Organisation for Economic Co-operation and Development

ENV/EPOC/WPCID(2018)4

For Official UseFor Official Use

English - Or. EnglishEnglish - Or. English

23 January 201823 January 2018

ENVIRONMENT DIRECTORATE
ENVIRONMENT POLICY COMMITTEE

Cancels & replaces the same document of 23 January 2018

Working Party on Climate, Investment and Development

Drivers and barriers to the decarbonisation of the electricity sector

Effects of climate policies, policy misalignments and political economy factors on decarbonisation

A rapid decarbonisation of the electricity sector is necessary to achieve the goal of the Paris Agreement to limit the average global temperature increase above pre-industrial levels to well-below 2°C. This analysis investigates the drivers and barriers to the decarbonisation of the electricity sector focusing specifically on the influence of core climate policies, policy misalignments in the broader policy framework and political economy factors.

ACTION: for discussion

Dirk Röttgers, ENV/CBW and DAF/INV (Ext: 6058; Dirk.Rottgers@OECD.org)
Brilé Anderson, ENV/CBW (Ext: 8257; Brile.Anderson@OECD.org)

JT03425834JT03425834

Abstract

A rapid decarbonisation of electricity is necessary to limit global temperature increase to well-below 2°C pre-industrial levels. This empirical analysis investigates the drivers and barriers to the decarbonisation of electricity in OECD countries with a focus on the role of climate policies, policy misalignments between other policy areas and climate policies, as well as political economy factors. Results are consistent with the finding that climate policies are insufficient to decarbonise electricity. Policymakers need to review the broader policy environment to understand how this is enabling or impeding decarbonisation. Moreover, climate and non-climate policies significantly affect the share of renewables in capacity and generation; but there is no observable robust effect on emissions. In contrast, political economy factors, that is, stakeholders' underlying interests towards decarbonisation, are a significant and robust determinant of emissions in addition to the share of renewables in generation and capacity. Government rents from fossil fuels and employment in the fossil fuel industry are a major impediment to decarbonising electricity. Governments must concentrate on integrating these interests in their decarbonisation strategy.

Acknowledgments

This working paper is prepared for the Climate, Biodiversity and Water Division in the OECD Environment Directorate, under the supervision of the Working Party on Climate, Investment and Development (WPCID) of the Environment Policy Committee (EPOC). This working paper is co-authored by Dirk Röttgers and Brilé Anderson, under the supervision of Virginie Marchal and Simon Buckle and with substantial support on data collection and management from Mariana Mirabile.

The authors are extremely grateful to their OECD colleagues who provided valuable comments on this draft working paper. They include: Geraldine Ang, Rodney Boyd, Jennifer Calder, Kurt van Dender, Luisa Dressler, Florens Flues, Raphael Jachnik, Etienne Lepers, Daniel Nachtigall, Lauren McNicoll, Caroline Roulet, Robert Youngman, Ziga Zarnic and participants of the Applied Economics seminar at the OECD.

The authors are also thankful for valuable advice and inputs received from other experts, including: Heymi Bahar, Andrew Prag, Michael Waldron (all IEA); Ted Nace (Coal Swarm); and Professor Tobias Schmidt, Professor Thomas Bernauer, and other colleagues from the Institute of Science Technology and Policy at ETH Zürich.

All errors and inconsistencies remain the responsibility of the authors.

Table of contents

Tables

Figures

Boxes

Acronyms

ACME	Average causal mediation effect
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CCS	Carbon capture and storage
EPOC	Environment Policy Committee
ETS	Emission Trading System
EU	European Union
FIT	Feed-in tariff
FSB	Financial stability board
G20	Group of Twenty
GDP	Gross domestic product
GHG	Greenhouse gas
GW	Gigawatt
GWh	Gigawatt hour
HHI	Herfindahl-Hirschman Index
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
ITF	International Transport Forum
KWh	Kilowatt hour
LCA	Lifecycle Assessment
MICE	Multivariate imputation by chained equations
MWh	Megawatt hour
NEA	Nuclear Energy Agency
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary least squares
PPA	Power purchase agreement
PV	Photovoltaic
RD&D	Research, development and demonstration
R&D	Research and development
REQ	Renewable energy quota
SOE	State-owned enterprise
t	tonnes
tCO2e	tonnes of CO_2 equivalent
TWh	Terawatt hour
UN	United Nations
USD	US dollars
WB	World Bank
WPCID	Working Party on Climate, Investment and Development

Executive Summary

1. Achieving the goals of the Paris Agreement to limit global temperature increase to well-below 2°C requires peaking global greenhouse gas (GHG) emissions as soon as possible. Accomplishing an early peak in GHG requires fundamental changes in the energy sector, especially in regards to electricity. OECD countries must rapidly decarbonise electricity by transitioning electricity towards less emission-intensive technologies.

2. This analysis investigates the effects of climate policies, policy misalignments, and political economy factors on the decarbonisation of the electricity sector in OECD members from 2000 to 2015. Climate policies include carbon prices as well as targeted incentives like feed-in tariffs, public tenders and renewable energy quotas. Policy misalignments are non-climate policies that foster fossil fuels, in particular: fossil fuel subsidies, public finance for research development and deployment (RD&D) in fossil fuels and renewables, and the enforcement of leverage ratio regulations under Basel III. Lastly, political economy factors represent stakeholders' interests towards decarbonisation, specifically: state-ownership of electricity companies, market concentration in the electricity sector, employment in fossil fuel industry, government rents from fossil fuel-based activities, the age of fossil fuel plants, and public environmental concern.

3. This analysis uses three measures to capture the different phases of decarbonisation: proportion of renewables in installed capacity (GW), proportion of renewables in generated electricity (GWh) and electricity emissions per capita. Decarbonisation in terms of installed capacity captures the long-term decarbonisation including a potential infrastructure lock-in, generation captures the use of existing infrastructure, and emissions capture the eventual target of decarbonisation.

4. Results are consistent with the finding that climate policies are insufficient to decarbonise electricity. Policymakers need to review the broader policy environment to understand how this is enabling or impeding decarbonisation. It is ineffectual to implement climate policies if non-climate policies continue to foster the usage of fossil fuels. Moreover, climate and non-climate policies significantly affect the share of renewables in capacity and generation; but there is no observable robust effect on emissions. In contrast, political economy factors, that is, stakeholders' underlying interests towards decarbonisation, are a significant and robust determinant of emissions in addition to the share of renewables in generation and capacity. Government rents from fossil fuels and employment in the fossil fuel industry are a major impediment to decarbonising electricity. Governments must concentrate on how to meet these needs and decarbonise.

5. Policymakers must understand the importance of transition policies and identify the effects of decarbonisation policies. Given these results, it is particularly relevant for

OECD members to consider labour market reforms, not only in the context of the fossil fuel industry, but across sectors.

1. Introduction

6. Achieving the Paris Agreement and limiting global temperature increase to well-below 2°C means peaking global greenhouse gas (GHG) emissions as soon as possible, a subsequent rapid fall of emissions, and net zero or net-negative emissions by mid-century (OECD, 2017[1]). Realising these objectives requires fundamental changes in the energy sector, starting with a decrease in the emissions-intensity of energy especially electricity (OECD, 2017[1]). OECD members must rapidly decarbonise electricity by installing greater renewable capacity (in terms of Gigawatts, GW) and shifting generation (in terms of Gigawatt hours, GWh) towards less emission-intensive technologies while managing electricity demand.

7. Even though OECD member countries are trying to decarbonise electricity and foster the low-carbon transition by implementing climate policies, through explicit carbon pricing mechanisms or other market-based instruments, the emissions intensity of energy continues to rise (OECD, 2017[1]; OECD/IEA/NEA/ITF, 2015[2]). This is partly due to the lack of ambition of these climate policies (OECD/IEA/NEA/ITF, 2015[2]). But is also linked to a number of political economy constraints and pre-existing non-climate policies that send conflicting signals with the low-carbon transition (OECD/IEA/NEA/ITF, 2015[2]; OECD, 2017[1]). OECD members have been locked into carbon-intensive development for the past two centuries and tailoring policies to a world of abundant and relatively cheap fossil fuels. Emissions from electricity will persist unless countries resolve these contradictory signals and mainstream the low-carbon transition across the economy.

8. This working paper aims to better understand these dynamics by testing the effects of a selected set of policies, climate specific and non-climate specific, as well as political economy factors on the decarbonisation of electricity. Climate policies broadly refer to any policy aiming to foster the low-carbon transition. The non-climate policies included are policies without a climate objective (e.g., financial regulation) but may indirectly foster fossil fuels and other emission-intensive activities (OECD/IEA/NEA/ITF, 2015[2]). These are subsequently referred to as policy misalignments. Political economy factors are not policies per se but represent key stakeholders' interests towards the decarbonisation of electricity (OECD, 2017[1]).

9. The analysis captures different phases of decarbonisation of electricity using; the proportion of renewables (comprising solar, wind, geothermal, hydropower, ocean, biomass) in installed capacity[1] (GW), proportion of renewables used in generating electricity (GWh), and per capita emissions from electricity (tonnes of CO_2e; tCO2e). Decarbonisation cannot occur without installing renewable capacity (i.e., adding GW to the grid). Yet, measuring decarbonisation only in terms of capacity overlooks the

[1] Installed capacity includes all technologies: coal, natural gas, nuclear plus renewables (solar, wind, geothermal, hydropower, ocean, biomass).

different capacity factors of fossil fuel and renewable technologies. Renewable technologies generate far less electricity than fossil fuels in terms of GWh. Unlike solar and wind power, fossil fuel plants are not subject to weather conditions. Therefore, greater renewable capacity does not always translate to a shift in generation away from fossil fuels. Additionally, even if technology shifts towards renewables in generation, GHG emissions from electricity may not reduce. Germany is a notable example of this. Renewable capacity and generation in Germany drastically increased in the last decade, yet electricity simultaneously switched from nuclear to coal, resulting in relatively stable emissions despite the shift. Importantly, these phases of decarbonisation may respond differently to policies. Shifting towards renewables in generation can respond quicker in the short-term to incentives than adding renewable capacity, which is a longer term planning decision. The rest of the paper refers to each of these measures as "decarbonising electricity", which means installing renewable capacity, shifting towards renewables in generation, and reducing emissions from electricity.

10. This paper builds on prior OECD work on the decarbonisation of electricity, which investigates the effects of different policy factors (e.g., climate policies, investment environment) on investments in renewable energy (Ang, Röttgers and Burli, 2017[3]) and the aligning policies for the low-carbon transition (OECD/IEA/NEA/ITF, 2015[2]). This analysis adds to Ang, Röttgers and Burli (2017[3]) by examining whether investments actually lead to greater installed capacity of renewables, shift towards renewables in generation, and a parallel reduction in GHG emissions of electricity. Moreover, this analysis empirically investigates to what extent policy alignments and misalignments with the low-carbon transition affect the decarbonisation of electricity. This working paper adds to existing work by:

- Going beyond measuring installed capacity to include generation as well as the emissions of electricity,
- Capturing non-green energy by using proportions as well as emissions,
- Broadening the set of independent variables to include: climate policies, policy misalignments, and political economy factors.

11. Results are consistent with the finding that climate policies are important but currently insufficient to decarbonise electricity. Policymakers need to review the broader policy environment to understand how this is enabling or impeding decarbonisation. It is futile to implement climate policies if non-climate policies continue to foster the usage of fossil fuels. The results also show that climate and non-climate policies significantly affect the share of renewables in capacity and generation; but there is no observable robust effect on emissions. In contrast, political economy factors, in particular stakeholders' underlying interests, are a significant and robust determinant of emissions in addition to the share of renewables in generation and capacity. Government rents from fossil fuels and employment in the fossil fuel industry are a major impediment to decarbonising electricity. Governments must concentrate on how to meet these needs and decarbonise electricity.

12. Policymakers must understand the importance of transition policies and identify the effects of policies for decarbonisation. Given these results, it is particularly relevant for OECD members to consider labour market reforms, not only in the context of the fossil fuel industry, but across sectors.

2. Framework for the decarbonisation of the electricity sector

13. The remainder of the section overviews prior work on the decarbonisation of electricity focusing on the effects of climate policies, policy misalignments and political economy factors. It then outlines hypotheses tested in the regression analysis. Hypotheses are italicised and summarised in each subsection in Tables 2.1, 2.2, and 2.3. Even though the analysis uses three measures of decarbonisation, the hypotheses are stated in terms of the effect on the decarbonisation of electricity.

2.1. Climate Policy

14. Strong financial incentives such as carbon prices or targeted support for renewable energy are a necessary condition for the decarbonisation of electricity (OECD/IEA/NEA/ITF, 2015[2]; IRENA, 2017[4]), since they correct for existing market failures and incentivise a reduction of emissions (Cárdenas Rodríguez et al., 2015[5]). GHG emissions can be priced explicitly, via an emissions trading system or carbon tax, or implicitly, by subsidising emissions-reducing activities such as Feed-in-Tariffs (FITs) or Renewable Energy Quotas (REQs) (OECD/IEA/NEA/ITF, 2015[2]). The remainder of this subsection reviews prior work and formulates hypotheses on the impacts of implicit and explicit pricing instruments on the decarbonisation of electricity as well as the effects of the design of such pricing instruments (i.e., how long a given carbon price is in effect) as summarised in Table 2.1.

Table 2.1. Climate policy hypotheses

Explanatory variable	Effect on decarbonisation	Mechanism: Why the expected effect on decarbonisation?
Explicit carbon price (USD/tCO2e)	+	Changes the order in which utilities dispatch technologies giving renewables preference, shift consumers' behaviours towards lower usage, and stimulates private investment in renewable energy.
Planning horizon of carbon price (years)	+	Encourages public and private investment in renewables by signalling the government's commitment to the low-carbon transition.
Public tenders	+	Increase private investment in renewable energy.
Feed-in tariffs (USD per kwh)	+	Foster private investment in renewable energy by guaranteeing producers a fixed price.
Feed-in tariff contract length (years)	+	Stimulates private investment in renewables by guaranteeing producers long-term contracts with a secure income.

Renewable Energy Quota (percent)	+	Creates an economic incentive for utilities to shift towards renewables in electricity.

