decisions to adopt versus not to adopt renewable energy policies. All 194 countries including non-adopting countries were analyzed to offer a global perspective on policy dynamics and avoid selection bias. In Table 3, the main results on adoption of renewable power generation policies are laid out across the three dependent variables – pooled dataset, FIT and RPS. For each dependent variable, models 1-2 are specified for internal factors, models 3-4 for external factors and model 5 includes both internal and external factors. Parsimonious models are used to deal with multicollinearity and correlation (see Appendix G). In Appendix H and I, results of robustness checks are provided for the two other coding assumptions.

4.2.1 What factors influence renewable power generation policy adoptions?

Hazard ratio estimates of the independent variables in Table 3 are persistent across different model specifications, signaling the robustness of the results. Table 3 shows that both internal and external factors are positively associated with the probability of renewable power generation policy adoption but there is somewhat stronger empirical evidence for internal factors as they are significant in most models. This is in agreement with the results of other studies, e.g., on RPS and climate change policies in the US (Lyon & Yin, 2010; Matisoff, 2008) and renewable energy supporting policies in developing countries (Stadelmann & Castro, 2014), that also find more support for internal factors. Nonetheless, there is evidence that internal and external factors together are associated with decisions to adopt renewable power generation policies as presented by model evaluation criteria (Akaike information criterion; AIC).

[Table 3]

4.2.1.1 Internal factors

In terms of internal factors, environmental pressure including increasing population size, CO_2 emissions and energy dependence play an especially important role in decisions to adopt renewable power generation policies as they are positive and significant in almost all model specifications across all three dependent variables. One unit increase in log population size, which is significant in almost all models, and one unit increase in log CO_2 emissions can be associated with 22-92% and 33-88% increased probability of renewable energy policy adoption, respectively. Energy dependence is especially large and significant in all models except for RPS adoptions; countries that are net energy importers are 34-166% more likely to adopt renewable power generation policies compared to countries that are net energy exporters.

Surprisingly, environmental endowments seem to play a less important role in renewable energy policy adoption as they are insignificant across all models. It is counterintuitive that countries with lower solar PV potential are more likely to adopt renewable energy policies but this result could be related to the fact that earliest adopters generally came from the Global North with less solar potential. It could also be that countries with less solar PV potential were planning to use other types of renewable sources such as wind, which is positive but not significant in this analysis, or those not measured here including biomass, hydropower, geothermal, etc. While wind potential is in accordance with the hypothesis that countries with more of it are more likely to adopt renewables policies, this variable is not significant. These results therefore suggest that endowments are not a strong decision factor when it comes to policy tool choice relative to environmental pressures.

A positive and mostly significant (except for RPS) relationship is also observed between democratic political system and renewable power generation policies. More democratic regimes are found to be important in other studies even if operationalized using considerably different variables such as the percentage of democrats in state legislature in the US (e.g., Lyon & Yin, 2010). Economic development is also positive in all models and significant in models 1 and 6. More specifically, the results show that one unit increase in log GDP per capita can be associated with a 30-55% increase in the likelihood of renewable energy policy adoption. These results suggest that wealthier countries with more democratic governments are better positioned to adopt renewable power generating policies as hypothesized. The full model of RPS may lack significance on its variables due to the fact that out of 194 countries, only 19 adopted RPS, potentially limiting statistical power of the analysis.

4.2.1.2 External (diffusion) factors

Results show that external diffusion factors considered in the analysis are indeed associated with renewable power generation policy diffusion in a positive direction as hypothesized. However, their significance varies across models. In terms of normative emulation and social learning, political globalization is especially significant when all external diffusion factors are included (model 3, 8 and 13). One unit increase in political globalization can be associated with increasing probability of adoption by 2-13%. By removing political globalization which may be masking the effect of other variables due to multicollinearity, following adoptions by regional neighbors and OECD membership also become significant. However, the hazard ratio estimate of OECD in model 14 needs to be interpreted with caution. Overall, these results provide evidence that normative emulation and social learning could be the most useful tools for diffusing policies.

Evidence for the EU's coercive power and economic competition – operationalized as countries with similar sized exports that are likely to be competitors in the global arena – is mixed but mostly positive. When political globalization is not accounted for, the institutional role of EU is positive in different models and significant in the case of the pooled dataset.

Although external factors are not significant in full models, including them in addition to internal factors improves model fit compared to having internal factors alone as shown by lower AIC scores across models 5 and 10. Thus, there is empirical evidence that both factors are associated with decisions to adopt renewable energy policies.

4.2.2 Policy tool choice: FIT or RPS policy adoptions?

The magnitude of hazard ratio estimates of independent variables differs across FIT and RPS, which could in broad terms suggest which factors may have led to different policy tool choices (as highlighted in Table 2). However, comparisons between FIT and RPS can only be made with caution here as hazard ratio estimates are not relative.

