University of East Anglia
NORWICH BUSINESS SCHOOL

The Effects of Public Industrial Policy on Renewable Energy Innovation

A Thesis submitted in accordance with the requirements for the degree of Doctor of Philosophy

By

Alkis Theonas Pitelis

September 2018

Abstract

The key research question of this thesis is to what extent and what types of public industrial policy and their interactions affect innovation in renewable energy (RE) as a whole and in different RE technologies (RETs). Innovation in RE is widely believed to be important in helping change the energy mix away from fossils and hence contribute to a more sustainability-friendly energy transition.

In the introductory chapter I outline the problem of climate change and the impact of fossils-based energy use to that change. In the second chapter entitled "Theoretical Framework: Determinants of Innovation and the Role of Public Industrial Policy", focuses on the conceptual foundations, notably on the role of innovation in fostering positive change in general and in RE in particular, as well as on how public industrial policy may help address problems of market failures and foster innovation in RETs. The third Chapter entitled "Empirical Protocol and Method" explains the main variables, data sources and our empirical methodology.

Chapter four on 'Industrial policy for renewable energy: The innovation impact of European policy instruments and their interactions', examines the impact of RE policies as well as three RE policy instruments (demand-pull, technology-push and systemic), and their interactions on RE innovation in 15 European Union states for the period 1995–2014. Following a critical literature survey, I developed a conceptual framework and hypotheses which I then tested by employing a comprehensive data set that we collected for this purpose. I found that RE policies as a whole as well as demand-pull and technology-push instruments affect RE innovation positively. The impact of interactions between instruments on RE innovation was also found to be positive and significant, except in the case of specific pairs of instrument interaction where the outcome was contingent on the specification used. I discussed reasons for these

findings, as well as implications for public policy, limitations and opportunities for further research.

In the fifth Chapter, entitled “Can Industrial Policy Pick Winning Renewable Energy Technologies?”, a lasting debate in Industrial Policy (IP) literature concerns whether government support to sectors and firms can help ‘pick winners’. More recent literature has shifted attention to picking winning policies, policy instruments and/or technologies, in particular General Purpose Technologies (GPTs). I suggested that RE can qualify as GPT that incorporates a number of more specific RE technologies (RETs). I developed theory and Hypotheses, and provide econometric evidence for the impact of three IP policy instruments on different RETs. I also examined the unexplored role of country experience in mediating this relationship, as well as regional variations in the EU. In addition, I constructed a quality adjustment indicator to examine whether IP affected the quality of the innovation outcomes. I employed a comprehensive data set for the OECD and EU and North and South EU regions and found support for our the theory-derived Hypotheses.

In Chapter 6 (“Fostering Innovation in Renewable Energy Technologies: Choice of policy instruments and effectiveness”), I examined the effectiveness of different types of RE policy instruments (demand-pull, technology-push and systemic) on innovation, for an array of RETs. More specifically, I collected and analysed data on policy intervention, innovation activity and performance for 21 countries over the period 1990-2014 – which I then used to evaluate and compare the effect of different instruments on different RETs. Our results showed that demand-pull policy instruments have been the most effective of all in fostering innovation activity, and that their level of effectiveness increases when they are used to target a specific RET.

In Chapter 7 (“The Interrelationship Between Subsidies to Fossil Fuels and to Renewable Energy Sources in the OECD”), I looked at the question of the substitutability between subsidies to fossil fuels and to RETs. While the issue of substitutability between energy sources has been widely examined in literature, the argument that supporting fossils fuels will hamper energy transitions, has been taken as self-evident. However, the relationship between subsidies to RE and to fossil fuels is more nuanced. In theory the two types of subsidies can substitute each other, be unrelated or even be complementary to each other. The overall impact on RE transition will depend on the exact relationship. In this context I examined three different specifications, each time with a more disaggregated independent variable. I found that overall subsidies to fossil fuels have a negative effect on subsidies to RE and that this varies between different types of fossil-based energy sources.

In the eighth and final chapter (‘Summary, Conclusions and Policy Implications”), I summarised the key innovations and contributions of the thesis and examined its policy implications, as well as the limitations and opportunities for further research. Key contributions of this thesis alongside their policy implications are that the use of different policy instruments and their interactions matter; different RE technologies require different types of policy instruments in order to induce innovation; policy experience also matters; and public policy interventions can help induce lower quality innovations. In addition I found that different RET technologies require different types of RE policy instruments in order to induce innovation. Moreover I found that instruments that aim to increase demand are more effective in fostering RE innovation. Finally, I found evidence that subsidies to fossil fuels, impacts negatively on the subsidies on RETs. This is an extra reason that can hinder energy transitions to RE.

In all, by cross-fertilising IP and RE literature, by developing and testing econometrically a number of novel Hypotheses, by employing a comprehensive data set created for the purposes of this thesis, and by extending the debate on IP from targeting sectors and firms to that of policies, policy instruments and RETs, I believe that our thesis makes significant inroads and provides useful implications for policy making. Clearly more is better, and I hope to continue and to motivate others to contribute in this very important issue.

Acknowledgements

Thanks are due to the *Onassis Foundation* for providing me with a scholarship to fund my studies.

I would like to thank my supervisor, *Professor Konstantinos Chalvatzis*, for his support throughout the duration and for providing me with invaluable comments and information on the thesis. I am grateful to my second supervisor *Dr. Nicholas Vasilakos* for his valuable comments, guidance and information, especially in relation to the empirical/statistical methods of my dissertation. I would also like to acknowledge the help of my third supervisor, *Dr. Tiago Botelho*, for his useful comments.

The dissertation benefited from feedback throughout by a number of colleagues at conference presentations, notably at the University of Ferrara, Universities of Bath, and University of Cambridge and on chapter drafts. I am especially thankful to *Christos Pitelis*, *Michael Pollitt*, and *David Teece*. I would also like to take this opportunity to thank *Dr. Jenny Fairbrass* and *Dr. Kosmas Kavadias* – my viva examiners, for their meticulous comments and suggestions that greatly benefited my thesis.

I would also like to thank my friends, '*Τα Παιδιά*', for their support and patience throughout these years.

Last but not least, I would like to thank my parents *Christos* and *Ioanna* and my sister *Elena*, for their support throughout my life, for motivating me, for generously advising me on all matters and especially for being so patient with me.

