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The empirics of enabling investment and innovation in renewable energy

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Pralhad Burli

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THE EMPIRICS OF ENABLING INVESTMENT AND INNOVATION IN RENEWABLE ENERGY - ENVIRONMENT WORKING PAPER No. 123

Geraldine Ang, Dirk Röttgers (OECD) and Pralhad Burli (Montclair State University)

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This working paper is a joint endeavour of the Climate, Biodiversity and Water Division of the OECD Environment Directorate and the Investment Division of the OECD Directorate for Financial and Enterprise Affairs, under the supervision of the Working Party on Climate, Investment and Development (WPCID) of the Environment Policy Committee (EPOC) and the OECD Investment Committee.

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ACRONYMS AND ABBREVIATIONS

CO_2	Carbon dioxide
CCS	Carbon capture and storage
c-Si	Crystalline silicon
COP	Conference of the Parties
EPO	European Patent Office
EPOC	Environment Policy Committee
ETS	Emission Trading System
EU	European Union
FiT	Feed-in tariff
GHG	Greenhouse gas
GNI	Gross national income
GWh	Gigawatt hour
HVDC	High Voltage Direct Current
IEA	International Energy Agency
IFI	International finance institution
INDC	Intended Nationally Determined Contributions
ITC	Investment tax credits
IRENA	International Renewable Energy Agency
ITF	International Transport Forum
JWPTE	Joint Working Party on Trade and Environment
Lasso	Least absolute shrinkage operator
LCOE	Levelised cost of electricity
MCM	Ministerial Council Meeting
MWh	Megawatt hour
NEA	Nuclear Energy Agency
NEM	Net energy metering
OECD	Organisation for Economic Co-operation and Development
PPA	Power purchase agreement
Ppml	Poisson pseudo-maximum likelihood
PTC	Production tax credit
PV	Photovoltaic
RD&D	Research, development and demonstration
R&D	Research and development
REC	Renewable energy certificate
RPS	Renewable portfolio standard
TWh	Terawatt hour
UNFCCC	United Nations Framework Convention on Climate Change
USD	US dollars
Wp	Watts-peak
WPCID	Working Party on Climate, Investment and Development

COUNTRIES CONSIDERED AND THEIR CLASSIFICATION

Table 1. List of countries considered in this working paper

Country	OECD member countries	G20 members (including all EU member states)	G19 countries (without the EU)	European Union (EU) member countries	Advanced countries (among OECD, EU and G20)[1]	Emerging economies (amongst G20 and OECD)[2]
Argentina		x	x			x
Australia	x	x	x		x	
Austria	x	x		x	x	
Belgium	x	x		x	x	
Brazil		x	x			x
Bulgaria		x		x		x
Canada	x	x	x		x	
Chile	x				x	
China		x	x			x
Croatia		x		x	x	
Cyprus		x		x	x	
Czech Republic	x	x		x	x	
Denmark	x	x		x	x	
Estonia	x	x		x	x	
Finland	x	x		x	x	
France	x	x	x	x	x	
Germany	x	x	x	x	x	
Greece	x	x		x	x	
Hungary	x	x		x	x	
Iceland	x				x	
India		x	x			x
Indonesia		x	x			x
Ireland	x	x		x	x	
Israel	x				x	
Italy	x	x	x	x	x	
Japan	x	x	x		x	
Korea	x	x	x		x	
Latvia	x	x		x	x	
Lithuania		x		x	x	
Luxembourg	x	x		x	x	
Malta		x		x	x	
Mexico	x	x	x			x
Netherlands	x	x		x	x	
New Zealand	x				x	
Norway	x				x	
Poland	x	x		x	x	
Portugal	x	x		x	x	
Romania		x		x		x
Russia		x	x			x
Saudi Arabia		x	x		x	
Slovak Republic	x	x		x	x	
Slovenia	x	x		x	x	
South Africa		x	x			x
Spain	x	x		x	x	
Sweden	x	x		x	x	
Switzerland	x				x	
Turkey	x	x	x			x
United Kingdom	x	x	x	x	x	
United States	x	x	x		x	

Notes:

[1] For the purpose of the present working paper, a country is defined as an advanced country (among G20 and OECD countries) if it belongs to the list of OECD or G20 countries (including EU member countries) and is listed in the income group “high income” country in the World Bank’s *List of Economies* (World Bank, 2016b).

[2] For the purpose of the present working paper, a country is defined as an emerging economy (among G20 and OECD countries) if it belongs to the list of OECD or G20 countries (including EU member countries) and is listed in the income group “lower middle income” or “upper middle income” country in the World Bank’s *List of Economies* (World Bank, 2016b).

ABSTRACT

This working paper undertakes econometric analysis to assess the impacts of climate mitigation policies and the quality of the investment environment on investment and innovation in renewable power in OECD and G20 countries. It also assesses how countries' investment environments interact with climate mitigation policies to influence investment and patent activity in renewable power. The paper gathered and tested data across OECD and G20 countries on more than 70 explanatory variables, which were analysed using two Poisson-family regression models: one to investigate determinants of investment flows in renewable power from 2000 until 2014; and one to investigate determinants of patent counts in renewable-power technologies from 2000 until 2012. Results of the econometric analysis are consistent with the main hypothesis in this paper that beyond setting climate mitigation policies, policy makers need to strengthen the general investment environment and align it with climate mitigation policies in order to mobilise investment and innovation in renewable power across OECD and G20 countries.

RÉSUMÉ

Ce document de travail développe une nouvelle étude économétrique pour analyser l'impact de politiques publiques d'atténuation du changement climatiques et la qualité des conditions d'investissement sur l'investissement et l'innovation dans la production d'électricité d'origine renouvelable dans les pays de l'OCDE et du G20. Ce rapport évalue également comment le climat d'investissement et les défauts d'alignement de politiques publiques influencent la capacité des politiques d'atténuation du climat à mobiliser les flux d'investissement ainsi que l'innovation technologique et dépôts de brevets dans la production d'électricité d'origine renouvelable. Le rapport a testé et recueilli des données dans les pays de l'OCDE et du G20 sur plus de 70 variables explicatives, qui ont été analysées dans deux modèles, en utilisant les régressions de Poisson: un modèle qui analyse les déterminants des flux d'investissement dans la production d'électricité d'origine renouvelable de 2000 à 2014; et un modèle qui étudie les déterminants du nombre de brevets dans les technologies liées à la production d'électricité renouvelable de 2000 à 2012. Les résultats de l'analyse économétrique sont cohérents avec l'hypothèse principale du rapport selon laquelle au-delà de la mise en place de politiques d'atténuation du changement climatique, les gouvernements doivent également améliorer le cadre d'action et règlementation pour l'investissement, et l'aligner avec les objectifs climatiques afin de mobiliser les investissements et l'innovation dans la production d'électricité d'origine renouvelable.

FOREWORD

This working paper presents results of an econometric study on the impact of climate mitigation policies and investment environment variables on investment and innovation in renewable power, along with underlying assumptions and methodology. This technical working paper will be complemented by a policy paper on *Enabling Investment and Innovation in Renewable Energy* (Organisation for Economic Co-operation and Development, 2017a forthcoming), which will consider implications of its findings for G20 and OECD policymakers and provide policy recommendations to help mobilise investment and innovation in renewable power.

This working paper is jointly developed by the Climate, Biodiversity and Water Division of the OECD Environment Directorate, and the Investment Division of the OECD Directorate for Financial and Enterprise Affairs. It has been developed as part of the OECD project on "Improving the Investment Climate to Achieve the Clean Energy Transition". A further report that is part of the same project will focus on "State-owned enterprises and the Low-carbon Transition" (OECD, 2017b forthcoming). Using elements of the econometric model developed in the current paper, the forthcoming report will examine the effects of competition policy and state-ownership on investment in renewable power and the role of state-owned enterprises in the energy transition more broadly.

Acknowledgements

This working paper is a joint endeavour of the Climate, Biodiversity and Water Division of the OECD Environment Directorate, and the Investment Division of the OECD Directorate for Financial and Enterprise Affairs, under the supervision of the OECD Investment Committee and the Working Party on Climate, Investment and Development (WPCID) of the OECD Environment Policy Committee (EPOC). It is co-authored by Geraldine Ang, Dirk Röttgers (OECD) and Pralhad Burli (Montclair State University), under the guidance of Simon Buckle, Ana Novik, Robert Youngman and Cristina Tebar-Less. The project on “Improving the Investment Climate to Support Low-Carbon Investment and Innovation” was led by Geraldine Ang, with substantial inputs from Dirk Röttgers, who developed and implemented the econometric modelling.

This working paper is part of the OECD project on “Improving the Investment Climate to Achieve the Clean Energy Transition”, which benefits from Central Priority Funding provided by the OECD Secretary-General. The project was undertaken in co-operation with several OECD bodies, including: the OECD’s Centre for Tax Policy (CTP), which has provided valuable data and inputs to incorporate energy taxation levels in the electricity sector; the OECD Trade and Agriculture Directorate, which has provided data on fossil-fuel support measures in the power sector; and the Research Collaborative on Tracking Private Climate Finance, which specifically looks at publicly-mobilised private finance for climate action in developing countries. The project was also undertaken in consultation with the International Energy Agency (IEA), drawing on its expertise and extensive work on renewable-power generation.

The authors appreciate the substantial contributions and methodological peer review provided by Dr Ralf Martin (Imperial College London) in August 2016. The authors also appreciate valuable comments received from OECD and IEA colleagues on this working paper, the overall project and previous versions of this paper, including the draft interim report on “Investment Reform for Low-Carbon Investment and Innovation” circulated in February 2016. They include: Johanna Arlinghaus, Heymi Bahar, Manuel Baritaud, Richard Baron, Simon Bennett, Winfrid Blaschke, Adrian Blundell-Wignall, Gregory Briner, Antonio Capobianco, Miguel Cárdenas Rodríguez, Anthony Cox, Karim Dahou, Alexandros Dimitropoulos, Dennis Dlugosch, Pamela Duffin, Jane Ellis, Kate Eklin, Florens Flues, Jean-Marc Fournier, Paolo Frankl, Andres Fuentes, Jean-Francois Gagne, Gregoire Garsous, Michael Gestrin, Ivan Haščič, Jessica Isaacs, Raphaël Jachnik, Nick Johnstone, Christopher Kaminker, Osamu Kawanishi, Berenice Lasfargues, Jean Le Cocguic, Alexander Lembcke, Dejan Makovsek, James Mancini, Lauren McNicoll, Mathilde Mesnard, Fernando Mistura, Miza Noor Muhamad Razali, Michael Mullan, Simon Müller, Walid Oueslati, Chung-a Park, Lorenzo Pavone, Pierre Poret, Andrew Prag, Mikaela Rambali, Caroline Roulet, Julien Salanie, Jehan Sauvage, Jérôme Silva, Ronald Steenblik, Simon Upton, Lola Vallejo, Kurt Van Dender, Michael Waldron, Gert Wehinger and Martin Wermelinger.

The authors also appreciate valuable inputs received from non-OECD colleagues, including: Adrian Raftery (University of Washington); Alex Lenkoski (Norwegian Computing Center); Fernando Lasheras García (Iberdrola); David Foster and William Francis (Bloomberg New Energy Finance, BNEF); Alexander Jordan (Heidelberg Institute for Theoretical Studies); Helena Wright (E3G); and the participants of the joint University of Sussex and BNEF workshop “Financing Innovation in Renewable Energy: Who is doing what, where and when?”, organised in February 2016 by Abraham Louw (BNEF), Mariana Mazzucato (University of Sussex) and Gregor Semieniuk (University of Sussex).

This working paper incorporates feedback received from delegates during meetings in 2016 on earlier versions of the paper, respectively on 23-24 February and 21-22 November for WPCID delegates, and 14-18 March and 20 October for the Investment Committee, as well as on the concept note of the project in 2015. This working paper also incorporates inputs received during other OECD meetings, including: the Research Collaborative meeting in March 2016; the “Workshop on Climate Finance Tracking” organised by the Research Collaborative and the Development Assistance Committee on 12-13 September 2016; the expert workshop on “Optimising Global Value Chains in Environmental Goods and Services” on 8 June 2016; and an internal OECD Secretariat seminar on Applied Economics Work-in-Progress on 27 January 2016. Assistance with editing and formatting was provided by Thierry Cellier, Sama Al Taher Cucci, Laurence Langanay Rageau, Pascale Rossignol and Lesley O’Sullivan.

EXECUTIVE SUMMARY

Mobilising investment in low-carbon technologies, including in renewable-power generation, is central to meeting the commitment in the 2015 Paris Agreement to "holding the increase in the global average temperature to well below 2°C above pre-industrial levels" and "making finance flows consistent with a pathway towards low greenhouse gas emissions" (Article 2; UNFCCC, 2015). This working paper provides insights on the key policy drivers and barriers to investment and innovation in renewable power in OECD and G20 countries. Based on econometric analysis, it assesses the impacts of climate mitigation policies and the quality of the investment environment on both investment and patenting activity in renewable-power generation since 2000. The analysis also assesses how the investment environment and related policy misalignments influence the effect of climate mitigation policies in encouraging renewables investment and innovation.

The study gathered and tested data on more than 70 explanatory variables across OECD and G20 countries. These variables included: (i) climate mitigation policies (explicit carbon prices, feed-in tariffs, public tenders, renewable energy certificates, public spending for research, development and demonstration (RD&D) in renewables technologies, energy taxation in electricity sector, and fossil-fuel support measures in power generation); (ii) investment environment variables (more than 50 variables); (iii) innovation environment variables; and (iv) control variables (to account for non-policy factors). These explanatory variables were analysed using two econometric models: one to investigate determinants of investment flows in renewable-power generation from 2000 until 2014; and a second model to investigate determinants of patent counts in renewable-power technologies from 2000 until 2012. The effect of policy variables is demonstrated when relevant policy variables are found to have statistically significant results in the regression models.

Results of the econometric analysis are consistent with the hypotheses that policy makers need to set stronger, coherent climate mitigation policies, enhance the quality of the investment environment, and align it with climate mitigation policies in order to mobilise effectively investment and innovation in renewable power. The project provides empirical evidence that reinforces the main messages of earlier OECD reports, including *Aligning Policies for a Low-Carbon Economy* (2015) and the *Policy Guidance for Investment in Clean Energy Infrastructure* (2015), as well as other studies.

Policy drivers of investment in renewable power

The results on climate mitigation policies indicate that across OECD and G20 countries, renewables investment from 2000 until 2014 was primarily driven by targeted investment incentives, i.e. feed-in tariffs (FiTs), renewable certificates (RECs) and public tenders. While all three incentives were used by both advanced and emerging economies, results in geographic sub-samples show positive effects of FiTs and RECs in advanced countries, while public tenders have a positive impact in emerging economies. Other mitigation policies showed positive effects for investment in specific geographic or technology sub-samples. For example, explicit carbon prices have driven investment in renewable power in the European Union (EU) and emerging economies as well as investment in solar power across OECD and G20 countries. Energy tax rates in the power sector have driven investment in solar power across OECD and G20 countries. Support measures for fossil fuels used in power generation deter renewable investment for emerging economies, where these measures tend to concentrate. In addition, interactions between climate mitigation policies show that mitigation policies can enhance each other’s effect when they are combined, e.g. in emerging economies: explicit carbon prices with public RD&D spending; or RECs with public RD&D spending.

Results suggest that investment flows in renewable power also depend on the attractiveness of the broader investment environment. These results are particularly relevant for investment in solar and wind energy, as well as in advanced countries. Significant factors across OECD and G20 countries (or in specific geographic or technology sub-samples wherever specified) include: the overall ease of doing business; investment policy (e.g. registering property; and corruption perception and regulatory quality for solar energy); investment facilitation (e.g. licenses and permit system for wind energy); competition policy (e.g. direct control of the state over enterprises); trade policy (ease of trading across borders in the EU and for wind power); and financial market policy (e.g. access to domestic credit for private sector, sovereign credit rating and implementation of Basel III leverage ratio). Results suggest that until 2014, the implementation of Basel III leverage ratio (which aims at restricting excessive leverage and exposure from banks) may have had the unintended consequence of constraining access to long-term financing for capital-intensive renewables projects, despite important caveats (for instance, this analysis does not assess the impact of Basel III on capital-intensive infrastructure assets other than renewables).

Results also suggest that broader investment conditions interact negatively with climate mitigation policies in terms of their effect on investment in renewables. For example, explicit carbon prices interact negatively with the implementation of Basel III leverage ratio, showing that their cross-effect hinders investment in renewable power. This result suggests that the effect of explicit carbon prices in encouraging a shift towards investment in renewables might be hampered by the ability of the banking system in G20 and OECD countries in providing long-term debt financing for capital-intensive infrastructure project such as renewable projects. Likewise, public tenders interact negatively with direct control of the state over enterprises in advanced countries. This cross-interaction could be a result of the deterring presence of dominant state-owned enterprises on investment from independent renewable power producers entering a market through tendering procedures.

Policy drivers of patenting and innovation in renewable-power technologies

The results from the innovation model suggest that feed-in tariffs and public RD&D spending stimulate patenting activity in renewable-power technologies across OECD and G20 countries and across all geographic sub-samples. This is consistent with existing studies on the impact of feed-in tariffs on patenting of solar photovoltaic (PV) energy (Ghambir et al., 2014; Spencer et al., 2015; Johnstone et al., 2010). Public tenders do not, however, stimulate patents and innovation in renewable-power technologies across OECD and G20 countries, while results on RECs show that they do so only in emerging economies. Public RD&D spending encourages patenting in renewables technologies across OECD and G20 countries and especially in emerging economies. Explicit carbon prices do not appear to stimulate renewables patenting across OECD and G20 countries. As in the investment model, this result may be due to holding constant for factors that are the same or similar across countries, which includes carbon prices in some models, as well as data limitations of the analysis. Additional analysis and better data could bring out the effect of an explicit carbon price more clearly.

Broader investment conditions also stimulate or deter patenting activity in renewable-power technologies. Significant factors across OECD and G20 countries include: ease of doing business; ease of trading across borders; direct control of the state over enterprises; and governance of state-owned enterprises. Investment conditions also influence the effect of climate mitigation policies in stimulating renewables patenting activity. In particular, increasing direct control of the state over enterprises reduces the effect of public tenders and energy taxation in stimulating patent activity across OECD and G20 countries, and also reduces the effect of explicit carbon prices in stimulating patent activity in emerging economies.

The innovation model also captures the positive effects of the broader innovation environment on renewable patenting activity, e.g. variables such as the number of universities and a "knowledge stock" variable constructed based on a cumulative count of patents related to renewable-power technologies.

Initial policy implications

These results potentially have important policy implications. In particular, the influence of the investment environment on both investment and innovation in renewable power across OECD and G20 countries highlights the need for policy makers to strengthen the investment environment in order to meet renewables deployment goals. The results also suggest that specific policy incentives and other climate mitigation policies cannot be considered in isolation from the broader environment for investment and innovation in renewable power. This assessment may be particularly relevant in the context of reforms to incentive schemes for renewable power, as governments need to understand how the broader investment environment influences the effects of these incentives. In addition, the finding that feed-in tariffs and public RD&D spending stimulate renewables patenting may be a particularly relevant consideration in the context of: i) ongoing policy shifts away from feed-in tariffs and towards public tenders, and ii) historically low levels of public RD&D. The policy recommendations and implications for OECD and G20 governments from this analysis will be elaborated in a forthcoming policy paper on *Enabling Investment and Innovation in Renewable Energy* (2017a forthcoming).

OVERVIEW OF THE PROJECT

Introduction

Mobilising investment in low-carbon technologies[1] is central to meeting the commitment in the 2015 Paris Agreement to transition to "aggregate emission pathways consistent with holding the increase in the global average temperature to well below 2°C above preindustrial levels" (United Nations Framework Convention on Climate Change or UNFCCC, 2015). A large potential for "decarbonisation" lies in the power sector, which accounts for around 40% of global primary energy use and energy-related carbon dioxide (CO_2) emissions in 2012 (IEA, 2015b). But despite generally rising levels of low-carbon investment in the past decade, including in renewable power, far greater investment will be required to transition to a low-carbon economy. According to the UNFCCC and the IEA, current (Intended) Nationally Determined Contributions (NDCs)[2], including energy-sector investments under the INDCs, will be insufficient to meet the 2ºC goal (UNFCCC, 2016; IEA, 2015a; United Nations Environment Programme or UNEP, 2016). The deployment of most low-carbon technologies would need to significantly accelerate in order to put the global energy system on track to achieve the 2°C goal (IEA, 2016a, d). Achieving substantial carbon dioxide (CO_2) emissions reductions would require important changes in investment patterns, including in renewable power (IPCC, 2014). Incremental cumulative investments of more than USD 6 trillion would be needed for renewable power between 2016 and 2040 to meet the 2°C goal, compared to a scenario under current policies (IEA, 2016a). Investing in renewable power can also help achieve other policy goals, such as enhanced energy security, reduced local air pollution or improved energy access in rural or remote areas.

There is no shortage of globally-available capital (OECD, 2016c). In addition, some renewable-power technologies have gone through dramatic cost reductions, and are increasingly cost-competitive against fossil fuels. Globally, the capital cost of onshore wind has decreased by 20% since 2010, and that of utility-scale solar photovoltaic (PV) has fallen by more than 60% since 2010 (IEA, 2016a). Partly driven by lower costs, investors spent less money in 2016, while adding more renewables capacity than any previous year, a 9% increase in 2016 compared to 2015 (FS-UNEP and BNEF, 2017). Despite a continuous increase in renewables investment between 2004 and 2011, IEA estimates did not show a clear diminishing trend in the share of fossil-fuel investment between 2000 and 2014 (IEA, 2014e; FS-UNEP and BNEF, 2017). Since 2014 however, there has been a reorientation of energy-related investments (IEA, 2016a). The share of fossil-fuel supply has decreased to 50% in 2015, down from 60% in 2014 (OECD/IEA and IRENA, 2017). Renewable power generation represents 70% of power generation investment in 2015, compared to 30% for conventional power (OECD/IEA and IRENA, 2017). Despite significant progress, fossil-fuel supply still represents half of energy investment, and renewable investment will need to significantly increase in the upcoming decades. What has constrained investment in renewable power until 2014, and what is needed to further accelerate the pace of deployment of renewables? There is significant consensus that in many countries, renewable power investment growth can be impeded by the lack of a level playing field vis-à-vis fossil-fuel-based generation (Global Commission on the Economy and Climate, 2016; Bridle and Kitson, 2014; OECD, 2015b). Possible obstacles relate to a lack of coherent

[1] Low-carbon technologies as defined in this paper include: electricity-generating and heating and cooling technologies using renewable energy sources; electric vehicles; energy-smart technologies such as smart grids and demand-side management in distribution; goods and services used to improve energy efficiency; energy storage and carbon capture and storage (CCS) technologies; nuclear energy; and other technologies used to reduce conventional pollutants from fossil-fuel-fired plants.

[2] For INDCs submitted by countries as of May 2015 in advance of COP 21.

and stable policies, or misalignments in electricity regulations and system operations, in addition to country-specific impediments, constrained access to financing, technical obstacles and outstanding barriers to international trade and investment. In contrast, fossil-fuel-based power does not appear to be suffering from the same impediments.

Conceptual model and rationale

What are key policy drivers and barriers to investment and innovation in renewable-power technologies? This paper examines this question by testing a broad range of potential explanatory variables in an econometric model, based on a number of initial hypotheses. The project examines quantitatively the evidence for some of the key messages of previous OECD reports, including *Aligning Policies for a Low-Carbon Economy* and the *Policy Guidance for Investment in Clean Energy Infrastructure*, as well as other studies (OECD/IEA/NEA/ITF, 2015; OECD, 2015b). First, it tests whether mobilising investment and innovation in renewable-power technologies requires setting stronger, coherent climate mitigation policies (IEA, 2016b, d; IPCC, 2014; Stern, 2006). Climate mitigation policies include: explicit carbon prices (i.e. emissions trading schemes and carbon taxes); targeted investment incentives (e.g. feed-in tariffs, renewable energy certificates and public tenders); targeted innovation incentives (e.g. public expenditures to research, development and demonstration or RD&D); and reform of fossil-fuel support measures.[3] This analysis assumes that support is needed not only for investment in deployed low-carbon technologies, but also for innovation in earlier-stage technologies. For this reason, this analysis considers policy support to both increasingly mature renewables technologies, such as onshore wind and solar PV power, and to earlier-stage technologies such as marine power. Second, this paper tests whether supporting investment and innovation in renewables requires governments to strengthen broader investment conditions, beyond setting targeted investment incentives and other climate mitigation policies. Third, this paper assesses how this wider business and investment environment interacts with climate mitigation policies in terms of their effect on investment and innovation in renewable power (Global Commission on the Economy and Climate, 2016; OECD, 2015b; OECD/IEA/NEA/ITF, 2015; IPCC, 2014). Annex A.2 outlines the hypotheses and conceptual model.[4]

This study aims to fill a research gap on the impacts of climate policies and business conditions on investment and innovation in renewable-power technologies. Several studies (including OECD studies) have considered the impact of particular climate policies or particular investment conditions on investment or innovation in renewable power.[5] To the authors' knowledge, however, no study has yet assessed empirically how both climate mitigation policies and the quality of the broader investment environment influence investment and innovation in renewable-power generation. Annex A.2 provides a detailed literature review.

For the conceptual model on renewables investment, this study relies on the OECD *Policy Framework for Investment* (PFI) and the *Policy Guidance for Investment in Clean Energy Infrastructure* to provide a framework for assessing which factors within the investment environment influence investment

3 Tax incentives and renewable targets are relevant policies that are not considered in this study due to resources constraints.

4 I.e. the hypotheses made on the expected impact of explanatory variables on the two dependent variables.

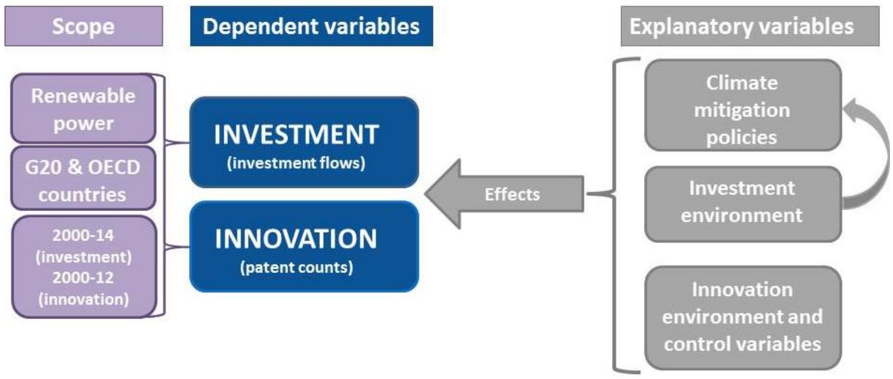
5 For investment, see: Cárdenas Rodriguez et al., 2014; Haščič et al., 2015a; Criscuolo and Menon, 2014; Criscuolo et al. 2014; OECD, 2015a, b; OECD/IEA/NEA/ITF, 2015; Corfee-Morlot et al., 2012. For innovation, see: IEA, 2015a, b; Andrews and Criscuolo, 2013; Haščič et al., 2015a; Haščič and Migotto, 2015; Johnstone et al., 2010; Gambhir et al., 2014; Groba and Breitschopf, 2013; Friebe, 2014; Iršová and Havránek, 2013; Furman et al., 2002; Johnstone et al., 2010; Criscuolo and Menon, 2014; For more details on the literature review, please see Annex A.2.

and innovation in renewable power (OECD, 2015b, f). Drawing on the PFI, the investment (or business) environment is defined as the range of "policy fields critically important for improving the quality of a country's enabling environment for investment". Key policy fields include notably: investment policy; investment promotion and facilitation; competition; financial markets; trade; and public governance. This explains why this study considers a large number of investment conditions within those policy areas.

Summary overview of the research project

This study undertakes new econometric analysis to assess how key policy factors affect investment and innovation in renewable power across OECD and G20 countries. More precisely, the analysis estimates the impacts of climate mitigation policies, broader investment conditions, the innovation environment and other variables on investment flows and patenting activity in renewable-power generation, in OECD and G20 countries, from 2000 until 2012 (innovation) and 2014 (investment). This section provides a summary overview of the research project, including its aim, research questions, methodology and scope. Figure 1 presents a schematic overview of the research project.

Figure 1. Overview of the research project



This study focuses on measuring the effect of climate mitigation policies on investment and patenting activity in renewable power. An effect is demonstrated when relevant policy variables are found to have statistically significant results in the regression model. The study also assesses which investment conditions have a direct impact in encouraging or deterring investment and innovation in renewable power. In addition, by considering the interactions of climate mitigation policies and other investment conditions, the study assesses how the investment environment influences the extent to which climate mitigation policies mobilise investment flows and patent activity in renewable-power sources – i.e. how much they are able to mobilise investment and innovation in renewable power, as demonstrated by the size of the coefficient for statistically significant regression results. The report however does not provide information on the cost-effectiveness of policies in driving investment and innovation. This is due to: (i) comparability issues, as policies are typically measured in different units (e.g. feed-in tariffs are expressed in USD/kWh and tenders in kW), which limit options to compare policy impacts; and (ii) insufficient data on renewables projects' costs and public expenditures.

Aim

The aim of the project is to estimate the impacts of climate mitigation policies and other investment environment variables – as well as their interactions – on investment and innovation in renewable power. Investment flows and patent counts in renewable-power generation are used to measure investment and innovation, respectively. Patent counts are a measure for technology development, a specific aspect of innovation serving here as proxy for technological development in general. The analysis

also considers the impact of the broader innovation environment on investment and patenting activity, along with a number of market and country conditions that are included in the analysis as control variables.

Research questions

The project addresses two research questions:

- Which climate mitigation policies and other investment environment variables influence (i) investment and (ii) innovation in renewable power in OECD and G20 countries?

- How do investment environment variables interact with climate mitigation policies in terms of their effect on investment and innovation in renewable power?

Summary of the methodology and variables

The project has tested and gathered data on more than 70 explanatory variables to help analyse investment flows and patent counts in renewable power. The explanatory variables considered include:

- Climate mitigation policies (eight variables), including: explicit carbon prices (i.e. carbon taxes and emission trading schemes); targeted investment incentives for renewable power (feed-in tariffs[6], public tenders, renewable energy certificates); a variable measuring policy uncertainty on incentives, such as retroactive changes to FiTs; energy taxation rates and support measures to fossil fuels in the power sector; and public RD&D spending for renewables technologies;
- Investment environment variables (more than 50 variables);

- Innovation environment variables (four variables); and

- Other control variables (10 variables) to account for non-policy factors such as natural resource endowment.