Note: How to read "Effect on decarbonisation": "+" means that as the explicit carbon price increases, the decarbonisation of electricity is expected to be enabled while "-" means that as the explicit carbon price increases, the decarbonisation of electricity is expected to be inhibited.
Source: Authors

Higher carbon prices are expected to enable decarbonisation

15. An explicit carbon price can lead to decarbonisation due to changes in the dispatching of technologies, shifts in producer or consumer behavior, and greater innovation (Newcomer et al., 2008[6]; Choi, Bakshi and Haab, 2010[7]; Weigt, Ellerman and Delarue, 2013[8]; Tietenberg, 2013[9]). Modelling shows that as the price of emissions increases, utilities change the order in which existing generators are dispatched according to their GHG emissions, ultimately shifting away from emission-intensive technologies (Newcomer et al., 2008[6]). Likewise, consumers react to the increased energy prices by buying and using less electricity (Newcomer et al., 2008[6]; Choi, Bakshi and Haab, 2010[7]). A carbon price can also stimulate investment in new generation technologies since such instruments could provide a more reliable revenue stream and ameliorate the risk-return profile of renewable energy investments (Martin, Muûls and Wagner, 2011[10]; Fischer, 2008[11]; Acemoglu et al., 2010[12]; Cárdenas Rodríguez et al., 2015[5]). Increased investment could, in turn, lead to greater installed capacity of renewables, greater use of renewables in generation and a reduction of emissions from electricity. Therefore, as *the carbon price increases, decarbonisation is expected to increase.*

Longer planning horizons of carbon prices are expected to enable decarbonisation

16. An additional feature to the effectiveness of a carbon price is the perceived certainty and longevity of such a policy. If investors believe that a carbon price is subject to change, then there is little to no incentive for any stakeholder (e.g., utilities, consumers) to react and alter behaviour, especially if altering behaviour comes with a high sunk cost or implies substantial change. In contrast, a carbon price instituted for longer periods of time into the future signals the commitment of the government to mitigation and the low-carbon transition (OECD/IEA/NEA/ITF, 2015[2]). Planning horizon is defined as the remaining years on a given carbon price before the legislation is scheduled for evaluation or revision. Therefore, *as the planning horizon of a country's carbon price increases, decarbonisation is expected to increase.*

Public tenders are expected to enable decarbonisation

17. Public tender policies aim to incentivize public and private investment in the area of procurement. Therefore, public tenders that add renewable capacity should incentivize greater public and private investment in such technologies leading to enhanced innovation. These should, in turn, lead to greater installed renewables, shift towards renewables in generation, and a potential decrease in emissions. In practice, Ang, Röttgers and Burli (2017[3]) find public tenders stimulate investment in wind and solar, but cannot be shown to affect patents in renewable technologies overall in OECD and G20 member countries. The latter inconclusive result could be rooted in the tendency of tenders to be one-off measures to procure a certain quantity of installed renewables capacity in contrast to feed-in-tariffs (FITs), which are consistent price-based instruments

that provide long-term visibility to invest and innovate. Whether tenders directly affect decarbonisation consistently enough to yield a statistical signal remains to be empirically tested. In theory, *an increase in public tenders to install renewable capacity is expected to increase decarbonisation.*

Higher FITs and longer contract lengths are expected to enable decarbonisation

18. FITs are a widely used as a targeted incentive to shift electricity from fossil fuels to renewables either as a compliment or alternative to explicit carbon pricing. In theory, FITs should accelerate renewable energy deployment by guaranteeing renewable energy producers long-term contracts at a fixed price. Empirically, the evidence is mixed. One strand of literature examines the impacts of FITs (operationalised as a dummy variable) on renewable generation as a percentage of cumulative generation in cross-sectional data instead of a time-series (Menz and Vachon, 2006[13]; Jenner, Groba and Indvik, 2013[14]). These authors find a statistically significant positive relationship between FITs and renewable energy deployment, which is attributed to the certainty of long-term contracts that FITs offer to investors. Another strand of literature accounts for the effects of country characteristics over time when analysing the effect of FIT on electricity generation. Under this specification, the relationship between FIT and renewable energy deployment is often statistically insignificant (Carley, 2009[15]; Delmas and Montes-Sancho, 2011[16]; Nio et al., 2010[17]; Shrimali and Kniefel, 2011[18]). A third strand attempts to add greater nuance to the FIT variable by incorporating differences in policy design. For example, it shows that policy design, such as the price of USD/kWh, significantly affects renewable energy deployment (Nio et al., 2010[17]; Yin and Powers, 2009[19]; Jenner, Groba and Indvik, 2013[14]; Ang, Röttgers and Burli, 2017[3]). Given these mixed results, there is no convincing empirical reason to expect any given effect of FITs on decarbonisation.

19. This analysis separates two aspects of FIT design: height of the FIT (USD/kWh) and the contract length (years). These two aspects both can attract investors. However, they can serve investors differently, with varying effects on the market, which is why they are treated separately.

20. The height is relevant for whoever produces electricity at a given time, so it is relevant to any investor who plans to hold a plant benefiting from a FIT. In the long-run for investors with an appetite for stable rather than high returns, the tariff might be secondary as long as it turns the project profitable. The length of the contract is relevant to investors planning to hold a plant for a longer period (or planning to sell the asset to such an investor). If stable returns are a concern more than high returns, which is often the case for institutional investors like a pension fund, the length of the contract provides the sought-after certainty. As investors have separate appetites with respect to risk and returns, they might react differently to the amount and length of the feed-in tariff. In theory, *as the FIT amount or FIT contract length increases, decarbonisation is expected to increase*.

21. While it is straightforward to see how FITs have a positive effect on decarbonisation, the recent trend of declining tariffs accompanying higher installation rates in countries might suggest that the relationship could be negative. Indeed, it is smart policy design for a market-creation tool such as FITs to lower the rates persistently as the market develops. However, that does not mean that they do not still serve as an incentive, even while they keep being lowered. Hence, FITs are not expected to be negative, despite the overall decline coinciding with rising investments.

REQs is expected to enable decarbonisation

22. Renewable energy quotas (also known as renewable energy credits, quotas or REQs) emerged as a market-based alternative to FIT. REQs are used to fulfil predetermined quotas of renewables in electricity creating an economic incentive for utilities to shift (Toke, 2005[20]) and can often be traded to increase efficiency. By consequence of the policy design and aim, REQs should spur investment as well as innovation in different renewable energy technologies (Polzin et al., 2015[21]). However, similar to FITs, the effect of REQs is empirically uncertain. REQs combined with long-term power purchase agreements appear to foster public and private investment in solar and wind (Ang, Röttgers and Burli, 2017[3]). Yet, when expanded to a broader set of technologies, Cárdenas Rodríguez et al. (2015[5]) find that the effect of REQ is insignificant on private investment in a broader set of renewable technologies (i.e., wind, solar, biomass, small hydropower, marine and geothermal). It is possible that REQs only induce innovation in technologies that are close to competitive with fossil fuels but not in historically costlier technologies such as solar power (Johnstone et al., 2010[22]). Whether increase in investment enhances innovation is dubious given the insignificant effect of REQ on patenting in wind and solar (Ang, Röttgers and Burli, 2017[3]). Theoretically, *as GW from REQs increases, decarbonisation is expected to increase*.

2.2. Policy misalignments

23. A potential obstacle to decarbonisation is existing policies unrelated to climate that continue to encourage the use of fossil fuels and other carbon-intensive activities, in other words, policy misalignments (OECD/IEA/NEA/ITF, 2015[2]). The policy misalignments included in this analysis are fossil fuel subsidies[2], public RD&D in renewables as well as in fossil fuels, and Basel III financial regulations (OECD/IEA/NEA/ITF, 2015[2]). Hypotheses are summarised in Table 2.2.

Table 2.2. Misalignment hypotheses

Explanatory variable	Effect on decarbonisation	Mechanism: Why the expected direct effect on decarbonisation?
Fossil fuel subsidies [3]	-	Fossil fuel support lowers the capital costs of fossil fuel infrastructure in comparison with renewables and stimulates investment as well as innovation in fossil fuels.
Public RD&D in fossil fuels	-	Public RD&D in fossil fuels stimulates investment and innovation in fossil fuels fostering their use.
Public RD&D in renewables	+	Public RD&D in renewables stimulates investment and innovation in renewables fostering their use.
Basel III	-	The high leverage requirements of Basel III restrict access to capital needed for renewable energy

[2] Includes the sum of upstream fossil fuel subsidies and public Research, Development & Deployment (RD&D) spending on fossil fuels excluding carbon capture storage

Explanatory variable	Effect on decarbonisation	Mechanism: Why the expected direct effect on decarbonisation?
		investments.

Note: How to read “Effect on decarbonisation”: “+” means that as the public RDD in renewables increases, the decarbonisation of electricity is expected to be enabled while “-” means that as the public RDD in fossil fuels increases, the decarbonisation of electricity is expected to be inhibited.
Source: Authors.

Fossil fuel subsidies are expected to impede decarbonisation

24. Fossil fuel subsidies (excluding public RD&D in in fossil fuels) perpetuate the use of fossil fuels in electricity by distorting prices and resource allocation decisions (OECD, 2005[23]). OECD countries and partner economies[4] spent nearly USD 160 to 200 billion annually on fossil fuel subsidies (OECD, 2015[24]). Given that renewable energy infrastructure is already more capital intensive in the building phase than fossil fuels; this further incentivizes installing fossil fuel capacity. The removal of such subsidies is expected to increase the installed capacity of renewables and the use of renewables in electricity by making these technologies cost competitive (Riedy and Diesendorf, 2003[25]; Ouyang and Lin, 2014[26]). Moreover, fossil fuel subsidies foster innovation and investment in high-emission fossil fuel activities (Rentschler and Bazilian, 2016[27]). This could hamper the necessary radical shift needed for the low-carbon transition, ultimately rendering the Paris goals out of reach and further entrenching the use of these technologies in electricity. Therefore, *increasing fossil fuel subsidies is expected to impede the decarbonisation of electricity.*

Public RDD on fossil fuels are expected to impede decarbonisation

25. Public RD&D in fossil fuels (excluding carbon capture and storage) is a specific type of fossil fuel subsidy, which perpetuates the use and deployment as well as signals a lack of governmental commitment to the low-carbon transition. Public RD&D spending on fossil fuels hinders investment from renewables, which ultimately, leads to slower adoption of renewables. This, in turn, reduces the pace of learning and cost reduction of renewables as the technologies mature. In other words, the more a government subsidises fossil fuels via RDD, the more it has to subsidise renewables if it wants these to compete fairly (Whitley and Van Der Burg, 2015[28]). Therefore, *increasing public RD&D spending on fossil fuels is expected to impede decarbonisation*.

Public RD&D on renewables enhances decarbonisation

26. Public RD&D in renewables can foster the installation and deployment of renewables, fund potentially disruptive technologies necessary for decarbonisation, and can signal the government’s commitment to the low-carbon transition. Governments try to improve the positioning and competitiveness of their domestic renewable industries via public RD&D (Rao and Kishore, 2010[29]). However, despite spending large amounts of public RD&D in renewables, experiences in different countries show that the development, diffusion and implementation of renewable energy technologies is a tedious process and varies by technology (Foxon et al., 2005[26]; Negro, Alkemade and Hekkert, 2012[27]; Negro, Hekkert and Smits, 2007[28]; Raven and Verbong, 2004[29]; Rao and Kishore, 2010[30]). This is partly due to innovation policies that favour

[4] Key partner countries include Brazil, China, India, Indonesia, Russia and South Africa.

incumbents, the risk return profiles of investments, and administrative barriers. Moreover, the optimal mix of public RD&D in renewables to support deployment is unclear (Neuhoff, 2005[30]). But theoretically, increases in public RD&D in renewables should lead to greater innovation and increase its competitiveness with other technologies. Therefore, *increasing public RD&D in renewables is expected to increase the decarbonisation of electricity.*

Basel III leverage ratio impedes decarbonisation

27. Basel III aims to restrict excessive leverage and exposure from banks in the wake of the 2008 financial crisis. Such regulations have been implemented to increase the overall stability of the financial system, which is a necessary condition for any investments including ones needed for the decarbonisation of electricity. Its capital and liquidity requirements may limit access to the long-term financing required for renewable investments (OECD/IEA/NEA/ITF, 2015[2]) The Financial Stability Board, mandated by the G20 to monitor financial regulatory factors, finds limited proof that capital requirements of Basel III harm long-term investments (FSB/IMF/WB, 2012[31]). Since compliance with Basel III only started relatively recently, empirical evidence on the effects of Basel III is scant with the exception of Ang, Röttgers and Burli (2017[3]), which finds a significant negative effect of Basel III on private and public investment in wind and solar. Therefore, *compliance with Basel III is expected to impede the decarbonisation of electricity.*

2.3. Political Economy

28. Political economy studies how various factors shape the policies in place. These factors can be grouped as: interests, ideology, and institutions. Policymakers constantly have to balance their own interests (e.g. economic interests or re-election) with interests of other stakeholders such as citizens, lobbies or political parties whose support may be needed to pass specific reforms. Likewise, ideology continues to be a significant driver of policy while institutions set the rules of the game (e.g., environmentalism vs. market liberalisation) configuring the incentives of political actors and the potential decisions that they can make. This analysis includes the following political economy factors:

- Share of state ownership in electricity companies,
- Market concentration of the electricity sector,
- Age of fossil fuel plants,
- Jobs in the fossil fuel industry,
- Government rents from fossil fuel-based activity, and
- Public environmental concern.

29. These variables capture key stakeholders' interests towards the decarbonisation of electricity: (1) producers (i.e., age of stranded assets and market concentration), (2) state (i.e., state ownership in the electricity sector, fossil fuel rents as well as fossil fuel jobs) as well as (3) consumers (i.e., public environmental concern). Ideology and institutional factors were excluded since this analysis concentrates on factors that policymakers could conceivably react to or change. Moreover, institutional ideology factors are relatively homogeneous amongst OECD members and relatively stable over time since 2000; therefore, unlikely to yield statistical results.

30. It is important to note that the effect of political economy factors on decarbonisation may not only be direct. Political economy factors likely affect climate policies and policy misalignments since political economy factors are part of the context in which climate policies and policy misalignments develop. Therefore, the effects of political economy factors on decarbonisation may interact with these other policies. Moreover, there could be "feedback loops", i.e. endogeneity, between the electricity mix (i.e., the proportion of fossil fuels and renewables installed or used in generation), climate policies, policy misalignments and political economy factors. For example, the electricity mix (i.e., ratio of renewables to non-renewables) influences political economy factors (i.e., stakeholder's interests) while political economy factors simultaneously influence decarbonisation creating endogeneity. Table 2.3 summarizes the direct effects of political economy factors on decarbonisation, while possible interaction effects are highlighted when relevant.

Table 2.3. Political economy hypotheses

Explanatory variable	Effect on decarbonisation	Mechanism: Why the expected direct effect on decarbonisation?
Share of state owned GW in the electricity sector	-	The high exposure of state-owned enterprises to carbon intensive technologies could be a disincentive for governments to decarbonise.
	+	State-owned enterprises could push a green agenda leading to decarbonisation.
Market concentration	-	Greater market concentration favours incumbents, which limits access to the electricity market for innovative newcomer firms and decreases investment in renewables.
Age of fossil fuel plants	-	The younger fossil fuel plants, the more assets, which are at risk of being stranded, hence creating a disincentive for asset holders to decarbonise.
Jobs in fossil fuels industry	-	The higher the number of jobs at risk due to the low carbon transition, the more difficult it is for a given country to decarbonise.
Fossil fuel rents	-	The greater proportion of government revenue from fossil fuel rents, the greater the disincentive for governments to shift towards renewables.
Public environmental concern	+	The greater the public environmental concern, the greater the incentive for governments to decarbonise in order to stay in office.

Note: How to read "Effect on decarbonisation": "+" means that as the public environmental concern increases, the decarbonisation of electricity is expected to be enabled while "-" means that as fossil fuel rents increase, the decarbonisation of electricity is expected to be inhibited.
Source: Authors.

State-owned enterprises in the electricity sector could enhance or impede decarbonisation.

31. State-owned enterprises (SOEs) could create an incentive or disincentive for governments to decarbonise electricity. SOEs account for 61 % of total installed capacity and 52 % of electricity plants currently planned or under construction in 2016 in OECD and G20 countries (Prag, Röttgers and Scherrer, 2018[32]). State ownership often results in preferential treatment (OECD, 2016[33]), which could be fortuitous for decarbonisation since the motivations of SOEs can extend beyond financial returns to include social and environmental objectives such as decarbonisation (OECD, 2016[33]). The preferential

treatment of SOEs from governments could lower the capital cost of renewables, which enables SOEs to invest in capital intensive renewable technologies. The presence of SOEs in a given country can therefore be an opportunity to foster decarbonisation. This is backed by the findings of a recent study that indicates that SOEs can positively affect the level of investment in renewable energy (Prag, Röttgers and Scherrer, 2018[32]). This increased investment could lead to more installed renewables or use of renewables in generation.