Table of Contents

List of Figures

List of Tables

Abbreviations

COP	Conference of Parties
EC	European Commission
EPO	European Patent Office
EU	European Union
GHG	Green-House Gases
GPT	General Purpose Technology(ies)
IEA	International Energy Agency
IP	Industrial Policy
IPCC	Intergovernmental Panel on Climate Change
NBRM	Negative Binomial Regression Model
OECD	Organisation for Economic Co-operation and Development
PCT	Patent Cooperation Treaty
RE	Renewable Energy
REP(s)	Renewable Energy Policy(ies)
RET(s)	Renewable Energy Technology(ies)
TRLs	Technology Readiness Levels
UNFCCC	United Nations Framework Convention on Climate Change
WIPO	World Intellectual Property Office

Chapter 1
General Introduction and Overview

It is widely recognised that climate change represents an important challenge for the sustainability of our planet, and that unless steps are taken to mitigate the impact of anthropogenic emissions on the environment, the consequences can be dire (Weitzman, 2007; CISL, 2014). Indicatively, extreme weather events have become more frequent and in cases severe, and some climate scientists expect the severity and frequency of extreme weather events to increase in the next decades (IPCC, 2014). The global average temperature of both land and ocean have increased by 0.85^{o}C, while ocean acidity has increased by 26% (IPCC, 2014; OECD, 2015a). As compared to pre-industrial levels, if no action is taken, average temperatures globally could increase by between 2.6^{o}C and 4.8^{o}C by 2100 and sea levels between 0.45 to 0.82 meters (IPCC, 2014). Apart from their environmental impacts, such developments are likely to have serious consequences on the different sectors and regions of the global economy. In a report by the OECD entitled *The Economic Consequences of Climate Change* that investigated such potentialities, it was found that the projected market outlook is expected to be negative because of climate change; in agriculture as a result of changes in crop fields, in coastal zones as a result from capital and land losses from the rising sea levels, from extreme events which may result in capital losses from hurricanes, in the health sector as a result of labour productivity losses from heat stress, costs of diseases, and health expenditures, and finally in demand on energy and tourism (OECD, 2015b).

Political responses internationally included a number of public sector initiatives nationally and internationally. Among the latter are conventions which are held annually, and are known as Conference of Parties (COP). In general, the objective of COPs is to review observance of the United Nations Framework Convention on Climate Change (UNFCCC) which came into force in 1994. The first COP took place in Berlin in 1995, and the most important meetings were

COP3 (1997) where the Kyoto Protocol was adopted. Kyoto protocol is important because it has helped redirect the innovative efforts of national governments towards renewables, and as a result it helped increase the expected size of the global market for clean energy, hence acting as a further inducement to policy makers to adopt policies related to Renewable Energy (Sterk, et al., 2007). Other important COPs include COP11 (2005) where the Montreal Action Plan was created, COP15 (2009) in which the Kyoto Protocol was reviewed, and finally COP17 (2011) where the Green Climate Fund was created (Climate Action, 2015). More recently, COP21 (or 2015 Paris Climate Conference) was the first after 20 years to produce a universal agreement, establishing the international climate change policy objectives by (UNFCCC, 2015):

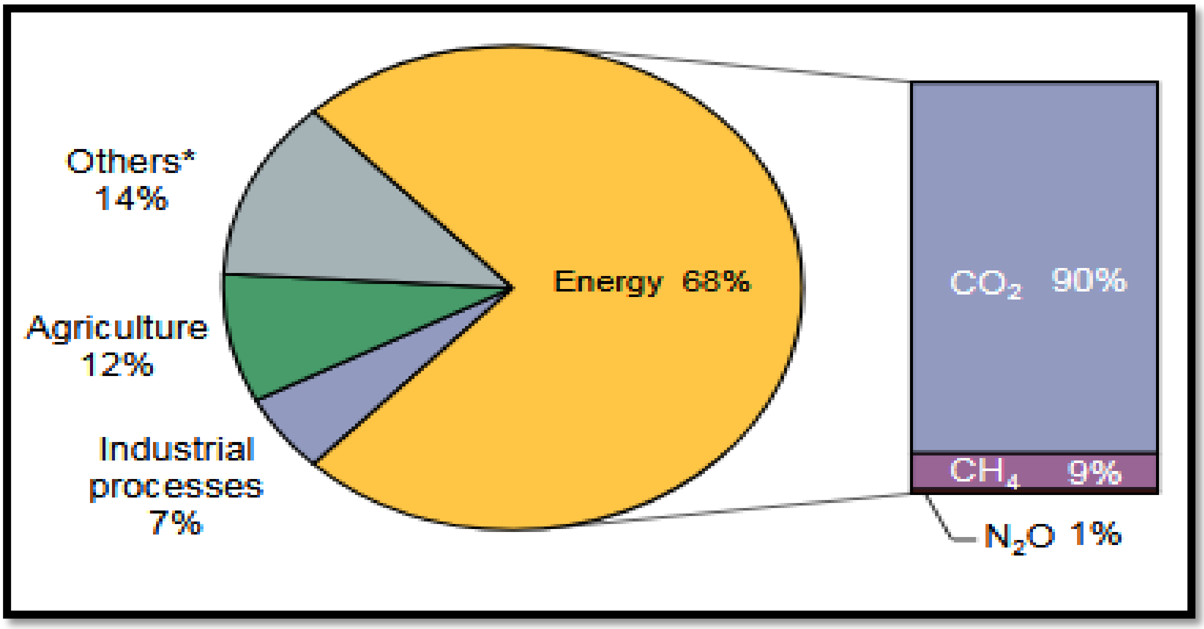
"[…] *holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels* […]" (Article 2, paragraph (a))

and

"[…] *achieve a balance between anthropogenic emission by sources and removals by sinks of greenhouse gases in the second half of this century* […]" (Article 4, paragraph (1))

While that landmark decision suffered a major setback after the withdrawal of the US, the remaining parties and a number of US states have pledged their commitment to it.

Figure 1: Estimated Shares of Global Anthropogenic GHG (2014)



Source: IEA, 2017c

Anthropogenic Green-House Gas (GHG) as well as CO_2 emissions can be produced from various sectors, including energy, agriculture, and industrial processes. However, two-thirds of all anthropogenic GHGs as well as CO_2 emissions come from the energy sector (CISL, 2014) (Figure 1). Within the energy sector, the largest gas contributor is CO_2 that results from the oxidation of carbon in fuels through combustion. CO_2 also holds the largest share of global anthropogenic GHG emissions, accounting for circa 58% of the global emissions (IEA, 2017c). At the same time, due to the world-wide economic growth and development, the energy demand is constantly increasing. As an example, the total primary energy supply (measure of energy demand), has increased by 150% between 1971 and 2015 (IEA, 2017c). Accordingly, improvements in the energy sector, can play a very important role in mitigating climate change.