A regression analysis with more than 70 explanatory variables could typically include redundant determinants and therefore risk misinterpreting results, due to the overburdened model. Consequently the study uses the so-called *lasso* approach (least absolute shrinkage and selection operator; Tibshirani, 1996) to narrow down the number of variables to a manageable set of relevant explanatory variables. The *lasso* approach weighs the added model accuracy gained from including a variable against the variable's relevance for the predictive capability of the model (see subsequent chapter for a detailed explanation of the *lasso* approach). Building on the *lasso* and other methodologies used in recent OECD empirical studies, the selected variables were analysed in two separate models:

- An investment model, to investigate determinants of investment flows in renewable power in OECD and G20 countries from 2000-14. The regression analysis of investment flow determinants uses Bloomberg New Energy Finance (BNEF) investment data for the renewables sector. Since the regression analysis is applied to a data set with an abundance of zero-investment observations, i.e.

6 The feed-in tariff (FiT) variable measures both feed-in tariffs and feed-in premiums, weighted with their contract duration Investment decisions in renewable projects are influenced not only by the level of a feed-in tariff (FiT), but also by the contract duration that guarantees the FiT, as part of power purchase agreements (PPAs). These lengths range from 5 to 35 years, which can impact the risk-return profile of renewables projects. Consequently the PPA length should be accounted for, by weighing the FiT with its contract length.

many country-sector-years for which there was no investment, it uses the Poisson pseudo-maximum likelihood (ppml) model, which deals efficiently with this zero-inflation.

- An innovation model, to investigate determinants of patent counts in renewable-power technologies in OECD and G20 countries from 2000-12. The regression analysis of technology development is based on a negative binomial model and uses patent data as a proxy for technological development in the renewables sector.

Scope

The sectoral scope of the analysis is on six renewable-power technologies, including: biomass and waste, geothermal, hydro, marine, solar and wind energy. Since the majority of observations are in the solar- and wind sub-sectors, the study presents sub-sample regressions only for solar and wind power.

The segments of the renewable-energy value chains considered by this study include: downstream activities (for investment flows and patenting), which typically include project development, installations and balance of renewables plants; and manufacturing (for patenting data). The definitions and scope of renewables technologies depend on data availability and classifications used in data sources. For instance, the project had to exclude large hydro power from the analysis, due to data availability constraints with the Bloomberg New Energy Finance (BNEF) database. Similarly, BNEF for the most part tracks investment flows in downstream renewable power, not in midstream manufacturing. Conversely, available patent data include both midstream manufacturing and downstream activities in the renewables value chains.

Due to data availability and resource constraints, this paper does not consider other low-carbon technologies in the power sector that are critical to meet the 2°C goal, such as electricity storage, smart grids and carbon capture and storage (CCS). In addition, this paper does not consider investment and innovation in electricity transmission and distribution grid, or key policy issues associated with system integration of variable renewables technologies, which are essential issues but would deserve and require a separate study. Nor does the paper consider the broader impact of carbon-intensive investments in the electricity sector on investment and innovation in renewable power, due to resource constraints.

The geographic scope is OECD and G20 countries (i.e. 49 countries, including all individual EU member states). The list of all countries considered is available in Table 1. This regression analysis had to exclude a few countries from the analysis wherever data was not available. In particular, Argentina, Indonesia and Saudi Arabia were excluded from both the investment and innovation models due to missing data for several explanatory policy variables.

The time period of the study spans from 2000 to 2014 for the investment model, and from 2000 to 2012 for the innovation model. The investment model's time period ends in 2014 due to missing data in the explanatory variables (e.g. CO_2 emissions). The innovation model only covers the years from 2000 until 2012 due to missing data for patents counts in years later than 2012.

Structure

This working paper includes: an overview of the variables considered and econometric methodology; and a summary of the empirical results and interpretations, along with important caveats and initial policy conclusions. Annex A.1 details data treatment and definitions of key policy variables considered by the study. Annex A.2 provides an overview of the conceptual model and hypotheses along with a literature review.

ECONOMETRIC METHODOLOGY AND VARIABLES

This chapter provides:

- A summary of the key variables considered by the econometric study, along with key trends across G20 and OECD countries from 2000 until 2014; and
- A description of the modelling strategies and empirical specifications of the study.

This chapter is complemented by detailed annexes. Annex A.1 includes information on the explanatory policy variables considered by the study. Annex A.2 provides an overview of the conceptual model and specific hypotheses, along with a literature review.

Key variables considered by the econometric study

This section presents the dependent and key explanatory variables considered by the econometric study, along with definitions and data sources. The definitions and scope of the study primarily depend on the definitions and classifications used by available datasets and indicators. Annex A.1 provides a detailed description of data sources, data treatment and definitions of the variables used in the regression models of this study, along with the descriptive summary statistics for all variables considered.

Dependent variables

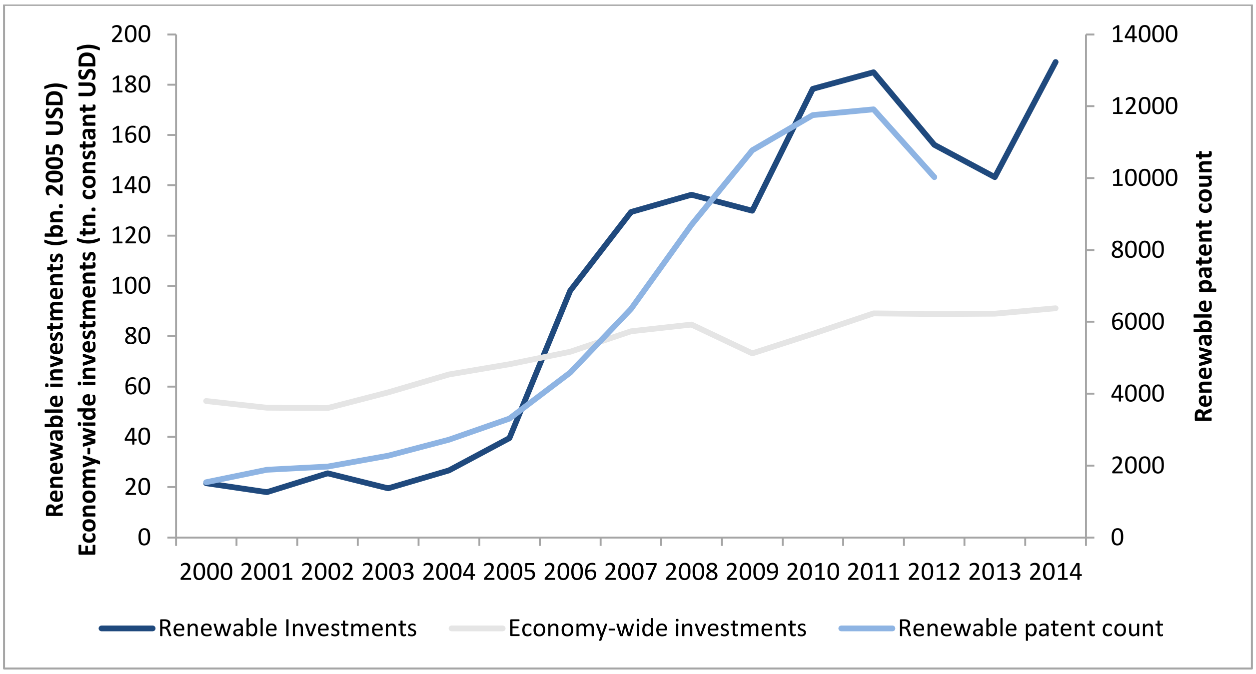
This research project estimates[7] the impacts of policies based on the two focus areas: investment and innovation in renewable-power sources. Investment flows and patent counts in renewable-power sources are the two dependent variables of the analysis, which are used as proxies to measure investment and innovation, respectively.

As shown in Figure 2, investment flows and patent counts grew in tandem, starting at a relatively low level of growth at the beginning of the 2000s, and strongly increased from the mid-2000s onwards. Investments and patent numbers showed smaller growth rates during (for investments) and shortly after (for patent counts) the 2008 global financial crisis. A comparison to economy-wide investments in OECD and G20 countries shows the different trends between overall investments, investments in the renewable sector and patented technology development (IMF, 2016). Though economy-wide investments have increased from 2000 onwards and were affected by the financial crisis – just like renewables investments –, overall investments grew more steadily and at a lower rate than the values for the renewables sector. Note here that the seeming sharp drop-off in patent counts in 2012 does not necessarily reflect a drop-off in activity, as it could be due to (as of yet) unfiled patents, which would not be unusual for patent data.

7 The estimation uses a regression analysis to assess how the "dependent variable" (e.g. investment flows, or patent counts, in renewable electricity generation) depend on a variety of factors or "explanatory variables".

Figure 2. Key trends in investment flows and patent counts in renewable-power sources in OECD and G20 countries

(2000-14 for investment flows, billion USD and trillion constant USD; 2000-12 for patent counts)



Source: Authors' calculations, based on BNEF (2015); IMF (2016); and Haščič and Migotto (2015).

Investment

Investment is measured by gross investment flows (in million USD) in the six renewable-power generation sectors (geothermal, marine, small hydro, solar, wind, and the combined sector biomass and waste) in the 49 OECD and G20 countries. Data of this form is available for the years 2000-14. Note here that the country set was reduced to 46 countries for the subsequent regression analysis due to missing data for Argentina, Indonesia and Saudi Arabia in some explanatory variables.

The Bloomberg New Energy Finance (BNEF) database, which includes data on investment deals for new built renewable power projects, is used to construct measures of investment flows in the renewable-power sector. The BNEF database reports more than 40000 investment deals, but provides investment values for only 29% of these deals. To be able to use available information contained in the full set of more than 40000 observed deals, investment values were replaced with predicted values. The estimation underlying these predicted values is based on the country, year and sector of the deal as well as the capacity (in MW) of the plant financed by the deal. BNEF reports project-level data for the six aforementioned sectors in renewable-power generation. Predicted values based on this estimation were then aggregated to the country-sector-year level and added to the country-sector-year aggregates of other investment types (see below). All investment values are deflated to 2005 USD values. See Annex A.1, Haščič and Migotto (2015) and Jachnik and Raynaud (2015) for further details on BNEF database and limitations with BNEF data.

The investment analysis focusses on grid-scale renewable-power projects and excludes small-scale distributed renewable projects. This focus on grid-scale projects is due to the lack of available BNEF data for small-scale renewables projects, since BNEF mostly reports deals financing projects with a

capacity larger than 1 MW. Additionally, BNEF does not track large hydro-power flows, so the analysis had to exclude large hydro power. The study also had to exclude nuclear power from the analysis due to lack of available BNEF asset finance data on nuclear power.

The investment flows considered by the project include both domestic and international flows of new investment in greenfield (i.e. newly built) infrastructure assets. They include: asset finance; corporate debt; venture capital (VC) and private equity (PE). Asset finance represents the majority of flows considered by the study. Since the analysis here focusses on the impact of policy on new investments rather than buying and selling existing projects and companies, the analysis disregards deals for mergers and acquisitions as well as for public markets. The exclusions of flows from mergers and acquisitions and public markets also safeguard against the possible risk of double-counting. Note that the investment data considers only gross investment flows, excluding account netting through loan repayments or equity exits.

The analysis considers the impact of policies on both domestic and foreign investment flows, for downstream activities and infrastructure assets of the renewables value chains. It does not consider investment flows to upstream activities of raw material extraction or to midstream renewable manufacturing (e.g. panel and wind turbine manufacturing), unlike for patent data. The share of manufacturing investment is small compared to the more capital-intensive downstream activities of the value chains (OECD, 2015a). In 2013, manufacturing equipment for renewable energy amounted to only 6% of new renewable-energy investment worldwide, i.e. USD 12 billion out of USD 214 billion (FS-UNEP and BNEF, 2014).

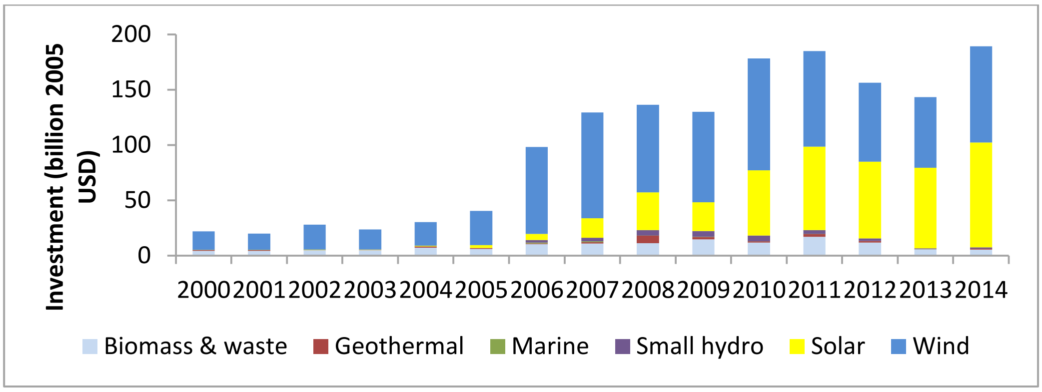
As Figure 3 shows, throughout all years covered by the analysis, the wind sector plays a dominant role, increasingly sharing this role with solar power from 2007 onwards. In both sectors, investments have increased over the study period, though for wind the strongest growth took place in the mid-2000s while solar-power investments took off only at the turn of the decade. Due to the dominance of these two sectors relative to biomass and waste, geothermal, marine and small hydro, their investments naturally drive the regression results presented in the results section. To do justice to the dominance of the solar- and wind-power sectors, the results section presents separate analyses for these two sectors, in addition to the analysis of the whole renewable-power sector.

The scope of the investment model is downstream investment flows in renewable-power generation, at the level of power-plant projects. For the innovation model, the scope is renewable technology patenting, both at the manufacturing and downstream segments of the value chains. Issues specific to patenting data are discussed in the subsequent section.

Note that the investment model is constrained by data availability for years later than 2013, for example for the necessary control variable of CO_2 emissions, which serves as a proxy variable for all GHG emissions. While an extrapolation of this emissions data to 2014 seems justified, further extrapolation of emissions as well as other variables would diminish the quality of the data set, which explains why the time period ends in 2014.

Figure 3. Key trends in investment flows in renewable-power sources in OECD and G20 countries

(2000-14 investments by sectors, in billion 2005 USD)



Source: Authors' calculations, based on BNEF (2015); IMF (2016); and Haščič and Migotto (2015).

Innovation

The innovation analysis uses sector-specific patent data as proxy for data on innovative activity, i.e. invention and technology development, drawing on Haščič and Migotto (2015) and Johnstone et al. (2010). The patent counts used for the analysis are based on patents filed in the six renewables sectors outlined above (geothermal, marine, small hydro, solar, wind, and the combined sector biomass and waste) in the years 2000 to 2012. The scope and definitions of patent counts in renewable-power technologies depend on the classes of patents defined by the International Patent Classification (IPC). This patent data is compiled by Haščič and Migotto (2015), using underlying patent data from the Worldwide Patent Statistical Database (PATSTAT). This OECD database comprises a patents selection that results from the search strategy outlined in Haščič and Migotto (2015). The first step of this search strategy is based on a literature research to identify relevant technologies within different low-carbon and environmental technologies. The second step verifies the list of IPC classes corresponding to the identified renewables technologies. Only the patents of classes remaining on the list after both steps are extracted from PATSTAT and included in the OECD database on technology development for environmentally relevant technologies. The innovation model's time period ends in 2012 due to lack of availability of patent data after 2012. This is due to the lengthy inventory and filing process for patents data, as well as time-intensive additional steps necessary to integrate published data into the continuously updated database of Haščič and Migotto (2015).

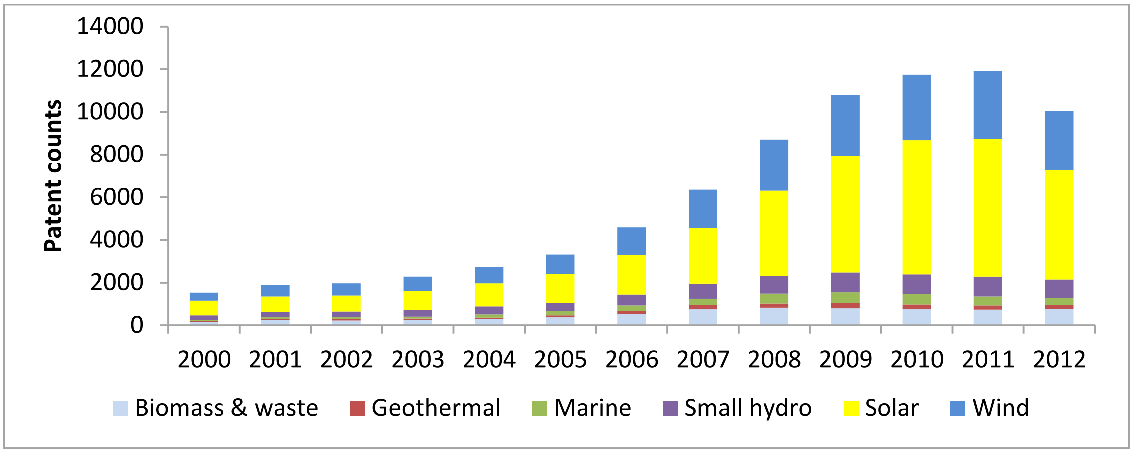
Similar to the investment regression analysis, the country set of 49 countries is reduced to 46 countries for the innovation analysis due to missing data for Argentina, Indonesia and Saudi Arabia on several explanatory variables. The underlying sector definition, rationale for technology selection, attribution to countries and method of extraction from official European Patent Office's PATSTAT patent data is outlined in detail in Haščič et al. (2015b) and Haščič and Migotto (2015). The methodology of this analysis follows Johnstone et al. (2010) in using the number of filed patents as a proxy for innovative activity.

This research project only assesses the impact of policies on invention and technology development, two characteristics of innovation (associated with "learning-by-R&D"). Other factors of innovation, such as learning-by-doing, are not accounted for in the regression analysis outlined in the methodology section.

Similar to investments, patenting activity is dominated by the wind- and solar-power sectors, as shown in Figure 4. Patents in both sectors have a large share and the largest growth in absolute numbers from 2000 to 2012, the latest year for which data is available. Unlike for investments, however, the solar-power sector already played the largest role in patent activity from 2000. Similar to the investment case, the regression analysis presented in the results section is supplemented by a separate analysis of the solar- and wind-power sectors for patents to do justice to the dominant role of these two technologies.

Figure 4. Key trends in patent counts in renewable-power sources in OECD and G20 countries

(2000-12 patent count by sectors)



Source: Author's illustration.

It is important to stress that patenting activity takes place both in the manufacturing and downstream segments of the renewable-power value chains (unlike investment flows in downstream power plants). This working paper acknowledges that the effects of policies on patenting could differ depending on whether patents are in manufacturing or downstream activities of the renewable-power value chains as well as related fields like smart grids and electricity storage. Assessing the impact of policies on patenting depending on the relevant segment would require refining the available patent data, which is outside the scope of this project due to time constraints.

Explanatory variables

The project has gathered data on more than 70 explanatory variables to capture possible factors for investment flows and patent counts in renewable-power sources. As outlined below and detailed in Annex A.1, the explanatory variables considered by the analysis include:

- Climate mitigation policies (eight variables);
- Investment environment variables (around 50 variables);
- Innovation environment variables (four variables); and
- Control variables (10 variables) to account for non-policy settings, such as market and country conditions.

The large number of possible explanatory variables leads to high model complexity, which can prove problematic for the evaluation and interpretation of a regression model. To resolve this issue, the

lasso model outlined subsequently in the methodology section reduces the number of variables to a smaller set of relevant variables.

Climate mitigation policies

This research project has tested and collected data for eight climate mitigation policies, including:

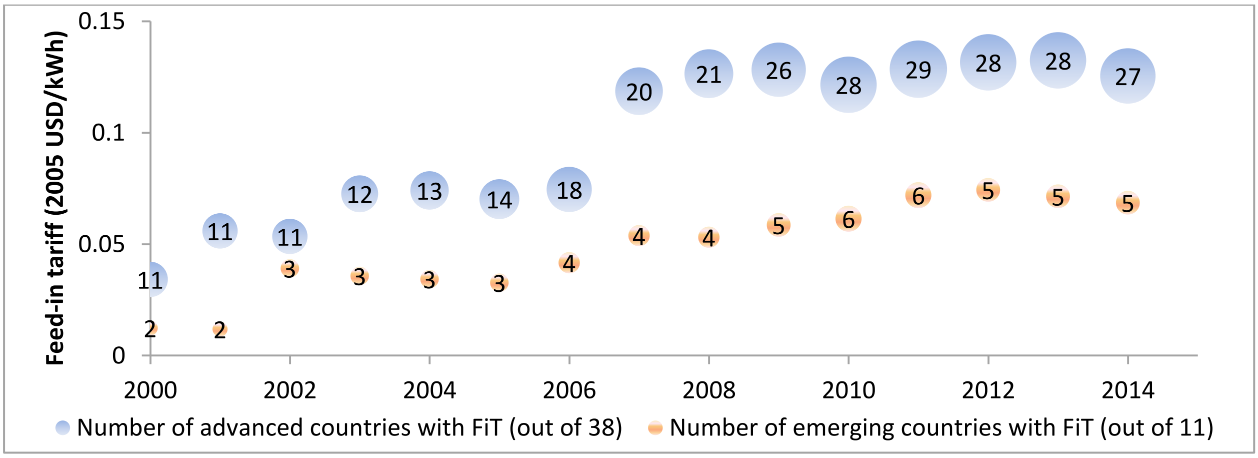
- Targeted investment incentive schemes for renewable power, including: ***feed-in tariffs*** and feed-in premiums (FiTs; in USD/kWh), weighted with the contract duration of FiTs, i.e. the length of associated power purchase agreements (PPAs; in years); ***public tenders***, including competitive bidding and auctions (in MW); ***renewable energy certificates*** (RECs; in % produced by a renewable power source), including renewable portfolio standards and renewables quotas; and ***significant changes in climate mitigation policies***, including retroactive changes and moratoriums to FiTs. In-house data gathering provided data on public tenders and updated the in-house database of FiTs and RECs for 2000-14 across OECD and G20 countries, building on Haščič et al. (2015a) and Cárdenas Rodríguez et al. (2014).

- ***Explicit carbon prices*** (including carbon taxes and emission trading schemes; in USD/tCO_2e) from Ecofys and World Bank (2015), amended by multiple national sources and data reported in OECD (2015q, r).
- ***Energy taxation*** rates in the power sector (in USD per MWh), including specific taxes on energy use in the electricity sector such as excise duties on electricity, based on OECD's Centre for Tax Policy (CTP) research and CESifo data (OECD, 2015l, 2013e; CESifo, 2015).
- ***Support measures to fossil fuels*** use in the electricity generation sector (in USD) from (OECD, 2015k, 2013d, e). The study has extracted data from the OECD's new online database of measures supporting fossil fuels and related publications (OECD, 2015k, 2013d, e).

- Targeted innovation incentives, i.e. ***public RD&D spending*** in renewables technologies (in USD).

Figure 5. Key trends of feed-in tariffs for OECD and G20 countries

(2000-14, by country group, in 2005 USD/kWh; average over countries and sectors with FiTs)



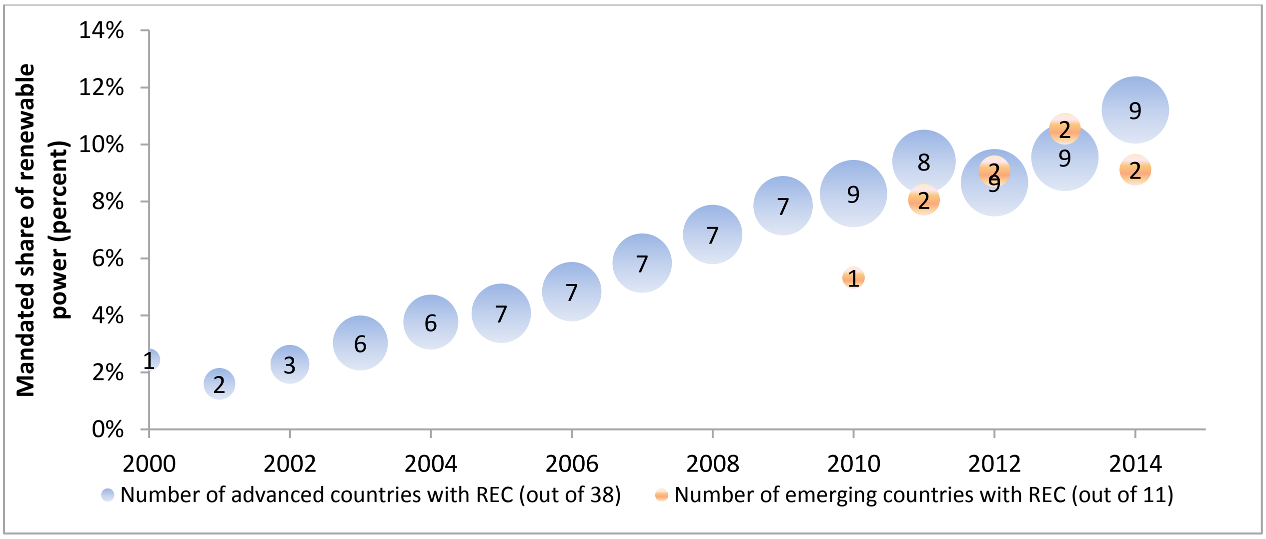
Source: Authors' calculations, based on in-house data gathering and Haščič et al. (2015a).

For a detailed explanation of data and details on comparability issues of policies, especially the FiTs, RECs and tenders, see Annex A.1. Figures 5 to 12 below describe key trends for the climate mitigation policies considered across OECD and G20 countries, from 2000 until 2014.

Figure 5 shows key trends in the development of the average feed-in tariff in the OECD and G20 countries that implemented feed-in tariffs and feed-in premiums.[8] The size of FiTs as well as the number of countries with FiTs roughly corresponds to the growth of investments and patent activity which both accelerated in the mid-2000s, mainly in the solar- and wind-power sectors, as shown in Figure 2. The strong growth in these two particular sectors follows the differentiated nature of FiTs, often targeting one or both of these sub-sectors heavily or exclusively. Though Figure 5 shows a mostly increasing use of feed-in tariffs in emerging countries throughout the sample time span as well, neither the increase nor the number of countries with the policies in emerging countries is as high as in advanced countries. The increase in feed-in tariffs in 2007-09, which was maintained until 2013, was largely driven by post-financial crisis recovery stimulus packages. As the figure also shows, the level as well as the number of countries has plateaued since 2010.

Figure 6. Key trends in renewable energy certificates in OECD and G20 countries

(2000-14, by country group, in percent)



Source: Authors' calculations, based on in-house data gathering and Haščič et al. (2015a).

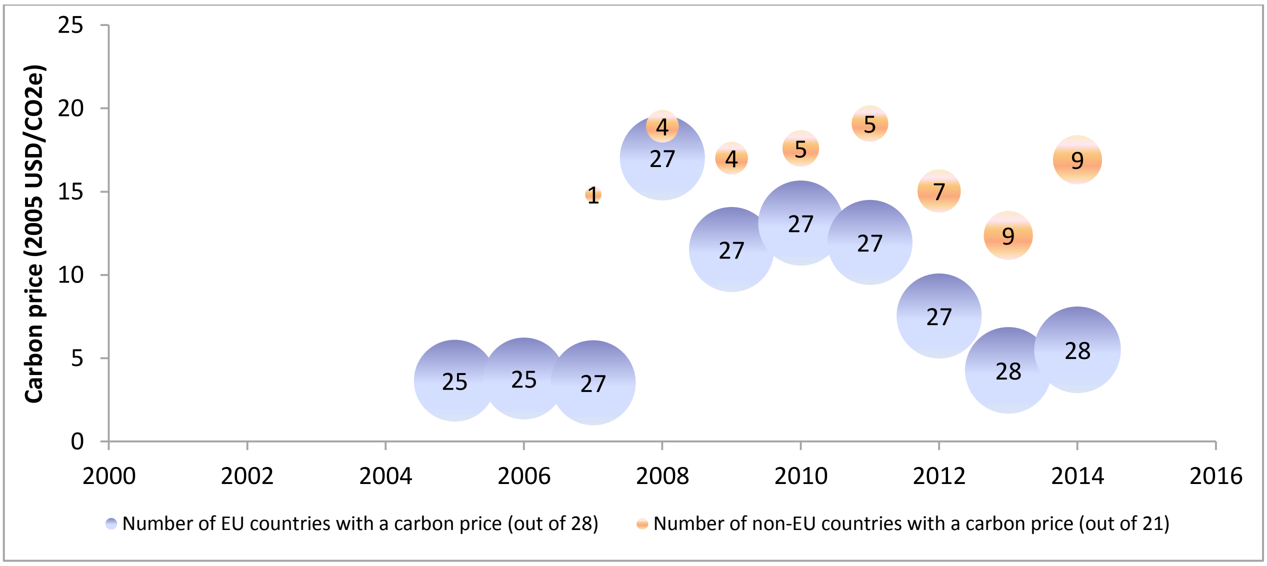
As Figure 6 shows, targets for renewable energy certificates (RECs) have increased steadily. This is due to the fact that such policies often evolve through incremental increases, to reach an eventual target percentage of renewable-power supply. India and Romania are the only emerging economies that implemented RECs in the observed time span. Despite the later start, both countries started at a percentage level comparable to the average value for advanced countries. The decline in 2012 for the sub-sample series for advanced countries is largely due to policy changes in two countries: Italy had relatively high levels of RECs when they stopped the policy in 2012, while Norway implemented a renewable certificate scheme in 2012, but started at the relatively low level of just 3%. The drop off in 2014 in emerging countries is due to Romania scaling back the policy in that year.

8 Note that about 35% of all observed country-sector-years have a FiT, while only 15% have a REC. For 127 country-sector-years these policies coexist. Likewise, FiTs coexist with public tenders in 30 cases.