32. However, SOEs accounted for 56 % of coal power plants and 52 % of planned coal plants as of 2014 in the OECD (Prag, Röttgers and Scherrer, 2018[32]). This carbon entanglement is in direct conflict with the decarbonisation of electricity. Potentially, acting as a disincentive for governments to decarbonise. Therefore, the effect of SOEs on decarbonisation is theoretically unclear; *SOEs could either increase or impede decarbonisation*.

33. SOEs may affect climate policies and policy misalignments. SOEs will lobby their interests, whether pro or contra to decarbonisation, in an attempt to steer the passage policies in line with them. Lobbyists are a key determinant of environmental policy in the European Union as well as in the United States (Baumgartner et al., 2009[34]; Michaelowa, 1998[35]; Gullberg, 2008[36]). Interests hostile to climate policy are able to prevent strong instruments from being put into place and, conversely, can further exacerbate misalignments of policies with the climate agenda (Michaelowa, 1998[35]). The analysis will test for interactions between SOEs and public tenders, carbon price, and Basel III.

Market concentration is expected to impede decarbonisation

34. Market concentration (i.e. when a small number of firms account for a large portion of market activity) could impede decarbonisation by restricting access to the electricity market for innovative newcomer firms and thereby decrease investment in renewables. First, incumbents in the energy sector, state-owned or not, face challenges to remain profitable with large investments in renewables because the latter have a lower capacity factor than fossil fuels. Fossil fuel plants can operate 24/7 while solar and wind power are subject to weather conditions (Prag, Röttgers and Scherrer, 2018[32]). Secondly, concentrated markets reduce competition and thereby impede entry of new renewable energy firms to the market (Prag, Röttgers and Scherrer (2018[32]). This is especially problematic as new entrants typically bring innovation (Johnstone et al. (2010[22]). Therefore, higher market concentration is expected to impede decarbonisation.

Older average age of power plants is expected to enhance decarbonisation

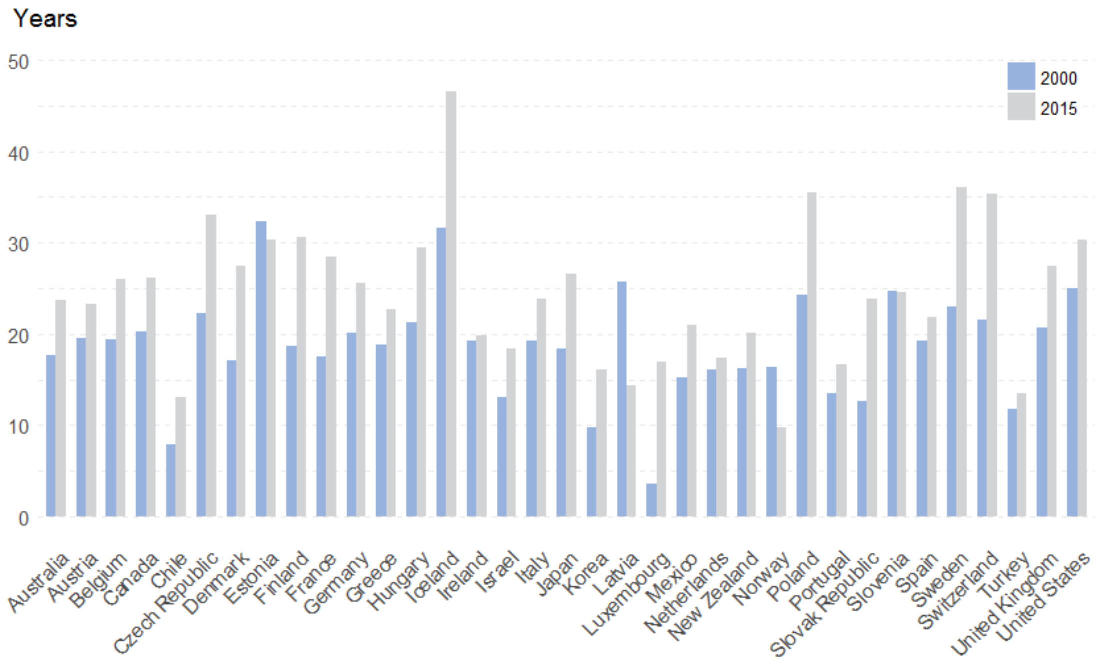
35. The magnitude of stranded assets from decarbonisation can create a disincentive for asset holders, public or private, to decarbonise electricity. Infrastructure in the energy sector is characterised by long lifetimes, typically, 20 to 60 years (OECD, 2017[1]). Figure 2.1 shows the average age of power plants in OECD members in 2000 and 2015. Estonia and Latvia are the only OECD members to have a younger average of fossil fuel plants in 2015 than in 2000. Transitioning to a low-carbon economy with existing fossil fuel infrastructure well before its end of life will lead to stranded assets. This means these fossil fuel assets will be devalued or converted to liabilities prematurely (Baron and Fischer, 2015[37]). The International Energy Agency’s 2°C-compatible ‘450 Scenario’ estimates the amount of stranded assets to be USD 180 billion for upstream oil and gas investments, USD 120 billion for new fossil fuel capacity in the electricity sector, and

USD 4 billion for coal mining (IEA, 2014[38]). In contrast, today's stock of energy generation infrastructure also includes assets over 50 years old in OECD countries. The older the average age of plants (oil, gas, and coal) results in fewer stranded assets meaning decarbonisation is less costly and resistance to decarbonisation will be lower. Therefore, *as the average age of power plants increases, decarbonisation is expected to increase.*

36. The potential stranded assets from decarbonisation could lead public and private asset holders to lobby in an attempt to weaken climate policy or create policy misalignments, which will impede the decarbonisation of electricity. The analysis will interact age of fossil fuel plants with carbon price, Basel III, and public RDD spending on renewables and fossil fuels.

Figure 2.1. Average age of fossil fuel plants

OECD members in 2000 and 2015



Source: Author's calculations using Global coal plant tracker (2017[39]) and Platts WEPP (2017[40]).

A high number of jobs in the fossil fuel industry is expected to impede decarbonisation

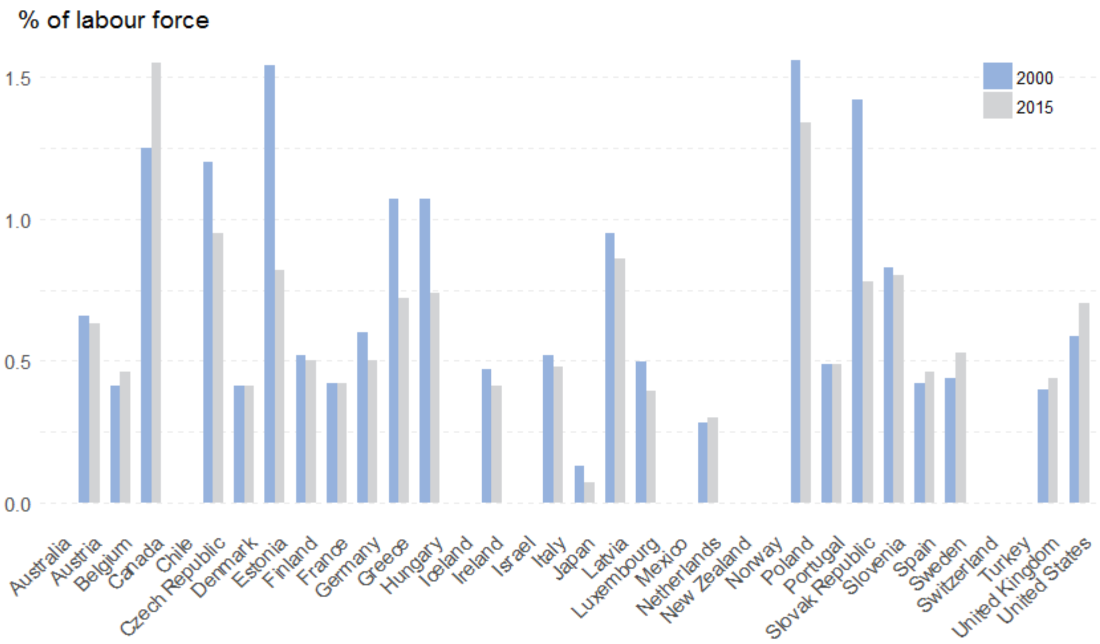
37. Sustained employment in fossil fuel related activities is a further disincentive for decarbonising electricity. The decarbonisation of electricity will cause structural shifts in employment, which means the livelihoods of employees in carbon intensive industries and along their supply chains, could be affected (Fankhauser, Sehlleier and Stern, 2008[41]; Martinez-Fernandez, Hinojosa and Miranda, 2010[42]). Therefore, employees in the fossil fuel sector have an incentive to organise and lobby against climate policies. Moreover, fossil fuel sector employees have concentrated interests meaning it is easier for them to organise and lobby policymakers (Dolšak and Prakash, 2016[43]; Olson, 1971[44]).

Figure 2.2 shows the employment in the fossil fuel industry in OECD members in 2000 and 2015. Employment in the fossil fuel industry is decreasing in all OECD members except for Canada, Sweden and the United States. Even though empirical work illustrates that fossil fuel jobs will be offset by jobs in the renewable sector, retraining demands time and effort (DOE, 2017[45]; Garrett-Peltier, 2017[46]; Fankhauser, Sehlleier and Stern, 2008[41]; Yi, 2013[47]). Even when accounting for jobs in the renewables sector, labour is a less mobile factor of production between industries than land or capital. Retraining individuals requires time, resources, and could even require individuals to physically relocate (Martinez-Fernandez, Hinojosa and Miranda, 2010[42]). Therefore, *high employment in fossil fuel jobs is expected to impede the decarbonisation of electricity*.

38. Similar to asset holders, fossil fuel employees will lobby in an attempt to weaken climate policy or create policy misalignments, which will impede the decarbonisation of electricity. This analysis investigates the interaction effects between fossil fuel jobs, carbon price as well as RD&D spending on fossil fuels and renewables.

Figure 2.2. Employment in fossil fuel industry

OECD members in 2000 and 2015



Note: Korea is omitted since it is an outlier.
Source: EU KLEMS (Jäger, 2017[48]) and WORLD KLEMS (WORLD KLEMS, 2017[49]).

Greater fossil fuel rents could impede decarbonisation

39. Moreover, in fossil fuel producing countries, regardless of ownership or market concentration, governments collect rents from fossil fuels. From 2011 to 2015, total revenues from fossil fuels reached up to nearly USD 1,130 billion in OECD countries (OECD, 2017[1]). The loss of this revenue could be a disincentive for governments to shift towards renewable sources of electricity and decarbonise. Therefore, *increasing fossil fuel rents is expected to impede decarbonisation*.

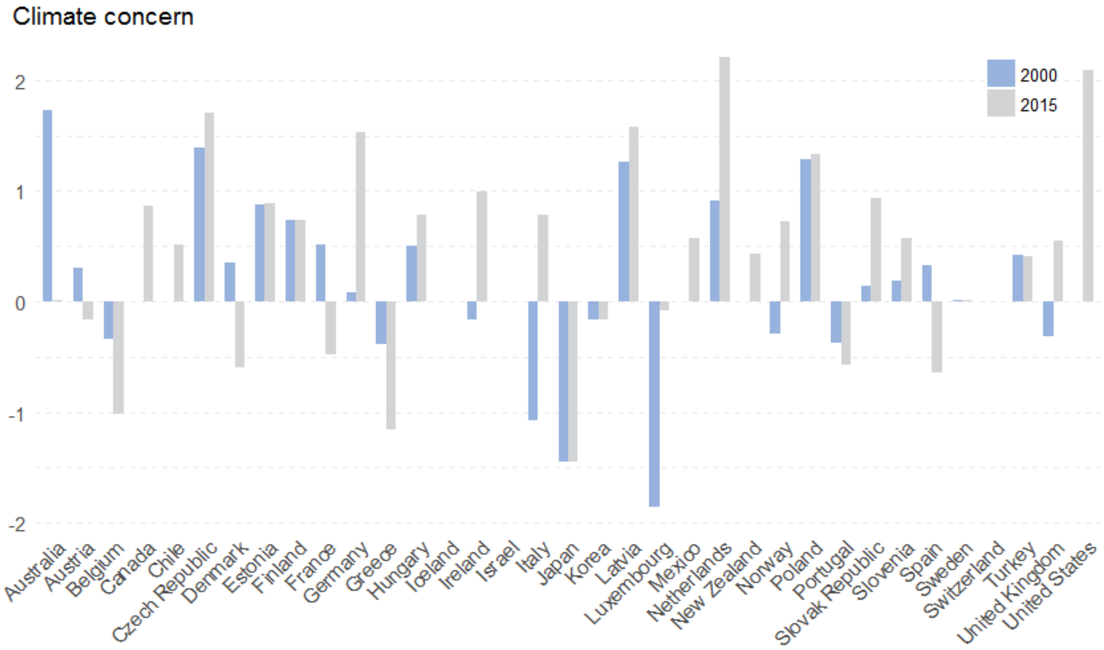
40. If government substantial government revenue is derived from fossil fuels, this likely affects carbon pricing legislation. The analysis will test for interactions between fossil fuel rents and carbon prices.

High public environmental concern should increase decarbonisation

41. The public's environment concern could also incentivize the decarbonisation of electricity by influencing governments to enact certain policies. Prior studies show that climate concern is mainly determined by age, education, political ideology and gender (Dunlap and Brulle, 2015[45]). This is a stronger predictor of environmental concern than climatic events (e.g., drought), which have a fleeting or non-existent effect (Brulle et al., 2002[46]). If the public is concerned about the environment, the government has reason to introduce environmental policies, in order to maximise their chances of staying in office (Anderson, Böhmelt and Ward, 2017[47]; Agnone, 2007[48]; Shum, 2009[49]). Figure 2.3 plots environmental concern in OECD members. Positive values indicate concern, zero ambivalent, and below, a lack of concern. Prior empirical work shows that policy output is responsive to changes in public environmental concern (Anderson, Böhmelt and Ward, 2017[47]). Therefore, *greater environmental concern is expected to enhance decarbonisation*.

Figure 2.3. Public Environment Concern

OECD members in 2000 and 2015



Note: Zero indicates ambivalence towards environment; positive values indicate high concern, while negative values indicate lack of concern.
Source: Aggregated a variety of sources, see Appendix C.

3. Empirical design

42. The analysis uses regressions (specifically, Tobit and OLS) to investigate the effects of the aforementioned climate policies, policy misalignments, and political economy factors on the three phases of decarbonising electricity. The panel dataset includes OECD members from 2000 to 2015 with country-year as the unit of observation. The remainder of this section details the dependent variables, independent variables, controls as well as the estimation strategy.