While the energy sector is the main contributor to anthropogenic GHG emissions and climate change, is also largely affected by it as well. The evident ambient temperature rises are likely to cause a decrease in the efficiency of the thermal conversion of thermal power plants. Additionally, the increased water temperatures and reduced water for cooling, may also reduce power operations or even result in temporary shutdowns. The rising sea levels are also likely to affect the infrastructure of the energy transport, and especially the oil and gas pipelines in coastal areas, thawing permafrost in areas with cold climates. This in return will probably cause new land zoning codes as well as additional risk-based design and construction standards, and require structural upgrades (CISL, 2014).

From all forms of energy, electricity can play an essential role in decarbonising the economy because:

1. It can be produced with very limited environmental impact, see for example low-carbon technologies such as renewables (CCC, 2016);
2. It gradually substitutes other forms of energy in a number of activities such as transport, households and industry-see for example the autonomous electric vehicles (Arbib & Seba, 2017);
3. Electricity use grows faster than any other form of energy growth, “due to the electrification of energy uses” (Enerdata, 2017).

The International Energy Agency’s (IEA) 2-degree compatible scenario (2DS) projected a 79% increase in electricity demand by 2050, with the share of electricity in the final energy mix growing by 10% (from 18% to 28%) by the same year (Baron, 2016). If we are to reduce GHG emissions, we must therefore shift the electricity generation to low carbon technologies, and especially from direct fossil fuels to more RE-based ones (Baron, 2016),

I examine six Renewable Energy Technologies (RETs) in this thesis, briefly reviewed below.

1.1 Overview of Renewable Energy Technologies

Renewable energy sources have been essential throughout the history of civilisation (for example biomass for heating and power generation; hydropower and wind energy for movement and later electricity) and can generally be distinguished into the following six categories (Turkenburg, 2000, p. 221):

- Biomass energy (plant growth driven by solar radiation)
- Wind energy (moving air masses driven by solar radiation)
- Direct use of solar energy (as for heating and electricity production)
- Hydropower (as for power and electricity)
- Marine energy (such as wave energy, marine current energy, and energy from tidal barrages).
- Geothermal energy (from heat stored in rock by the natural heat flow of the Earth)

There are three generations of RETs, dating back to more than 100 years (IEA, 2006).

Following the industrial revolution (end of the 19th century) the first generation of RETs included hydropower, biomass combustion, and geothermal power. Hydropower is considered as a very flexible technology with regards to power grid operations, because it is very responsive, allowing to meet sudden energy demand fluctuations, as well as to compensate for the possible losses of other power supply options. In addition, hydro reservoirs come with built-in energy storage, which allows for the optimisation of the electricity grid across the whole power grid. Finally, large-scale hydropower plants are cost –effective, mainly because they were built many years ago, and their facility cost have been amortised.

Heating and power generation from biomass combustion is considered a fully matured technology, while it offers an economic fuel option and a ready disposal mechanism for the waste produced. Despite biomass demand continuing to grow (especially in the developing word), the industry as such remained fairly stagnant. This can be attributed to that biomass combustion has two major flaws. Firstly, the material used is directly combusted in cook stoves, giving rise to severe health and environmental consequences (although technological advances alleviate some of these effects). Secondly, despite being considered as a "carbon-neutral" technology, among the pollutants emitted during the combustion is CO_2. It is considered neutral, because presumably, the CO_2 absorbed during growth is equal to the amount emitted. Overall, they are considered to be economically competitive, but in order to overcome the challenges of public acceptance and small-scale, deployment support is likely to be required.

The final first-generation technology is geothermal. Geothermal power plant can provide base-load capacity, as they can operate 24 hours a day and their cost has dropped significantly. However, this power is location-specific and despite its cost competitiveness, expanding it may require long developing times, and the risk and cost of exploratory drilling. Still, it can be useful in many countries producing geothermal electricity, and/or in regions with a lower temperature.

The second generation technologies started entering markets in the 1980s, responding to the IEA's RD&D investments, prompted by the oil crises of that era. These include solar heating and cooling, wind power, modern forms of bioenergy, and solar photovoltaics. Solar thermal collectors are widely used, mainly for heating water. Combined with heat pumps, they can also produce cooling. Wind technology, is very reliable, with more than 98% availability and a life-span of more than 20 years. Their cost also constantly declines and reliability increases. Intermittency, public acceptance, and grid reliability are some of the factors that prevent their penetration into the world market, these barriers however are constantly receding.

New, modern forms of bioenergy include biomass-based power and heat generation, co-firing, and others. As biomass can be used both as a stand-alone fuel and blended with other fuels, it seems more attractive. In terms of electricity, it can be generated from biomass based on a steam turbine technology, which is still abundant in many regions of the world. These could be converted into competitive priced electricity by using steam turbine power plants.

Third-generation technologies include concentrating solar power, which has three technology types, for electricity production based on thermodynamic processes, namely parabolic troughs, parabolic dishes and solar central receivers. However, as their optimal operating conditions are (semi)-arid climates, this limits its usefulness only to South Europe, North and South Africa, the Middle East, western India, Western Australia, the Andean Plateau, north-eastern Brazil, northern Mexico and the US Southwest. Energy from the ocean is not a new concept and there is currently renewed interest in it. That said, there are still two major problems; the energy conversion potential and the very high technical risk from a harsh environment. Other non-technical barriers also exist, such as the location barriers, and design tools.

Two more technologies that fall under the third-generation technologies are the enhanced geothermal systems, and the integrated bioenergy systems, however these are beyond the focus of this thesis, for reasons of comparability with other studies, and data limitations. The following table (Table 1) summarises the advantages and disadvantages of the six main RETs that are examined in this thesis.

Table 1: Advantages and disadvantages of the six main renewable energy sources

Renewable Energy Source	Advantages	Disadvantages
Biomass energy	• Abundant and renewable • Can be used to burn waste products	• Burning biomass can result in air pollution • May not be cost effective
Geothermal energy	• Provides an unlimited supply of energy • Produces no air or water pollution	• Start-up/development costs can be expensive • Maintenance costs, due to corrosion, can be a problem
Hydropower	• Abundant, clean, and safe • Easily stored in reservoirs • Relatively inexpensive way to produce electricity	• Can cause the flooding of surrounding communities and landscapes. • Dams have major ecological impacts on local hydrology. Can have a significant environmental impact

Renewable Energy Source	Advantages	Disadvantages
	• Offers recreational benefits like boating, fishing, etc.	• Can be used only where there is a water supply • Best sites for dams have already been developed
Marine (Ocean) energy	• Ideal for an island country • Captures energy that would otherwise not be collected	• Construction can be costly • Opposed by some environmental groups as having a negative impact on wildlife • Takes up lots of space and difficult for shipping to move around
Solar energy	• Potentially infinite energy supply • Causes no air or water pollution	• May not be cost effective • Storage and backup are necessary • Reliability depends on availability of sunlight
Wind energy	• Is a free source of energy • Produces no water or air pollution • Wind farms are relatively inexpensive to build • Land around wind farms can have other uses	• Requires constant and significant amounts of wind • Wind farms require significant amounts of land • Can have a significant visual impact on landscapes • Need better ways to store energy
		Source: Ellabban, Abu-Rub, & Blaabjerg (2014)

Contrary, however to the aforementioned, it should be noted that (i) since biomass depends on the consumption and recreation of the crops, it cannot be considered as an abundant form of energy, (ii) the gradual degradation of the energy in Geothermal fields means that the energy is limited in the long run, and (iii), the land used for installing wind farms can still be used for other activities.