The level of explicit carbon prices for EU countries (Figure 7) is a result of carbon prices determined by carbon trading as well as electricity-specific carbon taxes. The different prices and taxes are weighted by sector size and part of the economy covered, as far as data is available. Values for the EU shown in Figure 7 are mostly determined by allowance prices in the EU Emission Trading Scheme, which covers the largest emitting sectors in EU countries It is noteworthy here that the strong dependence of the carbon price on ETS price, especially in EU countries, leads to only a weak variation in prices across countries. However, the influence of various non-ETS policies is noticeable in the relatively high carbon price in emerging economies, driven by China's seven pilot carbon schemes.

Figure 7. Key trends in carbon prices in the power sector of OECD and G20 countries

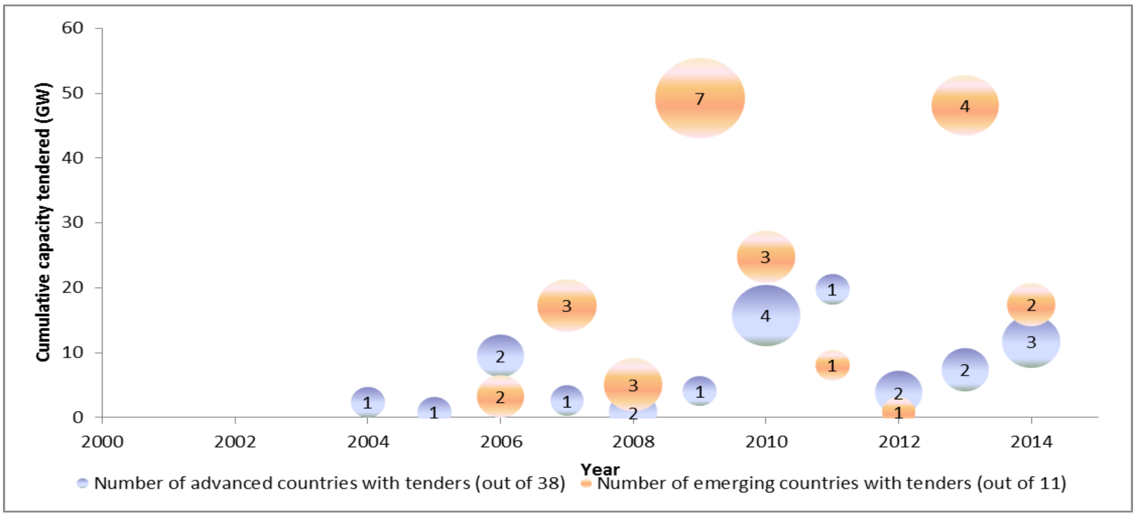
(2000-14, by country group, in 2005 USD/CO2e; average of carbon price for countries with a carbon price)



Source: Authors' calculations, based on in-house data gathering and Haščič et al. (2015a).

Figure 8. Key trends in public tenders and auctions for renewable power in OECD and G20 countries

(2000-14, by country group, in GW)

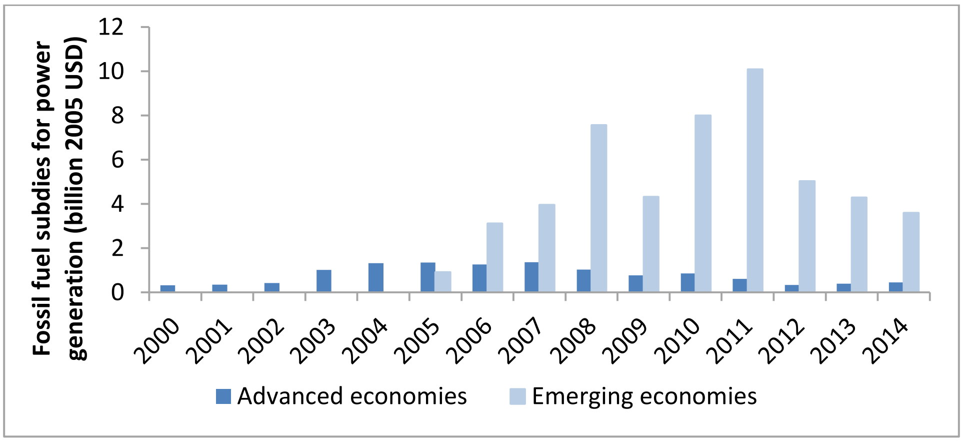


Source: Authors' calculations, based on in-house data gathering.

Even though tenders were not a widely used form of renewable support in OECD and G20 countries between 2000 and 2014, Figure 8 shows that they are more prevalent in number and size in emerging economies.[9] Despite the infrequent use which is owed to the nature of tenders, Figure 8 shows a slightly increased use of tenders in later years, with 2007 as a clear outlier. This overall increase is more pronounced in emerging countries.

Figure 9. Key trends in support for fossil fuels used in power generation

(2000-14, by country group, in billion 2005 USD)



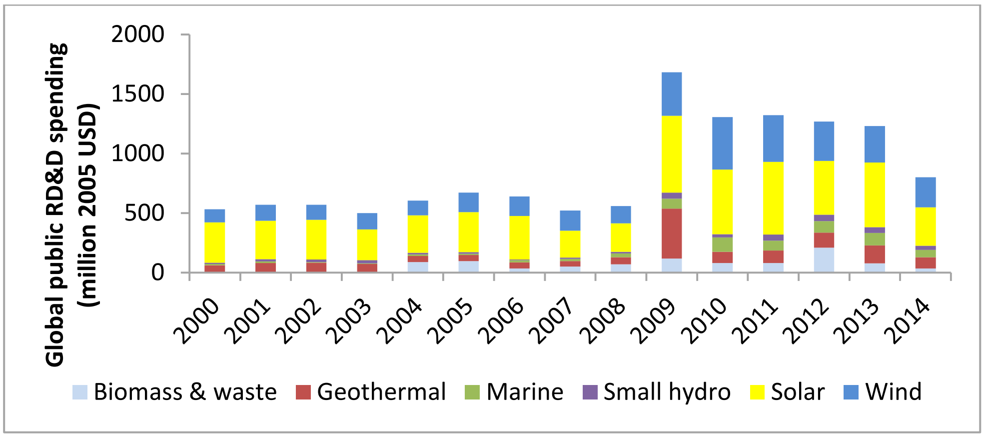
Source: Based on OECD (2015k).

Figure 9 shows that support measures to the use of fossil fuels in power generation have decreased in recent years across OECD and G20 countries. Support for fossil fuels in power generation amounted to almost USD 4 billion in OECD and G20 countries in 2014, primarily in emerging economies (OECD, 2015m). This corresponds to only 10% of total support for fossil fuels in 2014 in G20 and OECD countries. While in advanced countries support in the power sector peaked in the mid- to late-2000s, emerging economies began decreasing support only after the turn of the decade. The decrease in fossil-fuel support for both, emerging and advanced countries, coincides with an increase in renewable-power investments (not shown), warranting the inclusion of fossil-fuel support measures in the analysis, despite its indirect influence on renewable power (i.e. it affects the competitiveness of fossil fuels vis-à-vis renewable power).

9 Note that despite the relatively rare use of tenders in advanced countries in 2000-14, the sample contains 64 observations with tenders, of which 24 are in advanced countries. Of the 64 observations with tender, 30 coincide with FiT schemes in the same sector, country and year.

Figure 10. Key trends in global public RD&D in renewable energy across OECD and G20 countries

(2000-14, by renewable technology sectors, in million 2005 USD)



Source: Authors' calculation based on IEA (2015c), amended by various sources (see Annex A.1 for details).

Figure 10 shows a relatively steady support of public RD&D expenditures in renewables technologies until 2008, with a strong increase of public RD&D support after the financial crisis, likely as part of various post-2008 stimulus packages across OECD and G20 countries.[10] While the additional support for RD&D has been scaled back after 2008, it did not fall back to pre-2008 levels even in the lowest and last year, 2014. While the RD&D spending data suffers from missing values, Figure 10 shows that the majority of public RD&D spending for renewables benefitted the solar-power sector, as well as to some degree the wind-power sector. Since the descriptive figures on RD&D spending and renewable-sector investments cannot provide a completely clear picture of the indirect effect of innovation spending on investments, if any effect exists, an inclusion of RD&D spending in the regression models is warranted.

To cover radical policy changes and the impact of the sheer force of the change rather than the policies themselves, the study also tracks retroactive and significant policy changes to feed-in tariff and renewable energy certificate policies. OECD and G20 countries that implemented retroactive or significant feed-in tariff policy changes between 2000 and 2014 were Belgium, China, the Czech Republic, Finland, France, Greece, Italy and Spain. The study did not find significant policy changes to RECs.

It is important to remind that certain policies qualifying as "climate mitigation policies" for the purpose of this study can be and have been put in place primarily to achieve other policy goals, such as energy security, energy access and raising revenues to improve public finances. Nevertheless, their co-benefits for climate change mitigation are relevant to the present analysis.

The analysis here has excluded other relevant climate mitigation policies, either due to data availability or resource constraints, while recognising their importance. In particular, the study has excluded: net metering policies, since small-scale and distributed renewable-power projects are not covered by the BNEF database; wheeling schemes; tax incentives for renewable-power generation; regulations (such as emissions standards or performance indicators on coal-fired power plants); and

10 Comparing country level data on public RD&D spending for renewable energy reveals that an increase in spending in the United States is responsible for about two-thirds of the 2009 increase (IEA, 2015c). However, as described in Annex A.1, data on public RD&D spending for renewable energy is incomplete and cannot provide a satisfying overview over increases in spending in all countries.

mandates and targets (such as mandatory domestic renewable-power targets). In particular, while the current analysis excludes tax incentives, due to data availability and comparability issues, it recognises that tax incentives such as the United States' Production Tax Credit and Investment Tax Credit, have likely been important drivers of investment in renewable power. Similarly, tax incentives for R&D can be important drivers of innovation, but could not be included due to time constraints. Nonetheless, as highlighted by the report *Aligning Policies for a Low-Carbon Economy*, few tax incentives to leverage private R&D are designed to ensure new entrants are eligible, which may hinder innovation by independent power producers (IPPs; OECD/IEA/NEA/ITF, 2015).

Investment environment variables

The set of investment environment variables consists of more than 50 variables, to assess the investment environment for renewable-power projects and patents. All investment environment variables used in the regression analysis are briefly outlined below, and grouped by key policy areas identified by the OECD *Policy Framework for Investment*, including: investment policy; investment promotion and facilitation; competition policy; financial market policy; trade policy; and public governance. Annex A.1 provides more details on the data sources, data treatment and definitions for the investment environment variables selected by the *lasso* approach.

The investment environment variables identified and selected in the investment model by different iterations of *lasso* (for the base investment model and sub-sample regressions) include:

- Investment policy: ***registering property*** (index); ***regulatory quality*** (index); ***time required starting a business*** (days); ***time to build a warehouse*** (days); and ***time to get electricity*** (days);

- Investment promotion and facilitation: ***ease of doing business*** (composite index that covers investment facilitation, as well as other policy areas); and ***licenses and permit system*** (index);

- Competition policy: ***barriers to services*** (index); ***barriers to networks*** (index); ***direct control of the state over enterprises*** (index); and ***command and control regulation*** (index);

- Financial market policy: ***sovereign credit rating*** (ranks); ***credit to government and SOEs*** (% of GDP); ***domestic credit to private sector*** (% of GDP); ***implementation of Basel III risk-based capital requirements*** (dummy); and ***implementation of Basel III leverage ratio*** (dummy); and

- Trade policy: ***trading across borders*** (index);

- Public governance: ***corruption perception*** (index); and ***political stability*** (index).

The investment environment variables identified in the innovation model by different iteration of *lasso* are listed below (see Annex A.1 for a definition of each variable):

- Investment policy: ***cost of business start-up*** (% GNI per capita); ***resolving insolvency*** (index); ***local-content requirement*** attached to feed-in tariff (%);

- Investment promotion and facilitation: ***ease of doing business*** (index);

- Competition policy: ***direct control of the state over enterprises*** (index); ***governance of SOEs*** (index); ***barriers to services*** (index); and ***command and control regulation*** (index);

- Financial market policy: ***sovereign credit rating*** (index); ***credit to government and SOEs*** (% of GDP); ***domestic credit to private sector*** (% of GDP); ***getting credit*** (index); and ***implementation of Basel III leverage ratio*** (dummy); and

- Trade policy*:* ***trading across borders*** (index).

The study has not collected data on other investment variables, e.g. linked to corporate governance, and corporate disclosure of climate risks. The study has not tested those additional variables due to time and resource constraints, or data availability.

Innovation environment variables

The set of innovation environment variables includes four variables for the investment model, and two for the innovation model. They include, for the investment model: ***perpetual inventory of renewable power-related patents*** (patent count), which accounts for the stock of knowledge in a sector on which research can build; ***innovation spillover*** (patent count); ***number of universities*** (count), which captures directly the potential to create and, partly, to use human capital as input to technology development; and ***strength of intellectual property rights*** (index). The innovation environment variables for the innovation model are: ***number of universities*** (count); and ***perpetual inventory of renewable power-related patents***. Note here that the perpetual inventory variable also controls for the different patenting inventory methods underlying the patent data of the dependent variable, thus avoiding otherwise biased results.

Control variables

The study has collected and considered data on 14 control variables to account for non-policy domestic settings such as market and country conditions. Out of the 14 control variables considered, the 10 control variables selected by the *lasso* approach in the regressions are listed in Table A.1.1.

Methodology and empirical specifications

The overall strategy for the regression analysis is to estimate the effects of determinants on investments and the effects of a similar set of determinants on innovation in separate base regression models. Both analyses are repeated on sub-samples using the same set of variables to bring out results for specific country samples and as a robustness check of the base model results. To provide a more detailed picture of the specific conditions and developments in the largest renewable power sub-sectors, solar and wind, additional analyses are performed for these sectors with additional iterations of *lasso* and therefore re-specified models. The following sections describe the estimation strategy for the overall investment and innovation models, which are analogous to the strategy for the respective sub-sector analyses of the solar and wind sub-sectors.

Investment model

This section introduces the econometric model of the influence of climate mitigation policies, the investment environment factors as well as control variables on investment flows in renewables. The investment model assesses the impacts of explanatory policy variables on the volume of investment in renewable power. Starting with a base investment model, this section also outlines the methodology for additional models with sub-sample data and models testing the influence on the investment environment factors on climate mitigation policies, i.e. interactions between climate mitigation policies and investment conditions.

The empirical specification for renewable power investments follows the working hypothesis that both climate mitigation policies and investment environment variables influence these investments. Accordingly data are fitted to a Poisson model with the following equation:

$$Investment_{ist} = \exp(\,\alpha + \boldsymbol{\beta_1'ClimatePolicies_{ist}} + \boldsymbol{\beta_2'InvestmentEnvironment_{ist}} + \boldsymbol{\beta_3'InnovationEnvironment_{ist}} + \boldsymbol{\beta_4'Control_{ist}} + \gamma_i + \delta_s + \theta_t) + \boldsymbol{\varepsilon_{ist}} \qquad (1)$$

where $i = (1, \dots, I)$ indexes the country invested in, $s = (1, \dots, S)$ includes six renewable-power sub-sectors and $t = (1, \dots, T)$ indexes the years of the flows.

A large set of variables is considered for the four main vectors of equation (1). To avoid redundancy, multicollinearity and additional noise, the least absolute shrinkage and selection operator (*lasso*) selects a subset of the collected variables for use in equation (1)'s four vectors. This section presents only those variables selected by the *lasso*. For a full list of variables considered by the *lasso,* please refer to Annex A.1 and for a discussion of the *lasso* method please see below.

$\boldsymbol{ClimatePolicies_{ist}}$ is a vector of climate mitigation policy variables, which captures public policy interventions with a possible impact on renewables investments. Among the climate variables, the model includes sector-specific *feed-in tariffs* (in USD per kWh weighted with the power-purchasing agreement duration), *renewable energy certificates* (in percentage points) and sector-specific public renewable capacity tenders (*public tenders*, in MW) as proxies for the three main policy measures directly supporting the use of renewable power. Data for FiTs and RECs are updated based on data used in Haščič et al. (2015a) while data on tenders were newly collected for this report. Further, the vector of climate mitigation policy variables includes a proxy for *explicit carbon prices* (in USD), *energy taxation in the power sector* (in USD/MWh), *public RD&D spending* (in million USD) and the amount of *fossil fuel support for power generation* in a country (in USD, as natural logarithm). Note here that the data on RD&D spending is not country specific. Since many countries are missing data for many years we use the yearly sector-specific cumulative value for *public RD&D spending* as proxy, making the assumption that the RD&D supported by this spending is disseminated quickly enough to have a global effect. The binary variable on *significant changes in climate mitigation policies* (including retroactive changes) had to be excluded already at the stage of variable selection since it likely caused multicollinearity too strong for the *lasso* model to properly be calculated. With the exception of *fossil fuel support for power generation*, all variables in the $\boldsymbol{ClimatePolicies_{ist}}$ vector are expected to show a positive effect since they are either direct support policies of renewable power investments or cause a higher price on competing fossil fuel technologies. *Fossil fuel support for power generation* is expected to show a negative effect since it supports competing technologies to renewable power.

The $\boldsymbol{InvestmentEnvironment_{ist}}$ vector includes variables for the general investment environment possibly affecting investment in the renewables sector, which are previously listed. With few exceptions, these variables are expected to have a positive sign in the regression either because they are expected to be conducive to renewable-power sector investments or the indices that capture the variables' effect are created so that larger values represent greater conduciveness. Exceptions are *time required starting a business, barriers to services, barriers to network sectors*, *time to build a warehouse*, *time to get electricity* and *implementation of Basel III regulation* which are expected to have a negative effect on investments and *direct control of the state over enterprises*, for which the causal relationship with investment activity is unclear.

The $\boldsymbol{InnovationEnvironment_{ist}}$ vector includes variables specifically influencing the innovative capacity in a country, as described previously. All factors are expected to show a positive influence on investments in the regression analysis.

The $\boldsymbol{Control_{ist}}$ vector includes variables holding constant for factors that are neither climate mitigation policies nor directly part of the investment or innovation environment. Though their effects might be of general interest, they mainly serve to enable unbiased results of climate mitigation policy and investment environment variables. The control variables selected by the *lasso* for the base investment model are: *FDI inflows* (million USD); *natural resource endowment* (standardised unit), as proxy for natural conditions that each renewable energy source relies on, such as wind strength for wind energy or insolation for solar energy; *electricity generation* (GWh); *tertiary education* (percentage enrolment), *carbon intensity of energy* (tCO_2e/toe), *CO_2 emissions* (kton CO_2); *electricity consumption* (terajoule); *average most-favoured nation tariff* (percent); and *regulatory capital to risk-weighted asset* (ratio). Even though these variables serve as controls, they are expected to have a conducive relationship and therefore show a positive sign in the regression model, with the exceptions of *average most-favoured nation tariff* which is expected to hinder investments and *regulatory capital to risk-weighted asset* (ratio), *Carbon intensity of energy, Logarithm of CO_2 emissions* as well as *electricity consumption,* for which the causal relationship with investment activity are unclear.

Finally, γ_i controls for country fixed effects, δ_s controls for sector fixed effects and θ_t controls for year fixed effects. The remaining variation is captured by the residual ϵ_{ist}. Monetary values for all variables are in constant 2005 USD.

The estimation procedure applied to the above investment model has to account for sector-specific data which suffer from a so-called zero-inflation. The frequent occurrence of zeros in the dependent variable of the model is simply due to some countries not investing in some sectors in some years. While these observations might seem irrelevant, disregarding all observations with a zero-investment could exclude important information on the determinants of investments and would therefore likely lead to biased regression results. To counter this zero-inflation, we follow Santos Silva and Tenreyro (2006) and use their Poisson pseudo-maximum likelihood (*ppml*) method for log-linearised models. *Ppml* is an appropriate choice since it counters the zero-inflation bias without requiring additional information on the cause of the zero-inflation. *Ppml* also has two distinct advantages over alternative 2-step approaches like a Tobit II ("Heckman") model or a zero-inflated Poisson (*zip*) model. First, *ppml* does not have to rely on an exclusion restriction since the zero-inflation rather than selection bias is the issue. Second, the implementation of a Poisson *lasso* approach in statistical software is congruent with the *lasso* for *ppml*, whereas *lasso* for Tobit II and *zip* have not been implemented in standard software to our knowledge. As suggested in Santos Silva and Tenreyro (2006) the regression analysis uses the Poisson Stata command with the *robust* option.

Innovation model

This section introduces the econometric model of the influence of climate mitigation policies, the investment and innovation environment factors as well as control variables on technological development in the renewable-power sector.

Empirical specification of the innovation model

Building on seminal as well as recent literature (Dechezleprêtre et al., 2013; Johnstone et al., 2010; see Annex A.2), the innovation model follows a strategy of analysis similar to the above investment model. Since the model builds on hypotheses analogous to that of the investment model it also includes climate mitigation policies, and investment environment as well as innovation environment variables. Even though the content of the main vectors has changed slightly, the reduced-form equation for the negative binomial regression model is similar to that of the investment regression:

$$Patent\ Count_{ist} = exp(\zeta + \boldsymbol{\eta}_1' \boldsymbol{ClimatePolicies}_{ist} + \boldsymbol{\eta}_2' \boldsymbol{InvestmentEnvironment}_{ist} + \boldsymbol{\eta}_3' \boldsymbol{InnovationEnvironment}_{ist} + \boldsymbol{\eta}_4' \boldsymbol{Control}_{ist} + \gamma_i + \delta_s + \theta_t) + \boldsymbol{\varepsilon}_{ist} \quad (2)$$

where $i = (1, \ldots, I)$ indexes the country invested in, $s = (1, \ldots, S)$ indexes the six renewable-power sectors and $t = (1, \ldots, T)$ indexes the years of the flows.

In this equation $\boldsymbol{ClimatePolicies}_{ist}$ is the same vector as in the investment equation, i.e. also includes feed-in tariffs (FiT in USD per kWh), renewable energy certificates (REC, in percentage points), public renewable capacity tenders ($public\ tenders$ in MW) explicit carbon prices ($Carbon\ Price$ in USD), *energy taxation in the power sector* (in USD/MWh), *public RD&D spending* (in million USD) and the amount of *fossil fuel support for power generation* in a country (in USD, as natural logarithm). The same caveat with respect to data paucity of *public RD&D spending* as in the investment model applies here. The only added variable in this vector compared to the investment model is the binary variable on *significant changes in climate mitigation policies*.

As in the investment model all variables in the $\boldsymbol{ClimatePolicies}_{ist}$ vector are expected to show a positive effect except for *fossil fuel support for power generation* and s*ignificant changes in climate mitigation policies*. While the explanation of the positive effects of this vector's variables as well as the negative effect of *fossil fuel support for power generation* is analogous to the explanation in the investment case, the additional variable s*ignificant changes in climate mitigation policies* is expected to have a negative effect on innovation since it might capture uncertainty regarding long-term prospects of technology development.

The $\boldsymbol{InvestmentEnvironment}_{ist}$ vector includes variables for the general investment environment possibly affecting technology development in the renewables sector, which are previously listed. With few exceptions, these variables are expected to show a positive sign in the regression either because they are expected to be conducive to renewable-power sector investments or the indices that capture the variables' effect are created so that larger values represent greater conduciveness. Exceptions are *barriers to services, cost of business start-up, local-content requirement attached to feed-in tariff* and *implementation of Basel III leverage ratio* which are expected to have a negative effect on investments and *direct control of the state over enterprises* as well as *governance of SOEs*, for which the causal relationship with investment activity is unclear.

The $\boldsymbol{InnovationEnvironment}_{ist}$ vector includes the four innovation environment variables, which are previously described. All are expected to be conducive to innovation in renewables technology.

The $\boldsymbol{Control}_{ist}$ vector includes variables measuring non-policy settings: *natural resource endowment* (standardised units); *electricity generation* (GWh); *tertiary education* (percent enrolment); *FDI inflows* (million; *logarithm* USD); *CO_2 emissions* (ktoe CO_2e); *electricity consumption* (terajoule); and *average most-favoured nation tariff* (percent). Even though these variables serve as statistical controls, they are expected to show a conducive relationship in the regression model, with the exceptions of *average most-favoured nation tariff* which is expected to hinder investments.

Finally, γ_i controls for country fixed effects, δ_s controls for sector fixed effects and θ_t controls for year fixed effects. The remaining variation is captured by the residual ϵ_{ist}. Monetary values for all variables are in constant 2005 USD.

The empirical specification of the innovation model for patent count data follows empirical literature on technology development in general (Haussman et al., 1984; Meliciani, 2000) and recent literature on environmental patents in particular (Johnstone et al., 2010; see Annex A.2 for a discussion of

empirical literature on technology development). Consequently, patent counts in the renewables sector are modelled as negative binomial data, which is appropriate for count data[11].

Reducing model complexity

To reduce model complexity and increase interpretability, the innovation and investment models are based on variable selection by the *least absolute shrinkage and selection operator* (lasso). It is not trivial to reduce the large number of possible determinants of investment and innovation in the renewable-power sector to a manageable set of relevant determinants. As Annex A.1 shows, the study collected data for more than 70 determinants (i.e. explanatory variables). Using all of these possible determinants in the same regression model would mean including redundant determinants, causing multicollinearity and creating unnecessary white noise. Since no detailed understanding of the impact and interdependence of all investment environment factors or control variables exists, we rely on the *lasso*[12] to select statistically relevant determinants for these vectors (Tibshirani, 1996; for an application to patents see Zachmann et al., 2015).

The *lasso* method identifies a shrunk set of determinants by penalising the absolute size of determinants' coefficients in the regression procedure. This penalty creates a trade-off between finding the error-minimising estimators in the regression and the number of variables with non-zero coefficients. By assigning these penalties to coefficients, they are shrunk towards zero and some eventually to exactly zero according to how much or little they contribute to minimising the mean-squared error in the estimation. Determinants with a coefficient of zero can be discarded from the set of variables, so that the remaining determinants constitute the set of relevant variables.

The eventual number of determinants shrunk to zero depends on a tuning parameter λ which influences the size of the penalty. A λ set to zero corresponds to no penalty and the *lasso* would select all suggested determinants; a λ set to a large value would shrink a large portion of coefficients towards 0 and therefore the list of selected determinants would tend towards an empty list. To find an optimal λ, the cross-validation[13] identifies the λ that minimises the forecasting error of the *lasso* results, based on repeated random draws of observations (Park and Casella, 2008; Tibshirani 1996).

While all variables could be penalised, the *lasso* here neither applies a penalty to the climate mitigation policy determinants nor to the fixed effects. Previous analyses (Haščič et al., 2015a; OECD/IEA/NEA/ITF, 2015) as well as the very concept of climate mitigation policies show that climate mitigation policies are important factors for investments and innovation in the renewables sector. Not penalising the variables capturing these policies guarantees that these factors are selected by the lasso and enter the subsequent regression analysis. Not penalising climate mitigation policy variables and fixed effects, which are a modelling necessity given the panel structure of the data, also ensures that the selection of other variables is based on a variable set containing these unpenalised factors.

11 The negative binomial model also deals efficiently with overdispersion, which otherwise was present in an alternative Poisson model.

12 The lasso analysis was carried out using R version 2.15.3 with the "glmnet package 1.9-5". For both, the innovation and investment models, the link for the *lasso* is Poisson, which covers ppml as well as the negative binomial distribution.

13 Note that the cross-validation results present two alternative λs. For the investment model we use the minimising λ and for the innovation we use the heuristic λ which delivers a less complex model and estimates the expected generalisation error within one standard error of the minimum. In both cases these choices were the only possible λs delivering reasonably specified models.

Note that even though the resulting coefficients of the *lasso* technique are biased due to the applied penalty, the results of the subsequent ppml and negative binomial regression analysis presented in the results section are not. After the shrunk set of determinants is identified by *lasso*, the set is used in the Poisson or negative binomial estimation appropriate to the respective analysis. Since these estimations do not apply penalties they are free of bias caused by the penalties of the *lasso*, but can rely on a set of relevant variables delivered by the *lasso*.

This *lasso* procedure is carried out once for the investment model and once for the innovation model. Accordingly, the set of variables selected by the *lasso* for the investment model is different from the set of variables selected for the innovation model. In an additional analysis of the factors for the sub-sectors wind and solar, the *lasso* is applied to data of only these sub-sectors. Due to the strong technical development of later years of these sub-sectors and their size in terms of investments and patents filed, different factors apply to these sectors than to the renewables sector overall.

RESULTS AND INTERPRETATIONS OF THE ECONOMETRIC STUDY

This chapter presents key empirical results of the investment and innovation models. Results are consistent with the paper's hypothesis that, beyond setting stronger and coherent climate mitigation policies, policy makers also need to improve the quality of the investment environment and carefully assess its cross-effects with climate mitigation policies, to help drive investment and innovation in renewable power. The study analyses data of more than 70 explanatory variables to help explain investment flows and patent counts in renewable power. This chapter only presents results based on the explanatory variables that were selected for the investment and innovation models through the *lasso* approach. After using this approach, the investment and innovation models identify the set of variables that have a statistically significant impact on investment flows and patents in renewable power, and which therefore can be considered to mobilise or deter investment flows and patent activity in renewable power. Box 1 explains how to interpret the results of the investment and innovation models. Annex A.1 presents the descriptive statistics, sources and data treatment of each selected variable.

This chapter also briefly discusses policy implications, which will be further analysed in a forthcoming policy paper. It also highlights caveats to consider when interpreting results. In particular, despite this paper's robust variables' selection approach through the *lasso*, the results of the regression analysis are subject to the list of analysed variables, the quality of data and the prior understanding of causal links between the dependent and explanatory variables, as with any regression analysis.

Box 1. How to interpret the results of the investment and innovation models

Interpreting the results of the investment and innovation models requires looking at: 1. variables that have a "statistically significant" result; and 2. the sign and value of the estimated coefficient of such variables. First, a variable with a "statistically significant" result means that the effect of a variable is not zero and that the coefficient of the variable keeps its sign with high certainty. The statistical significance is represented in Tables 3, 4, 5, 7 and 8 by asterisks according to the level of certainty (at 1%, 5% or 10% significance levels). In those tables, the reader should only interpret the coefficient of variables that are statistically significant – i.e. the bold numbers in the tables. For the purpose of this working paper, the "effect" of a given policy variable in the investment model is determined by showing a statistically significant result in mobilising (or deterring) investment flows or patenting activity in renewable power in G20 and OECD countries. **Results that are not statistically significant should not be interpreted** (e.g. if a variable's coefficient is statistically significant in emerging economies but not in advanced countries, it does not have implications for advanced countries). Second, the estimated coefficient of policy variables indicates whether the effect of policies captured by this variable is positive or negative. It also provides the best point estimate of the size of the impact.