From internal factors, larger population size and higher CO_2 emissions can be associated with a higher likelihood of RPS adoption. In fact, many of the 19 countries that have previously adopted RPS are indeed countries with larger population size and higher CO_2 emissions – e.g., China, India, US, Japan, Philippines, United Kingdom, Italy – compared to those that have not adopted RPS. Counterintuitively, higher economic resources and more democratic political systems are also more strongly associated with increasing likelihood of RPS adoptions, though generally not significant. This is surprising given that it would be expected that FIT is more likely to be adopted by wealthier countries as it requires higher financial resources as opposed to RPS, which is probably why log GDP per capita is significant in the FIT model. It would also be expected that RPS is preferred by more authoritarian countries, coercing the development of renewable energy.

All the above factors are also important for decisions to adopt FIT, however, energy dependence is especially outstanding. Countries that are net energy importers are 111-145% more likely to adopt FITs than not compared to countries that are net energy exporters. This could be explained by the fact that the very first FIT adoption by the US by President Jimmy Carter was a response to the oil crisis of 1973 that had a far-reaching effect on its economy (Hirsh, 1999).

Solar PV potential seems to be negatively affecting both FIT and RPS adoptions, although the latter to a smaller extent. In addition, higher wind potential plays a more important role for RPS as also shown by Lyon & Yin (2010) across the US. These results are in line with the fact that under FIT, price for renewable energy generation is guaranteed and therefore it can support non-traditional renewable energy generators to enter the market regardless of renewable energy potential whereas for RPS, the least cost criterion plays an important role and therefore renewable energy potential needs to be considered (Lipp, 2007).

Considering external diffusion factors, the results show that normative emulation and social learning via membership in OECD and political globalization are more strongly and significantly associated with RPS adoptions when compared to FIT adoptions. This is in agreement with the fact that the use of RPS to address various problems, such as slow capital stock turnover and reforming electricity markets, has been advised in OECD documents as early as in the 2000s given its market-based nature especially when coupled with TGCs (e.g., IEA, 2000a; IEA, 2000b). While the appearance of FIT in documents occurred in the following years, but mainly mentioned as policy practices being used elsewhere (e.g., IEA, 2001).

On the other hand, following regional neighbors who have adopted the policy in previous years is positive and significant only in the case of FIT adoptions; one additional adoption by a country from the same region can be associated with 1-3% of increase in likelihood of FIT adoption. Furthermore, there is evidence that the coercive power of EU leads to increasing the likelihood of FIT adoptions slightly more than those of RPS adoptions. This slight preference for FIT conflicts with one of the most significant EU legislations, i.e., the *EU Directive 2001/77/EC*, on renewable energy production that does not prescribe the type of support mechanism to be used by members (EU, 2001). In addition, the EU has shown preference for more competition-oriented policies in experience, for example, it considered Germany's FIT as an illegal state aid (Leiren & Reimer, 2018). Thus, this could mean that the main mechanism of FIT diffusion was in fact following leading EU countries that adopted FIT – such as Portugal, Germany, and Denmark – which might have influenced other countries to adopt it.

Lastly, economic competition among countries in the same export bloc is somewhat larger for RPS but significant in both cases. In other words, there is limited evidence that economic competition is likely to be associated with adoptions. In the case of RPS, this is visible as the group of earliest adopters also corresponds with the group of largest exporters that belong to the same export bloc: US, Japan, China, United Kingdom, Canada, Italy, Belgium. This is not as clearcut in the case of FIT. Generally, this finding suggests that economic competition is important for decisions to adopt renewable energy policies and that countries are interested in gaining first movers' advantage in accumulating knowledge and achieving economies of scale and then exporting.

5 Conclusion

Renewable energy policies will continue to play an important role in achieving net-zero emissions in the decades to come. Therefore, understanding the factors and tools that can be used promote policies is of great importance, especially at a global scale.

By testing various factors, this study established evidence that internal factors – especially environmental pressure but also more democratic political systems and higher economic development – are associated with renewable power generation policy adoptions. Countries with more economic resources are better positioned to adopt policies that are capitally and technically intensive and take part in experimentation at early stages when the costs and impacts of policies are still uncertain. There is also increasing pressure on high-income countries with high GHG emissions to cut their emissions and support the most vulnerable countries. Energy dependence is especially significant and strongly associated with adoptions, and it is expected to continue being a priority given the energy shortages and price hikes that many countries have been experiencing, pointing out the importance of renewables to deal with market manipulation and geo-political tensions.