1.2 Overview of Renewable Energy Policy

The required transition to RETs is unlikely to happen if we rely exclusively on market forces, as numerous types of market failures can be identified that could prevent this from happening. Such failures include the un-priced costs or negative externalities (including the social costs of emissions and of supply vulnerability), the un-priced benefits or positive externalities (including the benefits of innovation), the information market failures and distortions, and failures that arise from economies of scale and market power (Groba & Breitschopf, 2013). These require government intervention to help steer the energy system towards renewable sources of energy. According to OECD, if no climate policies exist there will be an annual global GDP losses between 2% and 10% in 2100, while if both adaptation and mitigation climate policies are in place, annual global GDP losses will be between 1% and 3% (OECD, 2015a). Government intervention in support of RE energy constitute a of *public Industrial Policies.*

However, government intervention is subject to a number of important failures too, including rent seeking behaviour by public sector officials and the possibility of mistakes. All these can entail costs to the tax payers and in the case of sustainable energy to the producers of non-sustainable energy, as well as to business and consumers who have to pay higher prices (see Karnitschnig, 2014). It is quite conceivable that public policies can result in higher cost of energy as a result of the higher levelised cost of renewables as compared to the non-renewables (see Table 2 for comparison of the levelised costs for various power generation sources (IEA, 2017a, p. 8)) and the cost of subsidies. However, in 2017 a study was conducted that compared the levelised cost of energy for different conventional as well as alternative energy generation technologies, in order to examine which alternative energy generation technologies may be cost-competitive to conventional generation technologies. It was found that alternative energy technologies are complementary to conventional generation technologies (LAZARD, 2017). On the other hand, without policies that support innovation, profits-motivated producers have little incentive to invest on renewable energy[1]. This form of market failure results in a low penetration of RETs into the market place, and is usually considered a reason for public policy intervention. In the above context, various policies have been introduced by a number of countries in order to stimulate clean energy technological innovation (Johnstone et al, 2008)

[1] This may not be the case anymore, as at times renewable energy technologies tend to be cheaper than fossil fuels, especially when it comes to investing in new generation capacity. It was true however during most of the time under examination of this thesis (1990-2014).

and foster economic performance (Dechezlepretre & Martin, 2010), by lowering production costs and hence motivating the commercialisation of RE.

Table 2: Estimated Levelised Cost of Electricity (LCOE) (simple average of regional values) for new generation resources, for plants entering service in 2022

	U.S. Average LCOE (2016 $/MWh) for Plants Entering Service in 2022							
Plant Type	Capacity Factor (%)	Levelized Capital Cost	Fixed O&M	Variable O&M (including fuel)	Transmission Investment	Total System LCOE	Levelized Tax Credit[1]	Total LCOE including Tax Credit
Dispatchable Technologies								
Coal 30% with carbon sequestration[2]	85	94.9	9.3	34.6	1.2	140.0	NA	140.0
Coal 90% with carbon sequestration[2]	85	78.0	10.8	33.1	1.2	123.2	NA	123.2
Natural Gas-fired								
Conventional Combined Cycle	87	13.9	1.4	40.8	1.2	57.3	NA	57.3
Advanced Combined Cycle	87	15.8	1.3	38.1	1.2	56.5	NA	56.5
Advanced CC with CCS	87	29.5	4.4	47.4	1.2	82.4	NA	82.4
Conventional Combustion Turbine	30	40.7	6.6	58.6	3.5	109.4	NA	109.4
Advanced Combustion Turbine	30	25.9	2.6	62.7	3.5	94.7	NA	94.7
Advanced Nuclear	90	73.6	12.6	11.7	1.1	99.1	NA	99.1
Geothermal	91	32.2	12.8	0.0	1.5	46.5	-3.2	43.3
Biomass	83	44.7	15.2	41.2	1.3	102.4	NA	102.4
Non-Dispatchable Technologies								
Wind – Onshore	39	47.2	13.7	0.0	2.8	63.7	-11.6	52.2
Wind – Offshore	45	133.0	19.6	0.0	4.8	157.4	-11.6	145.9
Solar PV[3]	24	70.2	10.5	0.0	4.4	85.0	-18.2	66.8
Solar Thermal	20	191.9	44.0	0.0	6.1	242.0	-57.6	184.4
Hydroelectric[4]	59	56.2	3.4	4.8	1.8	66.2	NA	66.2

Source: IEA, (2017a), p. 8

It is therefore important to identify and substantiate the net benefits, if any, from public policies. One way to do this is to examine whether public policies foster RE innovation, after controlling for other variables that impact RE innovation.

(Industrial) Renewable Energy Policies (REPs) adopted from various countries are currently under attack for poor design, see for example The Economist who claimed that the main objective of public policy to raise the price of pollution and promote investment, research and development in RE, have failed to materialise (The Economist, 2014). Michalena and Hills (2012) undertook a meta-analysis of the international scientific literature of the European RE generation and found a total 54 challenges related to the implementation of RETs on a local basis. The authors concluded that the RE policies in the EU partially fail as they are limited in their scope in dealing with RE on a local basis (Michalena & Hills, 2012). On the other hand, Klessmann *et al*., (2011) suggested that although Europe may need additional policies in order to meet its 20% RES by 2020, this seems feasible especially since most of member states are well on track, and it is even possible that 15 member states may overachieve their national target (Klessmann, et al., 2011). Similarly, Fouquet (2013), argued that policies aiming at the 2020 target, appear to be successful, although there remain challenges such as grid access and the fact that some member states are reconsidering their policies. In the author's view Europe could serve as a role model for the rest of the world (Fouquet, 2013).

Given extraneous factors such as the European crisis, it is arguable that the impact of public policy on RE innovation, has not yet had a chance to fully materialise. If so, it can be argued that policies might appear to have been a failure in the short term, but could become a success in the longer term. This is not least as policy makers can learn overtime hoe to improve policy design. It is therefore important to examine how RE policy impacts on innovation particularly after the Kyoto Protocol came into force, based on a rigorous conceptual and econometric analysis. An important factor to be addressed moreover concerns the types of policies and policy instruments (see below) that are more likely to be successful in terms of fostering RE innovation.