The size of the impact on overall volumes of investment (in USD) and patent counts can also be interpreted directly. The reported coefficients can be transferred into percentage increases of investments or patent counts that would be caused by an increase of a variable by one unit, e.g. one USD or one MW, provided all other values in the model stay the same. These results provide a measure of the effect level of a given variable. For example:

- The results in Table 3 for the emerging economies sub-sample investment regression show a coefficient of 0.105 for ***explicit carbon price***. This means that an increase in ***explicit carbon price*** by 1 USD/tCO_2e would lead to a rise of investment by the exponential factor $e^{0.105} \approx 2.72^{0.105} \approx 1.11$, i.e. an increase of 11%.
- The results in Table 7 for the base innovation model show a coefficient of 0.039 for ***feed-in tariffs***. An increase of this variable by one percentage point would lead to an increase of patents by the exponential factor $e^{0.039} \approx 2.72^{0.039} \approx 1.04$, i.e. an increase of 4%.

This paper does not provide information on the "cost-effectiveness" of policies, since the study does not include data on the costs of renewables technologies and projects. It does not provide either information on the "value for money" of policies. Future work could relate the outcomes of this regression exercise to the cost structure of renewable power projects. Furthermore, this paper does not allow for an assessment of relative effectiveness across different policies. This is because the coefficient sizes of different policy variables are not comparable since these variables are measured in different units (FiTs for instance are expressed in USD/kWh, while public tenders are expressed in MW).

Results of the investment model

This section presents results from the investment model, to interpret the effects of explanatory policy variables on the volume of investments in renewable power in G20 and OECD countries[14] between 2000 and 2014. Statistically significant results are presented for the base investment model and in sub-sample investment regressions for sub-groups of countries and technologies (See Table 1 for a detailed list of the countries considered as advanced countries or emerging economies).[15] This section also presents results for the statistically significant interactions between climate mitigation policies and investment environment variables.[16] Table 2 gives an overview of key selected statistically significant results from the investment model. As mentioned in Box 1, results that are not statistically significant (in empty cells in Tables 3 through 8) should not be interpreted.

Table 2. Key policy drivers and deterrents of investment in renewable power in OECD and G20 countries

(Based on selected statistically significant results from the investment model)

		Investment model						
		Base investment model	Advanced countries	Emerging economies	EU countries	Non-EU (OECD and G20)	Solar power	Wind power
Climate mitigation policies	Feed-in tariffs	+	+		+	+	+	
	Renewable energy certificates	+	+				+	+
	Public tenders	+		+				+
	Explicit carbon prices			+	+		+	
	Public RD&D spending						-	+
	Energy taxation in power sector						+	-
	Support measures to fossil fuels in power sector			-			+	n/a
Investment conditions	Ease of Doing Business			+		+		
	Corruption perception	n/a	n/a	n/a	n/a	n/a	-	n/a
	Regulatory quality	n/a	n/a	n/a	n/a	n/a	+	n/a
	Registering property	+	+			+	+	n/a
	Time to build warehouse	n/a	n/a	n/a	n/a	n/a	-	n/a
	Licenses and permit system	n/a	n/a	n/a	n/a	n/a	+	-
	Direct control of the state over enterprises	+	+				+	+
	Sovereign credit rating	+	+					
	Domestic credit to private sector	+	+				n/a	n/a
	Credit to government and SOEs						-	n/a
	Implementation of Basel III leverage ratio	-	-			-		
	Trading across borders				+		n/a	+

Notes: "+" Indicates that the corresponding variable had a statistically significant and positive effect on investment in the base investment model or sub-sample regressions; "- " Indicates that the corresponding variable had a statistically significant and negative effect on investment in the base investment model or sub-sample regressions; n/a indicates that the variable was not selected by the lasso approach in a given investment regression, so the result for this specific variable and specific regression is not applicable. See Table 1 for a detailed list of the countries considered as advanced countries or emerging economies. See the subsequent section on results and interpretations as well as Tables 3, 4 and 5, for more information on these results.

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14 Please note that due to missing data for some explanatory variables, all observations for Argentina, Indonesia and Saudi Arabia are omitted from the regression analysis of the investment model.

15 The percentage value increase in investments caused by a one unit increase of a statistically significant variable is noted in brackets in the subsequent interpretation section.

16 The study has undertaken thorough tests with lagged variables (on most variables), which demonstrated that neither the set of variables selected through the *lasso* approach, nor the main results of the model, change in a meaningful way when using lagged variables compared to variables without lags.

Results from the base investment model

This section presents results from the base investment model, with climate mitigation policies and investment environment variables selected in the *lasso* approach, to interpret the impact of each explanatory policy variable independently of each other (see results in Table 3). These results are representative for the surveyed sample of OECD and G20 countries for the time period 2000-14, across the six sub-sectors of renewable-power technologies.

Results from the base investment model on climate mitigation policies are consistent with the hypothesis from Haščič et al. (2015a) and Polzin et al. (2015) that targeted investment incentives mobilise renewables investment:

- Targeted investment incentives, including ***feed-in tariffs*** and feed-in premiums (FiT) weighted with the duration of power purchase agreements (PPAs),[17] ***renewable energy certificates*** (REC) and ***public tenders***, all have positive and statistically significant impacts on the volume of investment in renewable power (corresponding to a 9%, 8% and 0.02% increase in investments per unit increase of FiTs, RECs and tenders, respectively).[18] These results confirm the hypothesis that investment incentives such as FiTs, RECs and public tenders, combined with long-term power purchase agreements, have contributed to encouraging investment in deployed, commercial-scale renewable power projects until 2014. Feed-in tariffs are statistically significant at the 1% level, while RECs and tenders are only statistically significant at the 10% level. It is important to note the differentiated nature of FiTs, which are often targeting a specific renewable technology, unlike RECs, which do not differentiate between renewables sub-sectors. Nonetheless, the similar percentage increases of FiTs and RECs (9% and 8% respectively) allow for an indirect comparison of FiT and REC policies. The similarity shows that an increase of either variable by one unit, i.e. an increase of the FITs by 1 USD/kWh or an increase of RECs by 1 percentage point, causes a similar increase in renewables investment across OECD and G20 countries. Therefore, since the effect of a unit increase on investment for either policy is similar, the policy change that comes with a smaller burden to the economy should be preferred. It is important to note however that this comparison may differ from country to country as costs might vary.

- The variable measuring ***explicit carbon prices*** does not have a statistically significant effect on the volume of investment in renewables in the base investment model. This result does not imply that carbon prices do not stimulate investments in the renewables sector. The regression results presented here are influenced by two aspects that might obfuscate the real impact of carbon prices in some models: 1. the presence of year-fixed effects in the investment model; and 2. the quality of carbon price data. Firstly, the year-fixed effects account for those factors which do not change between observations in given years and are not explicitly included in the model. This could for example be an energy price shock that affects all OECD and G20 countries and all sectors in a year. These year-fixed effects also take up parts of the effect of carbon prices, since carbon prices in the sample do not change much in given years. The fact that year-fixed effects take up the carbon price effect renders the carbon price variable itself statistically insignificant in the base model and some other models. Removing the year-fixed effects from the base investment model indeed reveals a statistically significant and positive effect of carbon prices (but is not shown here

[17] Note that the weighting of the feed-in tariff (FiT) with the length of the associated power purchase agreement (PPA) made the FiT variable more precise and accurate, but it did not change much the results compared to a simple FiT variable; Due to data availability constraints, the public tender is not weighted with the length of associated PPAs.

[18] As a reminder, the effect of different policy variables is not comparable as variables are expressed in different units, e.g. USD/KWh for FiTs, % for RECs and MW for tenders.

since it might be biased due to not controlling for year-fixed effects). Secondly, there is lack of variation in the variable measuring explicit carbon prices. Due to the lack of available and comparable data for carbon taxes or national or sub-national emissions trading schemes, the prices measured in the present analysis are primarily based on the EU ETS and comparable carbon trading price data. As a result, the data contains similar if not the same carbon prices in given years for a majority of countries. This probably explains why the effect of explicit carbon prices is not statistically significant. In future work, additional and more refined data (or a widening of the country set) could increase the variation within the explicit carbon price variable to help reveal the true effect of explicit carbon prices on investment in renewable power. Apart from methodological concerns on explicit carbon price, an additional reason for the statistically insignificant result might be of an economic nature, as discussed in Annex A.2. The statistically insignificant result does not mean that explicit carbon prices are not important to shift investment away from fossil-fuel technologies in the power sector and towards renewables. An alternate explanation could be that explicit carbon prices were too low across OECD and G20 countries between 2000 and 2014 to provide a strong enough signal to the investment market. In addition, explicit carbon prices target GHG emissions reductions across the economy, or across the power sector, so the impact of explicit carbon prices is by definition not directly targeting renewables investment, unlike feed-in tariffs and other investment incentives. Despite these shortcomings of the methodology and variable construction to capture the effect of explicit carbon prices, the variable still shows a positive and statistically significant effect in several sub-sample regressions, as discussed subsequently.

- Similarly, ***energy taxation in the power sector*** does not have a statistically significant effect on renewable investment. This is likely due to the relatively low energy taxation levels in the electricity sector in OECD and G20 countries. In addition, energy taxes in the electricity sector do not necessarily target fossil fuels. To have an effect on the carbon-intensity of electricity markets, taxes would have to be levied on the fossil-fuel inputs to power generation.

- ***Public RD&D spending*** does not have a statistically significant effect on renewable investment. This result can first be explained by the fact that levels of public RD&D expenditures across OECD and G20 countries from 2000-14 have not been in the same order of magnitude as public support through feed-in tariffs and other targeted deployment incentive schemes, as discussed in the introduction. In addition, public RD&D spending targets research, development and demonstration of earlier-stage technologies, not deployment of mature, grid-scale renewable power plants.

Results further verify the hypothesis that beyond climate mitigation policies, several investment environment variables also influence investment in renewable power, across key policy areas identified by the OECD *Policy Framework for Investment:*

Investment policy

- The variable ***registering property***, which measures the ease of purchasing lands and buildings and the quality of the land administration system, has a positive and statistically significant effect on investment flows in renewable power (a 3% increase in investments for an additional index point for ***registering property***). This result is consistent with the hypothesis that facilitating the acquisition process for land and real estate is critical to unlock investment in renewable power. This result is consistent with the hypothesis from the *Policy Guidance for Investment in Clean Energy Infrastructure* that land rights can hamper renewable power projects by creating delays, land speculation and increased transaction costs.

Competition policy

- Results suggest that ***direct control of the state over enterprises*** also has a positive and statistically significant impact on the volume of investment in renewable power (a 34% increase for one index point increase). This indicator captures the existence of special voting rights by the government in privately-owned firms and constraints to the sale of government stakes in publicly-controlled firms, across 30 business sectors. This result suggests that the presence of state-owned enterprises (SOEs) or government control on incumbent utilities does not necessarily create barriers to entry or other competitive disadvantage for investors in renewable power, unlike the initial hypothesis that market concentration and levels of state-ownership can hinder investment in renewable power. This result could reflect either the propensity of state-controlled or partially state-invested companies to invest in renewable power, or the positive impact of public investment in grid extension and connection on renewables investment. This suggests that countries where direct state control exists are likely to have more public investment and less private investment, and that the net impact is more overall investment. Indeed, grid capacity and investment gaps in the transmission and distribution grid are often highlighted as key impediments to renewable-power investment (OECD, 2015b). Another possible interpretation is that public support to investment in renewable power through investment incentives is provided through state-owned or state-controlled enterprises or public utilities in the power sector. The variable, however, is not specific to utilities in the power sector. Further research is therefore needed to refine the analysis in the electricity generation sector (OECD, 2017b forthcoming).
- The variable measuring ***barriers to network sectors*** has a positive and statistically significant impact on investment flows in renewable power (a 178% increase for one additional index point). This variable measures the inability to enter markets, in network sectors, including in transport, gas, telecommunications and power sectors. This result is inconsistent with the hypothesis from the *Policy Guidance for Investment in Clean Energy Infrastructure* that barriers to entry for independent power producers of renewable energy in the electricity market vis-a-vis incumbent utilities (e.g. in transmission and distribution) can significantly hamper investment in renewable power projects. This surprising result is probably driven by two factors. First, this variable captures the mixed effect of state-owned enterprises and state intervention in the power sector. This means that the presence of SOEs, incumbent utilities and state intervention in the power sector can have a mixed effect on investment in renewable power, which warrants additional research (OECD, 2017b forthcoming). Second, this result is likely due to the fact that the variable ***barriers to network sectors*** is not specific to the power sector; instead, it captures barriers in other network sectors. Such barriers are higher in emerging economies such as China and India, while investment in renewable power has increased significantly in those markets in the data set, which might explain the result.

Financial market policy

This section presents results on policy variables related to financial market policy, which have a statistically significant effect on renewables investment. They include: ***domestic credit to private sector; sovereign credit rating***; and ***implementation of Basel III leverage ratio***.

The variable ***domestic credit to private sector*** has a positive and statistically significant impact on investment flows in renewable power in OECD and G20 countries (a 1% increase for a percentage point of increase). This variable measures the financial resources provided to the private sector by financial corporations, through instruments such as loans, purchases of non-equity securities and trade credits. This result is consistent with the hypothesis that access to financing can encourage investment in capital-intensive renewable power projects (OECD, 2016a; Wohlgemuth and Madlener, 2000; Kahn, 1996).

The variable ***sovereign credit rating*** also has a positive and statistically significant impact on investment flows in renewable power in OECD and G20 countries (a 21% increase for one additional rank). Sovereign credit rating indicates the risk level of the investing environment of a given country, and evaluates a country's ability to repay obligations or its likelihood of not defaulting. This result is consistent with the hypothesis that financial market conditions, and especially countries' political risk, and their ability to meet their financial obligations, are influencing investment flows in grid-scale renewable projects, which often bear high upfront capital costs and require significant debt financing. Specifically, sovereign credit ratings reflect a country's budget situation, which in turn affects the perceived ability to pay feed-in tariffs and other support schemes over an extended period of time.

The investment model provides interesting results on the impacts of Basel III implementation on renewables investment. The new Basel III framework for bank regulation was introduced after the 2008 financial crisis to strengthen the resilience of the banking sector and provide an international framework for measuring and monitoring liquidity risk (Box A.1.1; BIC 2015a, b, c, 2014a, b, c; Blundell-Wignall and Atkinson, 2010). The different components of Basel III banking rules have been introduced gradually, starting in 2013, and as early as 2011 for a few countries, and are expected to be fully implemented by 2019. In particular, the Basel III framework introduced a simple, transparent, non-risk based leverage ratio to act as a credible supplementary measure to the risk-based capital requirements (BIS, 2014c). The leverage ratio is intended to: restrict the build-up of leverage in the banking sector to avoid destabilising deleveraging processes that can damage the broader financial system and the economy; and reinforce the risk-based requirements with a simple, non-risk based "backstop" measure (BIS, 2014c).

The dummy variable capturing ***implementation of Basel III leverage ratio*** until 2014 (see Box A.1.1 in Annex A.1) shows a negative and statistically significant impact on the volume of investment in renewable power of OECD and G20 countries (a 48% decrease if rule is implemented). This result is in line with public comments from several financial stakeholders that Basel III may have unintentionally constrained the ability of banks to provide long-tenor debt financing to capital-intensive renewable power infrastructure projects (UNEP, 2015b; OECD, 2015t). Although the variable only measures the implementation of Basel III leverage ratio in countries until 2014 (the last year in the dataset), it captures significant changes in the global financial system for infrastructure investment. Even in its relatively simple form as a dummy variable, it captures the effects of the regulation changes well enough to discern a negative effect. To exclude the possibility that the result on Basel III leverage ratio dummy variable is driven by banks' capitalisation levels and financial stability across countries, the study has considered a variable on ***regulatory capital to risk-weighted asset ratio*** from the IMF, which was not selected by the *lasso* in the base investment model, and tested the inclusion of this variable despite the *lasso* results. The tests reveal that the results on the Basel III leverage ratio are stable even in presence of the ***regulatory capital to risk-weighted asset ratio*** variable.

There are important caveats on the interpretation of the Basel III leverage ratio result. First, it may be difficult to disentangle the effects of the gradual implementation of Basel III leverage ratio from the effects of the banks anticipating their compliance to the new regulations, and from the more general deleveraging of bank balance sheets, which started in the aftermath of the global financial crisis of 2008. All three developments have been ongoing in parallel, all leading to leaner bank balance sheets and a strong preference for more liquid assets. Second, banking regulators may be more forceful in implementation where banking sectors are healthy (and therefore would do less harm, especially in a difficult post-crisis environment); in such cases implementation could indicate stronger banking sectors and more lending for new investment (although delays with implementation might indicate regulatory forbearance). Third, the simple dummy variables do not capture the granularity of Basel III regulation framework (e.g. regarding the treatment of certain asset classes), and the heterogeneity of country-specific financial and prudential regulations, beyond Basel III (Young, 2016; Sabel et al. 2013). Fourth, the leverage ratio dummy variables do not capture the granularity of the current discussions on the effects of

Basel III, e.g. in the detail of how certain asset classes are treated in the Basel III regulation framework. Finally, it is important to acknowledge that this study does not assess the impact of Basel III leverage ratio's implementation on long-term capital intensive investment other than renewable power, especially in other infrastructure sectors, so the study does not provide evidence that the impact of Basel III is specific to renewable power. Nonetheless, this econometric result is important, as it may suggest, despite important caveats, the need to consider the possible unintended consequences of Basel III leverage ratio in constraining renewables infrastructure investment (especially since the variable is extremely stable across multiple runs).

All control variables, as well as innovation environment variables, have the expected sign whsen statistically significant in the base investment model. They are therefore not interpreted in this section.

Results from sub-sample investment regressions

This section presents key results from sub-sample investment regressions using the *lasso* approach, to interpret the impact of each explanatory policy variable separately on specific sub-groups of countries (Table 3) and renewables technologies (Table 4). The sub-samples considered include: advanced OECD and EU member countries; emerging G20 and OECD countries; EU member countries; non-EU member countries; full sample without China and India; and solar and wind power (both with variable sets varying from the base investment model due to an additional application of the *lasso* approach). As a reminder, Table 1 at the beginning of this paper details which OECD, EU and G20 countries are considered as either advanced countries or emerging economies.[19]

Results in sub-groups of OECD and G20 countries

The results on climate mitigation policies (Table 3) are consistent with the hypothesis that public tenders drive renewables investment primarily in emerging economies, while feed-in tariffs and renewable certificates have an influence mostly in advanced countries.

- In the sub-sample regression for emerging economies, ***public tenders*** have a positive and statistically significant effect on investment volumes in emerging economies (a 0.1% increase for a 1 MW increase), while the impacts of ***feed-in tariffs*** and ***renewable certificates*** are not statistically significant. This is consistent with the fact that from 2000 until 2014, auctions and competitive public tenders for long-term contracts have increasingly been adopted in several emerging economies to award incentives for deployment such as long-term power purchase agreements, especially in Brazil or South Africa (Figure 8). While tenders are predominantly used in emerging countries, as Figure 8 shows, this result on the effect of tenders is not just a consequence of the sub-sample. Tenders and FiTs exist in both emerging and advanced countries, and co-exist in some countries. In fact, about half of the observations with tenders observe a FiT as well, i.e. at the same time, in the same country and for the same sector.
- In the sub-sample regression for advanced countries, both ***feed-in tariffs*** and ***renewable certificates*** have a positive and statistically significant effect on investment flows (a 11% and 8% increase for one additional unit, respectively), while public tenders are not statistically significant. This is consistent with the fact that from 2000 until 2014, most OECD countries have primarily relied on FiTs and certificates to support renewables investment (Figures 5 and 6).

19 The study also considered results on sub-sample investment regressions for different time periods, before and since the 2008 global financial crisis. The results however provide few additional results worth highlighting. This is likely due to the fact that the variables considered by the sub-sample regressions were those selected by the *lasso* approach in the base investment model.

- ***Explicit carbon prices*** have a positive and statistically significant effect in the sub-sample regression for EU member countries (a 35% increase for one additional USD/tCO_2e). This result is easy to interpret, given the presence of the EU emissions trading scheme (EU ETS) since 2005. This result suggests that explicit carbon prices can help shift investment decisions toward renewable power, by sending clear and long-term signals to investors, despite low allowance prices in the EU ETS. As the EU sub-sample regression shows, the shift can be substantial: one additional USD of explicit carbon price would lead to an increase of investments by more than a third.
- Surprisingly, ***explicit carbon prices*** also have a positive and statistically significant effect in the sub-sample regression for emerging economies (an 11% increase for one additional USD/tCO_2e). This result might be partly driven by the implementation of pilot emissions trading schemes (ETS) in seven Chinese provinces and cities (five in 2013 and two in 2014). The explicit carbon price result is not statistically significant in the full sample without China and India, which corroborates this interpretation.
- ***Support measures to fossil fuels in power generation*** have a negative and statistically significant effect on renewable investment for emerging economies, while results are not significant in other geographic sub-samples, unlike results on domestic credit to private sector, which is positive and statistically significant across several sub-sample regressions (Table 3). The result partially confirms the hypothesis that fossil-fuel support measures create disincentives to invest in low-carbon infrastructure projects, including renewable power, especially in emerging economies that still provide high levels of support to fossil fuels (OECD, 2015k). It provides empirical evidence in support of OECD and G20 recommendations to reform inefficient fossil-fuel support measures.

The results on investment environment variables (Table 3) are consistent with the hypothesis that investment volumes in renewable power depend on the attractiveness of a country’s investment environment, especially in advanced countries. Overall, the aggregated ***ease of doing business*** index, which combines several indicators on the broad investment environment, including investment facilitation, has a positive and statistically significant effect on renewable investment across several sub-sample regressions, including emerging economies, non-EU countries and the full sample without China and India (between 4% and 10% for an additional index point). Specifically, within each policy area:

Investment policy

The variable ***registering property*** has a positive and statistically significant effect on investment in renewables in advanced countries (3% increase for an additional index point), non-EU countries (9%) and the full sample without China and India (4%). These results suggest that across countries, barriers to land access and acquisition can significantly hinder investment in renewable-power projects, except possibly for large emerging economies with large markets for renewables such as China and India that can attract investment even with cumbersome land management and land rights processes.

Competition policy

- The variable measuring ***barriers to network sectors*** has a positive and statistically significant effect on investment in renewables in advanced countries (111% for an additional index point), non-EU (313%) and the full sample without China and India (131%). This result is consistent with results from the base investment model that outstanding electricity market design issues and barriers to entry in the power sector can hamper investment in renewable power in advanced countries. The results in advanced countries and the full sample without China and India, unlike the absence of statistically significance in the emerging economies sub-sample, might be explained by two factors: that in emerging markets such as China with large energy markets, investment

keeps flowing despite outstanding barriers to entry for IPPs; and that investment in countries such as China are driven by incumbent state-owned utilities.

- The variable estimating ***direct control of the state over enterprises*** also has a positive and statistically significant effect on investment in renewable power in the sub-sample regressions for advanced countries (38% increase for an additional index point) and the full sample without China and India (36%). These results further call for additional research to better understand how SOEs and government control of utilities impact investment flows in renewable power.

Financial market policy

- The variable measuring ***sovereign credit rating*** shows a positive and statistically significant effect in advanced countries (28% increase for an additional rank). This result is strengthened by the results for the variable measuring ***domestic credit to private sector***, which is positive and statistically significant across several sub-sample regressions, including advanced countries (1% increase for an additional percentage point), non-EU (3%) and the full sample without China and India (1%). The effect of ***sovereign credit rating*** might be captured in the domestic credit variable. Still, the results on both ***sovereign credit rating*** and ***domestic credit to private sector*** suggest that investment flows are influenced primarily by access to financing in OECD and G20 countries, as well as by the countries' broader political risk environment. In addition, the variable measuring ***credit to government and SOEs*** has a positive and statistically significant effect in the full sample without China and India. It is important to note that China and India are huge markets with large energy needs and a pipeline of bankable renewables projects, which may attract foreign and domestic investment in renewables projects regardless of availability and affordability of domestic financing. In addition, a large share of investment in China is driven by public investment from state-owned banks and public utilities, while affordability and access to financing remains an important barrier for India.

- The dummy variable capturing ***implementation of Basel III leverage ratio*** also shows a negative and statistically significant impact in advanced countries (a 66% decrease if the rule is introduced), non-EU member countries (40% decrease) and full sample without China and India (66% decrease). The dummy variable measuring ***implementation of Basel III risk-based capital requirements*** also has a negative and statistically significant impact in the full sample without China and India. These results confirm the result in the base investment model, and suggest that the potentially unintended consequences of Basel III leverage ratio, on investment in long-term capital intensive infrastructure projects such as renewables, are particularly relevant in advanced OECD and EU member countries.

Trade policy

- The variable ***trading across borders*** displays similar positive and statistically significant results in the sub-sample regressions for EU member countries (2% increase for an additional index point). This variable measures the time and cost (excluding tariffs) associated with the logistical procedures (documentary compliance, border compliance and domestic transport) to export or import a shipment of goods. Results suggest that removing outstanding barriers to international trade can help mobilise private investment in renewable power. The results also suggest that aligning trade policy with renewable deployment goals is critical in the EU. This is consistent with empirical results from the report *Overcoming Barriers to International Investment in Clean Energy* (OECD, 2015a). This report shows that barriers to international trade such as local-content requirements can hinder international investment in solar and wind energy by increasing the cost

of imported inputs for downstream renewable power producers, and that they have been increasingly used, along with trade remedies, across EU and other OECD countries.

With the exception of ***natural resource endowments*** in the EU sub-sample, all control variables have the expected sign when statistically significant. The negative effect of natural resource endowment in the EU is explained by the generally stronger sector activity especially in the solar sector in more northern countries, i.e. countries with less sunshine hours.

Results in sub-groups of technologies

Results of the sub-sample investment regressions for solar power and for wind power (Table 4) provide insights into the effects of climate mitigation policies and business conditions on investment in these sub-sectors. The growth in these two sectors and the overall dominance of investments in wind and solar over the other four renewable sub-sectors warrants a separate analysis of wind and solar investments. To analyse the factors specific to these sub-sectors rather than just test the robustness of the combined-sector base regression for solar and wind, the *lasso* is applied to the wind and solar sub-sectors separately to find the variable set relevant specifically to these sectors.

Key results for climate mitigation policies are presented below:

- The variable measuring ***renewable energy certificates*** has a positive and statistically significant effect on both solar- and wind-power investments (30% and 5% increase for an additional percentage point, respectively). Conversely, results for ***public tenders*** indicate a positive and statistically significant effect on wind-power investments (0.02% increase for an additional MW), but do not show a significant effect on solar-power investments. These results indicate that tenders have encouraged investment in wind farms, but not in solar-power plants. This could also indicate that policy makers across OECD and G20 countries, from 2000-14, have preferred to use tenders for wind energy, as tenders tend to differentiate among specific renewables technologies (61% of observed tendered capacity was tendered in the wind sector, 25% in the solar sector). Conversely, RECs do not differentiate between different technologies.

- ***Feed-in tariffs*** weighted with the duration of power purchase agreements have a positive and statistically significant effect on investment flows in solar energy (a 9% increase for an additional unit). These results are consistent with the result from the base investment model, and with the hypothesis that FiTs have mobilised investment in renewable power, especially in the solar sub-sectors (which accounted for 50% of total estimated investments in 2014 across OECD and G20 countries). This could also indicate that policy makers have typically preferred to use FiTs for solar energy as opposed to wind energy: for both sectors FiT policies exist for an equal amount of observations, but the average FiT for solar power is more than twice as high as for wind power.

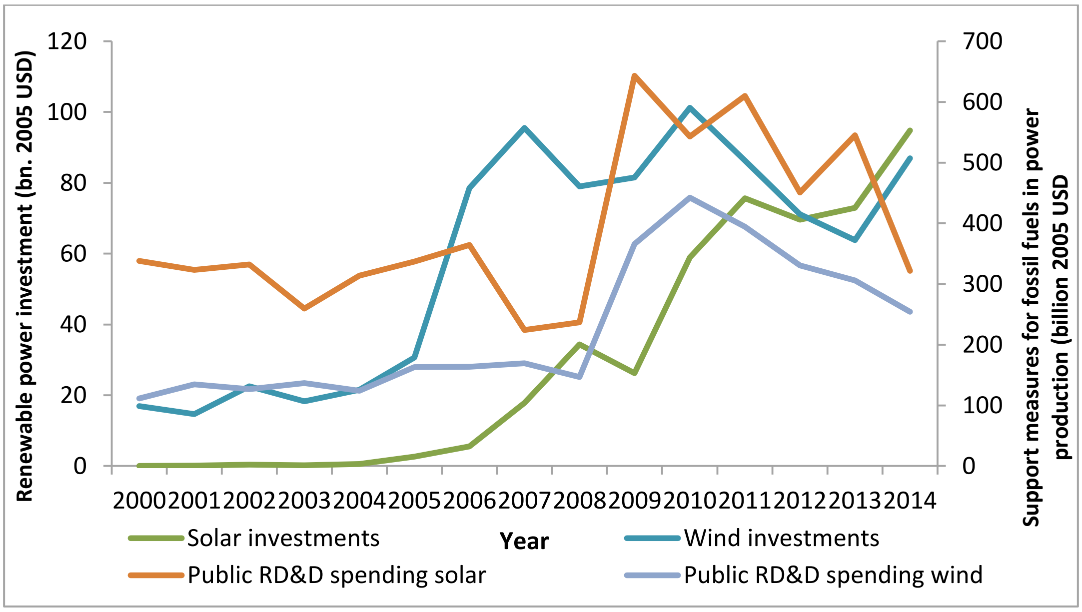
- ***Explicit carbon prices*** have a positive and statistically significant effect on investment in the solar-power sub-sector (5% increase for an additional USD/tCO_2e), while their effect is not statistically significant in the base investment model or in the wind-power sub-sample investment regression. The significance in the solar sub-sample might be due to the fact that new investment in solar power has increased in the more recent years of the dataset, since 2007, and especially since 2011, during the same period when the levels and scope of explicit carbon prices have increased. Indeed, the levels and share of global emissions covered by explicit carbon prices have increased since 2005, and especially since 2012 (Figure A.2.1). Due to the higher prices for carbon, fossil fuel-based power generation had become less attractive in these years and investors switched to solar power, which at the time was the newcomer technology. In addition, the solar-power sector has benefitted from huge technology costs reductions in the past five years. Therefore the political signal that carbon prices send might be strong enough to positively influence the solar-power sub-sector. As opposed to the solar sector, this effect of explicit carbon prices might not be strong

enough yet to influence the renewables power sector as a whole or other, less quickly advancing technologies, and even the wind-sector.