Furthermore, the results show that external factors are also important in policy diffusion via various mechanisms. Especially, normative emulation and social learning via political globalization and following regional neighbors are significant in diffusing renewable energy policies. Furthermore, the institutional role of EU and OECD as early movers and leaders in renewable energy policy adoption stands out. The policy diffusion dynamics at work is especially important to understand as it offers insights into how successful policies can be diffused readily and cost-effectively, which is urgently needed to achieve net-zero ambitions, and as the question of policy tool choice are always present.

The findings also suggest that certain factors are more important in the case of RPS adoptions and other in the case of FIT adoptions when examined separately. That is, larger population size, more CO_2 emissions, and emulation and learning via OECD membership and political globalization, and economic competition make countries more likely to adopt RPS (than not). Whereas energy dependence and following regional neighbors – especially EU leading countries – seem to matter more for decisions to adopt FITs. These findings are in accordance with the characteristics of the policies given that RPS is generally more market oriented than FIT. This also sheds light on the potential pattern of adoption based on policy tool type (e.g., price regulation versus quantity regulation).

In addition, cluster analysis has proven to be a useful addition to EHA, because its results provide more details about renewable energy policy adoption dynamics at work at a global scale: various factors such as environmental pressure but also shifts in norms in circles such as represented by membership in IGOs and coercion from EU led high-income countries to adopt policies in the early 2000s. As time proceeded and experience with the policies accumulated, middle-income countries outside of the influence of OECD and EU followed suit possibly because of shifting norms related to the climate change agenda and their aim to build innovative capabilities to boost economic growth and development and compete with developed countries. Furthermore, it has shown the importance of UNFCCC and that its level of stringency is also likely to be associated with increasing renewable energy policy adoptions. This implies that having international agreements and treaties could be used to accelerate technological innovation for the clean energy transition.

These findings offer strong policy implications for the energy transition in countries with lower income. These countries might have other policy priorities necessary for human well-being or may not have access to electricity, thus it is important to note that they may require more assistance when transitioning to clean energy, for example, through directly sharing experience and knowledge of policies adopted elsewhere or financially supporting the adoption of policies that they could otherwise not adopt. The results also suggest how other energy policy adoptions can be accelerated in the future through different policy diffusion mechanisms, so that renewable energy development can be sped up further.

The results also clearly show that policy makers do take into consideration environmental pressures, such as population size, energy dependence and CO_2 emissions, whether that is through direct or indirect consideration. Therefore, the question that remains is whether the right policy tools are available to deal with various socio-economic, political and environmental circumstances and whether they are available early enough – i.e., before crises occur. This explanation is even more convincing given that countries with lower environmental endowments are as likely or even more likely to adopt renewable energy policies.

Nonetheless, there are certain limitations of this study that could be addressed by future studies. Firstly, a limitation comes from concerns about the heterogeneity of policies and countries, which can lead to hiding interesting patterns. Both FIT and RPS have various forms in which they have been adopted by different countries. Likewise, examining subnational level adoptions requires assumptions that may lead to limited understanding of within-country differences such as policy ideas and learning, especially where such differences are large. Secondly, data is not readily available at a global scale, especially in the case of developing countries. This limits the external validity of the findings to other sectors and makes it difficult to include all independent variables that would be of interest. For example, other environmental variables such as environmental preferences and clean energy lobby (Jenner *et al.,* 2012; Stadelmann & Castro, 2014), fossil fuel lobby or influence (Jenner *et al.,* 2012; Nicolli & Vona, 2012), renewable energy or technology prices, and industrial structure (Zhou *et al.,* 2019) would be very interesting to examine at a global scale. This can also lead to problems of omitted variable bias and endogeneity. Lastly, it must be acknowledged that differentiation between the diffusion mechanisms is not simple because many of them overlap in practice and future research on their operationalization could provide more details.

References

Akaike, H. (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control, 19*(6), 716-723.

Alves, E. E. C., Steiner, A., de Almeida Medeiros, M., & da Silva, M. E. A. (2019). From a breeze to the four winds: A panel analysis of the international diffusion of renewable energy incentive policies (2005–2015). *Energy Policy, 125*, 317-329.

Baldwin, E., Carley, S., & Nicholson-Crotty, S. (2019). Why do countries emulate each others' policies? A global study of renewable energy policy diffusion. *World Development, 120*, 29-45. https://doi.org/10.1016/j.worlddev.2019.03.012

Barbieri, K., & Keshk, O. M. G. (2016). *The correlates of war project: Trade (v4.0).* Available from: https://correlatesofwar.org/data-sets/bilateral-trade [Accessed 1 Dec 2021].

Barbose, G. (2019). *US Renewables Portfolio Standards: 2019 annual status update.* US: Lawrence Berkeley National Laboratory. Available from: https://eta-publications.lbl.gov/sites/default/files/rps_annual_status_update-2019_edition.pdf [Accessed 24 May 2020].