Based on the above discussion, I aim to explore the role of public policy towards RE on RE innovation in theory and in terms of econometric investigations. In particular, I discuss whether and how RE policies and the various RE instruments impact on RE innovation, which is a major indicator of RE performance and hence potential for effective transition. With regards to the potency or otherwise of public policy, the research draws upon the extensive debates on Industrial Policy (IP) (Bailey et al., 2015). Traditionally IP has focused on support to particular sectors and firms (Bailey et al., 2018). While RE is a sector in itself, I also explore the role of different public policy instruments and their impact on particular RETs. This is in line with more recent thinking on public IP that shifted attention from sectors and firms to policies, policy instruments and technologies. In this context I make a number of important innovations and contributions.

The extent to which RE policies can help foster RE innovations, has been examined by a large literature body, and overall, it has shown that public policy does indeed foster RE innovation. The novelties of this thesis are both conceptual and empirical. In particular, I cross fertilise theory on IP and RE, develop novel hypotheses and examine the extent to which RE policy instruments and their interactions, have a positive effect on RE innovation. Taking this a step further, I explore if this effect varies between specific RE policy instruments and RETs and whether the impact of targeting particular RETs on RE innovation is mediated by a country's experience, and varies across regional blocks. I also examine if such effects are contingent on the instrument, and if the effect is moderated by the degree of targeting of one or more RETs. I also examine the effects of subsidizing fossil fuels on subsidies to RETs, and the extent to which the relationship between subsidies for fossil fuels and RETs is mediated by the type of fossil fuel technology. These questions result in a number of contributions: (i) the literature on RE innovation and IP is cross-fertilised and enriched, (ii) I draw on the innovation literature to focus on different RE policy, (iii) I explore the impact of REP on RETs, (iv) I analyse the role of more traditional IP tools such as subsidies, and the role of subsidies towards non-renewables on RE innovation, (v) I look at the moderating role of country experience with RE and with RETs on RE innovation and on regional variations in the EU, (vi) I provide original econometric evidence based on a unique data set I have collected for this purpose.

1.3 Structure of Thesis

Following the present introduction (Chapter 1), the subsequent chapters are as follows:

Chapter 2. Theoretical Framework: Determinants of Innovation and the role of Public Industrial Policy

This (second) chapter critically assesses debates on the two key conceptual aspects of the thesis, one on the nature and determinants of innovation and its impact on economic performance, the other on the role of pubic (industrial) policy in inducing innovation in general and in this case RE innovation. First, I discuss critically the literature on the determinants of innovation. Innovation is widely seen as a major contributor to economic development. It can take place within organisations and at the regional or macroeconomic level. In this chapter innovation is defined and distinguished from technological change and related concepts such as invention and diffusion. The focus is then placed on its determinants, paying attention to the macroeconomic and public policy determinants of innovations in RE and the role of RE policy. I then look at the long standing and ongoing and currently popular debate on industrial policy. In particular, the various arguments in favour or against and the debates on the role of public policy on innovation are discussed, paying attention to innovation in the RE sector.

Chapter 3. Empirical Protocol and Method

In this (third) chapter I present the methodology employed in the thesis. The focus on econometric investigation is explicated and appropriate (for the purposes of this thesis) econometric methods and techniques are detailed. Particular attention is paid to the use of "Negative Binomial Regression Analysis". I mostly employ this method since in most cases the data for the dependent variable (RE innovation) is count data (i.e. patent counts related to RETs) in which case the aforementioned method is considered to be the most suitable one. Various equations have been used to express the relationship between the dependent (or response) variable (DV) and one or more independent (or explanatory) variables.

Chapter 4. Industrial policy for renewable energy: The innovation impact of European policy instruments and their interactions

The forth chapter examines the impact of REPs as well as three REP instrument types (demand-pull, technology-push, and systemic) and their interactions on RE innovation in 15 European Union member states for the period 1995–2014. A conceptual framework and hypotheses are developed and then tested by employing a unique and comprehensive data set. I found that REPs as a whole as well as demand-pull and technology-push instruments affect RE innovation positively and significantly.

Chapter 5. Can Industrial Policy Pick Winning Renewable Energy Technologies?

Following that, in the sixth chapter we cross-fertilised the literature on *Industrial Strategy* and RE. I suggested that the long lasting and ongoing debate on IP and industrial strategy has relied overly on conceptual arguments and case studies with little large data- based econometric support. At the same time work on public policy towards renewables has employed econometric techniques but mostly failed to draw the link with IP.. Given that the RE sector is an industrial one and that it has over the years received substantial public sector support, the failure to cross fertilise the two sets of literature is a glaring omission and presents a literature gap to be explored. Firstly, I have analysed and tested the ideas that public sector's industrial strategy towards RE is effective. Secondly I tested whether targeted industrial policies (the so called "picking winners" approach) is more or less likely to succeed.

Chapter 6. Fostering Innovation in Renewable Energy Technologies: Choice of policy instruments and effectiveness

The fifth chapter served as a continuation of the previous one. In it I evaluated the effectiveness of the aforementioned types of REP instruments (i.e. demand-pull, technology-push and systemic) on innovation for an array of specific RETs. More specifically, I collected and analysed data on policy intervention, innovation activity and performance for 21 countries over the period 1990-2014. I then used these to evaluate and compare the effect of different instruments on different RETs.

Chapter 7. The Interrelationship Between Subsidies to Fossil Fuels and to Renewable Energy Sources in the OECD

In the seventh chapter I examined the substitutability between subsidies to fossil fuel and subsidies to RETs. A joint paper from the International Monetary Fund and the University of California, that estimated fossil fuel subsidies along with the economic and environmental benefits from reforming them, found that in 2013 4.9 trillion USD, and 5.3 trillion USD in 2015 (6.5% of global GDP in both years) were spent on subsidies (Coady et al., 2016). In another report by the International Energy Agency (2016), for the year 2015, fossil fuels subsidies amounted to 325 billion USD (from almost 500 billion USD in 2014), while for the same year for RE they were 150 billion USD. Unlike the substitutability between different types of energy sources, the relationship between subsidies to RE and to fossil fuels has not been explored in literature. In theory the two types of support can be substitutes, unrelated or even complements. Evidently, the impact on energy transition will depend in part on the exact relationship, something not tested before. My aim is to do this both conceptually and econometrically.

Chapter 8. Summary, Concluding Remarks, Limitations, and Policy Implications and Opportunities for Further Research

Finally, the eighth and last chapter presents a summary, concluding remarks, implications for public policy, as well as limitations and opportunities for further research.