- Levels of ***energy taxation in power sector*** also have a positive and statistically significant effect on investment in both solar and wind power (9% increase for an additional USD/MWh), while the effect is not statistically significant in the base investment model. This might be due to high energy taxation often going along with generally strong renewables agenda. That might prompt companies to especially re-invest in fast-growing and attractive technologies that have experienced dramatic costs reductions, such as solar and wind power. Solar power for instance accounted for 50% of total new renewables investments in 2014 according to estimates from this study (Figure 3) and 51% of new renewable-related patents in 2014 (Figure 4). While the base model captured all six sub-sector technologies, the solar and wind sub-sample regressions can show the relationship between energy taxation and investments without the obfuscating influence of the other four sub-sectors.
- The variable measuring ***public RD&D spending*** has a positive and statistically significant effect for wind power (a 2% increase in investment for an additional million USD of public RD&D for wind power across the OECD and G20). The negative and statistically significant result for public RD&D spending in the solar sub-sample regression (41% decrease) can be explained by both the structure of the variable and the trend in public RD&D spending for solar energy versus wind energy. First, the variable captures the yearly spending of all OECD and G20 countries combined and therefore does not vary over country observations of a year and sector. This means that in a regression with just one sector it only varies over time, but not over other dimensions. However, sub-sample regressions also contain year-fixed effects. The variable therefore only captures the variation between years of RD&D but not between countries. In addition, the overall RD&D spending across OECD and G20 countries for solar energy decreased when solar investments increased in 2013-14 (Figure 11), so the variable represents this negative correlation, unlike for wind energy, where the contrast is smaller around 2013-14 (Figure 11). The positive effects, if any, are captured in the year fixed effects, indistinguishable from other time-fixed effects.

Figure 11. Trends in investments and public RD&D spending in solar and wind energy

(2000-14 investments and public RD&D spending by year)



Source: Author's estimates based on BNEF (2015) and IEA (2015h), amended by various sources.

Results on investment environment variables (Table 4) suggest that investment conditions are particularly critical in driving investment volumes in both solar- and wind power, especially for solar projects. This conclusion has important implications for policy makers who wish to scale up private investment in solar- and wind-power projects. It is important to note that the econometric analysis presented in this working paper is particularly relevant to explain the policy drivers of investment in solar and wind energy, and less so in other renewables technologies (i.e. biomass and waste, geothermal, marine and small hydro). This is due to the focus of specific investment incentives (such as tenders and feed-in tariffs) on solar and wind, as well as rapid growth rates of solar and wind investment flows in recent years, unlike other renewables technologies. In particular:

- Compared to the base investment model, the solar sub-sample investment regression includes many more investment environment variables that are selected using the *lasso* selection method, and that have a statistically significant effect on investment. The variables measuring ***registering property***, ***direct control of the state over enterprises***, ***barriers to network sectors***, ***credit to government and SOEs***, ***time to build a warehouse, corruption perception***, ***licenses and permit system, political stability*** and ***regulatory quality*** all have a statistically significant effect on solar investment flows.
- The wind sub-sample investment regression also displays several investment environment variables with a statistically significant effect on investment, although to a lesser extent than for solar power. The variables measuring ***trading across borders, time required starting a business, direct control of the state over enterprises*** and ***licenses and permit systems*** all have a statistically significant effect on wind-power investment.
- In particular, the variable measuring ***trading across borders*** has a positive and statistically significant effect on wind-power investment (3% increase for an additional index point), as in the base investment model, while the effect of the variable is not statistically significant in the case of solar power. This result might stem from the significantly larger physical size of wind turbines compared to solar PV panels, which means that wind turbines are associated with higher transport costs than solar PV panels (excluding tariffs and non-tariff trade barriers; OECD, 2015a). The variable trading across borders includes a weighted indicator of procedures associated with domestic transport to export or import a shipment of goods (see Annex A.1), so this variable might impact wind investment (by raising transport costs) more so than for solar investment flows, which are mostly driven by solar PV deals.
- As in the base investment model, the variable measuring the level of ***direct control of the state over enterprises*** has a positive and statistically significant effect in both the solar and wind sub-sample investment regressions (150% and 101% increase for an additional index point, respectively). As noted for the base investment model, these results go against the initial hypothesis of this study that government control of SOEs can hinder renewable investment. This result is also positive and statistically significant in the full sample without China and India, so it is not driven by the presence of large SOEs in China and India, but by broader issues across the OECD and G20. As discussed, this result calls for further research (OECD, 2017b forthcoming).

Interactions between climate mitigation policies and investment environment variables

The study has singled out four statistically significant interactions between the many possible interactions between climate mitigation policies or investment environment variables in the base investment model and sub-sample investment regressions for emerging economies and advanced countries (Table 5).

- ***Explicit carbon prices*** interact significantly and negatively with the dummy variable capturing ***implementation of Basel III leverage ratio*** in the base investment model with interactions. This

result suggests that the effect of explicit carbon prices in encouraging a shift towards investment in renewable power projects might be hampered by the ability of the banking system in G20 and OECD countries in providing long-term debt financing for long-term capital-intensive infrastructure project such as renewable projects, linked to unintended consequences of Basel III regulations, as discussed previously.

- ***Public RD&D spending*** interacts positively and statistically significantly with both ***renewable energy certificates*** and ***explicit carbon prices*** in the sub-sample regression for emerging economies. These results suggest that the effect of RECs and explicit carbon prices in encouraging patenting activity in renewable power is enhanced with increased public RD&D expenditures for renewable-power technologies.
- ***Public tenders*** interact significantly and negatively with ***direct control of the state over enterprises*** in the sub-sample investment regression for advanced countries. While in advanced countries tenders generally might attract investors and direct control of the state over enterprises might generally increase investment, say, due to a more direct implementation of a green political agenda, these two factors do not combine well. This could be a result of investors otherwise attracted by tenders being overly cautious in an environment where the tender is set by the state and the state or state-owned enterprises are perceived to have an inherent advantage. It might be deterring to compete against a perceived or actual dominant firm.

Table 3. Determinants of investment in renewable power in OECD and G20 countries from 2000-2014

(in the base investment model and sub-sample investment regression)

	Explanatory variable (i.e. *determinant*)	Unit	Expected sign	Investment (full sample)	Emerging countries	Advanced countries	EU	Non-EU	Full sample without China and India
Climate mitigation policy	Feed-in tariff	USD/kWh, weighted with power purchasing agreement-duration	+	0.083***	0.078	0.105***	0.061**	0.155***	0.098***
	Renewable energy certificate	Percent	+	0.074*	0.069	0.080*	0.069	-0.061	0.067
	Public tender	MW	+	0.235x10^{-3}*	0.001***	0.912x10^{-4}	-0.133x10^{-3}	0.292x10^{-3}	0.552x10^{-4}
	Explicit carbon price	USD/tCO2e	+	-0.001	0.105**	0.021	0.303**	-0.014	0.013
	Energy taxation in the power sector	USD/MWh	+	0.003	0.055	0.003	-0.002	0.024	0.001
	Logarithm of fossil fuel support for power generation	Ln USD	-	0.017	-0.074*	0.013	0.012	0.013	0.018
	Public RD&D spending	USD million	+	-0.148x10^{-3}	0.220x10^{-3}	-0.332x10^{-3}	-0.001	0.001	-0.205x10^{-3}
Investment environment	Time required starting business	Index	-	0.012**	0.030**	0.014*	0.021**	0.004	0.014**
	Registering property	Index	+	0.026**	0.074	0.027**	0.010	0.085*	0.027**
	Barriers to services	Index	-	-0.525	0.827	-0.548	0.366	-0.979	-0.335
	Barriers to network sectors	Index	-	1.023***	1.585	0.748**	0.207	1.419*	0.837***
	Ease of doing business	Index	+	0.029	0.095**	0.034	0.035	0.046*	0.036*
	Trading across borders	Index	+	0.013	-0.034	0.007	0.024*	-0.015	0.011
	Direct control of the state over enterprises	Index	Higher is more control	0.291**	-0.535	0.320**	0.144	0.342	0.310**
	Command and control	Index	Higher is more regulation	-0.061	-0.026	-0.098	0.336	-0.349	0.025
	Sovereign credit rating	Ranks	+	0.191*	-0.223	0.247**	0.049	-0.264	0.280**
	Credit to government and SOEs	Percent of GDP	+	0.016	0.016	0.028	-0.001	0.006	0.028*
	Domestic credit to private sector	Percent of GDP	+	0.010**	0.006	0.010**	0.006	0.026***	0.009*
	Implementation of Basel III risk-based capital requirements	Dummy	-	0.659	-0.296	1.016	-0.896	0.330	1.046*
	Implementation of Basel III leverage ratio	Dummy	-	-0.659**	0.404	-1.077***	-	-0.515**	-1.092***
Innovation environment	Perpetual inventory of renewable power-related patents	Patent Count	+	0.203x10^{-3}***	0.001***	0.254x10^{-3}***	0.719 x10^{-4}	0.241x10^{-3}***	0.225x10^{-3}***
	Innovation spillover	Patent count	+	0.001**	-0.001	0.001***	0.001***	0.001	0.001***
Controls	Natural resource endowment	Standardised units	+	0.209***	0.584***	0.074	-0.259**	0.424***	0.211***
	Electricity generation	GWh	+	0.001***	0.002*	0.002	0.011*	0.001	0.002
	Tertiary education	Percent enrollment	+	0.074**	-0.020	0.054	0.029	0.028	0.042
	Constant			-11.080***	-14.906*	-10.270***	-9.302**	-10.869*	-11.488***
	Observations			4113	805	3308	2510	1603	3935

Note: The asterisk *after the coefficient means that the coefficient of the variable is significant at the 10% significance level or lower, i.e. p<0.1; The asterisks ** after the coefficient means that the coefficient of the variable is significant at the 5% significance level or lower, i.e. p<0.05, The asterisks *** after the coefficient means that the coefficient of the variable is significant at the 1% significance level or lower, i.e. p<0.01; source: based on authors' calculations. In the EU sub-sample the variable Implementation of Basel III leverage ratio could not be included since the variable did not show any variation, as marked by a hyphen.

Source: Authors' calculations.

Table 4. Determinants of investment in solar and wind power in OECD and G20 countries from 2000-2014

(in the base investment model and sub-sample investment regression)

	Explanatory variable (i.e. *determinant*)	Unit	Expected sign	Investment	Solar	Wind
Climate mitigation policy	Feed-in tariff	USD/kWh, weighted with power purchasing agreement-duration	+	0.083***	0.086***	0.036
	Renewable energy certificate	Percent	+	0.074*	0.264***	0.050**
	Public tender	MW	+	$0.235x10^{-3}$*	$0.445x10^{-3}$	$0.172x10^{-3}$*
	Explicit carbon price	USD/tCO2e	+	-0.001	0.051**	-0.021
	Energy taxation in the power sector	USD/MWh	+	0.003	0.086***	-0.020**
	Logarithm of fossil fuel support for power generation	Ln USD	-	0.017	-0.006	
	Public RD&D spending	USD million	+	$-0.148x10^{-3}$	-0.538***	0.022***
Investment environment	Ease of doing business	Index	-	0.029	-0.045	0.029
	Registering property	Index	+	0.026**	0.095***	
	Trading across borders	Index	-	0.013		0.029**
	Time required starting business	Index	-	0.012**		0.026***
	Direct control of the state over enterprises	Index	+	0.291**	0.917***	0.697***
	Command and control	Index	+	-0.061		
	Barriers to services	Index	Higher is more control	-0.525		
	Barriers to network sectors	Index	Higher is more regulation	1.023***	1.921***	0.287
	Sovereign credit rating	Ranks	+	0.191*	-0.152	0.084
	Credit to government and SOEs	Percent of GDP	+	0.016	-0.060***	
	Domestic credit to private sector	Percent of GDP	+	0.010**		
	Implementation Basel III risk-based capital requirements	Dummy	-	0.659		
	Implementation of Basel III leverage ratio	Dummy	-	-0.659**	0.038	-0.298
	Time to build warehouse	Days	-		-0.012***	
	Time to get electricity	Days	-		-0.016	
	Corruption perception	Index	+		-0.741***	
	Licenses and permit system	Index	-		1.107***	-0.463**
	Political stability	Index	+		-1.080*	
	Regulatory quality	Index	+		2.196***	
Innovation environment	Perpetual inventory of renewable power-related patents	Patent count	+	$0.203x10^{-3}$***		-0.001***
	Innovation spillover	Patent count	+	0.001**	-0.001***	
	Strength of Intellectual Property Rights	Index	+		0.460	
	Number of universities	Count	+			-0.021**
Controls	Natural resource endowment	Standardised units	+	0.209***		
	Electricity generation	GWh	+	0.001***		$0.303x10^{-4}$
	Tertiary education	Percent enrollment	+	0.074**	0.161***	
	Constant			-11.080***	157.807***	-38.891***
	FDI inflows	USD million	+		$0.430x10^{-5}$***	$0.770x10^{-6}$
	Carbon intensity of energy	Kton CO2/ktoe TPES	-			-0.003**
	Logarithm of CO2 emissions	Ln kton CO2	+			2.847***
	Electricity consumption	Terajoule	+			$-0.889x10^{-13}$
	Implementation Basel III liquidity coverage ratio	Dummy	-			-0.559
	Average MFN tariff	Percent	-			-0.311
	Regulatory capital to risk-weighted asset	Ratio	-			-0.081***
	Observations			4113	675	676

Note: The asterisk *after the coefficient means that the coefficient of the variable is significant at the 10% significance level or lower, i.e. p<0.1; The asterisks ** after the coefficient means that the coefficient of the variable is significant at the 5% significance level or lower, i.e. p<0.05, The asterisks *** after the coefficient means that the coefficient of the variable is significant at the 1% significance level or lower, i.e. p<0.01; source: based on authors' calculations.* p<0.1, ** p<0.05, *** p<0.01.

Source: Authors' calculations.

Table 5. Determinants of investment in renewable power in OECD and G20 countries from 2000-2014 with interactions

(In the base investment model with interaction terms)

	Explanatory variable (i.e. *determinant*)	Unit	Expected sign	Investment	Interactions	Interactions; emerging only	Interactions: advanced only
Climate mitigation policy	Feed-in tariff	USD/kWh, weighted with power purchasing agreement-duration	+	0.083***	0.084***	0.041	0.104***
	Renewable energy certificate	Percent	+	0.074*	0.076*	-0.114	0.078*
	Public tender	MW	+	0.235x10^{-3}*	0.231x10^{-3}*	0.001***	0.001**
	Explicit carbon price	USD/tCO2e	+	-0.001	0.004	-0.030	0.020
	Energy taxation in the power sector	USD/MWh	+	0.003	0.003	-0.014	0.004
	Logarithm of fossil fuel support for power generation	Ln USD	-	0.017	0.017	-0.077*	0.013
	Public RD&D spending	USD million	+	-0.148x10^{-3}	-0.215x10^{-3}	-0.001	-0.278x10^{-3}
Investment environment	Time required starting business	Index	-	0.012**	0.013**	0.033***	0.014*
	Registering property	Index	+	0.026**	0.026**	0.052	0.029**
	Barriers to services	Index	-	-0.525	-0.479	0.725	-0.667*
	Barriers to network sectors	Index	-	1.023***	1.165***	1.778	0.734**
	Ease of doing business	Index	+	0.029	0.032	0.069*	0.033
	Trading across borders	Index	+	0.013	0.012	-0.030	0.009
	Direct control of the state over enterprises	Index	Higher is more control	0.291**	0.268*	-0.512	0.317**
	Command and control	Index	Higher is more regulation	-0.061	-0.051	0.155	-0.110
	Sovereign credit rating	Ranks	+	0.191*	0.165	-0.134	0.258**
	Credit to government and SOEs	Percent of GDP	+	0.016	0.016	0.012	0.028*
	Domestic credit to private sector	Percent of GDP	+	0.010**	0.010**	0.011	0.010*
	Implementation Basel III risk-based capital requirements	Dummy	-	0.659	0.757*	-0.243	1.123
	Implementation Basel III leverage ratio	Dummy	-	-0.659**	-0.241	0.224	-0.997***
Innovation environment	Perpetual inventory of renewable power-related patents	Patent Count	+	0.203x10^{-3}***	0.207x10^{-3}***	0.001***	0.261x10^{-3}***
	Innovation spillover	Patent count	+	0.001**	0.001**	-0.604x10^{-3}	0.001***
Controls	Natural resource endowment	Standardised units	+	0.209***	0.209***	0.536***	0.065
	Electricity generation	GWh	+	0.001***	0.001***	0.002**	0.002
	Tertiary education	Percent enrollment	+	0.074**	0.075**	-0.022	0.052
	Constant			-11.080***	-11.771***	-13.502	
Interactions	Implementation Basel III leverage ratio * Carbon price	Dummy * USD/tCO2e			-0.096*		
	Public RD&D spending * Renewable energy certificate	USD million * percent				0.493x10^{-4}*	
	Public RD&D spending * Carbon price	USD million * USD/tCO2e				0.186x10^{-3}***	-0.348x10^{-3}**
	Direct control of the state over enterprises * Public tender	Index * MW					-10.285***
	Observations			4113	4113	805	3308

Note: The asterisk *after the coefficient means that the coefficient of the variable is significant at the 10% significance level or lower, i.e. p<0.1; The asterisks ** after the coefficient means that the coefficient of the variable is significant at the 5% significance level or lower, i.e. p<0.05, The asterisks *** after the coefficient means that the coefficient of the variable is significant at the 1% significance level or lower, i.e. p<0.01.

Source: Authors' calculations.

Results of the innovation model

This section presents results from the innovation model, to interpret the impact of each explanatory policy variable separately, as well as their interactions, using a negative binomial fixed effects regression on patent counts.[20] Table 6 gives an overview of key results from the innovation model (as a reminder, empty cells for results that are not statistically significant should not be interpreted).

Table 6. Key policy drivers and deterrents of innovation and patenting activity in renewable-power technologies in OECD and G20 countries

(drawing on selected statistically significant results from the innovation model)

		Innovation model				
		Base innovatio n model	Advanced countries	Emerging economies	EU	Non-EU
Climate mitigation policies	Feed-in tariffs	+	+	+	+	+
	Renewable energy certificates			+		
	Public tenders					
	Explicit carbon prices					
	Public RD&D spending	+		+		
	Energy taxation in power sector					
	Support measures to fossil fuels in power sector			+		+
Investment conditions	Ease of Doing Business	+	+		+	+
	Direct control of the state over enterprises	-	-	-		-
	Governance of state-owned enterprises	+		+		+
	Trading across borders	+	+			
Innovation conditions	Number of universities	+	+	-	+	+

Notes: +: Indicates that the corresponding variable had a statistically significant and positive effect on investment in the base investment model or sub-sample regressions; -: Indicates that the corresponding variable had a statistically significant and negative effect on investment in the base investment model or sub-sample regressions; See Table 1 for a detailed list of the countries considered as advanced countries or emerging economies. See the subsequent section on results and interpretations as well as Tables 7 and 8, for more information on these results.

Results from the base innovation model

The base innovation model estimates the separate impacts of climate mitigation policies and investment environment variables on patent activity related to renewable-power technologies[21]. Table 7 presents the results from the base investment model, as well as sub-sample regressions.

The results on the effects of climate mitigation policies on renewables patenting activity verify most of the hypotheses of the research on innovation in renewables technologies:

- ***Feed-in tariffs*** and premiums (FiTs), weighted with duration of power purchase agreements, have a significant and positive effect in encouraging patent counts in renewable-power technologies (4% increase for an additional unit). This suggests that feed-in tariffs stimulate patent activity in renewable-power technologies across OECD and G20 countries. It is important to remind that this econometric study provides non-country specific results. This result is fully consistent with results from a recent literature review on the impact of FiTs on innovation in renewables, especially in solar PV power (Gambhir et al., 2014; Annex A.2). Conversely, the impacts of ***renewable energy***

[20] Please note that due to missing data for some explanatory variables, all observations for Argentina, Indonesia and Saudi Arabia are omitted from the regression analysis of the innovation model. In addition, as for the investment model, the percentage value increase in innovation caused by a one unit increase of a statistically significant variable is noted in brackets in the following interpretation of the results.

[21] Including in manufacturing and downstream power-plant installations activities.

certificates and ***public tenders*** are not significant. These results can probably be explained by the fact that feed-in tariffs have been generous in the past across OECD and G20 countries, and that these price-based instruments provide long-term incentives and visibility to innovators, unlike tenders that are quantity-based tools that can be used on a one-off basis, without visibility for future tendering procedures.

- Targeted innovation incentives through ***public RD&D support*** also encourage patent activity in renewable-power technologies (0.05% increase for an additional global million USD spent). This result is consistent with the study's hypothesis.

- Similar to the investment model, the statistically insignificant result for explicit carbon pricing does not necessarily mean that a carbon pricing policy does not support technology development. Like in the investment model, the result on ***explicit carbon prices*** might be statistically insignificant here due to possible collinearity with year fixed effects, the data quality or the low carbon prices for the countries and years in the sample.

Results show that several **investment environment variables have a statistically significant effect on patent counts in renewable-power technologies**. Overall, the aggregated ***ease of doing business*** index has a positive and statistically significant effect on patenting activity in renewables (1% increase for an additional index point). Policy issues measured by the ***ease of doing business*** index' sub-indicators include notably: land rights; contract enforcement; permitting and licensing procedures; access to credit; and trading across border. In addition, for significant investment environment variables:

- ***Local-content requirements*** have a statistically significant and positive influence on renewable-power innovation. Given that demand for renewable-power inputs and installations exists, the perceived need for a local-content requirement as industrial policy suggests that local producers might need additional support to be competitive. The positive sign of the local-content requirement variable shows that in countries with such a requirement, companies and other researchers work on bridging that gap to competitiveness, possibly because they have to fill the gap between investors' quality demands and the quality or prices of locally supplied inputs.

- The variable capturing the ***governance of state-owned enterprises*** (SOEs) has a positive and statistically significant effect on renewable patenting (74% increase for an additional index point). This result is consistent with the result from the investment model. This indicator measures the degree of insulation of SOEs from market discipline and degree of political interference in the management of SOEs. The positive and significant impact on patenting of the governance of SOEs could be a sign that government authorities are supporting activities that other stakeholders judge as too risky or unprofitable, such as basic or applied research or investment in the grid extension and renovation (Martin and Scott, 2000; OECD, 2015b). The relationship between SOE activity and patenting may be due to public utilities being primary recipients of public RD&D support in renewable power, or to the state providing broader support to RD&D through SOEs (beyond direct public RD&D expenditures, e.g. shared research centres). Further research is needed to refine the analysis of SOE influence on renewable power (OECD, 2017b forthcoming).

- Conversely, the variable capturing levels of ***direct control of the state over enterprises*** has a negative and statistically significant effect on renewable patenting (8% decrease for an additional index point). These results suggest that while independence of SOEs from government intervention can encourage renewable patenting activity in OECD and G20 countries, government stakes in publicly controlled firms possibly captures the effect of an incumbent firm. Being an incumbent can lead a large public utility to either their ability or incentives to innovate or obstruct opportunities for new entrants to innovate in renewable technologies.

Beyond targeted public RD&D spending, the innovation model also captures the effects of the broader *innovation environment* on renewable patenting activity:

- The variable measuring the ***number of universities*** has a statistically significant and positive effect on renewables patenting activity (a 2% increase in patenting for each additional university). This result is intuitive and consistent with existing literature on the role of universities and research departments to encourage technological development and patenting (Johnstone et al., 2010). This result however is important, as it reminds policy makers that wish to unlock innovation in renewables technologies not to neglect the development of research institutes and universities, possibly with renewable energy programmes.

- The innovation model also includes a knowledge stock variable constructed by ***perpetual inventory*** from past patents related to renewable-power technologies, which captures the accumulation of patents in previous years and has a positive and statistically significant effect on renewable patenting (0.05 increase for an additional patent). In line with the literature on innovation (Martin, 2002), this variable measures the effect of accumulated relevant knowledge on patenting activity in renewable power. It might also act as a proxy for human capital in renewable-power sectors. The importance of the current knowledge stock for further knowledge creation and the persistence that arises from this means that if a firm is specialised in a certain technology type (e.g. solar PV or wind energy), it is more likely to carry on in this irrespective of policy interventions than a firm that has no such history (Martin, 2016) The same will be true at the country level. In addition, a country level specialisation can plausibly stimulate policy support to a given technology, if there is lobbying by industry groups related to a specific policy (Martin, 2016).

The only control variable, ***natural resource endowment***, is statistically significant and shows the expected positive sign. This means that innovation just like investment is dependent on the availability of natural conditions necessary for renewable-power technology.

Results from sub-sample innovation regressions

This section presents results from sub-sample innovation regressions, to interpret the impact of each explanatory policy variable separately on patenting activity in specific sub-groups of countries (Table 7). The sub-samples considered include: advanced OECD and EU member countries; emerging G20 and OECD countries; EU member countries; non-EU member countries; full sample without China and India; and solar and wind power.[22] Table 1 (at the beginning of this paper) details which OECD, EU and G20 countries are considered as either advanced countries or emerging economies.[23] The study also considered the sub-sample innovation regressions for solar and wind power, which are not presented here as they did not provide additional information compared to the other regressions, unlike for the solar and wind sub-sample investment regressions.

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22 The sub-sample regressions for solar and wind include different sets of variables compared to the base investment model due to an additional application of the *lasso* approach.

23 The analysis also ran sub-sample investment regressions for different time periods, before and since the 2008 global financial crisis. The results however provided few additional results worth highlighting. This is likely due to the fact that the variables considered by the sub-sample regressions were those selected by the *lasso* approach in the base investment model.

Results in sub-groups of OECD and G20 countries

Results on the climate mitigations policies suggest that feed-in tariffs play a critical role in stimulating patenting activity in renewables technologies, unlike public tenders:

- Other than results in the sub-sample investment regression for emerging economies, results for the innovation model suggests that ***public tenders*** do not have a statistically significant effect on renewable patenting in any of the innovation regressions for sub-samples of countries (Table 7). Conversely, ***feed-in tariffs*** and ***renewable energy certificates*** both have a positive and statistically significant effect on patenting activity in renewable-power technologies (6% and 5% increase in patenting for an additional unit of FiTs and RECs, respectively). In fact, ***feed-in tariffs*** (including feed-in premiums) have a positive and statistically significant effect on renewable patenting in all the innovation regressions for sub-samples of countries (Table 7; ranging from 3% to 7% increase for an additional unit).[24] These strong results are consistent with the hypothesis of the report and findings from existing studies that feed-in tariffs are critical to encourage technology development and market creation in renewable-power technologies, especially in solar PV energy (Gambhir et al., 2014). Conversely, the results on *public tenders* show that public tenders have little influence on patenting activity in renewable power. As discussed in the base innovation model, this may be because FiTs are price-based instruments that provide long-term visibility to innovate, unlike tenders that can be used on a one-off basis to procure a certain quantity of electricity using renewable power.
- ***Renewable energy certificates*** have a positive and statistically significant impact in the sub-sample innovation regressions for emerging economies (a 6% increase in patenting for an additional percentage point of REC). Though it is plausible that RECs have a particular effect in emerging countries, this result relies on low variability in the REC variable for this sub-sample as only Romania and India have a REC policy.
- ***Fossil fuel support for power generation*** has a statistically significant positive effect in the emerging and non-EU sub-sample. This seemingly counter-intuitive result could be a sign for cross-subsidisation of renewables research projects within companies that receive fossil fuel support. This interpretation is supported by the fact that the variable is only statistically significant in samples with countries where a state-run monopolistic or oligopolistic utility dominates the power market. With political impulses influencing decision-making, those firms might use additional support for forward-looking investments such as renewable-energy research.
- As in the base innovation model, the variable measuring levels of ***public RD&D spending*** in renewables has a positive and statistically significant effect in the innovation regression for emerging economies' sub-sample (0.1% increase for an additional global million USD spent), unlike other sub-sample innovation regressions.

Results on investment environment variables suggest that business conditions impact innovation and patenting activity across geographic sub-samples. Overall, the aggregated ***ease of doing business*** Index has a positive and statistically significant impact on renewable patenting across most sub-sample innovation regressions for advanced countries, EU countries, non-EU countries and full sample without China and India (around 1% increase each for an additional index point). In particular, for specific variables and indicators:

[24] It is important to note that though the variable is weighted with duration of PPAs, the results are similar when considering the effects of feed-in tariffs and feed-in premiums alone.

- The variable measuring ***direct control of the state over enterprises*** has a negative and statistically significant effect on renewable patenting in the sub-sample innovation regressions for emerging economies (21% decrease for an additional index point), advanced countries (9%) and non-EU member countries (21%). Conversely, ***governance of SOEs*** has a positive and statistically significant effect on renewable patenting, in the sub-sample innovation regressions for emerging (198% increase for an additional index point) and non-EU member countries (112%). These mixed results suggest that while targeted government intervention to support renewables technologies (e.g. through public intervention through SOEs, as captured under the variable ***direct control of the state over enterprises***) can encourage renewable patenting activity in emerging economies and other OECD and G20 countries, government stakes in publicly controlled firms in emerging economies (as captured in the variable ***governance of SOEs***) can reduce either their ability or incentives to innovate or opportunities for new entrants to innovate in renewables technologies, as discussed for the base innovation model. These results suggest that government intervention, including through state-owned enterprises, has a mixed impact in stimulating patenting activity in renewables technologies. As with the investment model, these results go against the hypothesis of the report, and would deserve further analysis (OECD, 2017b forthcoming).

- The variable ***trading across borders*** has a positive and statistically significant effect on innovation in renewables technologies in advanced countries and full sample without China and India (both 1% increase for additional index point). This result is consistent with results from the base innovation model.