Bergero, C., Rich, M. J., & Saikawa, E. (2021). All roads lead to Paris: The eight pathways to renewable energy target adoption. *Energy Research & Social Science*, *80*, 102215. https://doi.org/10.1016/j.erss.2021.102215

Berry, F. S., & Berry, W. D. (1990). State lottery adoptions as policy innovations: An event history analysis. *American Political Science Review, 84*(2), 395-415.

Berry, F. S., & Berry, W. D. (2018). Innovation and diffusion models in policy research. In C. Weible (Ed.), *Theories of the policy process*. New York, NY: Routledge. https://doi.org/10.4324/9780429494284

Biesenbender, S., & Tosun, J. (2014). Domestic politics and the diffusion of international policy innovations: How does accommodation happen?. *Global Environmental Change*, *29*, 424-433.

Börzel, T. (2002). Pace-setting, Foot-dragging, and Fence-sitting: Member state responses to Europeanization. *Journal of Common Market Studies*, *40*(2), 193-214.

Box-Steffensmeier, J. M., & Jones, B. S. (1997). Time is of the essence: Event history models in political science. *American Journal of Political Science*, 1414-1461.

Box-Steffensmeier, J. M., & Jones, B. S. (2004). *Event history modeling: A guide for social scientists.* Cambridge, UK: Cambridge University Press. https://doi.org/10.1017/CBO9780511790874

BP. (2017). *BP Energy outlook 2017 edition*. Available from: https://www.bp.com/content/dam/bp/pdf/energy-economics/energy-outlook-2017/bp-energy-outlook-2017.pdf [Accessed 13 March 2018].

Congleton, R. D. (1992). Political institutions and pollution control. *Review of Economics and Statistics*, *74*, 412–421.

Couture, T. D., Cory, K., Kreycik, C., & Williams, E. (2010). *Policymaker's guide to feed-in tariff policy design* (Technical Report NREL/TP-6A2-44849). Colorado, CO: National Renewable Energy Lab. Available from: https://doi.org/10.2172/984987 [Accessed 14 Nov 2022].

Dahl, R. (1971). *Polyarchy: Participation and opposition.* New Haven, CT: Yale University Press.

Dobbin, F., Simmons, B., & Garrett, G. (2007). The global diffusion of public policies: Social construction, coercion, competition, or learning?. *Annual Review of Sociology, 33*, 449-472.

Dolšak, N. (2009). Climate change policy implementation: A cross-sectional analysis. *Review of Policy Research, 26*(5), 551-570.

Dolšak, N. (2013). Climate change policies in the transitional economies of Europe and Eurasia: The role of NGOs. *Voluntas: International Journal of Voluntary and Nonprofit Organizations, 24*(2), 382-402.

Edquist, C. (2005). Systems of innovation perspectives and challenges. In Fagerberg, J., Mowery, D. C., & Nelson, R. R. (Eds.). *The Oxford handbook of innovation.* New York, NY: Oxford University Press.

European Union. (2001). Directive 2001/77/EC of the European Parliament and of the Council on the promotion of electricity produced from renewable energy sources in the internal electricity market.

European Union. (2009). Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. *Official Journal of the European Union*.

Everitt, B. S., Landau, S., Leese, M., & Stahl, D. (2011). *Cluster analysis* (5th ed.). Wiley.

Fredriksson, P. G. (1997). The political economy of pollution taxes in a small open economy. *Journal of Environmental Economics and Management, 33*, 44–58.

Gan, L., Eskeland, G. S., & Kolshus, H. H. (2007). Green electricity market development: Lessons from Europe and the US. *Energy Policy, 35*(1), 144-155.

García-Álvarez, M. T., Cabeza-García, L., & Soares, I. (2017). Analysis of the promotion of onshore wind energy in the EU: Feed-in tariff or renewable portfolio standard?. *Renewable Energy, 111*, 256-264.

GovTrack.us. (2020). *H.R. 4018 — 95th Congress: Public Utility Regulatory Policies Act.* Available from: https://www.govtrack.us/congress/bills/95/hr4018 [Accessed 23 May 2020].

Grubb, M., Drummond, P., Poncia, A., McDowall, W., Popp, D., Samadi, S., … Pavan, G. (2021). Induced innovation in energy technologies and systems: A review of evidence and potential implications for CO2 mitigation. *Environmental Research Letters, 16*(4), 043007.