Chapter 2
Theoretical Framework: Determinants of Innovation and the Role of Public Industrial Policy

2.1 Introduction

Innovation in Renewable Energy (RE) sources is widely regarded as a key way through which energy transitions can come about. This is because innovation can improve products, services and processes, foster differentiation and/or reduce costs, in some cases help replace market incumbents with new challengers (Freeman, 1982). Innovation in RE can theoretically at least render RE both better and cheaper than energy through fossil fuels, hence gradually replacing them and benefiting the planet.

Given the importance of innovation, it is not surprising that the debate on the definition, determinants and effects of innovation is long standing and continuing. The aim of this chapter is to discuss critically the literature on the definition and most importantly determinants and effects of innovation in general and as they relate to innovation in RE in particular. This can serve as an introduction to, and justification of, the focus of most scholars in RE, on RE innovation. As noted, one of the key aims in this thesis is to look at the debates regarding the role of public policy in fostering (or not) innovation in general and innovation in RE in particular.

Innovation can be the result of efforts by corporate R&D departments, individual inventors, and/or of collaborative networks small and large firms, in the private, and/or the 'third' sectors, such as by the government, universities, and corporations (also known as the triple-helix), (Block & Keller, 2011). Innovation is widely seen as a major contributor to economic performance (Freeman, 1987). In what follows, I define innovation and distinguish it from other related concepts such as technological change, invention and diffusion. I then focus on the determinants of innovation, paying attention to the role of public policy as a determinant of innovation, particularly in the focus of my interest, which is RE. These are followed by brief concluding remarks.

2.2 Definition and Preliminaries

The importance of technological change has long been recognised. For example Adam Smith, (1776), the founder of economics, had advocated that specialisation and the division of labour within firms led to new ideas and inventions, higher productivity and higher economic growth (Conte, 2007). A more general theoretical framework was subsequently developed by Joseph A. Schumpeter (1934), who originally put forward some general taxonomies and definitions for the theoretical and empirical research on technological change. Schumpeter defined 'technological change' as new combinations of the means of production, and distinguished between invention, innovation, and diffusion (Schumpeter, 1934). The first stage (invention) related to the generation of new ideas and it was argued to be usually associated with basic and scientific research. The second one (innovation) was related to applied and technological research and development (R&D) and was said to determine the creation of economic value at the organisational level. The third one (diffusion) was associated to the spread of new products and process across markets. It also allowed for the measurement of the impact of new technologies on the economy (Conte, 2007).

Schumpeter's definitions remain influential. The European Commission for example, employed the concept of Technology Readiness Levels (TRLs) which can be seen as an elaboration upon Schumpeter's three types of technological change, see for example the EU's Horizon 2020 Work Programmes, (European Commission, 2016). TRLs are a systematic metric/measurement system that assesses the maturity (readiness) of particular technologies and serves as a comparison for the maturity among the different types of technology (Mankins, 1995). There are nine TRLs, with TRL 1 being the lowest and TRL 9 the highest, shown in the

Table 3. These correspond broadly to the first two of Schumpeter's three phases, namely invention (TRLs 1 to 6) and innovation (TRLs 7 to 9).

Table 3: Technology Readiness Levels and Schumpeter's Technological Change Aspects

Technology Readiness Level	**TRL Definition** (European Commission, 2014)
TRL 1	Basic principles observed
TRL 2	Technology concept formulated
TRL 3	Experimental proof of concept
TRL 4	Technology validated in lab
TRL 5	Technology validated in relevant environment
TRL 6	Technology demonstrated in relevant environment
TRL 7	System prototype demonstration in operational environment
TRL 8	System complete and qualified
TRL 9	Actual system proven in operational environment
Source: European Commission (2014)	

In the context of Schumpeter's work, innovation was therefore originally seen as a specific part of technological change. As the discussion below shows, in his later works and today the term *innovation* has acquired a broader meaning.

In his subsequent book on "Capitalism, Socialism and Democracy", Schumpeter (1942) presented his key idea that innovation was a force of 'creative destruction', in that it destroyed the old but replaced it with something more novel and better. Schumpeter had argued that innovation is reflected in novel outputs: a new good or a new quality of a good or service; a new method of production; a new market; a new source of supply; or a new organizational structure (Crossan & Apaydin, 2010). This implied a definition for innovation as "doing things differently" (Crossan & Apaydin, 2010) and also better. This may be seen as rather too general a definition, in that as Hansen and Wakonen (1997) have stated, doing things identically is practically impossible (Hansen & Wakonen, 1997). Moreover, today it is widely acknowledged that new need not mean better-consider the debates on new financial instruments such as financial derivatives that have been debited by many with the onset of the latest financial crisis.

Gradually the focus has been more narrowly on commercialisation, with innovation being seen as inventions that have been commercialised (Edison, et al, 2013).

Over the past fifty years or so, various studies and analyses explored the issue of innovation. These aspects relate to the nature of the innovation process itself (Dosi, 1988), as well as the relationship between inputs and outputs of innovative activities (i.e. the relationship between the resources devoted to innovative search and the rates of generation of innovations, however measured). In a survey of the literature by Edison et al., (2013) out of the 204 reviewed studies, 41 studies formulated their own or used existing definitions, 12 studies did not clearly defined innovation, and 151 studies did not define it at all. This has resulted in various and different definitions of the term, which may signify different aspects of innovation, and which in turn, can determine what are considered as elements of innovation and how these are measured (Edison, bin Ali, & Torkar, 2013).

To the best of my knowledge, one of the first attempts for a comprehensive definition of innovation was made by the Organisation for Economic Co-operation and Development (OECD) in 1991, who defined innovation as "*an iterative process initiated by the perception of a new market and/or new service opportunity for a technology-based invention which leads to development, production, and marketing tasks striving for the commercial success of the invention*" (OECD, 1991, p. 303). This definition incorporates two important aspects: firstly, that the innovative process comprises the technological development of an invention combined with the market introduction of that invention to end-users through adoption and later diffusion. Secondly, that the process is iterative in nature and as a result, it includes the first introduction of a new innovation and the reintroduction of an improved innovation (Garcia & Calantone, 2002). In 2005, the OECD "Oslo Manual" revisited the term innovation as being "*the implementation of a new or significantly improved product (goods or service), or process, a* *new marketing method, or a new organisational method in business practices, workplace organisation or external relations*" (OECD, 2005, p. 46). In 2010, Crossan and Apaydin (2010), redefined this to be "[Innovation is:] *production or adoption, assimilation, and exploitation of a value-added novelty in economic and social spheres; renewal and enlargement of products, services, and markets; development of new methods of production; and establishment of new management systems. It is both a process and an outcome"* (Crossan & Apaydin, 2010, p. 1155). The term value added is useful here as it addresses the challenge of non-value adding innovations, while also it adds a non-technological dimension to the definition, in line with more recent (broader) uses of the term. On the other hand, it raises the challenging question what constitutes value adding innovation and what not.