- The positive and statistically significant impact of the variable measuring ***implementation of Basel III leverage ratio*** is likely capturing a different effect than that of the introduction of Basel regulations. In the innovation data set, which covers the years 2000 to 2012, only China enforced Basel III regulations in 2012. Therefore the implementation of Basel III leverage ratio dummy is a dummy for not only this specific financial regulation, but likely also captures all else that happened in China in 2012 that could have had an influence on renewable power innovation.

The results of the sub-sample innovation regressions also confirm the effects of the broader innovation environment on renewable patenting activity, as discussed in the base innovation model.

Interactions between climate mitigation policies and investment conditions

This paragraph presents results on statistically significant interactions between climate mitigation policies and investment environment variables, in the sub-sample groups and in the base innovation model and sub-sample innovation regressions for emerging economies and advanced countries (Table 7).

- ***Feed-in tariffs*** and ***public RD&D spending*** interact positively and statistically significantly in emerging economies. This result suggests that policy makers in emerging economies should consider providing support to renewables technologies across development stages to support innovation, including through both push-side policies such as public support to RD&D, and pull-side policies like feed-in tariffs to support the deployment of renewables technologies. The result for the same interaction in advanced countries is not statistically significant, and therefore should not be interpreted.

- ***Feed-in tariffs*** and feed-in premiums (weighted with duration of power purchase agreements) interact positively and statistically significantly with the variable capturing the presence of ***local-content requirements*** attached to a feed-in tariff or feed-in premium in the base innovation model. While previous OECD research (OECD, 2015a) has highlighted the negative impacts of local-content requirements on international investment flows in solar and wind energy, this result

suggests that requirements to purchase renewables inputs domestically to benefit from a feed-in tariff can send positive signals encouraging the filing of new patents in renewables technologies in the same country.

- ***Public tenders*** interact negatively and statistically significantly with the investment variable capturing ***direct control of the state over enterprises*** in both the base innovation model and sub-sample innovation regression for emerging economies. In addition, when considering interactions between climate policies and investment conditions, ***public tenders*** become positive and statistically significant in the innovation model. This result suggests that the presence of state-owned enterprises and incumbent public utilities or of government intervention in the power sector might decrease the effect of public tenders, especially in emerging economies, although additional research is needed to refine the analysis to the power sector (OECD, 2017c forthcoming).

- ***Direct control of the state over enterprises*** also interacts negatively and statistically significantly with ***explicit carbon prices*** in the sub-sample innovation regression for emerging economies. This result suggests that in emerging economies, the presence of state-owned enterprises, or incumbent utilities with direct control of the state, reduces the effect of explicit carbon prices to act as an incentive for investors to innovate in early-stage renewables technologies, e.g. due to lack of level playing field for new entrants in the power sector at commercial and deployment stages in emerging markets.

- ***Direct control of the state over enterprises*** interacts positively and statistically significantly with **energy taxation** in the base innovation model. This result shows that state intervention is increasing the effect of energy taxes in the power sector in stimulating patenting in renewable-power technologies. This result suggests that state intervention, e.g. through state involvement in corporate governance (e.g. in corporate boards) can stimulate patenting activity directly (e.g. through public support other than public RD&D spending for renewables technologies, as this effect is already captured by the ***public RD&D spending*** variable) or indirectly (e.g. through public utilities in the power sector acting as key innovators). One channel for this might be that a possibly renewable-friendly policy agenda is spurred by high energy prices, but even more clearly so if the government has direct control over implementing action on the innovation in the sector through state-controlled companies.

- Both ***public tenders*** and ***energy taxation*** in the power sector interact positively and statistically significantly with the control variable measuring ***perpetual inventory of renewable power-related patents.*** These results are consistent with the hypothesis that climate mitigation policies such as public tenders and energy taxation are more likely to have an effect stimulating patenting activity for renewables technologies in countries that have provided historical support to renewables patenting.

These results provide interesting findings. In particular:

- The fact that ***feed-in tariffs, tenders*** and ***explicit carbon prices*** all interact statistically significantly with investment conditions in emerging economies suggest that the effect of climate mitigation policies in stimulating renewable innovation depends particularly on the broader investment environment in emerging economies. This is likely because even in the presence of a carbon price and targeted investment incentives, renewable patenting activity remains constrained by broader market and regulatory rigidities in the power sector, e.g. linked to state intervention. This result is consistent with the hypothesis from the study. This result is also consistent with the result of the variable measuring ***direct control of the state over enterprises***, as discussed previously. It is an important conclusion for policy makers in emerging economies, who wish to

stimulate innovation in renewables technologies. It is important to note that this result bear not implications for advanced countries, as the interactions are not statistically significant.

- Public tenders may not send sufficient signals to innovators and early adopters of renewables technologies in emerging economies with government control of incumbent SOEs, likely due to risks of uncompetitive power market and barriers for new entrants.

- The variable ***direct control of the state over enterprises*** interacts significantly with several climate mitigation policies – with mixed results as the interaction is negative with carbon prices and tenders, but positive with energy taxation. This variable relates to competition policy. This is an important finding: results suggest that in order to enhance the effect of targeted incentives and carbon prices in stimulating renewable patenting, a priority for policy makers is to align competition policy and electricity market design with renewable innovation goals, including government involvement with state-owned enterprises. As discussed previously, more research is needed to better understand the implications of SOEs and competition policy on investment and innovation in renewable-power technologies in OECD and G20 countries.

The only control variable, ***natural resource endowment***, is statistically significant in all sub-samples except for the emerging sample and positive throughout, as expected.

Table 7. Determinants of innovation in renewable power in OECD and G20 countries from 2000-2012

(in the base innovation model and sub-sample innovation regressions)

	Explanatory variable (i.e. *determinant*)	Unit	Expected sign	Innovation	Emerging countries	Advanced countries	EU	Non-EU	Full sample without China and India
Climate mitigation policy	Feed-in tariff	USD/kWh, weighted with power purchasing agreement-duration	+	**0.039*** **	**0.055***	**0.034*** **	**0.044*** **	**0.063*** **	**0.036*** **
	Renewable energy certificate	Percent	+	0.011	**0.044** **	0.007	0.010	0.013	0.006
	Public tender	MW	+	0.207x10^{-3}	0.186x10^{-3}	0.203x10^{-3}	0.140x10^{-3}	0.220x10^{-3}	0.197x10^{-3}
	Explicit carbon price	USD/tCO2e	+	-0.002	-0.006	0.001	0.023	-0.006	-0.001
	Energy taxation in the power sector	USD/MWh	+	-0.001	0.138	-0.003	0.460x10^{-3}	0.013	-0.002
	Logarithm of fossil fuel support for power generation	Ln USD	-	0.003	**0.038***	-0.006	-0.004	**0.021***	0.001
	Significant changes in climate mitigation policies	Dummy	-	0.119	-0.105	0.103	0.033	-0.079	0.176
	Public RD&D spending	USD million	+	**0.457x10^{-3}***	**0.001** **	0.275x10^{-3}	0.001	0.485	0.238
Investment environment	Local-content requirement attached to feed-in tariff	Percent	-	**0.005*** **	**0.007***	**0.005** **	**0.007*** **	-0.001	0.003
	Ease of doing business	Index	+	**0.007** **	-0.003	**0.007** **	**0.008***	**0.014***	**0.008** **
	Trading across borders	Index	+	**0.005** **	-0.003	**0.008*** **	0.003	0.009	**0.006*** **
	Direct control of the state over enterprises	Index	Higher is more control	**-0.079** **	**-0.234*** **	**-0.098** **	0.041	**-0.232*** **	**-0.106*** **
	Governance of SOEs	Index	Higher is more control	**0.556*** **	**1.093*** **	0.165	0.207	**0.750*** **	0.203
	Implementation of Basel III leverage ratio	Dummy	-	0.553	**1.569*** **	-	-	**1.204*** **	-
Innovation Environment	Number of universities	Count	+	**0.019*** **	**-0.161***	**0.013*** **	**0.014** **	**0.022*** **	**0.014*** **
	Perpetual inventory of renewable power-related patents	Patent count	+	**0.470x10^{-3}*** **	**0.001*** **	**0.458x10^{-3}*** **	**0.001*** **	**0.381x10^{-3}*** **	**0.487x10^{-3}*** **
Controls	Natural resource endowment	Standardised units	+	**0.095*** **	0.005	**0.108*** **	**0.106*** **	**0.119*** **	**0.117*** **
	Constant			**-4.182*** **	**-3.222** **	**-1.824** **	**-0.817***	**-6.526*** **	**-1.992** **
	Observations			3576	702	2874	2184	1392	3420

Notes: The asterisk *after the coefficient means that the coefficient of the variable is significant at the 10% significance level or lower, i.e. p<0.1; The asterisks ** after the coefficient means that the coefficient of the variable is significant at the 5% significance level or lower, i.e. p<0.05, The asterisks *** after the coefficient means that the coefficient of the variable is significant at the 1% significance level or lower, i.e. p<0.01. For a list and definition of OECD member and emerging economies, see Table 1. In the EU sub-sample the variable Implementation of Basel III leverage ratio could not be included since the variable did not show any variation, as marked by a hyphen.

Source: Authors' calculations.

Table 8. Determinants of innovation in renewable power in OECD and G20 countries from 2000-2012

(in the base innovation model and sub-sample innovation regressions)

	Explanatory variable (i.e. *determinant*)	Unit	Expected sign	Innovation	Interactions	Interactions; emerging only	Interactions: advanced only
Climate mitigation policy	Feed-in tariff	USD/kWh, weighted with power purchasing agreement-duration	+	**0.039*** **	**0.038*** **	-0.052	**0.032*** **
	Renewable energy certificate	Percent	+	0.011	0.009	**0.047** **	0.008
	Public tender	MW	+	0.207x10^{-3}	**0.001*** **	**0.003*** **	-0.442x10^{-3}
	Explicit carbon price	USD/tCO2e	+	-0.002	-0.003	**0.071*** **	0.002
	Energy taxation in the power sector	USD/MWh	+	-0.001	-0.004	0.115	-0.003
	Logarithm of fossil fuel support for power generation	Ln USD	-	0.003	0.001	**0.037* **	-0.006
	Significant changes in climate mitigation policies	Dummy	-	0.119	-0.016	-0.174	0.096
	Public RD&D spending	USD million	+	**0.457x10^{-3}* **	**0.443x10^{-3}* **	**0.001* **	0.209x10^{-3}
Investment environment	Local-content requirement attached to feed-in tariff	Percent	-	**0.005*** **	0.195x10^{-3}	0.006	**0.005** **
	Ease of doing business	Index	+	**0.007** **	0.005	0.008	**0.007** **
	Trading across borders	Index	+	**0.005** **	**0.006*** **	**-0.010** **	**0.008*** **
	Direct control of the state over enterprises	Index	Higher is more control	**-0.079** **	**-0.140*** **	**-0.236*** **	**-0.093** **
	Governance of SOEs	Index	Higher is more control	**0.556*** **	**0.541*** **	**1.063*** **	0.145
	Implementation of Basel III leverage ratio	Dummy	-	0.553	**0.630* **	**1.477*** **	-
	Number of universities	Count	+	**0.019*** **	**0.018*** **	-0.122	**0.013*** **
Innovation Environment	Perpetual inventory of renewable power-related patents	Patent Count	+	**0.470x10^{-3}*** **	**0.478x10^{-3}*** **	**0.001*** **	**0.410x10^{-3}*** **
Controls	Natural resource endowment	Standardised units	+	**0.095*** **	**0.090*** **	-0.018	**0.111*** **
	Constant			**-4.182*** **	**-3.955*** **	**-3.899*** **	**-1.671* **
Interactions	Local-content requirement attached to feed-in tariff * Feed-in tariff	Percent * USD/kWh, weighted with power purchasing agreement-duration*			**0.002** **		
	Direct control of the state over enterprises *Public tender	Index * MW			**-0.001*** **	**-0.001*** **	
	Direct control of the state over enterprises * Energy taxation in the power sector	Index * USD/MWh			**0.006*** **		
	Public RD&D spending * Feed-in tariff	USD million * USD/kWh, weighted with power purchasing agreement-duration				**0.282x10^{-3}** **	
	Direct control of the state over enterprises * Carbon price	Index * USD/tCO2e				**-0.075*** **	
	Perpetual inventory of renewable power-related patents * Public tender	Patent count * MW					**0.189x10^{-5}** **
	Perpetual inventory of renewable power-related patents * Energy taxation in the power sector	Patent count* USD/MWh					**0.486x10^{-5}* **
	Pseudo-R-squared			0.297	0.298	0.302	0.302
	Observations			3576	3576	702	2874

Notes: The asterisk *after the coefficient means that the coefficient of the variable is significant at the 10% significance level or lower, i.e. p<0.1; The asterisks ** after the coefficient means that the coefficient of the variable is significant at the 5% significance level or lower, i.e. p<0.05, The asterisks *** after the coefficient means that the coefficient of the variable is significant at the 1% significance level or lower, i.e. p<0.01.

Source: Authors' calculations.

Initial policy implications

This section briefly discusses initial policy implications from the results of the investment and innovation models across OECD and G20 countries. Key policy recommendations and implications for OECD and G20 governments will be set out in-depth in a forthcoming policy paper on *Enabling Investment and Innovation in Renewable Energy* (2017a forthcoming).

In particular, the important role of the investment environment on both investment and innovation in renewable power across OECD and G20 countries highlights the need for policy makers to enhance the quality of the investment environment, and factor cross-effects between targeted climate mitigation policies and broader investment conditions. These findings have important implications for policy makers who wish to create a pipeline of bankable renewable-power projects. Beyond setting targeted investment incentives, and other climate mitigation policies, policy makers need to consider outstanding regulatory and market barriers to renewables investment, including within investment policy and facilitation, competition, trade policy, public governance and financial market policy (including Basel III regulations). In the solar sector for instance, results show that across OECD and G20 countries, outstanding barriers to solar investment are notably linked to: competition policy and regulatory and market rigidities in the power sector, e.g. to connect solar PV projects to the grid; cumbersome licensing and permitting procedures; property registration procedures and land rights; transparency of infrastructure procurement; and access to financing. These results suggest that improving the attractiveness of the broader investment environment is critical to unlock investment in solar energy. This is particularly important for solar PV power plants, which represent the majority of solar investment deals across OECD and G20 countries. These results also show that the presence of a conducive regulatory environment can spur investment decisions both at the early and deployment stages of technology development. The influence of the broader investment environment on patenting activity and renewable technology development is less intuitive than its role to support investment in deployed renewable-power projects. This result may suggest that strengthening the investment environment and carefully assessing how it interacts with innovation incentives can help enhance the effect of targeted incentives for innovation in low-carbon technologies such as renewable power.

The results also suggest that the effect of climate mitigation policies in mobilising investment and patenting in renewable power depends on a favourable investment environment. This is true both in advanced and emerging economies within the OECD and G20. In particular, the presence of direct control of the state over enterprises decreases: 1. the effect of public tenders in mobilising renewables investment in advanced countries; and 2. the effect of both public tenders and explicit carbon prices in stimulating renewables patenting in emerging economies.

The fact that explicit carbon prices mobilise investment in renewable projects in the EU and emerging economies, but not in the base investment model, suggest that current carbon pricing levels remain too low to show an effect on encouraging direct investment in renewables, beyond data quality issues. In addition, the analysis of explicit carbon prices in the sub-sample investment regression for EU countries show that a substantial increase in explicit carbon prices, at current levels in the EU, would lead to substantial increases in renewables investment. These results call for setting stronger and more consistent carbon prices.

Beyond the need to address market and regulatory rigidities in the power sector and across investment conditions, the effect of targeted investment incentives in mobilising investment in renewable-power projects is a reminder of the importance of providing short-run, targeted support to renewables deployment until the technologies become fully cost-competitive against fossil fuels. In addition, the effect of climate mitigation policies in mobilising renewables investment is enhanced when they are combined, e.g. in emerging economies explicit carbon prices with public RD&D spending, or RECs with public RD&D spending.

In addition, the effect of feed-in tariffs on stimulating renewables patenting, and the insignificant results for tenders, have policy implications, in the context of ongoing policy shifts away from feed-in tariffs and towards public tenders. Decreasing policy support through feed-in tariffs may have implications across OECD and G20 countries on innovation in the next generation of renewable-power technologies. These findings provide important conclusions for policy makers who are gradually phasing down the use

of feed-in tariffs across OECD and G20 countries, to switch to public tenders. The decreasing use of feed-in tariffs may have implications across OECD and G20 countries on the potential to innovate in the next generation of renewables technologies. Conversely, public tenders may not send sufficient signals to innovators and early adopters of renewables technologies in emerging economies with government control of incumbent SOEs, which is an interaction effect likely stemming from risks of an uncompetitive power market and barriers for new entrants. More research is needed to better assess effects of tenders on patenting. Furthermore, the presence of state-owned enterprises and incumbent public utilities or of government intervention in the power sector decreases the effect of public tenders, especially in emerging economies, as the tested interaction shows, although additional research on market structure specifically in the power sector might reveal a refined result here. This is nonetheless an important conclusion, which suggests that policy makers should ensure public tenders are fair and competitive tenders, e.g. by addressing possible issues with incumbent utilities and state-owned enterprises in the power sector.

The positive effect of public RD&D spending for renewables technologies in stimulating renewables patenting also has policy implications in the context of historically low levels of public RD&D since the 2008 financial crisis (OECD, 2015q). Though this result is unsurprising, it suggests that public RD&D levels should be increased, to catalyse technological development and inventive capacity in the next generation of renewables technologies in the mid- to long-term.[25] This is an important policy conclusion, consistent with existing calls for increased public RD&D budgets to support innovation in low-carbon technologies, including for renewable-power generation. Policy makers have recently favoured public support to the deployment of mature renewables technologies through targeted investment incentives such as FiTs, RECs and public tenders, whereas public RD&D levels are historically low, as discussed in Annex A.2. The results on public RD&D spending are in particular significant in emerging economies. Further research is needed to assess whether providing targeted public support to RD&D in renewables technologies in specific emerging economies may give those emerging economies a competitive edge in using the patents for technology development and deployment in their own countries.

Important caveats

A number of caveats need to be considered in the interpretation of results presented in this working paper. In particular:

- The policy recommendations included in this analysis are non-country specific across G20 and OECD countries or sub-groups of countries, and not tailored to national circumstances. It is important to account for national circumstances to acknowledge the complexity of national policy and regulatory settings. However, these national circumstances cannot be factored into the regression analysis.

- The impacts of different policy variables cannot be compared directly, as discussed previously. Though the significance and signs of coefficients provide valuable information on the effect of each individual policy, the coefficient sizes are not comparable so this working paper does not allow comparing the relative effectiveness between different policies. This is because policy variables are typically measured in different units: the impact level of RECs for instance is expressed in percent, feed-in tariffs in year-weighted USD/kWh and public RD&D support in USD. Policy variables' impacts on investment and innovation must thus be interpreted in terms of their units of measurement (e.g. the impact of a USD 1/kWh increase in a feed-in tariff, or of a 100

25 Alongside the current budget, the model also tests the effect of a lagged budget variable since technology developments tend to take time to unfold. As the model shows, the lagged variable has a stable and equally high effect on innovation, showing that there is not only an immediate effect, but also a lagged effect.

MW increase in a procurement) and are difficult to compare due to their different units. It is important to recognise that incentives such as RECs, feed-in tariffs and public RD&D support are thus not comparable (e.g. with regards to their goals, metrics, and targeted stage of technology development). Their relative impacts are thus not easy to compare.

- Both the investment and the innovation analysis might suffer from possible omitted variable bias, due to missing variables capturing the price of the substitute of renewable power (e.g. market prices of coal or natural gas in the power sector[26]). The need to capture such prices is singled out as an important factor in the induced innovation literature. Such data however was not available across countries and years. Further, due to resource constraints, renewable-energy targets were excluded from the analysis, although they are partly captured in the climate mitigation policy variables included in the study. Several other possible factors were excluded from the analysis, linked to the broader regulatory and investment environment, or specific to renewables (such as mapping of available wind or solar resources).

- In addition, the costs and value for money of policy support to renewables technologies for policy makers are not considered in the present study, as discussed previously. This means that the study is not assessing the effects of climate mitigation policies and investment conditions on renewable technology costs – e.g. the role of public tenders in driving solar PV and wind power prices down.

- This empirical study only considers renewables sectors and therefore may not capture effects linked to the fossil-fuel power sector, and investment levels in fossil-fuel relative to renewables. For instance, fossil-fuel regulations (e.g. on emissions standards of coal-fired power plants), prices of coal and natural gas prices, as well as the substitutive relationship between renewable power and fossil-fuel electricity could create a bias even beyond the controls already included in the model. In addition, the study is not considering the impacts of climate policies and other investment conditions on fossil-fuel investment.

- Not all renewable-power technologies are patented, as discussed previously.

- With the exception of the solar- and wind-power sectors, this analysis does not provide results specific to renewable sectors, so the econometric results are relevant for six renewable-power technologies considered (biomass and waste, geothermal, marine, small hydro, solar and wind energy). However, there are both mature and early-stage technologies across and within renewable-power sources. The analysis may not be able to provide sufficient granularity within each sector and technology, due to data limitations, i.e. lack of data for sufficiently large sub-sample sizes in available dataset.

- Although the study provides results specific to solar and wind power, the analysis may not be able to provide sufficient granularity within each renewable sector, e.g. on the differences between onshore and offshore wind, or between solar PV and solar CSP, due to data limitations.

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[26] The study looked for data for coal and natural gas prices to include as control variables but could not find country-specific data on those prices for each OECD and G20 country considered by the analysis.

ANNEX A.1 OVERVIEW OF THE VARIABLES CONSIDERED BY THE ANALYSIS

This annex provides a summary of the variables' descriptive statistics, along with their definitions, data sources and data treatment.

Data summary

Table A.1.1. provides a summary of the descriptive statistics of all the variables presented in the investment and innovation models, including the variables that were not selected by the *lasso* approach. Please note that the negative minimum values for FDI inflows are reported here as they were retrieved from the sources (after adjusting for exchange rate and inflation). Negative FDI inflows are not uncommon and often the result of divestment. Further, values for policy support to fossil fuels in electricity generation have been adjusted with exchange rates, adjusted for inflation and additionally were logged.

Overview of the variables considered by the study

This annex provides additional information for variables used in the econometric analysis of renewable power investments and innovation. Variables not selected by the *lasso* are not further explained. Note that whenever necessary, local currency units were converted into USD using average currency exchange rates (World Bank, 2015a), and current USD values were deflated to 2005 deflator values (World Bank, 2015a).

BNEF investment data: Limitations

The coverage of the BNEF database (BNEF, 2015) is limited since BNEF imposes restrictions on observed projects taken up in the database. For renewable power investments only projects of over 1 MW capacity are considered, except for: onshore wind projects, for which projects of over 0.1 MW capacity are considered; offshore wind projects for which all capacity sizes are considered; and small hydro, for which projects of under 1MW and over 50 MW are not considered. Further, BNEF distinguishes between *new built*, *acquisition* and *refinancing* deals and several status levels of projects. This analysis considers only new built power plants since acquisition might lead to double counting of investments and refinancing is conceptually different and would require a different modelling approach. Moreover, only *commissioned* and *permitted* projects as well as projects which fall into the category *financing secured / under construction* are considered. Only values from those projects which were actually carried out allow for an inference on the effect of policies. In principal deal types could overlap since the recorded equity of a company could be sourced through venture capital. This would lead to bias in the regression due to double counting. Thorough checks of the original data reveal that no such case is present in the deal data used in this study.

Climate mitigation policy variables

This section gives an overview over all climate change mitigation policy variables included in this analysis.

Feed-in tariffs

Sectoral data on the ***feed-in tariff*** (FiT; in USD/kWh) is weighted with the length of PPAs awarded under a country's FiT policy (in years). Building the variable required making some adjustments for sector and country idiosyncrasies, as the following paragraphs will explain.

Table A.1.1 Descriptive statistics

Variable	Unit	Observations	Mean	Standard Deviation	Minimum	Maximum	Source
Feed-in tariff	USD/kWh, weighted with power purchasing agreement-duration	4410	0.82	1.99	0.0	15	Updated based on Haščič et al. (2015)
Renewable energy certificate	Percent	4404	1.03	3.04	0.0	21	Updated based on Haščič et al. (2015)
Public tender	MW	4410	6.85	86.19	0.0	3000	Own data gathering
Explicit carbon price	USD/tCO2e	4404	3.98	6.80	0.0	72	Ecofys and World Bank (2015), OECD (2015q,r)
Energy taxation in the power sector	USD/MWh	4410	4.45	12.13	0.0	108	CESifo (2015), OECD (2015l)
Logarithm of fossil fuel support for power generation	Ln USD	4410	3.23	7.04	0.0	23	OECD (2015m), Oosterhuis (2013)
Significant changes in climate mitigation policies	Dummy; narrow	4410	0.01	0.09	0.0	1	Own data gathering
Public RD&D spending	USD million	4410	141.88	153.00	0.8	643	IEA (2015h), BNEF (2015), Harvard Belfer Center (2010)
Antitrust Exemption	Index	4230	0.48	0.75	0.0	3	Koske et al. (2015)
Implementation Basel III risk-based capital requirements	Dummy	4410	0.08	0.27	0.0	1	Own data gathering
Implementation Basel III leverage ratio	Dummy	4410	0.01	0.10	0.0	1	Own data gathering
Implementation Basel III liquidity coverage ratio	Dummy	4410	0.02	0.13	0.0	1	Own data gathering
Barriers to entry	Index	4230	1.20	0.73	0.0	4	Koske et al. (2015)
Barriers to FDI	Index	4230	0.74	0.75	0.0	4	Koske et al. (2015)
Barriers to network sectors	Index	4230	3.06	0.80	0.7	6	Koske et al. (2015)
Barriers to services	Index	4230	3.37	0.89	0.9	6	Koske et al. (2015)
Banking competitiveness	Boone indicator	4404	-0.04	0.25	-2.1	6	Koske et al. (2015)
Command and control	Index	4230	2.14	0.84	-0.0	4	Koske et al. (2015)
Carbon intensity of energy	Kton CO2/ktoe TPES	4410	9.25	43.90	0.0	588	Olivier et al. (2014), IEA (2015e)
Corruption perception index	Index	4410	6.07	2.15	1.7	10	Transparency International (2015)
Sovereign credit rating	Ranks	4410	7.28	1.60	1.0	9	Moody's (2015)
Direct control of the state over enterprises	Index	4140	1.41	0.93	-1.2	5	Koske et al. (2015)
Ease of acquiring construction permit	Index	4410	65.73	16.56	-5.9	92	World Bank (2015e)
Contract enforcement	Index	4410	66.53	12.36	25.8	86	World Bank (2015e)
Getting credit	Index	4410	63.18	22.02	-47.7	100	World Bank (2015e)
Ease of getting electricity	Index	4410	74.47	16.30	-18.0	100	World Bank (2015e)
Resolving insolvency	Index	4410	58.23	28.29	-32.2	107	World Bank (2015e)
Minority Investor Protection	Index	4410	58.38	14.07	-2.7	97	World Bank (2015e)
Registering property	Index	4410	69.97	15.68	-24.9	97	World Bank (2015e)
Ease of doing business	Index	4410	79.71	14.19	16.8	100	World Bank (2015e)
Paying taxes	Index	4410	71.56	16.11	7.3	99	World Bank (2015e)
Trading across borders	Index	4410	77.41	16.15	-54.9	94	World Bank (2015e)
Electricity consumption per capita	Terajoule per capita	4410	7.32	6.78	0.4	55	World Bank (2015e)
Electricity consumption	Terajoule	4410	3.19e+11	7.36e+11	1.7e+09	5.51e+12	World Bank (2015e)
Electricity generation	GWh	4410	343.81	778.57	0.4	5533	IEA (2015e)
FDI inflows	USD million	4338	25211.60	57119.30	-41305.3	705267	World Bank (2015a)
Local-content requirement attached to feed-in tariff	Percent	4410	1.13	8.44	0.0	100	OECD (2015a)
Treatment of foreign suppliers	Index	4230	1.00	0.83	0.0	5	Koske et al. (2015)
GDP per capita	USD	4356	24.43	18.52	0.6	86	World Bank (2015a)
Network involvement	Index	4230	3.37	1.20	0.1	6	Koske et al. (2015)
Governance of SOEs	Index	4140	3.79	1.38	0.5	6	Koske et al. (2015)
Strength of Intellectual Property Rights	Index	4410	4.91	1.05	1.8	8	Property Rights Alliance (2016)
Licenses and permit system	Index	4230	3.64	1.56	0.0	7	Koske et al. (2015)
Innovation spillover	Patent count	4410	58.38	171.54	0.0	2011	Haščič and Migotto (2015)
Perpetual inventory of renewable power-related patents	Patent count	4410	129.52	601.12	0.0	10343	Haščič and Migotto (2015)
Price Controls	Index	4230	1.92	1.09	0.1	6	Koske et al. (2015)
Domestic credit to private sector	Percent of GDP	4404	95.18	59.78	7.1	311	World Bank (2016a)
Regulatory capital to risk-weighted asset	Ratio	4410	13.52	4.43	-1.9	33	IMF (2016)
Communication and simplification	Index	4140	1.12	0.86	0.0	6	Koske et al. (2015)
Scope of state-owned enterprises	Index	4230	3.32	1.18	1.0	6	Koske et al. (2015)
Credit to government and SOEs	Percent of GDP	4404	13.81	11.17	0.0	73	World Bank (2016a)
Natural resource endowment	Various units	4400	0.01	0.91	-1.7	8	World Bank (2015a), IEA (2015e), World Resource Institute (2015), CIA (2015), SolarGIS (2013), Lu et al. (2009)
Tariff barriers	Percent	4230	0.51	1.06	0.0	6	Koske et al. (2015)
Tertiary education	Percent enrolment	4410	27.28	13.67	0.0	102	World Bank (2015a)
Electricity transmission loss	Percent of output	4410	8.45	4.66	-1.2	28	World Bank (2015a)
Number of universities	Count	4410	18.63	37.89	0.0	245	Webometrics (2016)
Contract Enforcement Time	Index	4410	534.96	268.50	210.0	1580	World Bank (2015a)
Business extent of disclosure	Index	4410	6.26	2.50	0.0	10	World Bank (2015a)
Time resolve insolvency	Days	4410	2.29	1.50	0.4	10	World Bank (2015a)
Time required starting business	Days	4410	27.17	29.30	0.5	168	World Bank (2015a)
Cost of business start-up	Index	4410	10.86	16.50	0.0	137	World Bank (2015a)
Procedures registering property	Count	4410	5.43	2.26	1.0	14	World Bank (2015a)
Time registering property	Days	4410	50.04	100.95	1.0	956	World Bank (2015a)
Procedures to build warehouse	Count	4410	14.66	6.91	6.0	51	World Bank (2015a)
Time to build warehouse	Days	4410	196.46	120.14	27.0	678	World Bank (2015a)
Time to get electricity	Days	4410	107.58	67.58	18.0	302	World Bank (2015a)
Procedures to enforce contracts	Index	4410	33.95	5.28	21.0	46	World Bank (2015a)
Control of corruption	Index	4410	0.89	0.98	-1.1	3	World Bank (2016c)
Quality and independence of government service	Index	4410	1.02	0.76	-0.8	2	World Bank (2016c)
Political stability	Index	4410	0.49	0.76	-2.1	2	World Bank (2016c)
Regulatory quality	Index	4410	0.99	0.68	-1.1	2	World Bank (2016c)
Rule of law	Index	4410	0.91	0.83	-1.1	2	World Bank (2016c)
Voice and accountability	Index	4410	0.87	0.74	-1.9	2	World Bank (2016c)
Stability of financial institutions	Score	4404	16.66	12.48	-7.9	74	World Bank (2016)
Population	Count (thousand)	4410	89.91	245.32	0.3	1364	World Bank (2015a)
Logarithm of GDP	Ln USD	4356	26.33	1.65	22.5	30	World Bank (2015a)
Logarithm of sector-specific trade	Ln USD	4410	11.37	2.86	0.0	17	Comtrade (2015)
Average MFN tariff	Percent	4410	3.07	3.53	0.0	29	UNCTAD Trains (2016)
Logarithm of CO2 emissions	Ln kton CO2	4410	11.69	1.75	7.3	16	Olivier et al. (2014)

Source: Authors' calculations.