Haas, R., Meyer, N. I., Held, A., Finon, D., Lorenzoni, A., Wiser, R., & Nishio, K. (2008). Chapter 12: Promoting electricity from renewable energy sources – Lessons learned from the EU, United States, and Japan. In F. P. Sioshansi (Ed.), *Competitive electricity markets* (pp. 419-468). Elsevier. https://doi.org/10.1016/B978-008047172-3.50016-7

Hall, P. A. (1993). Policy paradigms, social learning, and the state: The case of economic policymaking in Britain. *Comparative Politics*, 275-296.

Hirsh, R. F. (1999). PURPA: The spur to competition and utility restructuring. *The Electricity Journal*, *12*(7), 60-72.

IEA. (2000a). *Electricity market reform: An IEA handbook.* Paris, France: OECD Publishing. Available from: https://doi.org/10.1787/9789264180987-en [Accessed 1 Dec 2021].

IEA. (2000b). *Energy technology and climate change: A call to action.* Paris, France: OECD. Available from: https://doi.org/10.1787/9789264189171-en [Accessed 1 Dec 2021].

IEA. (2001). *Towards a sustainable energy future.* Paris, France: OECD Publishing. Available from: https://doi.org/10.1787/9789264193581-en [Accessed 1 Dec 2021].

IEA. (2021). *Mission: The IEA works with governments and industry to shape a secure and sustainable energy future for all.* Available from: https://www.iea.org/about/mission [Accessed 1 Dec 2021].

IPCC. (2018). Global warming of 1.5 ºC: An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways. Available from: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf [Accessed 1 February 2022].

IRENA, IEA, & REN21. (2018). *Renewable energy policies in a time of transition*. Available from: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Apr/IRENA_IEA_REN21_Policies_2018.pdf [Accessed 9 December 2018].

Jänicke, M. (2005). Trend-setters in environmental policy: The character and role of pioneer countries. *European Environment*, *15*(2), 129–142.

Jenner, S., Chan, G., Frankenberger, R., & Gabel, M. (2012). What drives states to support renewable energy? *The Energy Journal*, *33*(2), 1–12. http://www.jstor.org/stable/23268075

Jones, B. S., & Branton, R. P. (2005). Beyond logit and probit: Cox duration models of single, repeating, and competing events for state policy adoption. *State Politics & Policy Quarterly*, *5*(4), 420-443.

Kammerer, M., & Namhata, C. (2018). What drives the adoption of climate change mitigation policy? A dynamic network approach to policy diffusion. *Policy Sciences*, 1-37.

Knill, C., Heichel, S., & Arndt, D. (2012). Really a front-runner, really a straggler? Of environmental leaders and laggards in the European Union and beyond – A quantitative policy perspective. *Energy Policy*, *48*, 36-45.

Knill, C., Sommerer, T., & Holzinger, K. (2008). Degree and direction of environmental policy convergence: Analysis of aggregate data. In K. Holzinger (Ed.*), Environmental policy convergence in Europe: The impact of international institutions and trade* (pp. 98-143). Cambridge, UK: Cambridge University Press.

Leiren, M. D., & Reimer, I. (2018). Historical institutionalist perspective on the shift from feed-in tariffs towards auctioning in German renewable energy policy. *Energy Research & Social Science, 43,* 33-40.

Lindblom, C. E. (1959). The science of "muddling through". *Public Administration Review*, 79-88.

Linder, S. H., & Peters, B. G. (1989). Instruments of government: Perceptions and contexts. *Journal of Public Policy, 9*(1), 35-58.

Lipp, J. (2007). Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom. *Energy Policy, 35*(11), 5481-5495.

Lyon, T. P., & Yin, H. (2010). Why do states adopt renewable portfolio standards?: An empirical investigation. *The Energy Journal*, 133-157.

Marques, A. C., Fuinhas, J. A., & Manso, J. P. (2010). Motivations driving renewable energy in European countries: A panel data approach. *Energy Policy, 38*(11), 6877-6885.

Matisoff, D. C. (2008). The adoption of state climate change policies and renewable portfolio standards: Regional diffusion or internal determinants?. *Review of Policy Research*, *25*(6), 527-546.

Matisoff, D. C., & Edwards, J. (2014). Kindred spirits or intergovernmental competition? The innovation and diffusion of energy policies in the American states (1990–2008). *Environmental Politics*, 23(5), 795-817.

Minstrom, M., & Vergari, S. (1996). Advocacy coalitions, policy entrepreneurs, and policy change. *Policy Studies Journal*, *24*(3), 420-434.

Nicolli, F., & Vona, F. (2012). *The evolution of renewable energy policy in OECD countries: Aggregate indicators and determinants* (Working Paper No. 51). Fondazione Eni Enrico Mattei. Available from: https://feem-media.s3.eu-central-1.amazonaws.com/wp-content/uploads/NDL2012-051.pdf [Accessed 1 August 2022].