For the purposes of this thesis, and based on the above definitions, in order for an invention to become an innovation, it must be commercialised and diffused into the market. It includes both basic and applied research, as well as product development, manufacturing, marketing, distribution, servicing, and later product adaptation and upgrading (Smith & Barfield, 1996). Schumpeter (1934) had originally identified five types of innovation (I) product innovation, which is the introduction of a new good, or of a new quality of a good, (II) process innovation, related to a new method of production, (III) opening of a new market, (IV) discovering new resources or intermediates, and (V) a new organisational form (Schumpeter, 1934). Many more types and categories have been identified since by many authors. For example, Daft (1978), Kimberly and Evanisko (1981), and Damanpour (1987) distinguished between administrative and technical innovations. Dewar and Dutton (1986), Ettlie, Bridges, and O'Keefe (1984), and Nord and Tucker (1987) focused on the difference between radical innovations (ones that involve and lead to significant transformations, such as the commercialisation of electricity) and incremental innovations (like for example improving the functionality of an existing product). Marino (1982) and Zmud (1982) separated the initiation and implementation stages of the adoption of innovation; Aiken, Bacharach, and French (1980) distinguished between innovations in different levels in organizations.

In 1995, Clayton Christensen distinguished between two more major categories of innovation, sustaining and disruptive. According to his analysis, a sustaining innovation does not significantly affect existing markets and can be evolutionary, in which case a product is improved by an innovation in an existing market as the customers would expect, or revolutionary (discontinuous, radical), when an innovation is unexpected but does not affect existing markets. On the other hand, a disruptive innovation was one that creates a new market (Christensen, 1997). According to Damanpour (1991), among the various typologies of innovation that emerged from the relevant literature, three have gained the most attention, administrative and technical, product and process, and radical and incremental (Damanpour, 1991).

More recently, innovations related to the way an organisation goes about creating and capturing value and known as the "Business Model Innovation", (Teece, 2010) has acquired significance. Last but not least a category that is particularly useful for this thesis is that of "General Purpose Technologies" (GPTs)-based innovations. Bresnahan and Trajtenberg (1995) identified GPTs by using three criteria: (1) pervasive, i.e., in wide use, (2) capable of ongoing technical improvement, and (3) enabling complementary innovations in application sectors. In other words, GPTs are those that have economy-wide effects, improve over time, and help trigger discoveries in other activities.

For the purposes of this thesis GPTs are particularly important because

1. RE can be seen as a GPT.

2. There are recent debates suggesting that it may be easier and/or best for governments to focus on fostering GPTs and leaving commercialisation to the private sector.

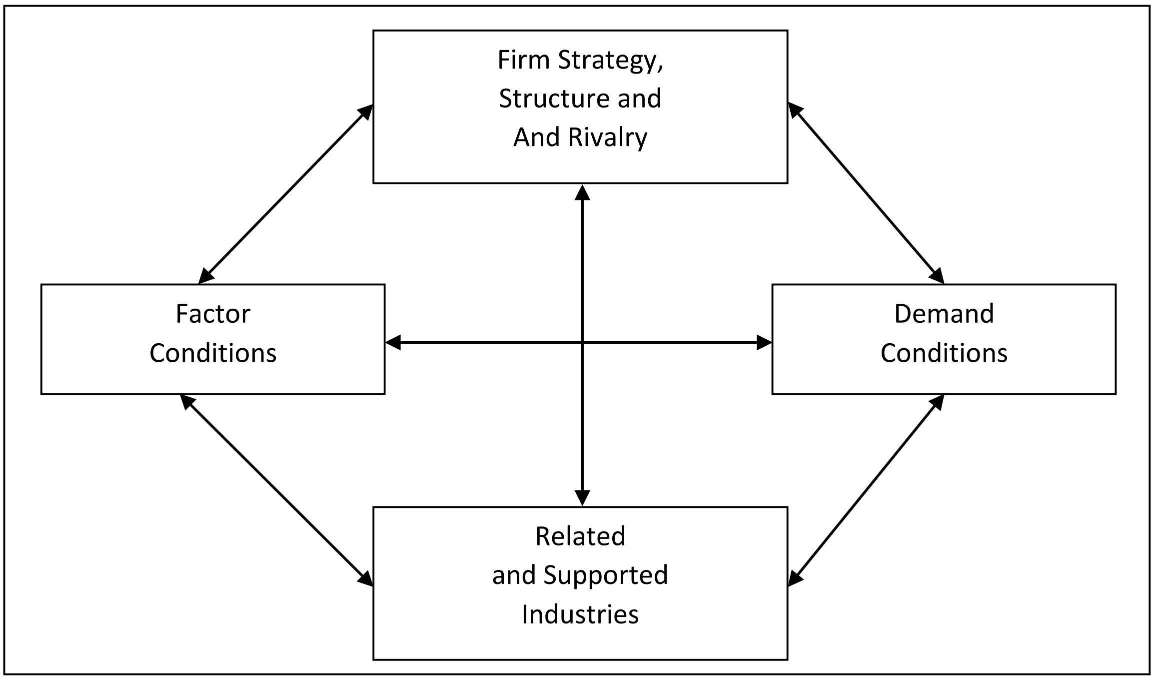
RE qualifies as a GPT because it can be applicable in virtually every economic activity-from construction to manufacturing, to agriculture (consider energy self -sufficient greenhouses), as a result of scale flexibility and the potential for electricity transmission. Beyond scale flexibility, the existing power grid and virtual power markets allow physical and logistical power transmission between producers and consumers. This enables large power consumers to sign private Power Purchase Agreements (PPAs) with wind or solar farms (see Google, Facebook etc.) or residential consumers to sign up for RE tariffs (Bird, et al., 2017). RE technologies also improve over time in terms of their efficiency in energy generation and in terms of their own manufacturing - solar PV cost for example has gone down over twelve times during the last decade (LAZARD, 2017). Last but not least, innovation and growth of RE applications has triggered further innovation in adjacent sectors; for example, long-distance High Voltage Direct Current (HVDC) transmission systems have been developed to take RE from remote offshore wind farms to urban consumption centres (Elliott, et al., 2016); smart grid applications were developed to facilitate grid services and power multi-directionality (Batista, et al., 2017) and grid-scale batteries were developed to improve demand and supply timing with intermittent output renewables (Zafirakis, et al., 2016).

I develop these ideas further in the subsequent chapters. The next section focuses on the determinants of innovation.