Adjustments for biomass and waste were made so that if no other waste types were present, landfill gas was chosen representatively for all waste feed-in tariffs. This choice was made mainly to be consistent with previous and secondary data collection. If many waste types were present, the midpoint between all categories were chosen, which includes but is not limited to anaerobic gases, biomass waste (as opposed to biomass or renewed biomass) and municipal waste-fired plants.

Adjustments for scale of projects (e.g. small-scale versus large-scale) and different capacity brackets (in KW) of FiT levels were made so that in case of solar tariffs, ground-mounted tariffs were prioritised since BNEF investment data excludes small roof-mounted projects by default (since they are mostly homeowners' efforts). A weighted average was impossible due to lack of data, i.e. a lack of classification within the BNEF database. Given the difference in size and number of roof-mounted and ground-mounted solar PV, a simple average would likely have distorted the tariff. Note that if brackets were not classified as roof-mounted or ground-mounted, all brackets were considered, even though it is likely that brackets with small capacities contain disproportionally many roof-mounted solar collectors.

Adjustments for to be as consistent as possible with BNEF exclusion criteria were made so that if a policy distinguished between small and large, only the values for large were included. If a policy distinguished between household and industrial, only data for industrial were included. Generally, the capacity limits of BNEF and BNEF's focus on the industry as opposed to households were relevant. Notably this results in the exclusion of capacity brackets for capacities smaller than 1MW (except for onshore wind power plants). Note that the scale of projects is not always expressed in capacity bracket (in KW), but also by use, e.g. household use, implying small capacity.

Adjustments on FiT policy design were made. Some countries, for example Finland and the Netherlands, do not have a fixed-price tariff, but rather pay a premium-price on top of the market price. In line with literature (NREL and US Department of State, 2010), we consider this a feed-in tariff as well. Since our research aims at incentives for investors and project developers these premiums fulfil the same role as other FiTs. In addition, for countries with a cap-less premium-price FiT, the premium was added to the market price. Specifically, the premium was added to a given year's average electricity market price for industrial consumers, i.e. non-household consumers. End-consumers' prices were disregarded since they include the VAT, which accrue to the state, not to the electricity producer, and thus are not an investment incentive. Furthermore, countries' micro-FiT policies have been excluded. Micro-FiT policies apply to or are at least targeted at private households, i.e. are likely (and sometimes legally) relevant only for capacity ranges outside of BNEF's scope.

In addition, adjustments, averaging or re-categorisation for congruence with BNEF data were based on multiple distinctions, including on: *Technology types*, since most FiTs include wind, solar and hydro separately, many include biomass separately, and some include certain forms of waste, like gases and trash burning, and few include geothermal and oceanic energy specifically; sub-national levels, since for India, the United States and Canada sub-national differences play a large role, feed-in tariff values are averages of relevant tariffs of states or provinces weighted with the energy generation (in MWh) in the respective states or provinces; *Timing of provision*, e.g. according to peak hour, off-peak and valley demand; *Types of tariff setting*, either as: a set price, an additional premium (as long as the market price was low enough) or a flat premium; *Degression*[27] *types and periods*. The majority of tariffs did not degress over years automatically; some had an agreed upon decay rate over years; some were regularly revised by a government body; even monthly and quarterly degression exists. If it was a degression within the PPAs themselves, the start value was recorded. If it was a degression of starting values of PPAs, the years' starting values were recorded; *Modes of connection to the grid*, for example for special island location

27 I.e. a gradual decrease in the feed-in tariff rate on amounts below a specified sum.

tariffs; and *other technical details*, like type of waste burned, technical properties of the generator other than capacity.

Renewable energy certificates

While the ***renewable energy certificates*** (REC) variable, which was updated based on Haščič et al. (2015) includes any mandatory renewable-power generation share imposed on power producers as state-mandated obligations or state-mandated voluntary goals, with or without the option to trade certificates or quotas, voluntary systems without a goal (e.g. subnational voluntary quota pledges in US states) and mandatory measures from non-governmental entities are excluded. The unit of the variable is in percentage points of produced electricity output (based on the REC's yearly obligation or goal). Note that for subnational RECs in the United States, RECs are averaged with electricity production as weights.

Public tenders

Data on ***public tenders*** (including public competitive bidding or auctions) was gathered from multiple sources, including countries' or state agencies' announcements and news outlets. The resulting set of continuous tender data includes tenders with a set capacity as well as tenders for single large scale RE projects. Tenders are included if bidding was for an electricity price or other form of support and thus the bidder would become the eventual seller of the produced power, as opposed to bids for turnkey-type projects. Values for the separate sectors are recorded as capacity in MW tendered. Though the average or winning bidding price would have been a more suitable comparison to FiT values, these data are often not available. However, auctioned-off capacity relates to resulting prices, given the near-perfect market conditions of an auction, and also has a relation to the size of the county's market. Impact of this determinant is expected to be positive.

Explicit carbon prices

Explicit carbon price data from Ecofys and World Bank (2015) as well as from multiple sources reported in OECD (2015q, r) includes only those carbon prices relevant for the electricity sector. If more than one relevant carbon price existed, prices were averaged and weighted. In case of regionally different programs (e.g. China or Canada) and also in case of different sectors targeted (e.g. the UK), the prices were weighted by the emissions the system covered or, if available, the amount of certificates traded. In case of the ETS the average value of 40% emissions coverage is used as weight for all EU countries. Taxes covering the transport sector only and taxes EU ETS participants were exempted from are excluded since this analysis focusses on power production. Regional Greenhouse Gas Initiative values included in United States data are auction values rather than after-market prices. Please note here that available secondary data only shows the percentage of GHG covered by tax or permit policies, but not necessarily which sectors are covered. An exception to this is the transport sector, which is often treated separately and is excluded here whenever reported separately.

Energy taxation in the power sector

Data for the ***energy taxation in the power sector*** stem from different sources with manifold definitions of electricity taxes. The main sources are CESifo (2015), based on Eurostat data, and OECD (2015l), which, however, has only data for 2014. Based on the mostly incomplete data, taxes are assumed to continue for unrecorded years until a different value has been recorded. Whenever data indicate otherwise, CO2-levies, other levies, excise taxes, other taxes, fees and contributions, as long as they are electricity-specific, are added up for the electricity tax value. Values before 2003 in EU countries are assumed to be equal to 2003 values; values past 2012 are assumed to be equal to the value in 2012. If no data before 2015 is available, we assume the absence of an electricity tax. In the cases of Australia, China

and Mexico OECD (2015l) reports a tax of less than 0.1 EUR/GJ. Therefore the value is set to the corresponding converted upper limit value of 0.36 EUR/MWh before conversion to 2005 USD/MWh.

Significant changes in climate mitigation policies

Policy changes were analysed through in-house data gathering by studying different sources including annual reports published by the Renewable Energy Policy Network for the 21st Century (REN21), reports published by the Keep on Track Project - specifically those focusing on the Analysis of Deviations and Barriers, International Energy Agency (IEA) country reports and other web-based sources.

The primary objective of ***significant changes in climate mitigation policies*** is to capture policies or policy changes that imposed retroactive changes on renewable-power projects. However, due to issues delineating between retroactive changes and changes that were drastic, but not necessarily retroactive, unanticipated changes are captured in a dummy for significant changes. Changes included are e.g. FiT rate reductions, imposition of annual fees on installations, abolishment of FiTs.

Logarithm of fossil-fuel support for power generation

The variable on ***fossil-fuel support in power generation*** entails all and only those support measures for the use of fossil fuels in electricity generation, within consumer and general services support for fossil fuels (mostly for consumption, with a few exceptions such as Korea, where existing fossil-fuel support fall in the category of general services support). Support to production of fossil fuels is excluded, especially in upstream mining sectors, just as much as consumer excise tax exemptions and reductions, as well as other indirect support measures in the electricity sector. The main data source is OECD (2015m), amended by Oosterhuis (2013) for missing data on six EU countries. Direct energy-production fossil-fuel support in Argentina and Iceland are not recorded in any source but are assumed to be zero due to these countries' energy sector structure. Fossil-fuel support in Saudi Arabia is also not recorded even though existent, but is also assumed to be zero since the effect of very low oil prices delivered as feedstock to Saudi Arabian utilities is countered by constraints for utilities to also sell electricity at a low rate. All values for sectors with unavailable data in OECD (2015m) are assumed to be 0.

Public RD&D spending

Public RD&D expenditures are typically provided via grants, awards and subsidies. The study primarily relies on IEA's Energy Technology statistics of RD&D budget in IEA's 27 member countries (IEA, 2015h), amended by various sources. To also include RD&D data for OECD member countries that are not IEA member countries (i.e. Chile, Iceland, Israel, Mexico and Slovenia), as well as non-OECD G20 member countries, the research also investigated other RD&D data sources such as BNEF's public R&D dataset and Harvard Belfer Center's data and research on energy technology innovation policy in emerging economies (BNEF, 2015; Harvard Belfer Center, 2010). The investigation revealed that though the breadth of the RD&D data would be increased by including other sources, the detail of the RD&D data with respect to sector-specificity would be diminished. Using detailed country-specific RD&D data would lead to a loss of observations. Therefore the regression analysis employs global RD&D data specific to sectors and years, but not to countries. This use of the data is justified by the relatively quick dissemination of technology in OECD and G20 countries: If RD&D spending has an effect it will likely have spillover effects even on countries where it was not disbursed. Where RD&D spending is available for comparison, regression results show only minor changes, confirming that global, but sector-specific RD&D is a useful proxy for country- and sector-specific RD&D.

Investment environment variables

This section presents the investment environment variables selected by the *lasso* approach in both the investment and innovation models. Most investment environment variables come from existing OECD and non-OECD indices and databases.

In addition to drawing on existing indices and databases, this study has created new investment environment variables (e.g. on implementation of Basel III framework) and employed other variables and existing indicators from other various sources, which are mentioned in the subsequent section.

The subsequent sections list the selected investment environment variables used in either an investment or an innovation model. Variables are listed by key policy areas identified by the OECD *Policy Framework for Investment*, including; investment policy; investment promotion and facilitation; competition policy; trade policy; financial market policy and public governance.

Note that for all variables from the OECD data base on Product Market Regulation (Koske et al., 2015) data only exist for 1998, 2003, 2008 and 2013. Missing values in between these four years were extrapolated from existing values. In the case of only one existing value and if the maximum of six or minimum of zero was the earliest available value, values were carried forward/carried backward. Exceptions in extrapolation were made for obvious breaks in policies, i.e. large changes in the indicator, in which case earliest/last values were carried backward/forward. Missing values for all other years were interpolated based on existing and extrapolated values. Data on Argentina and Saudi Arabia is unavailable for any year and indicator of the Product Market Regulation set.

Further, note that variables from the ***ease of doing business*** Index (World Bank, 2015e) are scored as the distance to frontier, i.e. as a comparison to the group of countries surveyed. Variable names are generally indicative of what is asked for in the questionnaire and converted to the distance to frontier measure. Missing data were inter- and extrapolated, which in some cases meant carrying backward or forward values from a single year of observation for some countries.[28]

Investment policy

The selected variables that measure promotion of sound **investment policy** principles include:

- ***Time required starting a business***: Measures the time that it takes to start a business in days, assuming no undue formal complications or delay through corruption (World Bank, 2015a).
- The ease of ***registering property***, measures the steps, time and cost involved in registering property to purchase land and building, as well as the quality of the land administration system (World Bank, 2015a, e).
- ***Time to build warehouse*** is the number of days needed for building a warehouse. If additional spending can sped up the process, the number of days for the speeded up process is recorded instead (World Bank, 2015a).
- ***Time to get electricity*****:** The definitions of ***time to build warehouse*** apply here as well, with respect to getting electricity (World Bank, 2015a).

[28] For the exact methodology and set of assumptions, please refer to *www.doingbusiness.org/Methodology*.

- ***Cost of business start-up*****:** Measures the cost of starting a business, measured as a percentage of the country's income per capita, including legally required and commonly used services, but excluding value added tax and bribery (World Bank, 2015a).

- The ease of ***resolving insolvency*** (World Bank, 2015e), which captures the administrative and legal framework for resolving insolvency, and aims to provide clarity to involved parties in case of insolvency. Since this variable has a particular impact on the risk-assessment of lenders, we expect this variable to exhibit a positive effect on investment and innovation.

Investment promotion and facilitation

The selected variables that measure **investment promotion and facilitation** include notably:

- The ***ease of doing business*** composite index (World Bank, 2015e), which covers aspects of the ease of starting a business related to investment facilitation, as well as other policy area. This variable is expected to exhibit a positive effect on investments and innovation since founding a company is often a natural step of building a power plant, but also in starting a research project.
- ***Licenses and permit system*** (Koske et al., 2015), which measures how stream-lined administration and institutional framework of a country are. With the caveat that this variable also might regulatory rigor, we expect a positive impact.

Competition policy

The selected variables that relate to **competition policy** include:

- ***Barriers to entry (***Koske et al., 2015), which measures the inability to enter the power sector market.

- ***Barriers to network sectors*****:** The variable equally weighs a) the degree of separation in network sectors and b) the entry regulation in the 8 network sectors gas, electricity, water, rail transport, air transport, road freight transport, postal services, and telecommunication (Koske et al., 2015).

- ***Barriers to services*****:** The variable captures entry barriers in professional services, freight transport services and retail distribution (Koske et al., 2015).

- The prevalence of ***command and control regulation*** (Koske et al., 2015), which covers direct regulation over a wide range of sectors throughout the economy and serves as proxy for government intervention through non-market instruments.

- The ***direct control of the state over enterprises***, and ***governance of state-owned enterprises (SOEs)*** (Koske et al., 2015). Both these variables capture the role of the state in a country's economy in general, either by exercising direct control, indirect control or occupying a special place in the market.

Trade policy

The selected variables that relate to **trade policy** include:

- ***Trading across borders*** (World Bank, 2015e), which tracks the ease of importing inputs and exporting outputs of production. Since less inhibited trade should make building and maintaining

power plants easier, we expect a positive sign for this variable in the investment and innovation regressions.

Public governance

- The ***corruption perception*** index from Transparency International (2015), for which missing values are extrapolated based on the previous or following three years, respectively. Since the change in methodology after 2011 did not seem to impact the data in any noticeable way except for a change in magnitude of about 10, no further adjustments were made other than dividing values from after 2011 by 10. Note that higher values of the variable mean *less* corruption.

- ***Political stability*** from the World Bank's Worldwide Governance Indicators (World Bank, 2016c) measures the perceived likelihood of political instability or politically motivated violence.

Financial market policy

The selected variables relating to **financial market policy** include:

- The ***sovereign credit rating*** from Moody's (2015), which measures trust in the solvency of the state, and is expected to have a positive impact on investment flows.

- The ***domestic credit to private sector*** (World Bank, 2016a) and ***credit to government and SOEs*** (World Bank, 2016a), both measured in % of GDP. These variables capture the outcome of the facilitation of finance, rather than the framework as other variables used here do. However, the outcome also is expected to show a positive effect on investment and innovation.

- The ease of ***getting credit*** (World Bank, 2015e), which covers the facilitation of financing, should have a positive effect on renewable power investments and innovation (See Annex A.1).

- Three dummies capture the impact on the financing sector of the ***implementation of Basel III leverage ratio, implementation of Basel III liquidity coverage ratio*** rules as well as ***implementation of Basel III risk-based capital requirements*** (authors' construction; see Box A.1.1 for details). These variables are based on bi-annual progress reports published by the Basel Committee on Banking Supervision, on implementation of the Basel regulatory framework in G20 countries and the EU (BIS, 2016, 2015a, b, 2014a, b, 2013a, b, 2012a, b, 2011). For other OECD member countries that are not monitored by the Basel Committee (Chile, Iceland, Israel, Norway, New Zealand, and Croatia in 2011-12 before joining the EU in 2013), the study has relied on individual reports. All EU member countries follow the EU process, so EU reporting by the Basel Committee is applicable to all EU member countries (except for 2014 data due to delayed implementation at national level). Accordingly the study has summarised the information in six dummy variables, based on reporting as of end 2014, as following: (i) issuance and (ii) implementation of Basel III's risk-based capital requirements; (iii) issuance and (iv) implementation of Basel III's liquidity coverage ratios; and (v) issuance and (vi) implementation of Basel III's leverage ratios.

Box A.1.1 Basel III banking rules

"Basel III" is a comprehensive set of reform measures aimed at strengthening the regulation, supervision and risk management of the banking sector in the aftermath of the global financial crisis, building on "Basel II" and "Basel 2.5" rules. The Basel Committee on Banking Supervision (referred to as "Basel Committee") has led the process of bank micro-prudential reforms since the crisis. Table A.1.2 presents Basel III's key components. Key milestones included:

- In 2004, the Basel Committee released **Basel II** rules. Basel II meant to strengthen measurement of credit risk and captured operational risk, through three pillars: minimum capital requirements; supervisory review process; and market discipline. Basel II rules were scheduled to be implemented by end of 2006.
- In July 2009, the Basel Committee released **Basel 2.5** rules. Basel 2.5 meant to improve risks measurements for securitisation and trading book exposures. Basel 2.5 rules were due for implementation by end of 2011.
- In December 2010, the Basel Committee released **Basel III** rules, which set higher levels for capital requirements (especially applied to risk-weighted assets) and introduced a new global liquidity framework. Basel III aim to: improving the banking sector's ability to absorb shocks arising from financial and economic stress; improving risk management and governance; and strengthening banks' transparency and disclosures. Basel III target: bank-level, or micro-prudential, regulation, to help raise the resilience of individual banks to stress periods; and macro-prudential, system-wide risks. Basel Committee members agreed to implement Basel III gradually and transitionally from January 2013.
- In July 2013, the Basel Committee published the "**G-SIB framework**" on assessment methodology and higher loss absorbency for global systemically important banks (G-SIBs). These requirements will be introduced in 2016 and become fully effective as of 2019. National jurisdictions agreed to implement the required regulations and legislations to establish the reporting and disclosure requirements by January 2014.
- In October 2012, the Basel Committee issued the "**D-SIB framework**" on assessment methodology and higher loss absorbency requirement for domestic systemically important banks (D-SIBs), for compliance from 2016.
- In January 2013, the Basel Committee issued the revised **liquidity coverage ratio** to underpin the short-term resilience of a bank's liquidity risk profile. It became effective in January 2015 and is subject to a transitional arrangement before reaching full implementation in 2019.
- In January 2014, the Basel Committee issued Basel III **leverage ratio framework**, along with disclosure requirements. Implementation has begun in January 2015.
- In October 2014, the Basel Committee issued the final standard for the **net stable funding ratio** (NSFR), which will become a minimum standard by 2018. Monitoring of the NSFR adoption started in October 2015.

Table A.1.2. Summary of Basel III banking rules

	CAPITAL					LIQUIDITY
	Pillar 1			Pillar 2	Pillar 3	
	Capital	**Risk coverage**	**Containing leverage**	**Risk management and supervision**	**Market discipline**	**Global liquidity standard and supervisory monitoring**
All banks	Quality and level of capita	Securitisations	Non-risk-based leverage ratio that includes off-balance sheet exposures	Requirements Address firm-wide governance and risk management	Disclosures requirements relate to securitisation and sponsorship of off-balance sheet vehicles	Liquidity coverage ratio
	Capital loss absorption at the point of non-viability	Trading book				Net stable funding ratio (NSFR)
	Capital conservation buffer	Counterparty credit risk				Principles for Sound Liquidity Risk Management and Supervision
	Countercyclical buffer	Bank exposures to central counterparties				Supervisory monitoring
SIFIS	In addition to meeting the Basel III requirements, global systemically important financial institutions (SIFIs), including global systemically important banks (G-SIBs) and domestic systemically important banks (D-SIBs), must have higher loss absorbency capacity to reflect the greater risks that they pose to the financial system					

Sources: OECD (2013), www.oecd.org/finance/Bank-Business-Models-Basel-2013.pdf; Bank for International Settlements (BIS) (2015b), "Eighth progress report on adoption of the Basel regulatory framework", www.bis.org/bcbs/publ/d318.pdf; BIS (2015c), International regulatory framework for banks (Basel III), www.bis.org/bcbs/basel3.htm; BIS (2015d), Basel Committee on Banking Supervision reforms, www.bis.org/bcbs/basel3/b3summarytable.pdf.

Innovation environment variables

The study also considered variables that capture the broader innovation environment for patenting activity in renewables technologies:

- The ***number of universities*** captures the effect of human capital or knowledge stock as well and stems from Webometrics (2016).

- The ***perpetual inventory of renewable power-related patents*** controls for the accumulation of all patents up to the year of the observation, discounting patents with 10%, as is usual in the literature (Bessen, 2008). It obviates other controls for factors that could be influenced by these patents and thus makes a control for a possible endogenous relationship between renewable power investment and renewable power patenting activity unnecessary. The related ***innovation spillover*** variable controls for the influence of patenting activity in other countries. It is the sum of patents in the sector of the observed country-sector-year from neighbouring countries. Both variables use patent data from OECD's database on *Technology Development in the Environmental Sector* and are outlined in Haščič and Migotto (2015).

- ***Strength of intellectual property rights*** (index) stems from the International Property Rights Index curated by the Property Rights Alliance (2016), and measures the importance of physical and intellectual property rights and how well they are protected in a country.

Control variables

This section outlines the ten control variables selected by the *lasso*. In particular:

Carbon intensity of energy accounts for the prevalence of fossil-fuel based energy production, or, in an alternative interpretation, for the available opportunity to replace fossil-fuel energy with renewable production. Values are carbon emissions in tonnes of CO_2-equivalent (Olivier et al., 2014) over total primary energy supply in kilo-tonne equivalent (IEA, 2015e).

The ***natural resource endowment*** variable consists of the following six different variables which each are a proxy for natural resource endowment relevant to their specific sectors, using various sources.

- Since the biomass and waste energy sector depends on the forestry- and wood-processing sector for their fuel sources (or at least has strong synergies with it), the proxy for the biomass and waste sector's natural resource endowment is a proxy for the underlying agro-forestry sector: The forest coverage in percent of a country's area. Values for this variable stem from the World Development Indicators (World Bank, 2015a).
- Since geothermal power is generally market-viable without incentive measures, the current use of geothermal power should be correlated to the natural resource endowment for geothermal power plants. Accordingly, in the absence of a comprehensive geological data set for geothermal activity, we use yearly power generation in the geothermal energy output data in TWh (IEA, 2015e) as relevant proxy for geothermal natural resource endowment.
- Ocean, marine or tidal wave renewable-power production cannot exist without a coast. Accordingly the model uses the length of the countries' coastline in meters as recorded by the World Resource Institute (2015) over the size of the country in 1000 km^2 (World Bank, 2015a) as proxy for the natural resource endowment relevant to marine-power production.

- Installations of small hydro-power plants depend on availability of suitable rivers. Accordingly the scope and suitability of a country's hydrological system would have to enter a relevant proxy for natural resource endowment. Due to lack of the data on the suitability (e.g. data on the water speed or ecological impact of a small hydro plant) we use the size of the hydrological system in a country as proxy for natural resource endowment relevant to small hydro, measured as total length of waterways in 100000 km (CIA, 2015), multiplied with precipitation data, measured in cm averaged over weather stations in the country and measurement periods (World Bank, 2015a).
- For solar energy, the proxy for natural resource endowment includes the mean number of daily hours of sunshine in a given country, averaged over the country's reporting weather stations (United Nations, 2015). The value for Russia is the average of Russia (Asia) and Russia (Europe) and missing values for Canada, Chile, Indonesia, Ireland, Malta, New Zealand, Saudi Arabia and Turkey had to be replaced by country values of Russia (Asia), Argentina, Thailand, United Kingdom, Australia and Spain, respectively. Replacement values were chosen based on the insolation similarity between countries on SolarGIS's (2013) global heat map of solar potential.
- For wind energy, the proxy for endowment is the rank between 1 and 10 of the respective country for wind energy potential measured as a combination of wind speed and air pressure. The rank is the average of the rank of offshore and onshore potential, each based on wind energy potential brackets derived in Lu et al. (2009). For the sake of scaling all values were multiplied by 10.

All six proxies are combined in one composite variable in which higher values always mean a more suitable endowment. Before combining, values are standardised over sectors (*z-score*) to assure comparability of values. The composite variable always takes on the value of the natural resource endowment proxy which corresponds to the sector of the observation. That means, for an observation of an investments in the solar sector, the natural resource endowment variable shows the standardised mean hours of sunshine, while for an observation of the wind sector the composite variable has the standardised value on the wind energy potential, and so forth.

The ***foreign direct investment*** (FDI) inflow holds constant for the dependence of the renewable-power sector on tangible business relations or intangible relationships associated with the FDI inflow. Since values are total amounts rather than fractions, this variable is one of the few variables in the set holding constant for the size of the economy. Data for the FDI inflows in million USD stem from the World Development Indicators (World Bank, 2015a). The same source provides data for the control variable on ***GDP***.

The amount of ***electricity generation*** holds constant for the total size of the power sector. It therefore also is an approximate indicator for the size of the country, similar to FDI. The values in GWh stem from IEA's World Energy Statistics and Balances (IEA, 2015e).

Olivier et al. (2014) provide data on ***CO_2 emissions*** from fossil fuel use and cement production in kton which serves as a proxy for greenhouse gas emissions and therefore emission abatement potential. Missing values for 2014 are extrapolated.

Data for percentage of labour force with ***tertiary education*** functions as a proxy for human capital or knowledge stock and stems from the World Bank (2015a). Replacements for missing values had to be interpolated and extrapolated based on existing values. Countries for which no values were recorded, values were replaced by percentage of gross enrolment in tertiary education offset by five years.

The ***electricity consumption*** in terajoule captures the power use per person in kWh, using data from World Bank (2015a).

The ***average most-favoured nation tariff*** variable uses data from UNCTAD Trains (2016) and is recorded in percent. It captures the specific trade barriers, recorded as the average most-favoured nation (MFN) tariff of the following trade groups of the harmonised system nomenclature. [29]

The ***regulatory capital to risk-weighted asset*** ratio stems from the IMF Financial Soundness Indicators (IMF, 2017) and is replaced with the bank capital to assets ratio from the World Development Indicators (World Bank, 2015a) for missing data of New Zealand and Denmark. It captures the capital adequacy of agents in the financial sector. Capital adequacy and availability have a strong influence on the stability of the financial sector, but might not only be determined by financial regulation such as the implementation or enforcement of Basel III regulations.

[29] Relevant HS groups for the renewable power sector are: 440122; 440131; 440139; 761100; 840219; 840220; 840290; 840681; 840682; 840690; 841011; 841012; 841013; 841090; 841780; 841861; 841899; 850161; 850162; 850163; 850164; 850239; 848230; 848210; 848360; 853650; 853690; 853720; 853890; 850422; 850231; 854140; and 854190.

ANNEX A.2 LITERATURE REVIEW, CONCEPTUAL MODEL AND HYPOTHESES

This annex provides a literature review, along with the conceptual model and hypotheses of the econometric study. This annex also reviews relevant empirical work for both the investment and innovation models. Both are discussed at the end of the annex.

As explained briefly in the introduction, several studies have assessed the impacts of either specific climate policies or specific investment conditions on investment or innovation in renewable power. Extensive IEA work models key policy pathways to support innovation in low-carbon energy technologies (IEA, 2015a, b). Recent studies have discussed the effects of selected investment incentives in mobilising private investment in renewable power, including feed-in tariffs and renewable energy certificates (Cárdenas Rodriguez et al., 2014; Haščič et al., 2015a; Criscuolo and Menon, 2014; Criscuolo et al. 2014). Another OECD study has assessed the impact of local-content requirements on international investment in solar and wind energy (OECD, 2015a). Other OECD and non-OECD studies have estimated the impacts of public support to research, development and demonstration (RD&D), carbon prices and access to capital on innovation in environmental technologies (Andrews and Criscuolo, 2013; Haščič et al., 2015a; Haščič and Migotto, 2015; Johnstone et al., 2010; Gambhir et al., 2014; Groba and Breitschopf, 2013). Recent qualitative studies have also provided recommendations on how to strengthen the enabling conditions for investment in renewable power (OECD, 2015b; OECD/IEA/NEA/ITF, 2015; Corfee-Morlot et al., 2012). A few studies considered the impacts of the investment environment on investment or innovation in renewable power (Friebe, 2014; Iršová and Havránek, 2013); however existing studies only considered one factor of the investment environment or only a small list of variables and cannot be comprehensive. In addition, a few studies have considered the impacts of investment conditions on innovation (Furman et al., 2002; Johnstone, Haščič and Kalamova, 2010; Criscuolo and Menon, 2014). However to the authors' knowledge, no study has assessed empirically the impacts of both climate mitigation policies and other investment conditions on both investment and patenting in renewable power.