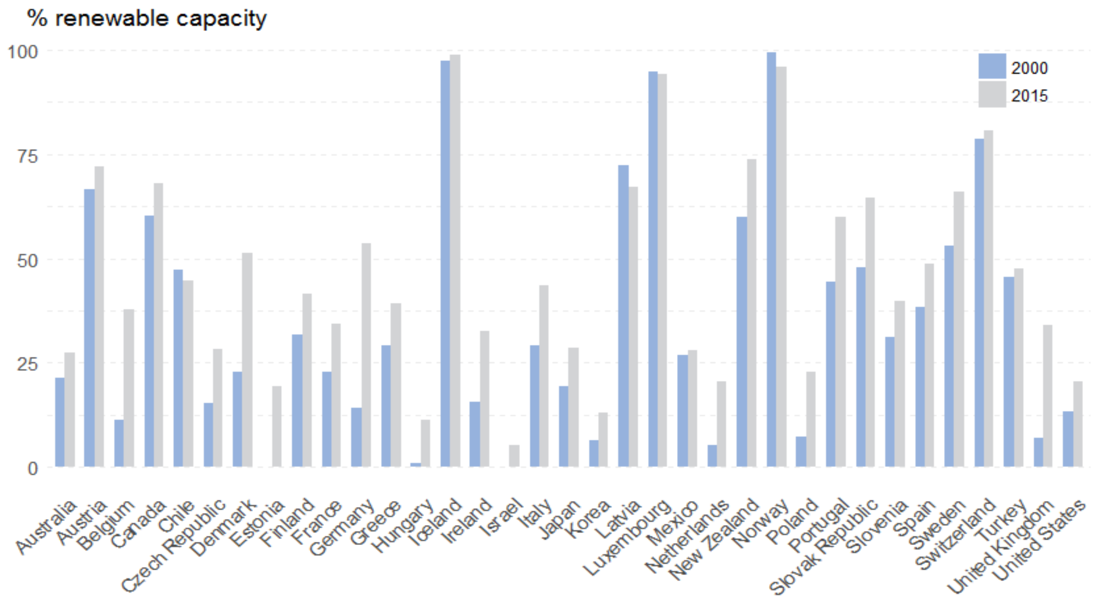
3.1. Dependent variables

43. The three dependent variables capture the three phases of decarbonisation: the percent of renewables in total installed capacity (referred to as CAPACITY), the percent of renewables used in generation (referred to as GENERATION), and electricity emissions per capita measured in tonnes of CO2e (referred to as EMISSIONS). CAPACITY is estimated by aggregating GW data from sources specialising in estimating the GWs of different technologies: coal (Global coal plant tracker, 2017[39]), oil and gas (Platts WEPP, 2017[40]), nuclear (IAEA, 2017[50]), and renewables (IEA, 2017[51]). CAPACITY is equal to renewable GWs in a given year (i.e., solar, wind, geothermal, ocean, hydropower and biomass) over total GW in that year (i.e. coal, oil, gas, nuclear, plus renewables). GENERATION estimates come from the IEA World Energy Balances database (IEA, 2017[51]). Data are available for all technologies per country from 2000 to 2015. GENERATION is equal to renewable GWh in a given year (i.e., solar, wind, geothermal, ocean, hydropower and biomass) over total GWh in that year (i.e. coal, oil, gas, nuclear, plus renewables). EMISSIONS estimates are from the IEA World Energy Balances database (IEA, 2017[51]), which estimates emissions from combustion used for electricity. For comparability between countries, per capita emissions were calculated.

44. Figures 3.1, 3.2 and 3.3 plot CAPACITY, GENERATION, and EMISSIONS, respectively, in OECD members in 2000 (red bar) and 2015 (green bar). % renewables in installed capacity is higher in 2015 compared to 2000 in OECD members with the exception of Austria, Chile, Iceland, Israel, Luxembourg, Latvia, and Norway. % renewables in generation is higher in 2015 compared to 2000 with the exception of in Austria, Switzerland, Chile, Czech Republic, Spain, France, Greece, Japan, Korea, Luxembourg, Latvia, Mexico, Norway and Turkey. Despite these trends, per capita emissions from combustion decreased from 2000 to 2015 in nearly all OECD members with the exception of Chile, Estonia, Japan, Korea, Luxembourg, Latvia, Netherlands, and Turkey from 2000 to 2015.

Figure 3.1. CAPACITY

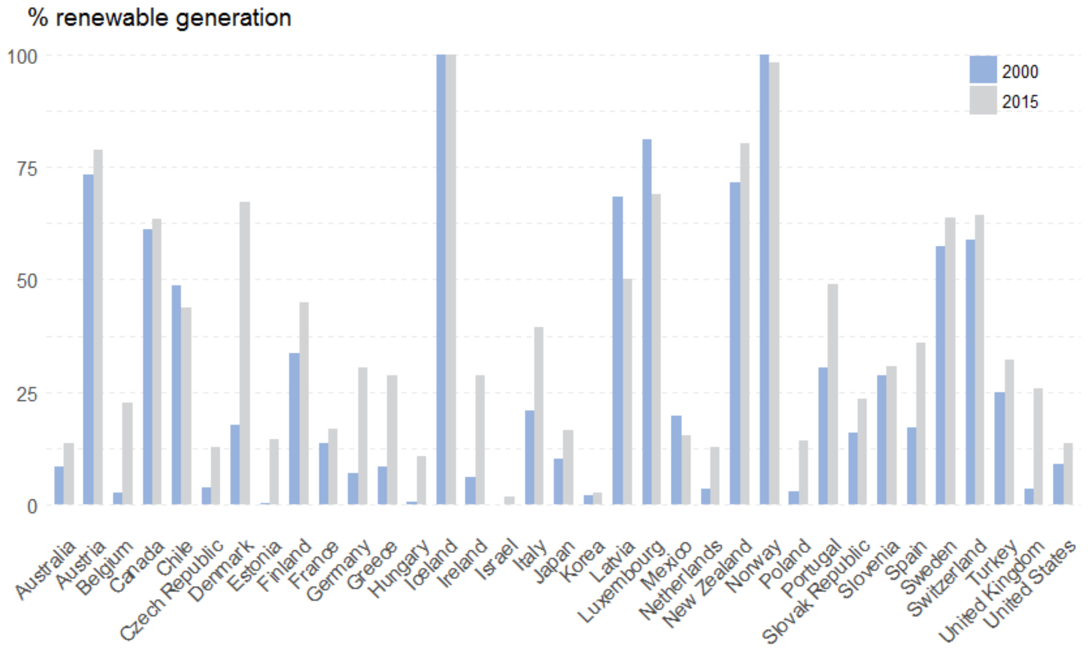
OECD members in 2000 and 2015



Source: Global coal plant tracker (2017[39]), IAEA (2017[50]), IEA (2017[51]), Platts WEPP (2017[40]).

Figure 3.2. GENERATION

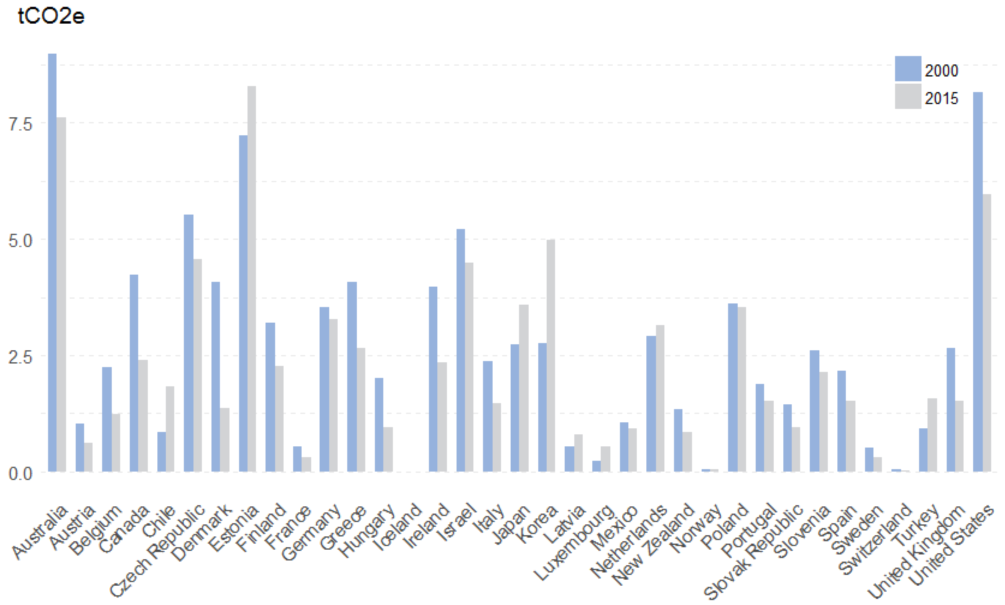
OECD members in 2000 and 2015



Source: IEA (2017[51]).

Figure 3.3. EMISSIONS

OECD members in 2000 and 2015



Source: IEA (2017[51]).

3.2. Independent variables

45. The climate policy variables include:

- **Explicit carbon price,**
- **Climate policy intention,**
- **Public tender,**
- **Feed-in tariff**
- **Feed-in tariff contract length, and**
- **Renewable energy quota.**

46. **Explicit carbon price** uses the World Bank's Explicit Carbon Price Database, which estimates the total USD/tCO2e from emissions trading systems and carbon taxes in OECD members from 2000 to 2015 (Ecofys and World Bank Climate Group, 2016[52]). The **climate policy intention** variable captures the years left on a carbon price until its revision. This is estimated using the Grantham Research Institute's Climate Change Laws of the World Database, which covers national-level climate change legislation in 164 countries (see Annex C for further details). This is estimated using the Grantham Research Institute's Climate Change Laws of the World Database, which covers national-level climate change legislation in 164 countries (see Annex C for further details). **Public tender** is the total amount of MW tendered across all renewable subsectors as share of newly installed renewable capacity, which is based on tender data used in Ang, Röttgers and Burli (2017[3]). **Feed-in tariff** is the average sectoral price of the feed-in tariffs (in USD/kWh) in each country year developed by Haščič and colleagues (2015[52]), whereas **feed-in tariff contract length** is the length of power purchase agreement awarded under a country's FIT policy in years (Ang, Röttgers and Burli, 2017[3]). **Renewable energy quota** includes any mandatory requirement to produce a certain share of generation from

renewables imposed on power producers as state-mandated obligations or voluntary goals proposed by the state, with or without the option to trade certificates or quotas[5] measured in percentage points of produced electricity output (based on the REQ's yearly obligation or goal) developed by Haščič and colleagues (2015[52]).

47. The misalignment variables are:

- **Fossil fuel subsidies**,
- **Public RD&D spending on fossil fuels,**
- **Public RD&D spending on renewables, and**
- **Implementation of Basel III leverage ratio**.

48. Data on **fossil fuel subsidies** is from the OECD Inventory of Support Measures for Fossil Fuels, and used to calculate the total USD per country year towards electricity power generation including relevant downstream activities such as mining (OECD, 2015[24]). The variable excludes subsidies for knowledge activities, which would include research grants and other R&D subsidies, to avoid overlap with public RD&D on fossil fuels. Estimates of **public RD&D spending on renewables** and **fossil fuels** come from IEA's Database on Detailed RD&D Budgets (IEA, 2017[53]) and is equal to total public RD&D in each country year towards renewables and fossil fuels, respectively, operationalized as % of GDP. Missing values in the RD&D data were imputed using predictive mean matching. Definitions of public RD&D in renewables and fossil fuels can be found in Annex C. **Implementation of Basel III leverage ratio** is a dummy variable indicating whether the country adopted Basel III leverage ratio requirements and uses data from Ang, Röttgers and Burli (2017[54]). The analysis below also tests for Implementation of Basel III liquidity coverage as an alternative to ensure that both of these aspects of constraining capital flows to infrastructure projects are covered.

49. The political economy variables include:

- **Capacity share of state ownership,**
- **Market concentration,**
- **Average age of fossil fuel plants,**
- **Jobs in fossil fuel industries,**
- **Government rents from fossil fuels, and**
- **Public environmental concern.**

50. The **capacity share of state ownership** is the percentage of installed capacity owned by state-owned enterprises from Prag, Röttgers and Scherrer (2018[32]). **Market concentration** is measured using the Herfindahl-Hirschman Index (HHI) of market power from Prag, Röttgers and Scherrer (2018[32]). The index ranges from 0 to 100 where high numbers indicate greater market concentration.[6] Risk of stranded assets is estimated using the **average age of fossil fuel plants** in a country year and calculated using the GW data on: coal (Global coal plant tracker, 2017[39]), oil and gas (Platts WEPP, 2017[40]) (see calculations in Annex C). **Jobs in fossil fuel industries** is the % of the labour force

[5] Voluntary systems without a goal (e.g., subnational voluntary quota pledges in US states) and mandatory measures from non-governmental entities are excluded.

[6] Herfindahl-Hirschman Index (HHI) of market power based on cumulative historic electricity capacity additions in a country collected in UDI's World Electric Power Plant Database. The HHI is constructed based on updated data from UDI (2016) and the calculations and estimations of Benatia and Koźluk (2016), including the estimation of capacity removal, i.e. exit from the market (Prag, Röttgers and Scherrer, 2018[31]).

working in the fossil fuel industry in country year, and estimated using EU KLEMS (Jäger, 2017[48])and WORLD KLEMS (WORLD KLEMS, 2017[49]) databases (see Annex C for further details). Missing values were imputed using predictive mean matching. **Government rents from fossil fuels** are equal to the total amount of fossil fuel rents collected by the government (as % of GDP) from the World Bank database on Natural Resource Rents (World Bank, 2017[55]). **Public environmental concern** aggregates responses on environmental concern questions from different population-based surveys (see Annex C for the list). For example, the Eurobarometer asks: "Please tell me, for the problem of protecting nature and fighting pollution, whether you personally consider it a very important problem (4), important (3), of little importance (2), or not at all important (1)". Survey responses are averaged for each country and year; missing values are imputed using predictive mean matching; and answers are then standardized on a 0 to 1 scale. Higher values indicate changes towards pro-environmentalism while negative indicates a shift away from pro-environmentalism.

3.3. Controls

51. The analysis controls for macroeconomic, institutional, sectoral and financial factors, which could affect decarbonisation.[7] These controls are omitted from the result tables in the forthcoming sections.

- **Macroeconomic factors**: unemployment (% of labour force), real GDP growth, real GDP per capita, and real GDP (World Bank, 2017[56]).
- **Institutional factors**: rule of law (index) and ease of doing business from World Bank database on Measuring Business Regulations (World Bank, 2017[56]).
- **Sectoral factors**: net imports of coal in USD over (UN Comtrade, 2017) electricity consumption (IEA, 2017[51]) , electricity transmission loss (% of output) (World Bank, 2017[56]), the per capita particulate matter concentration (2.5) (), and energy intensity of GDP (IEA, 2017[51]).
- **Financial sector controls:** Sovereign credit rating, interest rate, z-score, Boone indicator.

52. All models include a one year lag of the proportion of fossil fuel capacity to other capacity to control for the possibility of endogeneity between the dependent and independent variables. The models test the effects of policies on decarbonisation; however, it is conceivable that the degree of decarbonisation already achieved, in turn, impacts policies and political economy factors. Hence, a control variable is necessary to hold constant for the effect an existing degree of decarbonisation on policy.

- **Control for endogeneity**: Lagged share of installed fossil fuel capacity over installed non-fossil fuel capacity.

[7] The following variables were tested as controls, but eventually discarded as they did not change results in a meaningful way and might otherwise have caused spurious results if all included: Existence of green banks, wholesale coal price, electricity price, government effectiveness, investment in smart grids, investment in energy storage, electricity access, perpetual inventory of renewable technology patents, patent count for smart grids, patent count for energy storage, patent count for carbon capture and storage, spill over effects of renewable energy patent counts, barrier to entry, carbon intensity of GDP, per capita electricity consumption, and a binary variable for EU ETS participation.

3.4. Estimation strategy

53. This section outlines the estimation strategy for the three models of decarbonisation from 2000 to 2015. It shows the regression equations, explains the specification of models, outlines robustness checks with alternative sets of variables, and discusses alternative model specifications.