Oberthür, S., & Tänzler, D. (2002). International regimes as a trigger of policy diffusion: The development of climate policies in the European Union. *PIK Report*, 317.

OECD. (2019). *Discover the OECD: Together we create better policies for better lives.* Available from: http://www.oecd.org/general/Key-information-about-the-OECD.pdf [Accessed 26 May 2019].

Panayotou, T. (2000). *Population and environment* (CID Working Paper No. 54). Center for International Development, Harvard University. Available from: https://dash.harvard.edu/handle/1/39569843 [Accessed 1 February 2022].

Peñasco, C., Anadón, L.D., & Verdolini, E. (2021). Systematic review of the outcomes and trade-offs of ten types of decarbonization policy instruments. *Nature Climate Change, 11*, 257–265. https://doi.org/10.1038/s41558-020-00971-x

REN21. (2005). *Renewables 2005: Global status report.* Paris, France: REN21 Secretariat. Available from: https://www.ren21.net/wp-content/uploads/2019/05/GSR2005_Full-Report_English.pdf [Accessed 10 October 2018].

REN21. (2017). *Renewables 2017: Global status report.* Paris, France: REN21 Secretariat. Available from: https://www.ren21.net/wp-content/uploads/2019/05/GSR2017_Full-Report_English.pdf [Accessed 10 October 2018].

REN21. (2018). *Renewables 2018: Global status report.* Paris, France: REN21 Secretariat. Available from: http://www.ren21.net/wp-content/uploads/2018/06/17-8652_GSR2018_FullReport_web_final_.pdf [Accessed 10 October 2018].

Rogers, E. (1983). *Diffusion of innovations* (3rd ed.). New York, NY: Free Press.

Shipan, C. R., & Volden, C. (2008). The mechanisms of policy diffusion. *American Journal of Political Science*, *52*(4), 840-857.

Simon, H. A. (1957). *Models of man: Social and rational; Mathematical essays on rational human behavior in society setting.* New York, NY: Wiley.

Skovgaard, J., Ferrari, S. S., & Knaggård, Å. (2019). Mapping and clustering the adoption of carbon pricing policies: What polities price carbon and why?. *Climate Policy, 19*(9), 1173-1185.

SPSS. (2001). *The SPSS TwoStep cluster component: A scalable component to segment your customers more effectively.* Available from: ftp://ftp.spss.com/pub/web/wp/TSCWP-0101.pdf [Accessed 1 Dec 2021].

Stadelmann, M., & Castro, P. (2014). Climate policy innovation in the South–Domestic and international determinants of renewable energy policies in developing and emerging countries. *Global Environmental Change, 29*, 413-423.

Tobin, P. (2017). Leaders and laggards: Climate policy ambition in developed states. *Global Environmental Politics, 17*(4), 28-47.

United Nations. (1992). *United Nations Framework Convention on Climate Change* (FCC/INFORMAL/84/Rev.1). Available from: https://unfccc.int/sites/default/files/convention_text_with_annexes_english_for_posting.pdf [Accessed 1 August 2022].

United Nations. (2015). *Paris Agreement*. Available from: https://unfccc.int/sites/default/files/english_paris_agreement.pdf [Accessed 1 February 2022].

Walker, J. (1969). The diffusion of innovations among the American States. *American Political Science Review*, *63*(3), 880–899.

Yi, H., & Feiock, R. C. (2012). Policy tool interactions and the adoption of state renewable portfolio standards. *Review of Policy Research, 29*(2), 193-206.

Zhou, S., Matisoff, D. C., Kingsley, G. A., & Brown, M. A. (2019). Understanding renewable energy policy adoption and evolution in Europe: The impact of coercion, normative emulation, competition, and learning. *Energy Research & Social Science, 51*, 1-11.

Tables

Table 1 Summary of variables and their operationalizations and sources.

Variables	Definition	Source
Dependent variable		
Policy adoption	country adopted renewable energy policy at national level for first time = 1; otherwise = 0	a
Main independent variables		
1) Internal factors		
Economic development	GDP per capita (current US$)†	b
Political system	political regime ranging from +10 for strongly democratic to -10 for strongly autocratic (revised combined Polity IV)	c
Environmental pressure	net energy importer in given year = 1; otherwise = 0 †	b
	CO_2 emissions per capita (metric tons)†	b
	total population size†	b
Environmental endowments	solar photovoltaic (PV) potential based on the mean practical solar PV potential at level 1 (excludes areas due to physical/technical constraints) (kWh/kWp/day) †	h
	wind potential based on mean wind power density at a height of 100m at 10% of windiest areas (W/m^2) †	i
2) External (diffusion) factors		
Normative emulation and social learning	political globalization as an index between 1 (min) to 100 (max) calculated as the number of international intergovernmental organizations in which a country is a member, number of international treaties a country signed and number of distinct treaty partners a country has	d
	OECD member in given year = 1; otherwise = 0	e
	number of countries from same region (regional neighbors), representing geographical proximity, that adopted policy in previous years; countries are grouped into one of 7 regions based on the classification of World Bank	a, b
Coercion	EU member in given year = 1; otherwise = 0	f
Economic competition	number of countries from same export bloc that adopted policy in previous years; countries are grouped into one of 18 export blocs based on the size of their exports in the year of 2000, so each country belongs to an export bloc made up of 10 countries with closest export size; the year of 2000 is used as a base given the study period of pooled dataset 1973-2017; economic competition and its operationalization is not well established in the literature (e.g., Dobbin et al., 2007; Stadelmann & Castro, 2014; Zhou et al., 2019) but given that countries compete for capital and export markets, countries with similar sized exports are likely to be competitors in the global arena‡	a, g
Additional variables included in cluster analysis		