As discussed previously, the conceptual model of this econometric study builds on key messages of previous OECD reports, including *Aligning Policies for a Low-Carbon Economy* (OECD/IEA/NEA/ITF, 2015), and the OECD *Policy Guidance for Investment in Clean Energy Infrastructure* (OECD, 2015b), as well as other studies. In particular:

This annex reviews notably the hypotheses and literature pertaining to the role of climate mitigation policies to support the deployment of renewable-power technologies. This paper hypotheses that policy makers need to put in place a mix of coherent and stronger climate mitigation policies to unlock investment and innovation in renewable power, including through: setting a robust, credible long-term price on GHG emissions, through explicit carbon prices and regulations; designing targeted investment incentives to facilitate and accelerate emission cuts and complement explicit carbon pricing; removing disincentives to low-carbon investment, notably by eliminating climate-incompatible subsidies and other forms of support to fossil fuels; and supporting long-run investment and innovation in early-stage renewables technologies through targeted public support to RD&D.

This annex also reviews hypotheses and relevant studies on the impacts of the broader environment in driving investment decisions in renewable power, as well as patenting in renewable-power technologies. Beyond setting clear, predictable and credible climate mitigation policies, achieving the systemic transformation of the power sector calls for aligning a broad range of policy areas across and within levels of government. In particular, this paper hypothesises that policy makers need to assess whether and how the investment environment may hinder investment and innovation in renewable-power technologies.

The role of climate mitigation policies

This section presents a brief literature review and the hypotheses pertaining to climate mitigation policies. Several OECD and non-OECD reports emphasise that policy makers need to put in place a mix of coherent and stronger climate mitigation policies to bridge the gap between current and desired levels of GHG emissions, and unlock investment and innovation in renewable power. They include: 1. carbon pricing instruments; 2. targeted investment incentives; 3. targeted innovation incentives; and 4. reform of investment disincentives.

1. Setting a robust, credible long-term price on GHG emissions

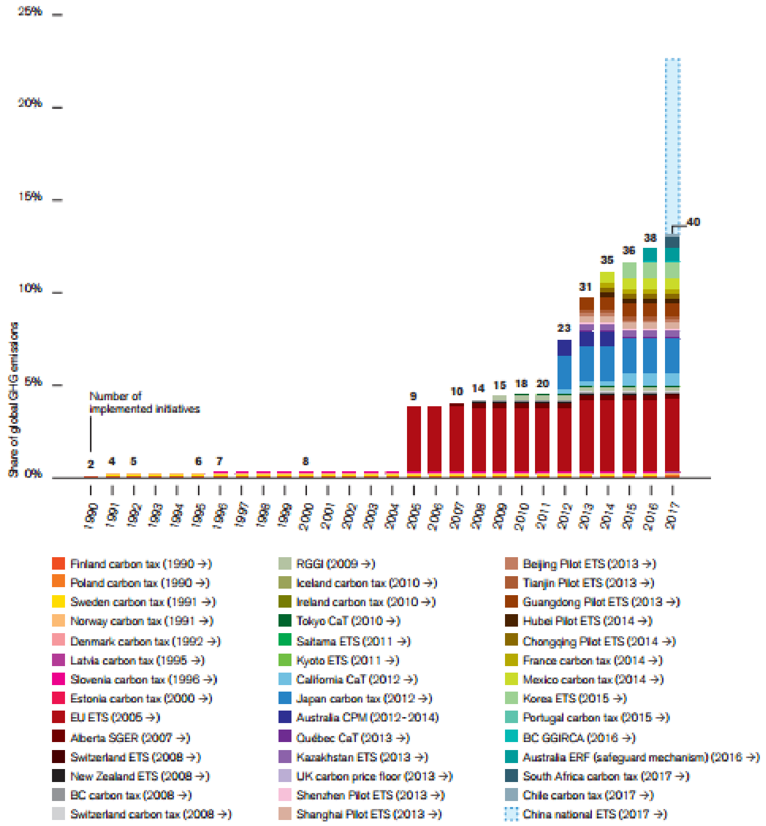
This study hypothesises that putting a price on carbon through explicit carbon prices (i.e. direct carbon taxes or emissions trading schemes) and regulations is a central feature of an efficient package of climate mitigation policies to encourage investment and innovation in renewable power. Explicit carbon-pricing tools are considered in theory to be more effective and efficient than other policy instruments in abating GHG emissions (OECD, 2013c). Numerous studies have emphasised the role of explicit carbon prices (i.e. carbon taxes or emissions trading schemes) in abating GHG emissions (Ecofys and World Bank, 2016, 2015; OECD, 2013b). Such studies suggest that explicit carbon prices are the most cost-effective way to reduce GHG emissions. Existing OECD analysis however shows that 60% of GHG emissions in OECD and partner economies are not priced at all (including through explicit and implicit carbon prices; OECD, 2015u). The share of GHG emissions not covered by explicit carbon prices is even greater at global level (over 85%; Figure A.2.1). In addition, existing studies suggest that carbon prices remain far below levels required to support investment in low-carbon technologies such as carbon capture and storage (IEA, 2015a, b; Bassi et al., 2015).

A few studies have also discussed the role of explicit carbon prices in encouraging investment in renewable power (Ecofys and World Bank, 2016, 2015; OECD, 2013b; OECD/IEA/NEA/ITF, 2015). Conceptually, this working paper assumes that higher explicit carbon prices (even in the absence of renewable-power incentives) would encourage a shift of investment away from fossil-fuel based plants and towards low-carbon technologies such as renewables, all else being equal. In principle, higher carbon prices give a cost advantage to low-carbon technologies such as renewable power, by leading to increased electricity prices in the short- to mid-run. Electricity pricing is currently based on the variable costs of the marginal power plant. Carbon prices would increase marginal costs for fossil-fuel based power plants, and would thereby increase electricity prices because fossil-fuel based power plants would continue to be marginal power generation suppliers. Explicit carbon prices can encourage investors to allocate capital towards new low-carbon generation technologies such as renewable power if they expect that "the cost of environmental impacts will be proportionally and permanently included in the private costs of generation" (Ecofys and World Bank, 2016). In practice, however, pricing of electricity based on variable costs of a marginal power plant, creates uncertainty on electricity prices and the ability of renewable plants to recover high upfront capital costs in light of uncertain electricity prices. This uncertainty diminishes the benefits to renewable-power technologies of the cost advantage created by higher carbon prices. In this sense, pricing of electricity through wholesale electricity markets is not well adapted to capital-intensive renewables technologies with low or zero marginal costs (OECD/IEA/NEA/ ITF, 2015). In addition, even with a carbon price, the risks associated with investment in renewable power may require the development of complementary policies, e.g. to address outstanding market and regulatory rigidities in the power sector that prevent the entry of independent power producers of renewable energy in transmission and distribution (OECD, 2015b; Ecofys and World Bank, 2016). In addition, existing studies suggest that existing carbon prices remain too fluctuating to sufficiently impact renewable investment, and are unstable, not applied widely enough or riddled with exemptions (OECD, 2013b; Ecofys and World Bank, 2016, 2015). Although additional research would be needed to calculate the implicit carbon pricing value of feed-in tariffs, to compare levels of FiTs with levels of explicit carbon prices, existing studies suggest that current carbon price levels need to be complemented with other policy measures, such as FiTs, to stimulate

investment in low-carbon technologies (IPCC, 2014; Mo et al., 2016). This is due to currently low levels of explicit carbon prices and uncertainty on the future of carbon markets, e.g. in China (Mo et al., 2016). This is also because the effect of explicit carbon prices depends on regulatory certainty and a credible and predictable policy framework (IPCC, 2014; Yang et al., 2008; Sustainable Prosperity, 2010).

A few studies have considered the impacts of carbon prices on low-carbon innovation (Martin and Wagner, 2009; OECD, 2009, 2013b; OECD/IEA/NEA/ITF, 2015; Dechezleprêtre et al., 2013). A study commissioned by the OECD has investigated the effects of carbon prices on innovation, using firm-level data on patent grants for climate-change related innovation; it found that UK firms subjected to the full rate of the UK Climate Change Levy on fossil fuels and electricity were more likely to innovate and register patents than firms subjected to a reduced rate (Martin and Wagner, 2009; OECD, 2009, 2013b).

Figure A.2.1 Regional, national and subnational carbon pricing initiatives: share of global emissions covered



Note: Only the introduction or removal of an ETS or carbon tax is shown. Emissions are given as a share of global GHG emissions in 2012. Annual changes in global, regional, national, and subnational GHG emissions are not shown in the graph. Data on the coverage of the city-level Kyoto ETS were not accessible; and the British Columbia Greenhouse Gas Industrial Reporting and Control Act (GGIRCA) does not cover any emissions yet; their coverages are therefore shown as zero. The information on the Chinese national ETS represents early unofficial estimates based on the Chinese President's announcement in September 2015. The Latvian carbon tax was not introduced before 2004; the figure shows the adoption of the underlying legal framework in the Law on Natural Resources in 1995.

Source: Ecofys and World Bank (2016), Carbon Pricing Watch 2016, *https://openknowledge.worldbank.org/bitstream/handle/10986/24288/CarbonPricingWatch2016.pdf?sequence=4&isAllowed=y*.

Recent OECD work suggests that, in addition to explicit carbon prices, other climate mitigation policies are needed to achieve sufficient GHG emissions reductions in the electricity sector without compromising other policy goals such as energy security and energy access. These policies include targeted investment and innovation incentives and the phase-out of fossil-fuel support measures, as discussed subsequently (OECD/IEA/NEA/ITF, 2015; OECD, 2015b).

2. Designing targeted investment incentives

Policy makers have provided significant support in the past decade to help deploy renewable-power technologies commercially through targeted incentives, facilitate and accelerate emission cuts and complement explicit carbon pricing. Governments have typically set investment incentive mechanisms in their climate mitigation policy to support the deployment of demonstrated renewable power projects at commercial-scale and encourage innovation in the renewables sector. Globally, government support for renewables amounted to USD 121 billion in 2013 – of which 80% went to renewables for power (and 20% to biofuels; IEA, 2014a). As of end-2015, 146 countries had implemented renewable-energy incentives, including feed-in tariffs (FiTs), renewable energy quotas, auctions and tax incentives, and 173 countries had renewable-energy targets (not considering INDCs; REN21, 2016). As of early 2015, governments had implemented at national or sub-national level one or a mix of: feed-in tariffs and feed-in premiums (75 countries and 35 states or provinces); technology-neutral and single-technology auctions or tenders (64 countries, up from 60 in 2014); quotas and renewable energy certificates (RECs; 26 countries and 74 states or provinces) (REN 21, 2016).

Recent studies suggest that such investment incentives have contributed to significant increases in renewables investment in the past decade (Haščič et al., 2015a; Cárdenas Rodríguez et al., 2014; Gambhir et al., 2014). New investment in renewable power and fuels increased six fold between 2004 and 2011 to reach USD 269 billion in 2011 (BNEF, 2015; REN21, 2015).[30] Renewables investment has remained relatively stable since 2011, reaching USD 286 billion in 2015. Despite this apparent slowdown in investment growth, the amount of renewable-power generation per dollar invested has increased significantly. Renewables will generate one-third more power generation annually in 2015 than in 2011, largely driven by technological progress and unit cost reductions (IEA, 2016a).

Existing studies suggest that policy support will continue to play a critical role in encouraging the deployment of renewable-power technologies. In particular, scenarios from the IEA's *World Energy Outlook 2016* estimate that sustained policy support to renewable power has and will continue to play a critical role on the pace of renewables deployment worldwide (IEA, 2016a).

In response to rapidly evolving market conditions and technology development for renewable power, as well as shifting policy priorities, policy makers have started reducing and restructuring their investment incentives in the past few years (Figure 5). In addition, feed-in tariffs have been criticised in recent years for increasing retail electricity prices when FiTs are not financed by governments, and for increasing public spending when FiTs are financed by governments themselves. Accordingly, and to factor in reduced technology costs, governments have recently lowered levels of feed-in tariffs and shifted to other incentive measures. In particular, auctions and competitive public tenders for long-term contracts have increasingly been adopted in recent years to award incentives for deployment such as long-term power purchase agreements, especially in emerging economies such as Brazil or South Africa. The number of countries using public auctions has increased sharply, from nine in 2009 to 64 as of end-2015 (Figure 8; REN21, 2016; Wang et al., 2014). The EU has also transitioned to supporting auctions as part of its competition policy since 2013, as emphasised in a statement from the European Commission in 2013, as well as in the 2014 *Guidelines on State Aid for Environment Protection and Energy* for 2014-20 and EU *2030 Climate and Energy Policy Framework* (European Commission, 2014, 2013). In particular, the EU's 2013 statement highlighted the use of auctions and public tenders to lower renewable-power prices and encourage the competitiveness of those technologies (European Commission, 2013).

30 Renewable-energy investment then declined in 2012-13 as a result of excess capacity, market consolidation and policy uncertainty, stabilising at USD 270 billion in 2014; BNEF, 2015; REN21, 2015.

This paper hypothesises that targeted incentives schemes cannot explain all of the difference in renewables investment between countries, therefore warranting new research in the present paper on the impact of the broader investment conditions, drawing notably on existing OECD studies (OECD, 2015b; OECD/IEA/NEA/ITF, 2015).

3. Removing disincentives to low-carbon investment

This paper hypothesises that investment in low-carbon technologies, including in renewables, remains constrained by outstanding support measures to fossil fuels. Eliminating climate-incompatible, inefficient subsidies and other forms of support for the consumption and production of fossil fuels is estimated to be critical to removing disincentives to low-carbon investment across sectors and countries. Support measures to the production or consumption of fossil fuels amounted to around USD 510 billion in 2014 according to the IEA across sectors (IEA, 2015a). Government support for fossil-fuel production and consumption in OECD countries and key partners was around USD 160-200 billion per annum in recent years across sectors (OECD, 2015k, m). Existing support measures to fossil fuels act as negative carbon prices, although they remain relatively limited in the power generation sector in OECD and G20 countries (around 4 billion in 2005 USD) compared to other sectors (such as upstream oil and gas; OECD, 2015k, m).

4. Supporting innovation and patenting in renewable-power technologies

To enhance the effects of policies across the stages of renewables technology development, this paper hypotheses that policy makers need to consider the impacts of the investment environment not only on investment, but also on innovation in renewable-power technologies. This paper hypothesises that ensuring cost-effective GHG reductions in the electricity sector also requires governments to provide policy support to long-run investment and innovation in early-stage low-carbon technologies, through targeted technology support, e.g. through public support to research, development and demonstration (RD&D). Innovation – which involves the creation and diffusion of new products, processes and methods – can help extend the range and the effectiveness of low-carbon technology options available to policy makers in the long run (OECD, 2015e). This support can accelerate technology development and cost reductions, e.g. through targeted and time-limited incentives to research, development and demonstration (RD&D). Moreover, support for earlier-stage mitigation technologies is essential to avoid dependency on technologies that could become costly or outdated in the long-run compared to the next generations of mitigation technologies (IEA, 2015a, b). To achieve the 2°C target, the majority of investment needs to 2020 in the power sector lie in low-carbon technologies that are commercially available today, such as onshore wind power (IEA, 2014e). On a longer timescale, however, current early-stage technologies will require sufficient investment in research, development and demonstration (RD&D) to succeed on the scale required after 2020 to achieve cost-effective and deep emissions cuts (IEA, 2014e).

This paper assumes that providing short-term, targeted policy support to low-carbon innovation, and especially to renewables technologies, is critical to address some of the market failures related to low-carbon innovation and investment. Market failures are notably linked to knowledge gaps, imperfect competition, financial market failures and failures to capture environmental externalities such as GHG emissions. Governments need to reconcile possible policy trade-offs between support to well-known low-carbon technologies in the short-run and to new technologies in the long-run.[31]

Based on existing studies, this paper hypothesises that targeted incentives (e.g. public RD&D support) can support private investment at all stages of the development chain of renewables technologies. Preliminary evidence from existing studies, however, suggests that policy makers have typically favoured

[31] At the Ministerial Council Meeting 2014, OECD Ministers insisted on the need for "investing in public research and fostering a strong investment environment for new technologies and innovations" (OECD, 2014a).

deployment of mature renewable-power technologies (through investment incentives), over support to early-stage renewables technologies (through public RD&D support). Data is not directly comparable since those policies are measured in different metrics (e.g. USD per kWh for FiTs versus USD for public RD&D). Nonetheless, public support to deployment through incentives and public RD&D support are not of the same order of magnitude: government incentives to renewable power amounted USD 121 billion in 2013, compared to only USD 5 billion in 2013 in government R&D spending in renewable power (IEA, 2014a; BNEF, 2015).

This paper tests the hypothesis that policy support is needed at all stages of the innovation chain of renewable-power technologies, including in: basic research; applied research; demonstration; deployment; and commercial diffusion (Groba and Breitschopf, 2013; IPCC, 2014; OECD, 2015e, q). Existing research on innovation suggests that "technology-push" policies (such as direct public R&D support through grants, or targeted innovation measures such as tax incentives) can usefully support the early stages of technology development. Conversely, "market-pull" policies can support the deployment and diffusion of demonstrated technologies at commercial scale (Groba and Breitschopf, 2013). Market-pull policies for deployment include technology-specific policies and investment incentive schemes (e.g. feed-in tariffs) and non-technology specific policies (e.g. carbon prices). Addressing funding gaps in early-stage R&D innovation for low-carbon technologies requires setting a package of market-pull and technology-push policies (Groba and Breitschopf, 2013). In addition, Criscuolo and Menon (2014) find that policy settings (including regulation price, regulation quantity, sales tax reductions, fiscal incentives and government R&D) are important at all stage of financing in green technologies such as renewables.

Patents are the outcome of technological innovation and can potentially serve as an input to new innovation in technological development and deployment of renewable-power technologies. Patents can influence the entire technology life cycle, including: to protect new technologies in the applied R&D stage; and to license patents out to third parties in the development and deployment stages (IRENA, 2013a). Patents can be analysed to assess technological progress and innovative activity in given technologies. Patenting activity in renewable-power technologies has increased significantly since the 1990s (IRENA, 2013a), and at increasing rates since 2000 and then 2008 (see Figure 2 and Figure 4). It is important however to acknowledge limitations with patents' analysis. In particular: not all renewable inventions lead to patent applications; there are other forms of intellection property protection, such as copyrights and designs; and not all inventions can be patented (IRENA, 2013a).

Specific hypotheses on the effects of climate mitigation policies

More precisely, the analysis is making the following hypotheses on the effects of climate mitigation policies on investment and innovation in renewable power:

- Targeted investment incentives for renewables deployment (i.e. feed-in tariffs and feed-in premiums weighted with duration of power purchase agreements, public tenders and renewable energy certificates) have a positive effect on mobilising investment flows in renewable power, especially feed-in tariffs (FiTs) and public tenders, based on previous OECD research (especially FiTs; Haščič et al., 2015a; Cárdenas Rodríguez et al., 2014).
- Targeted innovation incentives through public RD&D support have a positive effect in encouraging patent activity in renewable-power sources, and supporting the earlier stages of invention and innovation, through "learning-by-R&D".
- Feed-in tariffs and premiums have a positive effect on stimulating patent activity in renewable-power technologies, based on a recent literature review on the impact of FiTs on innovation in solar PV power (Ghambir et al., 2014).

- Current levels of explicit carbon prices remain too low to have an effect on investment and innovation in renewable-power technologies.
- Similarly, current levels of energy taxation in the power sector based on energy use (or carbon intensity of energy sources) are likely too low to have a significant impact in mobilising investment and innovation in renewable-power technologies

The role of the investment environment

This section reviews existing studies and key hypothesis pertaining to the role of the investment environment for renewable power deployment. Several OECD reports and instruments review qualitatively key policy barriers and drivers to investment in renewable power, within the broader investment environment. In particular, the OECD *Policy Guidance for Investment in Clean Energy Infrastructure* (OECD, 2015b), drawing on the OECD *Policy Framework for Investment* (OECD, 2015f), identifies key policy areas and factors influencing investment decisions in renewable energy in the power sector. Key issues identified by relevant OECD reports and other literature include:

- Promoting sound ***investment policy*** principles, including non-discrimination, investor protection, contract enforcement and transparency. Non-discrimination can help promoting equal treatment of foreign and domestic investment and addressing outstanding policy restrictions to international investment. New evidence gathered in the OECD report *Overcoming Barriers to International Investment in Clean Energy* (OECD, 2015a) suggests notably that policy measures such as local-content requirements may hinder international investment across the value chains by raising the cost of inputs for downstream activities. Investor protection includes: protection of intellectual property rights (i.e. patents law, copyrights, trademarks and industrial design rights), which on the one hand, investors will expect to capture the benefits from their technological innovations, and on the other hand, might hinder the transfer of low-carbon technologies; and land rights, which can help improve the predictability and legal security of investment, along with contract enforcement (Friebe, 2014). In addition, transparent and predictable policies give private investors the confidence to invest in capital- and technology-intensive technologies such as renewable power. Recent retroactive changes of climate mitigation policies, i.e. unpredictable policy shifts, represent an additional uncertainty for potential investors.
- Aligning ***investment promotion and facilitation***, through aligning the broad range of incentives and disincentives for renewable investment in the power sector. Beyond targeted incentives and other climate mitigation policies, key policies and regulations to promote and facilitate renewable investment include: promoting well-designed and time-bound support policies when needed; and facilitating licensing for renewable-power projects through establishing a “one-stop-shop” for investment promotion.
- Strengthening ***competition policy,*** to ensure a level playing field between incumbent utilities and independent power producers (IPPs) of renewable power, and reassessing the role and governance of state-owned enterprises in the electricity sector; addressing outstanding electricity market design issues that prevent the generation, transmission and distribution of renewables.
- Improving ***financial market policy***, to facilitate access to financing for renewable projects, including through assessing the effects of financial regulations and ensuring access to and affordability of financing, e.g. through establishing appropriate financing vehicles and institutions, such as blended finance, green bonds and green investment bonds (OECD, 2017, 2016a, 2015t; Kaminker et al., 2013).
- Enhancing ***public governance***, by improving co-ordination among multiple levels of governance on key issues such as grid capacity, human resources training and capacity, and governance of energy regulators.

Aligning policy support to both investment and innovation is critical to ensure that short-term policy support delivers mitigation options in the long-run. This study hypothesises that the investment environment influences both investment and innovation in renewable power, including patenting of renewables technologies. Indeed, decisions to develop new patents in renewables technologies could be influenced not only by long-term signals (such as carbon prices or mandatory targets) or targeted incentives (such as public RD&D), but also by the presence of a favourable environment for patenting, e.g. linked to intellectual property rights protection. Patent activity in manufacturing of solar PV panels, wind turbines and other renewable sources could also depend on demand for such technologies in the downstream segments of the value chains. Setting predictable and targeted incentives and aligning the investment environment seems critical to address barriers to invention of both early-stage and mature renewable-power technologies (OECD/IEA/NEA/ITF, 2015; IEA, 2015a, b).

Specific hypotheses on the investment environment

This paper hypothesises that despite the presence of incentive schemes and carbon pricing mechanisms, private investment in renewable power remains constrained by market barriers and government failures. These barriers include: issues with the quality and attractiveness of the broader investment framework, including market rigidities in the electricity system; limited access to financing; and outstanding barriers to international trade and investment (OECD, 2015a; Bahar et al., 2013). In particular the report hypothesises that:

The design of electricity network regulation, including the involvement of public stakeholders, and higher levels of public ownership (through state-owned enterprises) in both network regulation and power generation are likely to impact investment flows in renewable power. The impact may be either negative (e.g. by increasing market concentration in the electricity sector and creating barriers to entry for independent power producers, or IPPs) or positive (e.g. as a result of public investments in the grid and SOE appetite for investments in riskier renewables, or good practices to facilitate access of IPPs to the grid, e.g. through appropriate allocation of network charges and connection costs).

Overly complex and lengthy licensing, permitting and patenting procedures can act as a deterrent for both patent activity and investment flows by creating additional transaction costs for manufacturers and project developers. Conversely, ease of licensing, permitting and patenting process, e.g. through one-stop-shops dedicated to renewable-power projects, can influence both patent activity and investment flows positively.

Implementation of Basel III banking regulations until 2014 (the last year considered in the investment model) may have had possibly unintended consequences by constraining banks' long-term project financing, including renewable power infrastructure projects. Basel III requirements will gradually require banks to increase the share of equity in their balance sheets for higher-risk lending, which may create disincentives for banks to provide long-term loans for infrastructure projects. As discussed subsequently, interpretations of analytical results with respect to Basel III regulations require important caveats.

With respect to innovation, the investment environment may also impact patenting activity in renewable-power technologies. However, it is hypothesised that the investment environment for deployed infrastructure assets will have a smaller effect on invention and technology development in earlier stages of renewable-power technologies. Patent activity typically takes place in the manufacturing segment of the renewable-energy value chains (e.g. to produce solar PV panels or wind turbines) to a greater extent than in downstream activities (such as power plant installations and project development).

The study hypotheses that beyond climate mitigation policies and investment conditions, patenting activity is also influenced by the broader innovation environment, e.g. linked to presence of universities and accumulated patenting knowledge in renewable power.

The report also hypothesises that the effect of climate mitigation policies in mobilising renewable investment depends on the broader investment environment. Targeted incentives and other climate mitigation policies cannot be considered in a vacuum, in isolation from the broader environment for investment and innovation in renewables technologies. In particular, the study will test the following hypothesis: The effect of targeted investment incentives (i.e. FiTs, RECs and auctions) in attracting investment flows in renewable power at commercial scale depends on the investment environment; and each incentive interacts differently with different investment environment variables. Positive proof of this hypothesis would imply that policy makers can enhance the effects of investment incentives by choosing the incentives that interact well with their existing domestic investment environment. This hypothesis may apply to certain types of investment incentives but not others.

Relevant work for the investment model

The investment model of this project builds on recent OECD econometric analyses on investment in renewable-power sources. In particular:

- The working paper “Public Interventions and Private Climate Finance Flows: Empirical Evidence from Renewable Energy Financing” (Haščič et al., 2015a) assesses the impact of public finance (bilateral, domestic and multilateral) and selected policy instruments (feed-in tariffs, renewable energy quotas, the Clean Development Mechanism) in mobilising private climate finance flows in renewable-power generation globally, and specifically to and in developing countries.

- The working paper “Inducing Private Finance for Renewable Energy Projects: Evidence from Micro-Data” (Cardenas Rodriguez et al., 2014) analyses the effects of selected incentives (feed-in tariffs and renewable energy quotas (also called renewable energy certificates or RECs) and other public policy instruments on private finance for investment in renewable-power generation. It investigates two principal research questions: what is the effect of a range of public policy instruments on the ability of investors to raise private finance for renewables projects (inducement effect); and does direct provision of public finance for a project increase the likelihood of raising private finance (”crowding-in” effect).

- The report *Overcoming Barriers to International Investment in Clean Energy* (OECD, 2015a) assesses the impact of local-content requirements on global international investment in solar and wind energy, when such requirements are attached to feed-in tariffs.

This working paper also builds on relevant work from the IEA and other OECD bodies, including: data gathered for the OECD report *Climate Change Mitigation: Policies and Progress* (OECD 2015q) and its new online *Compare Your Country* tool (OECD, 2015q, r); IEA reports (IEA, 2015 forthcoming, 2015a, 2015b, 2014g, 2014i, 2014j, 2014k; 2013b); work by the OECD Centre for Tax Policy (CTP) on effective carbon rates (OECD, 2015l, 2013e); and OECD data on support measures to fossil fuels in the electricity sector (OECD, 2015k, 2013d, 2013e).

Relevant work for the innovation model

The innovation model builds on recent empirical OECD work (Haščič and Migotto, 2015), which refines indicators to measure innovation in environment-related technologies, including renewable-power sources, but also leans on literature of the wider field of innovation analysis. In the wake of a large and long-established body of empirical work on the analysis of innovation – see Feldmann (1999) for an early overview and Iršová and Havránek (2013) for a meta-analysis of empirical diffusion analyses – an increasing number of recent innovation studies have focussed on green and renewable sector. Research on innovation support and environmental policies suggests that governments could adjust environmental

policies to the technology portfolio for which they aim (Emodi et al., 2015; Johnstone et al., 2010; Söderholm and Klaassen, 2007). Notably, a clear signal to increase a price on carbon also plays an important role (Popp et al., 2011).

Next to environment and innovation specific policies, factors of the broader investment environment are only sparsely included in renewable sector innovation models. Kortum and Lerner (2000) as well as Hellmann and Puri (2000) find a positive impact of venture capital on innovation in general, while Iršová & Havránek (2013) analyse the effect of financial development on spillovers of technology, but find no evidence for an effect, and Furman et al. (2002) equally cannot discern an impact of the strength of venture capital markets. Despite these unclear empirical results, the impact of available capital, especially venture capital, is considered important to spur renewables innovation due to the risky nature and great capital need of infrastructure projects. Other important investment environment factors for innovation analysed in the above work are property rights, which can help secure the benefits of a risky investment in innovation, and trade openness, which can have a positive effect on innovation due to a country's exposure to competitors and the market activity this might encourage. Johnstone, Haščič and Kalamova (2010) emphasises the importance of setting predictable, robust and ambitious environmental policies to support innovation and investment in environmentally friendly innovation. They establish five principles of innovation-inducing environmental policy design: ambitious (i.e. how high is the price of not inventing and adopting "clean" innovation); flexibility (does the policy induce search across all options?); incidence (does the policy "hit" the policy objective directly?); depth (does it provide incentives across whole range of outcomes?); and predictability (can the investor foresee future likely policy context?).

Beyond environmental policies and investment variables, renewable innovation models also have to account for more general non-policy factors. Renewable-energy innovation models therefore also include the market size for electricity and energy prices (Noailly and Smeets, 2013; Popp, 2002) to account for market conditions. Further, innovation diffusion and spillovers have to be distinguished from the effect of a country's policies or conditions (Noailly and Shestalova, 2013; Peri, 2005; Dechezleprêtre et al., 2013; Glachant et al., 2010). Additionally, models account for the impact of more general control variables like patent or knowledge stocks, resources, institutions, conditions for adoption of new technologies, innovation capacity of a country, trade and FDI inflows and the general size of the economy (additionally to the above, Spencer et al., 2015; Grübler and Wilson, 2014).

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