54. Since CAPACITY and GENERATION range from 0% to 100%, a Tobit model is most appropriate to analyse the data. To adapt to censoring at 0 and 1, the Tobit model specification sets upper and lower limits at 0 and 1. A handful of OECD members have close to no renewables in installed capacity or generation for a subset of the years of the dataset (see Figure 3.1, 3.2, and 3.3). Therefore, an OLS specification might misestimate the impact of the independent variables: it places no restrictions on the linear relationship between independent variables and the dependent variable. Since this could lead to an impossible negative value and the few very low observations might skew the model in this direction, a Tobit specification with these restrictions is the more reasonable alternative. The Tobit model employed accounts for the panel dataset using a random effects specification (note that fixed effects are not available in Tobit regressions). The regression analysis employs the following model for CAPACITY and GENERATION:

$$= \alpha + \boldsymbol{\beta}_1' \boldsymbol{ClimatePol_{it}} + \boldsymbol{\beta}_2' \boldsymbol{Misalignments_{it}} + \boldsymbol{\beta}_3' \boldsymbol{PolEcon_{it}} + \boldsymbol{\beta}_4' \boldsymbol{Controls_{it}} + (\epsilon_{it} + \gamma_i + \delta_t),$$

with 0 < CAPACITY < 1 and 0 < GENERATION < 1

55. The third model for the decarbonisation of the electricity sector uses EMISSIONS (i.e., tonnes of CO_2e per capita) and employs a fixed effects model accounting for the country and time-fixed effects with the same independent variables as the CAPACITY and GENERATION models. The EMISSIONS model additionally accounts for heteroscedasticity by using robust standard errors[8].

56. Each model underwent robustness checks. The models account for idiosyncrasies of the three different dependent variables using different sets of controls. Variance inflation factors were calculated based on a pooled OLS model to verify that multicollinearity is unproblematic. Further, Annex A compares the Tobit model with the "within fixed-effects" model finding only slight differences.

57. Models originally included interaction effects as specified in Section 2 (marked as X in Table 3.1). These yielded insignificant results and are omitted in the forthcoming section. The unit of analysis, country-year, may be the cause of the insignificance. Perhaps, political economy factors only affect climate policy and policy misalignments over a greater period of time: two or five years. Yet, this is quite challenging to implement since it requires the lag of policies over time, which is cumbersome to analyse for a large number of the independent variables. Moreover, it greatly reduces the number of observations in the dataset.

[8] Note here that in the econometric program employed, robust standard errors were only available for the fixed effects model, but not for the Tobit model. However, a comparison of CAPACITY and GENERATION models using non-Tobit random effects regressions with and without robust standard errors shows that the difference of using robust standard errors is negligible. By transfer, this should also be true for the Tobit results.

58. While it would have been ideal, the model is too complex to test for all possible interactions or use a mediation analysis. Testing all possible interactions former is problematic since it could over-fit the data, which is why the models only tested a select set of theoretically grounded interaction terms. Mediation analysis would have enabled analysing the isolated effects: How much of an effect do political economy factors affect decarbonisation in isolation, and how much of their effects are mediated through climate policy and policy misalignments? However, the number of political economy factors, as well as the number of climate policies and policy misalignments renders this technically infeasible. Moreover, the possible mediation channels among the set of variables would also have been conceptually overwhelming. Therefore, while interaction terms are far from the ideal, it is the best option given the data constraints.

Table 3.1. Interaction terms

		Political Economy Factors			
		Capacity share of state ownership	Average age of fossil fuel plants	Jobs in fossil fuel industries	Government rents from fossil fuels
Climate policies	Explicit carbon price	X		X	X
	Public tender	X		X	X
Misalignments	Public RD&D spending on fossil fuels	X	X	X	
	Public RD&D spending on renewables	X	X	X	
	Implementation of Basel III leverage ratio	X	X		

Note: X represent interaction term between the row and column
Source: Authors' calculations.

4. Results and Interpretation

59. This section presents the empirical results of the models for the decarbonisation of electricity. Results illustrate that climate policies, policy misalignments and political economy factors impact the phases of decarbonisation differently. To enable a comparison between the phases of decarbonisation, the results are presented by category of independent variables: a sub-section for climate policies, policy misalignments, and political economy factors. These **results in Tables 4.2, 4.3, and 4.4 are from the same model**, but split by independent variables to help with interpretation. Please note that these models included the full set of controls outlined Section 3.3; however, these are not reported. Tables in Annex XYZ show the robustness of results to removing either all policy misalignment variables or political economy variables from the model. Table 4.1 presents a simplified overview of results showing the direction and robustness of significant effects, while blank cells identify statistically insignificant effects.

Table 4.1. Overview of results

	CAPACITY	GENERATION	EMISSIONS
Explicit carbon price (USD/tCO2e)			-
Climate policy intention (years left on carbon price)	+	+	
Public tenders (as ratio of newly installed renewable)			
Feed-in tariff (USD/kWh)	+	+	-
Feed-in tariff contract length (years)	+		
Renewable energy quotas (%)	+		
Fossil fuel subsidies relevant to electricity (bn USD)	-	-	
Public RD&D spending on fossil fuels (USD bn)			
Public RD&D spending on renewables (USD bn)			+
Partial implementation Basel III leverage ratio (dummy)	+	+	-
Capacity share of state ownership (incl. foreign)	+		
Market Concentration (HHI)	-	-	
Average age of fossil fuel plants (years)	+		
Government rent from fossil fuel-based activities (% of GDP)			+
Jobs in the fossil fuel industry (% of labour force)	-	-	+
Public concern for environmental issues (unit-less)			

Note: As the independent variable increases, the dependent variable (+) increases or decreases (-). Grey indicates results that are not robust. Note that signs for EMISSION are expected to be opposite than in CAPACITY and GENERATION to show the same direction of effect on decarbonisation.

Source: Authors' calculations.

60. Table 4.1 illustrates that results are consistent with the finding that climate policies are insufficient to decarbonise electricity and reduce emissions. Climate policies significantly impact the share of renewables in capacity and generation, but there is no robust effect on emissions. Likewise, non-climate policies also affect the share of renewables in capacity and generation, but not emissions with the exception of Basel III. This demonstrates that first, it is as important to ensure that the broader policy framework aligns with decarbonisation. Second, misalignments need to be adjusted. Non-climate policies can be as important as climate policy. Lastly, it appears that despite these necessary steps of increasing the share of renewables in capacity and generation, emissions are not reducing, at least not observably.

61. Government rents from fossil fuels and jobs in the fossil fuel industry have a significant and robust effect on emissions. Governments can pay lip service to the green agenda by implementing climate policies, but vested interests are a major impediment to decarbonisation. Governments need to realign their own interests with the low-carbon transition, and adopt structural labour reforms to facilitate a just transition of fossil fuel employees. The effects of each of the policies will be discussed in greater detail below.

4.1. Effects of climate policies on decarbonisation

62. Table 4.2 compares results of climate policy variables for the three phases of decarbonisation models for OECD member countries from 2000 to 2015. Results are interpreted for each variable and across models. Note that for all results presented in Table 4.2 are from the full model. In other words, the results account for the effects of policy misalignments, political economy factors as well as additional control variables.

Table 4.2. Results for climate policies across phases of decarbonisation

	CAPACITY	GENERATION	EMISSIONS
Explicit carbon price (USD/tCO2e)	-0.000	0.001	-0.010*
Climate policy intention (years left on carbon price)	0.001**	0.001***	-0.003
Public tenders (as ratio of newly installed renewable)	0.923	0.726	9.771
Feed-in tariff (USD/kWh)	0.013**	0.028***	-0.098**
Feed-in tariff contract length (years)	0.001**	0.000	-0.007
Renewable energy quotas (%)	0.002***	0.001	-0.003

Note: * 10% significance level or higher; ** 5% significance level or higher; *** 1% significance level or higher. The capacity and generation models are random effects Tobit model with a lower limit at 0 and an upper limit at 1. The emissions model is a fixed-effects least squares model.
Source: Authors' calculations.

63. The effects of climate policies in Table 4.2 are in line with the hypotheses, but show notable differences between phases of decarbonisation. Results show that **explicit carbon prices**, **climate policy intention**, **feed-in tariffs**, the **feed-in tariff contract length** and **renewable energy quotas** have the expected effect on different phases of decarbonisation. Results do not show a statistically significant effect of **public tenders**.

64. Results show the expected negative effect of **explicit carbon price** on **electricity emissions**; however, this result is not robust (see Table A.XYZ in Annex XYZ). The unstable effect of explicit carbon prices could be due to the weak price signal to markets caused by relatively low prices or volatility within years. Using annual averages masks

this volatility. Volatile carbon prices may have the same yearly average as non-volatile ones, but ultimately, send a very different price signal.

65. **Climate policy intentions**, i.e. years left on a given carbon price before revision, increases installed capacity of renewables as well as increases its use in generation. This is likely due to policy predictability and signals a governmental commitment to the low-carbon transition. This, in turn, affects long-term decisions such as investments in new capacity (Fuss et al., 2009[57]). However, there is no observable effect on emissions. The longevity of the carbon price may be insufficient if the carbon price is low and volatile.

66. The **height of the feed-in tariff** affects capacity and generation, while the **length of the feed-in-tariff** only affects capacity illustrating the effectiveness of this policy instrument. This result is stable in the robustness checks with the exception of the effect on emissions (see Table A.XYZ in Annex XYZ). This indicates that a generous subsidy targeting effectiveness over market-efficiency could have a sustainable and far-reaching effect than a policy merely targeting market efficiency. The price-premium above market price, while intended to cover a price gap between renewables cost of electricity and the price in a market dominated by fossil fuels, could also partly have spurred innovation, in turn decreasing renewables cost of electricity. Indeed, evidence on innovation in the renewables sector suggests that among targeted support policies, feed-in tariffs have a particularly strong effect on innovation (Ang, Röttgers and Burli, 2017[3]). Further, it is relevant here that the effect of the amount of the tariff is more than twice as high for generation as it is for capacity. This shows that while it incentivizes building new capacity, it incentivizes using this capacity even more, which is why it has a differentiated effect on building capacity versus using renewables in generation.

67. While the global trend is to lower feed-in tariffs, installation rates still keep soring. FIT results in Table 4.2 do not support the hypothesis of a negative relationship between feed-in-tariffs and shifting to renewables in capacity and generation. Even when observations without any feed-in tariff (i.e. a value of zero) are removed from the capacity regression, results still show a positive sign (regression XYZ in Table A.XYZ).Therefore, even though tariffs are indeed lower, they still function as an incentive. As long as tariffs provide a margin over the market price, they will serve to attract investments. This margin over the market price can be upheld with decreasing installation prices, despite drops in the tariff, resulting in consistently positive effects of feed-in tariffs.

68. Generally, climate policies show statistically significant effects on installed capacity rather than use of renewables in generation or emissions. This might partly be explained by investor decision-making driving the market rather producer decision-making, but also might be partly be due to the translation of generation capacity into actually generated electricity: The capacity factor for renewables electricity plants is generally lower than for other electricity generation plants. Therefore, due to technical reasons, renewables have a greater effect on capacity compared to the generation and emissions.

4.2. Effects of policy misalignments on decarbonisation

69. Table 4.3 compares results of policy misalignment variables from all three decarbonisation models for OECD member countries from 2000 to 2015. Results from Table 4.3 are interpreted for each variable and across models. Note that for all results

presented in table 4.3 the full model was employed, i.e. results account for the effects of climate policies, political economy factors as well as additional control variables.

Table 4.3. Results for policy misalignments across models

	CAPACITY	GENERATION	EMISSIONS
Fossil fuel subsidies relevant to electricity (USD B)	-0.014***	-0.007*	-0.034
Public RD&D spending on fossil fuels (USD 2014 PPP)	-0.001	-0.006	-0.012
Public RD&D spending on renewables (USD 2014 PPP)	-0.005	0.002	0.352*
Partial implementation Basel III leverage ratio (dummy)	0.018**	0.033***	-0.222**

Note: * 10% significance level or higher; ** 5% significance level or higher; *** 1% significance level or higher. The capacity and generation models are random effects Tobit model with a lower limit at 0 and an upper limit at 1. The emissions model is a fixed-effects least squares model.
Source: Authors' calculations.

70. Results on the misalignments of **fossil fuel subsidies relevant to electricity** are in line with the above hypotheses as well as previous research, particularly (OECD/IEA/NEA/ITF, 2015[2]), stating that they act counter to decarbonisation. The effect cannot be shown for the EMISSIONS model, but it stands to reason that the effect subsidies have on generation and especially on installed capacity will lead to lock-in, determining the emissions profile of a country for decades. While the effects of the **implementation of Basel III leverage ratio** and **public RD&D spending on renewables** in the emissions regression are counter to expectations, these results are not robust to the exclusion of political economy factors. Results do not show a statistically significant effect of **public R&D spending on fossil fuels**.

71. Results show that **fossil fuel subsidies relevant to electricity** have a negative effect on the share of renewables installed and shifting towards renewables in generation. The effect on capacity may be due to the longevity and predictably of these fossil fuel subsidies, which then influences the long term investment decisions on power plants. Since these subsidies mainly target mining raw material or the consumption of the final output, it is unsurprising to find an effect on generation. Despite the effect on generation, there is no observable effect on emissions. This could be due to the increasing efficiency of combustion engines, meaning that even if the share of fossil fuels used in generation increases, emissions remain stable.

72. The effect of **public R&D spending on renewables** is counterintuitive; increases in public RD&D spending on renewables increases emissions. This result, however, is not robust (see Table A.XYZ in Annex XYZ).

73. The result on the **partial implementation of the Basel III leverage ratio** shows that the Basel III prudential regulations have a positive impact on decarbonisation, which has to be put in context of the overall effect infrastructure investment, however. Results suggest that Basel III causes relatively more addition and use of renewables capacity and therefore less emissions. Substituting this variable with the **partial implementation of the Basel III liquidity coverage** results in similar evidence (not shown). However, this result should not be taken at face value, as it obscures the fact that Basel III likely has the unintended negative side-effect of constraining infrastructure investments in general. Results here only show that this side-effect is smaller for renewables investments. One explanation for this result could be that the large amounts of debt required for coal power plants are too burdensome on banks' balance sheets under the Basel III rules. Another possible reason could be that renewables are seen as less risky projects for the decades to come. Even though renewable projects are fraught with more technological risk than

established fossil fuel technologies, and therefore are riskier, it is foreseeable that this risk-evaluation will change in the upcoming decades. Solar and wind technologies are maturing and the electricity grid is adapted to their use, while the climate-related policy risks of fossil fuel plants are becoming more apparent. Given this risk-profile of investments, if banks decide to invest in infrastructure at all, they might prefer to take the lower long-term risk if Basel III results adjust for the risk involved. Additional to the risks themselves, the ability to hedge against them could have an influence, too. Currently at least it is easily possible to hedge against technical risk, but not so to hedge against climate-related risks. This hedging situation could also cause Basel III to push investments in the direction of renewables.

4.3. Effects of political economy factors on decarbonisation

74. Table 4.4 displays results of political economy factors from all three decarbonisation models for OECD member countries from 2000 to 2015. As for Table 4.2 and 4.3, results are interpreted for each variable across models. Note that for all results presented in Table 4.4 the full model was employed, meaning climate policies, policy misalignments as well as additional control variables are included only not displayed in Table 4.4.