Year of adoption	year of renewable energy policy adoption at national level for first time	a
Region	countries grouped into one of 7 regions based on the classification of World Bank	b

Notes: [†]GDP pc, CO_2 emissions pc, population size and mean wind power density were normalized using natural log transformations, while energy import and solar potential were converted into a categorical variable to avoid problems with the distributional properties of the data (see Appendix D). [‡]This period includes a five-year pre-specified interval before first policy adoption occurs in 1978 (see section 4. Data & Methodology for explanation). Sources: [a]Global Status Report on Renewables (REN21, 2017 & 2018). [b]World Bank (https://data.worldbank.org/). [c] Centre for Systemic Peace (http://www.systemicpeace.org/inscrdata.html). [d] ETH Zurich KOF Swiss Economic Institute (https://kof.ethz.ch/en/forecasts-and-indicators/indicators/kof-globalisation-index.html). [e]OECD (http://www.oecd.org/about/members-and-partners/). [f]European Union (https://europa.eu/european-union/about-eu/countries_en). [g] Correlates of War Project Trade Data Set Version 4.0 (Barbieri & Keshk, 2016). [h]Global Solar Atlas (https://globalsolaratlas.info/global-pv-potential-study). [i]Global Wind Atlas (https://globalwindatlas.info/en/).

Table 2 Clustering results for each country that adopted renewable power generation policy between 1978 and 2017 based on main independent variables.

Cluster 1	Cluster 2	Not assigned (NA)[†]
USA	India	Germany
Portugal	Sri Lanka	Liechtenstein
Switzerland	Armenia	San Marino
Italy	Indonesia	Serbia
Denmark	Brazil	Malta
Spain	Algeria	Bosnia and Herzegovina
Greece	Israel	Montenegro
Luxembourg	Nicaragua	Syria
Sweden	China	West Bank and Gaza
Norway	Ecuador	Vanuatu
France	Thailand	Zambia
Belgium	Argentina	Finland
Australia	Pakistan	
UK	Dominican Rep.	
Austria	Mongolia	
Czechia	Philippines	
Japan	Iran	
South Korea	Chile	
Hungary	Kenya	
Slovakia	Tanzania	
Canada	South Africa	
Poland	Malaysia	
Ireland	Belarus	
Netherlands	Mauritius	
Turkey	Vietnam	
	Ghana	
	Nigeria	
	Jordan	
	Kazakhstan	
	Egypt	
	Lithuania	
	Latvia	
	Estonia	
	Cyprus	
	Bulgaria	
	Croatia	
	Moldova	
	Albania	
	Romania	
	Ukraine	
	Slovenia	
	Macedonia	
	Uganda	
	Rwanda	

Notes: [†]Not assigned (NA) represents countries that were excluded from cluster analysis due to missing data on some variables.

Table 3 Cox regression models of renewable power generation policy adoptions at national level.