Table 4.4. Results for political economy factors across models

	CAPACITY	GENERATION	EMISSIONS
Capacity share of state ownership (incl. foreign)	0.098***	0.028	0.227
Market Concentration (HHI)	-0.003***	-0.002***	0.000
Government rent from fossil fuel-based activities (% of GDP)	-0.006	-0.004	0.314***
Average age of fossil fuel plants (years)	0.003***	0.002	-0.016
Jobs in the fossil fuel industry (% of labour force)	-1.034***	-0.994***	30.119***
Public concern for environmental issues (unitless)	-0.001	-0.004	-0.001

Note: * 10% significance level or higher; ** 5% significance level or higher; *** 1% significance level or higher. The capacity and generation models are random effects Tobit model with a lower limit at 0 and an upper limit at 1. The emissions model is a fixed-effects least squares model.
Source: Authors' calculations.

75. The effects of political economy factors in Table 4.4 are in line with the hypotheses as well as previous research. Results show that **capacity share of state ownership**, **market concentration**, **government rent in from fossil fuel-based activity**, **average age of fossil fuel plants**, and **jobs in the fossil fuel industry** have the hypothesized impact in at least one if not all models. **Public concern for environmental issues** cannot be shown to have a direct impact in any model.

76. The greater the **share of installed capacity owned by the state,** the greater decarbonisation of installed capacity. This substantiates Prag, Röttgers and Scherrer (2018[32]), who argue states channel a green agenda through SOE business decisions.[9]

[9] Tests show market concentration and capacity share of state-ownership do not suffer from multicollinearity.

This can lead to preferential financing for green projects, for example. The effect of state ownership is independent of **market concentration** in the electricity sector, which impedes the decarbonisation of installed capacity and generation. It is hard for newcomers to establish their business in markets with high concentration. Since renewable energy firms are typically newcomers, the renewables sector is systematically affected.

77. **Government rents from fossil fuels** significantly affect emissions but show no observable effect on generation or capacity. Governments may acquire rents from increasingly carbon-intensive sources, raising emissions even though the actual proportion of fossil fuel capacity and generation remains the same.

78. The results on the **average age of fossil fuel plants** highlight the need for careful management of stranded assets. Countries with older fossil fuel plants have a higher share of renewables in installed capacity on average. Conversely, younger fossil fuel fleets are harder to retire and replace with renewable capacity. This result is an affirmation of the "Tragedy of the Horizon" narrative (Carney, 2015[58]), which warns of the financial exposure of companies to the climate change, including exposure to a rapid transition to a low-carbon economy. Companies holding young fossil-fuel dependent assets might find these assets stranded in a mitigation-friendly policy environment. To limit this exposure, Carney (2015) suggests a more responsible handling of investments, which includes the prevention of stranded assets by avoiding unpredictable changes and acting in time so markets can adjust. Companies holding assets in the electricity sector could adjust their investments accordingly to reduce their exposure to changing climate policies by a reevaluation of assets. Otherwise, companies might invest in building or maintaining assets with false assumptions about their runtime or profitability.

79. Results also show that the share of a country's **jobs in the fossil fuel industry** has a negative effect on all measures of decarbonisation in the expected directions. The prospect of generating unemployment is a strong deterrent for governments to closing carbon-intensive plants. This result shows that the potential loss of fossil fuel jobs affects decarbonisation, even when accounting for the overall rate of unemployment in a country. The implementation of measures to accompany the labour market through the transition of the energy sector could facilitate the public acceptability of decarbonisation. Regarding the interpretation of the coefficients, it is important to note that while the maximum of the variable is 0.15, accounting for values of the outlier country reduces the maximum to 0.015. Accordingly, while the coefficients might seem large in comparison to the maxima of the dependent variables, a change of 1 percentage point change would only cause a change of 0.01 times the size of the coefficient, which is reasonable. Models omitting outliers showed virtually the same results. Further, as jobs in the fossil fuel industry are closely related to the dependent variables results were tested with stronger endogeneity controls. For example, even when controlling for the current ratio of fossil fuel capacity to renewables capacity, i.e. a variable controlling for the relative abundance of current employment opportunities to opportunities in the renewables sector, the effect holds.

5. Conclusions

80. The aim of this working paper is to better understand how a selected set of climate policies, policy misalignments as well as political economy factors affect the decarbonisation of electricity in OECD members from 2000 to 2015. Results confirm the finding that climate policies are insufficient to decarbonise electricity in isolation. Policymakers need to review the broader policy environment to understand how this is enabling or impeding decarbonisation. It is futile to implement climate policies if non-climate policies continue to foster the usage of fossil fuels. The results also show that climate and non-climate policies significantly affect the share of renewables in capacity and generation; but there is no observable robust effect on emissions. In contrast, political economy factors, in particular stakeholders' underlying interests, are a significant and robust determinant of emissions in addition to the share of renewables in generation and capacity. Government rents from fossil fuels and employment in the fossil fuel industry impede decarbonisation is a major impediment to decarbonising electricity. Governments must concentrate on how to meet these needs and decarbonise electricity.

81. Governments must anticipate the social and economic consequences of the decarbonisation (i.e., loss of jobs). Low-skilled or aged workers displaced from these fossil fuel intensive industries could face particular difficulties reintegrating into employment, because these workers tend to experience larger post-displacement difficulties. These workers also tend to live in remote areas where there are few alternative opportunities for employment (OECD, 2012[59]). With this said, there is great diversity in the employment in "brown" sectors. The workforce in the carbon-intensive electricity sectors includes high-skilled and low-skilled workers. Therefore, there is a need avoid a one-size-fits-all approach for labour market policy (OECD, 2012[59]).

82. Failure to implement structural policy reforms for a just transition (e.g., retraining workers from carbon-intensive industries) will ultimately slow down decarbonisation. OECD (2012[59]) work finds that employers and trade unions within the energy sector may also play a key role to transition fossil fuel employees. Preliminary investigations suggest that a significant share of the conversion of the electricity sector from fossil fuels to renewable sources is occurring within large electrical utilities, a number of which are actively retraining their workforces as part of their implementation of a transition to clean energy (OECD, 2012[59]).

References

Acemoglu, D. et al. (2010), "The Environment and Directed Technical Change", http://hassler-j.iies.su.se/courses/climate/ACEMOGLUetAl2010.pdf (accessed on 16 November 2017). [12]

Agnone, J. (2007), "Amplifying Public Opinion: The Policy Impact of the U.S. Environmental Movement", *Social Forces*, Vol. 4, https://watermark.silverchair.com/85-4-1593.pdf?token=AQECAHi208BE49Ooan9kkhW_Ercy7Dm3ZL_9Cf3qfKAc485ysgAAAawwggGoBgkqhkiG9w0BBwagggGZMIIBlQIBADCCAY4GCSqGSIb3DQEHATAeBglghkgBZQMEAS4wEQQMqpaMGWJ1EzAbaqhfAgEQgIIBX0puWlbXfO74JDJ415B3XzbKxTH2S9ddPgcYGpo14SNqY (accessed on 23 November 2017). [70]

Anderson, B., T. Böhmelt and H. Ward (2017), "Public opinion and environmental policy output: a cross-national analysis of energy policies in Europe", *Environmental Research Letters*, Vol. 12, https://doi.org/10.1088/1748-9326/aa8f80. [69]

Ang, G., D. Röttgers and P. Burli (2017), "The empirics of enabling investment and innovation in renewable energy", *OECD Environment Working Papers*, No. 123, OECD Publishing, Paris, http://dx.doi.org/10.1787/67d221b8-en. [3]

Ang, G., D. Röttgers and P. Burli (2017), "The empirics of enabling investment and innovation in renewable energy", *OECD Environment Working Papers*, No. 123, OECD Publishing, Paris, http://dx.doi.org/10.1787/67d221b8-en. [54]

Baron, P. and D. Fischer (2015), *Divestment and Stranded Assets in the Low-carbon Transition*, OECD , Paris, https://www.oecd.org/sd-roundtable/papersandpublications/Divestment%20and%20Stranded%20Assets%20in%20the%20Low-carbon%20Economy%2032nd%20OECD%20RTSD.pdf (accessed on 12 December 2017). [37]

Baumgartner, F. et al. (2009), *Lobbying and Policy Change: Who Wins, Who Loses, and Why.*, Chicago University Press, Chicago, http://dx.doi.org/doi:10.1017/S0022381610000691. [34]

Bruckner, T. et al. (2014), "ANNEX III: Technology-specific Cost and Performance Parameters Lead Authors: Technology-specific Cost and Performance Parameters Annex III", in *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* , Cambridge University, https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_annex-iii.pdf (accessed on 20 November 2017). [65]

Bruckner, T. et al. (2015), "III ANNEX Technology-specific Cost and Performance Parameters Lead Authors: Technology-specific Cost and Performance Parameters Annex III", https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_annex-iii.pdf (accessed on 16 January 2018). [74]

Brulle, R. et al. (2002), "Shifting public opinion on climate change: an empirical assessment of factors influencing concern over climate change in the", *Climatic Change*, Vol. 114, pp. 169-188, [68] http://dx.doi.org/10.1007/s10584-012-0403-y.

Cárdenas Rodríguez, M. et al. (2015), "Renewable Energy Policies and Private Sector Investment: Evidence from Financial Microdata", *Environ Resource Economics*, Vol. 62/62, pp. 163-188, http://dx.doi.org/10.1007/s10640-014-9820-x. [5]

Carley, S. (2009), "State renewable energy electricity policies: An empirical evaluation of effectiveness", http://dx.doi.org/10.1016/j.enpol.2009.03.062. [15]

Carney, M. (2015), *Speech: Breaking the tragedy of the horizon – climate change and financial stability*, https://www.bis.org/review/r151009a.pdf (accessed on 12 December 2017). [58]

Choi, J., B. Bakshi and T. Haab (2010), "Effects of a carbon price in the U.S. on economic sectors, resource use, and emissions: An input–output approach", *Energy Policy*, Vol. 38, pp. 3527-3536, http://dx.doi.org/10.1016/j.enpol.2010.02.029. [7]

Delmas, M. and M. Montes-Sancho (2011), "U.S. state policies for renewable energy: Context and effectiveness", *Energy Policy*, Vol. 39, pp. 2273-2288, http://dx.doi.org/10.1016/j.enpol.2011.01.034. [16]

DOE (2017), *U.S. Energy and Employment Report*, U.S. Department of Energy, Washington D.C., https://energy.gov/sites/prod/files/2017/01/f34/2017%20US%20Energy%20and%20Jobs%20Report_0.pdf (accessed on 06 December 2017). [45]

Dolšak, N. and A. Prakash (2016), "We feel your pain: Environmentalists, Coal miners, and "embedded environmentalism"", *Solutions* , Vol. 7/1, https://www.researchgate.net/profile/Aseem_Prakash/publication/286779959_We_feel_your_pain_Environmentalists_Coal_miners_and_embedded_environmentalism/links/566dee5a08aea0892c528ef8/We-feel-your-pain-Environmentalists-Coal-miners-and-embedded-environmenta (accessed on 06 December 2017). [43]

Dunlap, R. and R. Brulle (eds.) (2015), *Climate Change and Society: Sociological Perspectives*, Oxford University Press. [67]

Fankhauser, S., F. Sehlleier and N. Stern (2008), "Climate change, innovation and jobs", *CLIMATE POLICY*, Vol. 8, pp. 421-429, http://dx.doi.org/10.3763/cpol.2008.0513. [41]

Fischer, C. (2008), "Emissions pricing, spillovers, and public investment in environmentally friendly technologies", *Energy Economics* , Vol. Energy Economics /30, http://dx.doi.org/10.1016/j.eneco.2007.06.001. [11]

FSB/IMF/WB (2012), *Identifying the Effects of Regulatory Reforms on Emerging Market and Developing Economies: A Review of Potential Unintended Consequences*, Financial Stability Board, http://www.fsb.org/wp-content/uploads/r_120619e.pdf (accessed on 23 November 2017). [31]

Fuss, S. et al. (2009), "Impact of climate policy uncertainty on the adoption of electricity generating technologies", *Energy Policy*, Vol. 37/2, pp. 733-743, http://dx.doi.org/10.1016/J.ENPOL.2008.10.022. [57]

Garrett-Peltier, H. (2017), "Green versus brown: Comparing the employment impacts of energy efficiency, renewable energy, and fossil fuels using an input-output model", *Economic Modelling*, Vol. 61, http://dx.doi.org/10.1016/j.econmod.2016.11.012. [46]

Global coal plant tracker (2017), "Global coal plant tracker database", http://endcoal.org/tracker/. [60]

Global coal plant tracker (2017), "Global coal plant tracker database", http://endcoal.org/tracker/. [39]

Global Coal Tracker (2017), *Global Coal Tracker Database*. [75]

Gullberg, A. (2008), “Rational lobbying and EU climate policy”, *International Environmental Agreements: Politics, Law and Economics*, Vol. 8/2, pp. 161-178, http://dx.doi.org/10.1007/s10784-008-9067-5. [36]

Haščič, I. and M. Migotto (2015), “Measuring environmental innovation using patent data”, *OECD Environment Working Papers*, No. 89, OECD Publishing, Paris, http://dx.doi.org/10.1787/5js009kf48xw-en. [52]

IAEA (2017), “Power Reactor Information System, International Atomic Energy Agency”. [62]

IAEA (2017), *Nuclear Power Plant Information*. [76]

IAEA (2017), “Power Reactor Information System, International Atomic Energy Agency”. [50]

IEA (2014), *World Energy Outlook 2014*, IEA, Paris, http://www.oecd-ilibrary.org/docserver/download/6114031e.pdf?expires=1513085483&id=id&accname=ocid84004878&checksum=B4BDB05925243114ABDD1C2EDC75B097 (accessed on 12 December 2017). [38]

IEA (2017), *Renewables 2017: Analysis and Forecasts to 2022*, IEA, Paris, http://dx.doi.org/10.1787/re_mar-2017-en. [63]

IEA (2017), *Energy Technology and RD and D Budgets: Database Documentation*, IEA, Paris, http://wds.iea.org/wds/pdf/RDD_Documentation.pdf (accessed on 01 December 2017). [73]

IEA (2017), *RD&D Online Data Service*, http://www.iea.org/statistics/RDDonlinedataservice/ (accessed on 16 January 2018). [53]

IEA (2017), *IEA Statistics*, https://www.iea.org/statistics/. [78]

IEA (2017), *World Energy Balances*, http://dotstat.oecd.org/?lang=en (accessed on 13 December 2017). [51]

IRENA (2017), *Accelerating the Energy Transition through Innovation About IRENA*, IRENA. [4]

Jäger, K. (2017), *EU KLEMS Growth and Productivity Accounts 2017 Release, Statistical Module*, European Commission, http://www.euklems.net/TCB/2017/Metholology_EU%20KLEMS_2017.pdf (accessed on 18 April 2018). [48]

Jenner, S., F. Groba and J. Indvik (2013), “Assessing the strength and effectiveness of renewable electricity feed-in tariffs in European Union countries”, *Energy Policy*, Vol. 52, pp. 385-401, http://dx.doi.org/10.1016/j.enpol.2012.09.046. [14]

Johnstone, N. et al. (2010), “Renewable Energy Policies and Technological Innovation: Evidence Based on Patent Counts”, *Environmental Resource Economics*, Vol. 45, pp. 133-155, http://dx.doi.org/10.1007/s10640-009-9309-1. [22]

Martinez-Fernandez, C., C. Hinojosa and G. Miranda (2010), “Green jobs and skills: the local labour market implications of addressing climate change”, *CFE/LEED*, OECD, Paris, http://www.oecd.org/dataoecd/54/43/44683169.pdf?conte (accessed on 06 December 2017). [42]

Martin, R., M. Muûls and U. Wagner (2011), *Climate Change, Investment and Carbon Markets and Prices – Evidence from Manager Interviews Carbon Pricing for Low-Carbon Investment Project* [10]

Evidence from Manager Interviews Carbon Pricing for Low-Carbon Investment Project, Climate Policy Initiative, https://s3.amazonaws.com/academia.edu.documents/30697541/Climate-Change-Investment-and-Carbon-Markets-and-Prices.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1510916098&Signature=Zk1WNsqUYpD7l1INmR9hoIzv6ao%3D&response-content-disposition=inline%3B%20f (accessed on 17 November 2017).

Menz, F. and S. Vachon (2006), "The effectiveness of different policy regimes for promoting wind power: Experiences from the states", *Energy Policy*, Vol. 34, pp. 1786-1796, http://dx.doi.org/10.1016/j.enpol.2004.12.018. [13]

Michaelowa, A. (1998), "Impact of interest groups on EU climate policy", *European Environment*, Vol. 8/5, pp. 152-160, http://dx.doi.org/10.1002/(SICI)1099-0976(1998090)8:5<152::AID-EET165>3.0.CO;2-A. [35]

Neuhoff, K. (2005), "Large-scale deployment of renewables for electricity generation", *Oxford Review of Economic Policy*, Vol. 21/1, http://dx.doi.org/10.1093/oxrep/gri005. [30]

Newcomer, A. et al. (2008), "Policy Analysis Short Run Effects of a Price on Carbon Dioxide Emissions from U.S. Electric Generators", *Environmental Science and Technology*, http://dx.doi.org/10.1021/es071749d. [6]

Nio, A. et al. (2010), "Motivations driving renewable energy in European countries: A panel data approach", *Energy Policy*, Vol. 38, http://dx.doi.org/10.1016/j.enpol.2010.07.003. [17]

OECD/IEA/NEA/ITF (2015), *Aligning Policies for a Low-carbon Economy*, http://www.oecd-ilibrary.org/docserver/download/0315021e.pdf?expires=1510835480&id=id&accname=ocid84004878&checksum=CAF8D360F2C9DCED4002CAE73DD7F463 (accessed on 16 November 2017). [2]

OECD (2005), *Environmentally Harmful Subsidies: Challenges for Reform*, OECD, http://www.sourceoecd.org/agriculture/9264012044. [23]

OECD (2012), *The jobs potential of a shift towards a low-carbon economy*, OECD, http://www.oecd.org/els/emp/50503551.pdf (accessed on 20 April 2018). [59]

OECD (2015), *OECD Companion to the Inventory of Support Measures for Fossil Fuels 2015*, OECD, Paris, http://www.oecd-ilibrary.org/docserver/download/2215011e.pdf?expires=1512121908&id=id&accname=ocid84004878&checksum=FEE13AA93E43CB8EE689830C37282772 (accessed on 01 December 2017). [24]

OECD (2016), *State-Owned Enterprises as Global Competitors: A Challenge or an Opportunity?*, OECD, Paris, http://www.oecd-ilibrary.org/docserver/download/2616021e.pdf?expires=1512563617&id=id&accname=ocid84004878&checksum=589F1F15461CD6BC671B3D91BD7CD387 (accessed on 06 December 2017). [33]

OECD (2017), *Investing in Climate, Investing in Growth*, OECD Publishing, http://www.oecd-ilibrary.org/docserver/download/9717061e.pdf?expires=1511263658&id=id&accname=guest&checksum=1A7E03B32D7079B807ECEF0BCAC610E9 (accessed on 21 November 2017). [1]

Olson, M. (1971), *The logic of collective action; public goods and the theory of groups.*, Harvard University Press. [44]

Ouyang, X. and B. Lin (2014), "Impacts of increasing renewable energy subsidies and phasing out fossil fuel subsidies in China", *Renewable and Sustainable Energy Reviews*, Vol. 37, pp. 933-942, http://dx.doi.org/10.1016/j.rser.2014.05.013. [26]

Platts WEPP (2017), “World Electric Power Plants Database”, http://www.platts.com/products/worldelectric-power-plants-database. [61]

Platts WEPP (2017), “World Electric Power Plants Database”, http://www.platts.com/products/worldelectric-power-plants-database. [40]

Polzin, F. et al. (2015), “Public policy influence on renewable energy investments—A panel data study across OECD countries”, *Energy Policy*, Vol. 80, pp. 98-111, http://dx.doi.org/10.1016/j.enpol.2015.01.026. [21]

Prag, A., D. Röttgers and I. Scherrer (2017), “State-Owned Enterprises and the Low-Carbon Transition”, *Environment Working Paper*, OECD, Paris. [79]

Prag, A., D. Röttgers and I. Scherrer (2018), “State-Owned Enterprises and the Low-Carbon Transition”, *OECD Environment Working Paper Series*, No. XXX, OECD. [32]

Rao, K. and V. Kishore (2010), “A review of technology diffusion models with special reference to renewable energy technologies”, *Renewable and Sustainable Energy Reviews*, Vol. 14, pp. 1070-1078, http://dx.doi.org/10.1016/j.rser.2009.11.007. [29]

Rentschler, J. and M. Bazilian (2016), “Reforming fossil fuel subsidies: drivers, barriers and the state of progress”, *Climate Policy* , Vol. 17/7, http://dx.doi.org/10.1080/14693062.2016.1169393. [27]

Riedy, C. and M. Diesendorf (2003), “Financial subsidies to the Australian fossil fuel industry”, *Energy Policy*, Vol. 31, https://ac.els-cdn.com/S0301421502000174/1-s2.0-S0301421502000174-main.pdf?_tid=9c658862-ce0b-11e7-a982-00000aab0f26&acdnat=1511193681_1b579b3aa0ed6e7d711d9c53ea6ca944 (accessed on 20 November 2017), pp. 125-137. [25]

Shrimali, G. and J. Kniefel (2011), “Are government policies effective in promoting deployment of renewable electricity resources?”, *Energy Policy*, Vol. 39, pp. 4726-4741, http://dx.doi.org/10.1016/j.enpol.2011.06.055. [18]

Shum, R. (2009), “Can Attitudes Predict Outcomes? Public Opinion, Democratic Institutions and Environmental Policy”, *Environmental Policy and Governance*, Vol. 19, http://dx.doi.org/DOI: 10.1002/eet.518. [71]

Tietenberg, T. (2013), “Reflections—Carbon Pricing in Practice”, *Review of Environmental Economics and Policy*, Vol. 7/2, pp. 313-329, http://dx.doi.org/10.1093/reep/ret008. [9]

Tingley, C. et al. (2014), “mediation: R package for causal mediation analysis Terms of Use mediation: R Package for Causal Mediation Analysis”, *Journal of Statistical Software JSS Journal of Statistical Software*, Vol. 59/5, http://www.jstatsoft.org/v59/i05. [72]

Toke, D. (2005), “Are green electricity certificates the way forward for renewable energy? An evaluation of the United Kingdom's Renewables Obligation in the context of international comparisons”, *Environment and Planning C: Government and Policy*, Vol. 23, http://dx.doi.org/10.1068/c0414j. [20]

Tullock, G. (1989), *The Economics of Special Privilege and Rent Seeking*, Kluwer Academic Publishers. [66]

UDI Platts (2017), *World Electric Power Plants Database*. [77]

Weigt, H., D. Ellerman and E. Delarue (2013), “CO2 abatement from renewables in the German electricity sector: Does a CO 2 price help?”, *Energy Economics*, Vol. 40, pp. S149-S158, http://dx.doi.org/10.1016/j.eneco.2013.09.013. [8]

Whitley, S. and L. Van Der Burg (2015), “Fossil Fuel Subsidy Reform: From Rhetoric to Reality”, New Climate Ecpmp,u, http://newclimateeconomy.report/2015/wp-content/uploads/sites/3/2015/11/Fossil-fuel-subsidy-reform_from-rhetoric-to-reality.pdf (accessed on 18 April 2018). [28]

World Bank (2017), *World Development Indicators | Data*, https://data.worldbank.org/data-catalog/world-development-indicators (accessed on 13 December 2017). [56]

World Bank (2017), *Total natural resource rents (% of GDP)*, World Bank, https://data.worldbank.org/indicator/NY.GDP.TOTL.RT.ZS. [55]

WORLD KLEMS (2017), *WORLD KLEMS*, http://www.worldklems.net/data.htm. [49]

World Nuclear Association((n.d.)), “Comparison of Lifecycle Greenhouse Gas Emissions of Various Electricity Generation Sources”, http://www.world-nuclear.org/uploadedFiles/org/WNA/Publications/Working_Group_Reports/comparison_of_lifecycle.pdf (accessed on 17 November 2017). [64]

Yi, H. (2013), “Clean energy policies and green jobs: An evaluation of green jobs in U.S. metropolitan areas”, *Energy Policy*, Vol. 56, pp. 644-652, http://dx.doi.org/10.1016/j.enpol.2013.01.034. [47]

Yin, H. and N. Powers (2009), “Do state renewable portfolio standards promote in-state renewable generation<”, *Energy Policy*, Vol. 38, pp. 1140-1149, http://dx.doi.org/10.1016/j.enpol.2009.10.067. [19]

Annex A. Robustness checks

Table A A.1. Determinants of the change in the rate of renewable electricity in the power sector in OECD members

	Capacity rate without political economy	Capacity rate without misalignments	Generation rate without political economy	Generation rate without misalignments	Emissions rate without political economy	Emissions rate without misalignments
Constant	0.016	0.033	0.368**	0.246	0.107	0.246
Explicit carbon price (USD/tCO2e)	0.000	0.000	0.001***	0.001	-0.000	0.001
Renewable energy quotas (%)	0.001***	0.001**	0.002	-0.001	-0.007	-0.001
Feed-in tariff (USD/kWh, weighted with power purchasing agreement-duration)	0.000	0.000	-0.002**	-0.003***	0.000	-0.003***
Public tender (MW)	0.000	-0.000	-0.000	-0.000***	-0.000***	-0.000***
Climate policy intention (years left on target)	0.000	0.000	0.002*	0.002*	-0.001	0.002*
Support to fossil fuels (USD)	-0.000		-0.000		0.000	
Public RD&D spending on renewables (% of GDP)	-0.003		-0.036		0.347	
Partial implementation Basel III leverage ratio (dummy)	-0.002		-0.032		-0.063	
Capacity share of state ownership (incl. foreign)		0.011		-0.004		-0.004
Market Concentration (HHI)		-0.001**		-0.003**		-0.003**

Government rent from fossil fuel-based activities (% of GDP)		-0.000		-0.001		-0.001
Average age of fossil fuel plants (years)		0.000		0.009***		0.009***
Jobs in the fossil fuel industry (% of labour force)		-0.038		-0.923**		-0.923**
Public concern for environmental issues (unitless)		0.001		-0.002		-0.002
Observations	349	299	349	299	349	299

Note: * signifies statistical significance at the 10% significance level or higher; ** signifies statistical significance at the 5% significance level or higher; *** signifies statistical significance at the 1% significance level or higher; the model is a OLS fixed effects model. Results for control variables listed in Section 3.3 are not shown here.
Source: Authors

Annex B. Summary Table of Variables

83. Table A B.1 shows the summary values of all variables used in regressions models. It also includes those variables that were tested but discarded since they did not add value to the model.

Table A B.1. Summary table

	Observations	Mean	Minimum	Maximum
Explicit carbon price (USD/tCO2e)	734	3.98	0.0	72
Renewable energy quotas (%)	734	1.03	0.0	21
Feed-in tariff (USD/kWh, weighted with power purchasing agreement-duration)	735	2.14	0.0	15
Public tender (MW)	735	41.10	0.0	3000
Energy taxation in the power sector (USD/MWh)	735	4.45	0.0	108
Climate policy intention (years left on target)	705	3.41	0.0	42
Support to fossil fuels (USD)	432	171718.29	0.0	2490253
Public RD&D spending on renewables (% of GDP)	432	0.11	0.0	1
Partial implementation Basel III leverage ratio (dummy)	735	0.01	0.0	1
Capacity share of state ownership (incl. foreign)	735	0.49	0.0	1
Market Concentration (HHI)	735	39.59	2.1	100
Government rent from fossil fuel-based activities (% of GDP)	735	2.19	0.0	56
Average age of fossil fuel plants (years)	735	21.08	0.8	46
Jobs in the fossil fuel industry (% of labour force)	472	0.01	0.0	0
Public concern for environmental issues (unitless)	564	0.05	-2.1	3
Sovereign credit rating (ranks)	735	7.28	1.0	9
Presence of a green bank (binary)	735	0.02	0.0	1
Interest rate (%)	670	4.45	-18.3	49
Coal price index (unitless)	735	85.77	30.2	150
Average electricity price (index)	735	92.97	45.8	136
Stability of financial institutions	734	16.66	-7.9	74
Banking competitiveness (Boone indicator)	734	-0.04	-2.1	6

Quality and independence of government service	735	1.02	-0.8	2
Credit to government and SOEs (percent of GDP)	734	13.81	0.0	73
Domestic credit to private sector (% of GDP)	734	95.18	7.1	311
GDP (USD)	726	926.75	5.6	14797
Real GDP growth (%)	670	0.03	-0.6	2
Unemployment rate (%)	705	8.34	1.9	27
GDP per capita (USD)	726	24.43	0.6	86
Ease of doing business (index)	735	79.71	16.8	100
Rule of law (index)	735	0.91	-1.1	2
Barriers to services (index)	705	3.37	0.9	6
Net imports of coal/electricity production (kg/GWh)	735	-8287041.26	-2.0e+09	1.08e+09
Electricity generation capacity (MW)	735	266.20	146.2	2900
Energy intensity of GDP (toe/USD)	726	0.00	0.0	0
Electricity transmission loss (% of output)	735	8.45	-1.2	28
Proportion fossil fuel capacity to other capacityt-1	666	157.88	0.0	30451
Coal price index (unitless)	735	85.77	30.2	150
Tertiary education	735	27.28	0.0	102
Infrastructure assets in ICT and transport (index)	735	0.38	0.1	1
Access to electricity (% of population)	720	98.44	62.3	106
Renewables over fossil fuel (%; electricity generation capacity)	720	4.96	0.0	187
Perpetual inventory of renewable power-related patents	735	777.11	0.0	16256
Country spillover of patenting (patents)	731	43.27	0.0	3780
Barriers to entry (index)	705	1.20	0.0	4
Carbon intensity of energy (kton CO2/ktoe TPES)	735	9.25	0.0	588
Electricity consumption per capita	735	7.32	0.4	55
Infrastructure assets in ICT and transport (index)	735	0.38	0.1	1
Electricity generation (GWh)	735	343.81	0.4	5533
EU ETS participant (dummy)	735	0.37	0.0	1
Administrative Burden (index)	705	2.06	0.0	6

Source: Author's calculations

Annex C. Notes on Data

CAPACITY (GWs)

84. Different data sources specialise in specific technologies. Data from the data sources in Table A C.1 have been merged to ensure the best possible coverage per technology.

Table A C.1. Construction of the GW data

Technology	Source	Date of reference	Level of data disaggregation
Coal	(Global coal plant tracker, 2017[60])	July 2017	Power plant
Oil	(Platts WEPP, 2017[61])	March 2017	Power plant
Gas	(Platts WEPP, 2017[61])	March 2017	Power plant
Nuclear	(IAEA, 2017[62])	May 2017	Power plant
Renewables	(IEA, 2017[63])	October 2017	Country level

Source: Authors

85. The level of disaggregation of data varies between sources. The unit is at the plant level in GCT, Platts and IAEA (i.e., one row in the database is a power plant); while IEA data on renewables is aggregated at the country-level per year (i.e., a row refers to the GWs in operation in a specific country in a specific year).