	Pooled					**Feed-in Tariffs (FIT)**					**Renewable Portfolio Standards (RPS)**				
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Log GDP pc^	1.44** (0.11)					1.30* (0.11)					**1.55** **(0.26)**				
Log CO_2 emissions pc		1.57*** (0.13)			1.42* (0.17)		1.42** (0.13)			1.33 (0.16)		**1.84** **(0.32)**			**1.88** **(0.40)**
Political system	1.07* (0.03)	1.09** (0.03)			1.06* (0.03)	1.05 (0.03)	1.06* (0.03)			1.04 (0.03)	**1.14** **(0.10)**	**1.17** **(0.09)**			**1.10** **(0.09)**
Energy dependence	2.24* (0.32)	2.66** (0.34)			2.28* (0.35)	**2.11*** **(0.34)**	**2.45*** **(0.36)**			**2.30*** **(0.36)**	1.34 (0.59)	1.65 (0.60)			2.22 (0.63)
Log population size	1.46*** (0.09)	1.45*** (0.09)			1.36* (0.14)	1.30** (0.10)	1.30** (0.10)			1.22 (0.13)	**1.92***** **(0.17)**	**1.86***** **(0.16)**			**1.79*** **(0.23)**
Log solar PV potential	0.19* (0.79)	0.25 (0.80)			0.96 (1.08)	0.33 (0.79)	0.46 (0.79)			0.57 (1.11)	**0.74** **(1.47)**	**0.64** **(1.38)**			0.09 (2.02)
Log wind power density	1.19 (0.20)	1.21 (0.20)			1.11 (0.23)	1.12 (0.21)	1.10 (0.21)			1.06 (0.23)	**1.83** **(0.51)**	**1.91** **(0.48)**			**1.70** **(0.52)**
Political globalization			1.06*** (0.01)		1.02 (0.01)			1.06*** (0.01)		1.03 (0.02)			**1.13**** **(0.04)**		**1.06** **(0.04)**
OECD member			1.29 (0.38)	2.78* (0.37)	1.05 (0.43)			1.16 (0.37)	2.51* (0.37)	0.87 (0.44)			**3.52** **(0.74)**	**16.00***** **(0.67)**	**1.91** **(0.82)**
Regional neighbors			1.02 (0.01)	1.03* (0.01)	1.01 (0.02)			**1.02** **(0.01)**	**1.03*** **(0.01)**	**1.01** **(0.02)**			0.79 (0.14)	0.81 (0.14)	0.72 (0.17)
EU member			1.93 (0.41)	2.80* (0.42)	2.05 (0.50)			**1.04** **(0.43)**	**1.53** **(0.45)**	0.83 (0.52)			0.67 (0.67)	1.24 (0.69)	1.20 (0.76)
Same export bloc			1.03 (0.07)	1.13 (0.06)	0.99 (0.09)			1.01 (0.08)	1.12 (0.08)	1.00 (0.11)			**1.1** **(0.15)**	**1.25** **(0.14)**	0.80 (0.21)
N	3772	4015	6220	7082	3971	3,837	4,076	6,291	7,158	4,032	2,472	2,475	3,788	4,087	2,436
DF	6	6	5	4	11	6	6	5	4	11	6	6	5	4	11
AIC†	545.34	538.65	631.99	676.09	**525.07**	536.81	528.76	623.48	665.15	**518.25**	152.81	151.82	156.5	168.58	**155.33**
Wald test‡	81.30 ***	71.92 ***	117.99* **	124.20* **	85.16 ***	51.71 ***	48.15 ***	69.03 ***	62.62 ***	46.80 ***	31.41 ***	30.67 ***	26.74 ***	35.24 ***	29.45 **

Likelihood-ratio test‡	83.33 ***	82.56 ***	112.00 ***	82.79 ***	86.76 ***	51.07 ***	51.60 ***	74.36 ***	47.10 ***	52.67 ***	40.04 ***	41.12 ***	47.28 ***	34.56 ***	46.93 ***
Score Logrank test‡	99.70 ***	88.03 ***	200.57 ***	196.97 ***	134.33 ***	60.24 ***	55.58 ***	96.08 ***	83.55 ***	59.19 ***	44.03 ***	39.57 ***	61.21 ***	60.27 ***	50.06 ***

Notes: Exponentiated coefficients exp(β), also known as hazard ratios (HR), and their corresponding standard errors are shown. These hazard ratios represent changes in the hazard rate of two observations that differ in their x-values. To facilitate the interpretation of the results, hazard ratios greater than one can be interpreted as having increased hazard probability of experiencing adoption and vice versa for hazard ratios of less than one (Box-Steffensmeier & Jones, 1997). Significance levels are shown as *p<0.05**p<0.01***p<0.001. †Akaike information criterion (AIC) was calculated for model evaluation because it allows comparing the relative quality of statistical models. Generally, the lower the AIC score the better the model fit (Akaike, 1974). ‡Wald, Likelihood-ratio, and Score Logrank test statistics are asymptotically equivalent tests of the omnibus null hypothesis that all the β estimates are zero. ^The variance inflation factor of log GDP pc is 8.3, which is why parsimonious models are presented.

Figure legends

Figure 1 Cumulative number of FIT, RPS and pooled policy adoptions between 1978-2017. Note: Pooled data is based on FIT and RPS adoptions according to whichever of the two policies was adopted earlier. Data is adapted from REN21 (2017; 2018).

Figure 2 Temporal distribution of main clustering results for each country that adopted renewable power generation policy between 1978 and 2017. Note: Grey circle markers (NA) represent countries that were excluded from cluster analysis due to missing data on some variables.