86. Time series are available from 2000 to 2015 for renewable installed capacity in operation at the country level. Plants are labelled as: planned, under construction, in operation, or decommissioned for coal, oil, and gas. Plants "in operation" refer to plants in operation in 2017.

87. Using the information on the status of the plant, together with the date in which the power plant was built or retired, it is possible to retroactively construct a time series of generation capacity in operation from 2000 to 2017. Whenever information on the built or retired date was missing, dates were estimated. The following steps are carried out:

(1) Estimates of missing dates

88. For gas and oil, a large part of the sample missed retirement dates (see table below). Therefore, the decommissioning data is estimated using the average lifetime per technology and per country (Table A C.2)

Table A C.2. Share of generation capacity data with built and retired dates

	In operation with date built	Retired with both dates
Coal	100%	95%
Gas	99%	55%
Oil	97%	58%
Nuclear	100%	99%

Source: Authors

(2) Construction of time series

89. Using built and retirement dates for each plant, it is possible to reconstruct a time series from 2000 to 2017, as follows:

$$\boldsymbol{Plants\ in\ operation\ in\ year_i} = \\ plants\ in\ operation\ in\ 2017\ built\ after\ or\ at\ year_i + \\ plants\ marked\ decommissioned\ \ in\ 2017, but\ decommissioned\ after\ year_i$$

GENERATION (GWh)

90. The electricity output (GWh) is based on the IEA World Energy Balances database. Data are available for all technologies per country from 2000 to 2015.

EMISSIONS (Tonnes of CO2e)

91. The CO2e emissions are estimated based on the IPCC lifecycle assessment estimates per unit of electricity output per technology (t) (Table A C.3), as follows:

$$EMISSIONS_{iqy} = \sum_{q=1} LCA_q \times GWh_{qiy}$$

Where LCA represents the estimated life cycle emissions from technology *q* multiplied by the GWh of technology *q* in country *i* in year *y*

Table A C.3. LCA Estimates from IPCC (tCO_2eq/GWh)

Technology	Median	Min	Max
Coal - PC	820	740	910
Gas-Combined Cycle	490	410	650
Biomass – co-firing	740	620	890
Biomass - dedicated	230	130	420
Geothermal	38	6	79
Hydropower	24	1	2200
Nuclear	12	3.7	110
Concentrated solar power	27	8.8	63
Solar PV - rooftop	41	26	60
Solar PV - utility	48	18	180
Wind onshore	11	7	56
Wind offshore	12	8	35
Ocean	17	5.6	28
Oil	733	547	935

Note: The IPCC does not include an estimate for oil's life cycle emissions. The estimates in the table are taken from the World Nuclear Association. Since oil accounts for only a small portion of electricity generation, this should not have a major impact on results.
Source: IPCC (Bruckner et al., 2014[49]), (World Nuclear Association,(n.d.)[64])

92. The level of disaggregation presented in table C.3 did not match the disaggregation of the electricity output (GWh) data. The median of the sub-technology estimates were used as described in Table A C.4.

Table A C.4. LCA Estimates from IPCC (tCO2eq/GWh)

	Median	Min	Max
Coal	820	740	910
Oil	733	547	935
Gas	490	410	650
Solar	38.66667	17.6	101
Bioenergy	485	375	655
Nuclear	12	3.7	110
Hydro[10]	24	1	2200
Wind	11.5	7.5	45.5
Geothermal	38	6	79
Marine	17	5.6	28

Source: Author's calculation based on IPCC (Bruckner et al., 2014[65])

Age of fleet

93. The age of fleet for the period 2000 to 2017 was estimated for coal, oil, gas and nuclear, which are the technologies for which data are available at the power plant level (see Table C.1).

94. Starting from the time series of generation capacity - estimated as explained in section "Capacity (GWs)" above - a weighted average is used to calculate the age of the fleet per country (c) and technology (t):

$$\frac{\sum_{c,t,i} Age_{\ i} * MW_i}{\sum_{c,t,i} MWi}$$

Where i= power plants in country c and technology t.

Fossil fuel jobs

95. The EU KLEMS and WORLD KLEMS database includes indicators on economic growth, productivity, employment creation, capital formation and technological change at the industry level for varying countries from 1970 until 2015.

96. The EU KLEMS database includes: Austria, Belgium, Bulgaria, Croatia, Cyprus[11], Czech Republic, Denmark, Estonia, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and United Kingdom. The World KLEMS database includes: Japan, Canada, Russia, China, Korea, India, and United States.

97. Data for Australia, Iceland, Israel, Mexico, Norway, New Zealand, Sweden, and Turkey is missing.

98. EU KLEMS and World KLEMS include the indicator, the number of persons engaged (in thousands), by industry. We coded the following industries as related to the fossil fuel industry: (1) mining and quarrying, (2) coke and refined petroleum products, as well as (3) electricity, gas and water supply. Find a complete list of categories in the **Appendix**.

99. A subset of countries modified (2) to include nuclear fuel: coke, refined petroleum products and nuclear fuel. These countries include: Austria, Canada, Japan, Russia and Korea. For each of these countries, we attempted to estimate the percent of number of persons engaged in jobs related to nuclear fuel. We calculated the GWs per job for the year with data, estimated the number of jobs in nuclear fuel each year using

[11] Note by Turkey The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the "Cyprus issue".

Note by all the European Union Member States of the OECD and the European Union The Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

this ratio, and subtracted this from (2). This assumes that GWh to job ratio is constant over time (Table A C.5).

$GWh_{NUCLEAR\_YR} \times (Job_{NUCLEAR}/GWh_{NUCLEAR}) = Job_{NUCLEAR\_YR}$

Table A C.5. Nuclear Jobs

Country	Source	Nuclear-fuel cycle related jobs[12]	$Job_{NUCLEAR}/GWh_{NUCLEAR}$
Austria	FORATOM (European Atomic Forum): Nuclear industry jobs in Europe per country	0 jobs	No adjustment required
Canada	Canada Manufacturers and Exporters (Nuclear jobs in Canada)	**10,000 jobs** in mining uranium (as of 2010) No nuclear fuel processing	90,658 GWh in 2010 1 job per 9.1 GWh
Japan	Japan Nuclear Fuel Limited	No uranium mining **2,658 jobs** in nuclear fuel cycle (in 2017)	18,060 GWh in 2016 1 job per 6.8 GWh
Russia	Russia Nuclear Industry Business opportunities	Employs **200,000** (as of 2009) in uranium mining and fuel cycle	No nuclear GWh data for Russia – Subtract jobs in total from each year
Korea	Korean Nuclear Fuel Company	Involved in nuclear fuel cycle, not in uranium mining (Approx. **700 jobs** as of 2008)	150,958 GWh 1 job per 215.7 GWh

Source: Authors

Public opinion

100. This variable captures changes in the public's environmental concern over time (Table A C.6).

Operationalization

1. Identified surveys with similar questions
2. Revalued scaled (when necessary). Ascending order equals greater concern.
3. Aggregated individual responses on the relevant question for each country year

4. Imputed missing country-year values using the MICE Package in R (Multivariate Imputation by Chained Equations) with predictive mean matching as the method.
5. Responses were standardized from 0 to 1 since questions from different surveys use varying scales.
6. Calculated the weighted mean of each country year if weights were provided in the original survey otherwise the mean was used.
7. Calculated the difference between years to find the change in public mood.

Table A C.6. Selected surveys

Countries	Survey	Question
Austria, Belgium, Croatia, Cyprus[13], Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, South Korea, Latvia, Lithuania, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States	Eurobarometer conducted by European Commission	Please tell me, for the problem of protecting nature and fighting pollution, whether you personally consider it a very important problem, important, of little importance, or not at all important.
Australia	Australian Election Study is a collaboration of several national universities, and led by Australian National University.	Here is a list of important issues that were discussed during the election campaign. When you were deciding about how to vote, how important was each of these issues to you personally? The environment... (Extremely important, quite important, not very important)
Japan, Korea, Canada	World Values Survey is a collaboration of several research institutions worldwide. The	Government should reduce environmental pollution (Strongly Disagree ... Strongly Agree)

[13] Note by Turkey The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the "Cyprus issue".

Note by all the European Union Member States of the OECD and the European Union The Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

	presidency is based at the Institute for Comparative Research in Vienna, Austria.	
Chile, Mexico * See note below deviated from procedure above	Latinobarómetro is a non-profit NGO based in Santiago, Chile, and is solely responsible for the production and publication of the data.	How concerned are you personally about environmental problems - would you say a great deal, a fair amount, not very much, or not at all?
USA	American National Election Studies is a collaboration of several national universities, and led by University of Michigan.	Some people think it is important to protect the environment even if it costs some jobs or otherwise reduces our standard of living. (Suppose these people are at one end of the scale, at point number 1). Other people think that protecting the environment is not as important as maintaining jobs and our standard of living. (Suppose these people are at the other end of the scale, at point number 7. And of course, some other people have opinions somewhere in between, at points 2,3,4,5, or 6).
New Zealand	New Zealand Election Study led by Victoria University of Wellington	For the next questions, please indicate whether you think there should be more or less public expenditure in each of the following areas. Remember if you say “more” it could require a tax increase, and if you say “less” it could require a reduction in those services. Please tick one box in each row (Much More ... More less)

Source: Authors

Notes on Chile and Mexico:

101. The question above (*How concerned are you personally about environmental problems …*) was only asked in 2001. A different survey question was asked more frequently from 2000 to 2015 including 2001: *All things considered, as far as you know or have heard, how would you rate the environment in (country)? Would you say that it is very good, good, about average, bad, or very bad?* Using 2001 data (N = 273 in Chile, N = 273 in Mexico), we regressed the frequent question (*All things considered …*) on the infrequent question (*How concerned …*). We then used this model to predict responses to the infrequent question, *how concerned are you,* in the years where it was not asked. After predicting these values, we preceded as normal.

Climate Intention

102. This variable captures the national government’s intention to mitigate climate change, which is measured by the planning horizon of a country’s mitigation policy.

Planning horizon is the remaining number of years that a country's mitigation policy is in force. Mitigation policy is defined as carbon price. This definition could be seen as overly restrictive, but this is the strongest signal that a government can send regarding their intention to mitigation, which is by actually correcting the market failure and the longevity of the law signals the continued commitment of a government to mitigate.

Operationalization

103. The *Climate Intention* variable uses the database, Climate Change Laws of the World, from the Grantham Institute at the London School of Economics. It covers national-level climate change legislation and policies in 164 countries and is regularly updated.

104. Given the scope of the analysis, we restricted the dataset to laws in G20 and OECD member states.

105. We further reduced the dataset by the purpose of each law, which is coded as either: (1) Mitigation, (2) Mitigation and Adaptation, or (3) None. We restricted the dataset to laws labelled as (1) Mitigation and (2) Mitigation and Adaptation to form the *Climate Intention* variable.

106. Mitigation and Mitigation/Adaptation laws are further categorized by subject area. Out of the 58 subject areas, we restrict *Climate Intention* to those related to carbon pricing:

- Carbon Pricing, Energy Supply, Energy Demand, Institutions / Administrative arrangements
- Carbon Pricing, Energy Supply, Energy Demand, REDD+ and LULUCF, Adaptation, Institutions / Administrative arrangements
- Carbon Pricing, Energy Supply, Energy Demand, REDD+ and LULUCF, Adaptation, Research and Development, Institutions / Administrative arrangements
- Carbon Pricing, Energy Supply, Energy Demand, REDD+ and LULUCF, Transportation, Adaptation
- Carbon Pricing, Energy Supply, Energy Demand, REDD+ and LULUCF, Transportation, Adaptation, Research and Development, Institutions / Administrative arrangements
- Carbon Pricing, Energy Supply, Energy Demand, REDD+ and LULUCF, Transportation, Institutions / Administrative arrangements
- Carbon Pricing, Energy Supply, Energy Demand, Transportation, Adaptation, Institutions / Administrative arrangements
- Carbon Pricing, Energy Supply, Energy Demand, Transportation, Adaptation, Research and Development
- Carbon Pricing, Energy Supply, Energy Demand, Transportation, Adaptation, Research and Development, Institutions / Administrative arrangements
- Carbon Pricing, Energy Supply, Energy Demand, Transportation, Institutions / Administrative arrangements
- Carbon Pricing, Energy Supply, Energy Demand, Transportation, Research and Development, Institutions / Administrative arrangements
- Carbon Pricing, Energy Supply, REDD+ and LULUCF, Adaptation, Research and Development, Institutions / Administrative arrangements

- Carbon Pricing, Energy Supply, Transportation, Adaptation, Research and Development, Institutions / Administrative arrangements
- Carbon Pricing, Institutions / Administrative arrangements

107. *Climate Intention* captures the planning horizon of the mitigation strategy (i.e., carbon pricing law). For example, New Zealand instituted the Climate Change Response Act in 2002 with a planning horizon until 2020. Table A C.7 illustrates the coding of the *Climate Intention* variable.

Table A C.7. Climate intention variable

Country	Year	Climate Intention
New Zealand	2000	0
New Zealand	2001	0
New Zealand	2002	18
New Zealand	2003	17
New Zealand	2004	16
New Zealand	2005	15
New Zealand	2006	14
New Zealand	2007	13
New Zealand	2008	12
New Zealand	2009	11
New Zealand	2010	10
New Zealand	2011	9
New Zealand	2012	8
New Zealand	2013	7
New Zealand	2014	6
New Zealand	2015	5
New Zealand	2016	4

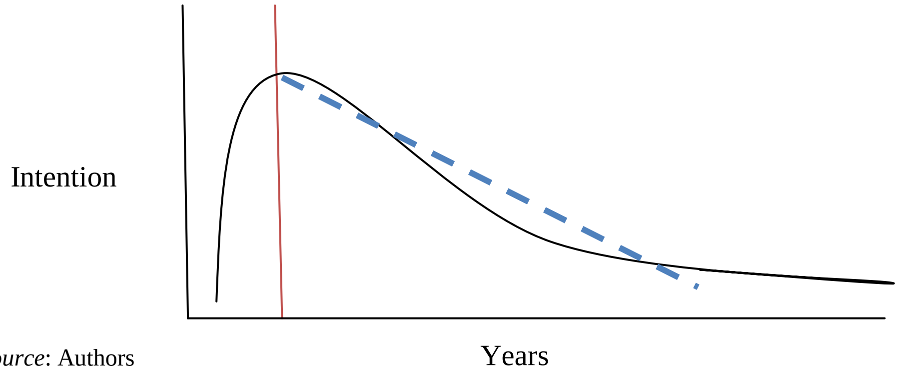
Note: Add the note here. If you do not need a note, please delete this line.
Source: Add the source here. If you do not need a source, please delete this line.

108. The *Climate Intention* of EU member states are coded using the 2020 Climate and Energy Package in 2009 and a 2030 Strategy Climate and Energy Policies in 2014. We only use the national policy of EU member states if it occurs before 2009.

Assumption of linearity

109. We assume linearity of *Climate Intention*. The objective is to capture the intention of the government to mitigate. After a law is enacted, the government's intention to tackle climate change is signalled not only by the enactment of a mitigation policy with carbon pricing, but by the planning horizon of this law. We imagine the distribution of intention for a fictionalized country to reflect the figure below. The intention of the government to tackle mitigation is strongest as soon as the law is enacted, and this wanes with time unless the government enacts a new law with a longer planning horizon. Our measure captures the blue dotted line in Figure A C.1.

Figure A C.1. Climate intention



Source: Authors