2.3 Determinants of Innovation

2.3.1 Theoretical Considerations

Figure 2: Porter's Diamond: Determinants of National Competitive Advantage



Source: Porter, 1990

Innovation can be driven by individuals and their personal traits and motives and/or by organisations and organisational l factors, such as the capabilities, processes and infrastructure (such as R&D labs) within a company. The *external* environment for innovation is also important (Porter & Stern, 2001). This relates to the wider macroeconomic, institutional, cultural, and policy environment. These two can be interrelated, with certain companies in specific nations being more capable of consistent innovation. The reason for that according to Porter's (1990) *Diamond of National Advantage*, (see *Figure 2*) is due to the existence or absence of four interrelated factors or attributes. According to (Porter, 1990) these are the: (1) Factor Conditions, which refers to the nation's position in factors of production (such as skilled labour or infrastructure, necessary to compete in a given industry), (2) Demand Conditions, which refers to the nature of home-market demand for the industry's product or service, (3) Related and Supported Industries which refers to the presence or absence in the nation of supplier industries and other related industries that are internationally competitive, and (4) Firm

Strategy, Structure and Rivalry, which refers to the conditions in the nation governing how companies are created, organised, and managed, as well as the nature of domestic rivalry between firms. According to Porter (1990), these determinants create the national environment under which a company is born, innovates and competes (Porter, 1990).

The "diamond" is related to the earlier concept of a *National Innovation System* (NIS). The notion of NIS, dates back to Freeman (1987). Since then, different definitions have been provided, summarised in the *Table 4* below:

Table 4: Definitions of National Systems of Innovations

"[…] The network of institutions in the public- and private-sectors whose activities and interactions initiate, import, modify and diffuse new technologies" (Freeman, 1987)
"[…] The elements and relationships which interact in the production, diffusion and use of new, and economically useful knowledge […] and are either located within or rooted inside the borders of a nation state" (Lundvall, 1992)
"[…] The set of institutions whose interactions determine the innovative performance of national firms" (Nelson & Rosenberg, 1993)
"[…] the institutions and economic structures affecting the rate and direction of technological change in the society" (Edquist & Lundvall, 1993)
"[…] the system of interacting private and public firms (either large or small), universities, and government agencies aiming at the production of science and technology within national borders. Interaction among these units may be technical, commercial, legal, social, and financial, in as much as the goal of the interaction is the development, protection, financing or regulation of new science and technology" (Niosi, et al., 1993)
"[…] The national institutions, their incentive structures and their competencies, that determine the rate and direction of technological learning (or the volume and composition of change generating activities) in a country" (Patel & Pavitt, 1994)
"[…] That set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts which define new technologies" (Metcalfe, 1995)
Source: Niosi, (2002)

Key in all definitions is the inter-linkages between organisations, institutions and the private, public, and civic spheres. This concept of linkages is central also in Porter's "diamond". In this argument, strong linkages facilitate innovation, weak linkages hinder it. As noted, innovations can take place at the individual, organisational or macroeconomic/national levels. As most individual inventors eventually require an organisation in order to commercialise their inventions, below I look at the organisational and the national levels.

2.3.2 Determinants of innovation at the organisational/firm level

In order to analyse the determinants of innovation on an organisational/firm level, one should first have a clear understanding of the various types of firms and sectors. This is because both firms and sectors can differ significantly in their capabilities, the sources of technology they adopt, the users and technology developed and the methods they use to capture value from an innovation. Pavitt (1984) based on a number of previous studies, identified four categories of firms. The first, supplier *dominated firms*, are found in the traditional sectors of manufacturing and are usually small with weak R&D and engineering capabilities. Most of their innovations come from suppliers of equipment and materials although in some cases large customers and government research institutions also make a contribution. The second, *production intensive firms*, are further divided into *large scale producers*, which are usually big and produce a high proportion of their process technologies to which they devote relatively high proportion of their resources. They have a relatively high level of vertical technological diversification into equipment related to their own process technology and they make a relatively big contribution to all the innovations produced in their principal sectors of activity. The second subcategory is the *specialised suppliers* who also produce a high proportion of their own process technologies but the main focus of their innovative activities is the production of product innovations for use in other sectors. They diversify technologically relatively little and they do not make a big contribution to all the innovations produced in their principal sector of activity. Users and other firms outside the sector make significant contributions. The third, *science-based firms* have their main source of technology in internal R&D. Such firms produce a relatively high proportion of their own process technology, as well as a high proportion of product innovations that are used in other sectors. They are also relatively big, most of their technological diversification is conglomerate (in unrelated sectors) and they produce a relatively high proportion of all the innovations made in their principal sector of activity (Pavitt, 1984). Table 5, extracted from Pavitt (1984), summarises the main sectoral technological trajectories for each category.

Table 5: Sectoral technological trajectories

Category of firm	Typical core sectors	Determinants of technological trajectories			Technological trajectories	Measured characteristics			
		Sources of technology	Type of user	Means of appropriation		Source of process technology	Relative balance between product and process innovation	Relative size of innovating firms	Intensity and direction of technological diversification
Supplier dominated	Agriculture; housing; traditional manufacture	Suppliers, research extension services, big users	Price sensitive	Non-technical (trademark, marketing, advertising, aesthetic design)	Cost-cutting	Suppliers	Process	Small	Low vertical
Scale intensive	Bulk materials (steel glass); assembly (consumer durables and autos)	PE suppliers; R&D	Price sensitive	Process secrecy and know-how; technical lags; patents; dynamic learning economies	Cost-cutting (product design)	In-house; suppliers	Process	Large	High vertical
Specialised suppliers	Machinery; instruments	Design and development users	Performance sensitive	Design know-how; knowledge of users; patents	Product design	In-house; customers	Product	Small	Low concentric

Category of firm	Typical core sectors	Determinants of technological trajectories			Technological trajectories	Measured characteristics			
Science-based	Electronics/electrical; chemicals	R&D; public science; product engineering department	Mixed	R&D know-how; patents; process secrecy and know-how; dynamic learning economies	Mixed	In-house; suppliers	Mixed	Large	Low vertical; high concentric
Source: Pavitt, 1984									

Later studies have identified additional categories. For example Archibugi et al. (1991), identified the *suppliers of traditional intermediate goods* which falls between traditional firms and specialised suppliers and operate by selling their products to other companies and receiving information through this channel (Archibugi, Cesaratto, & Sirilli, 1991). In 1997, Tidd et al., identified the *information intensive firms*, which are usually found in newly emergent service industries (Tidd, Bessant, & Pavitt, 1997).

Regardless, of the type of organization/firm, an innovation is adopted in order to foster the performance or effectiveness of the adopting organization, either as a response to changes in its internal or external environment, or as a pre-emptive action taken to influence the environment (Damanpour, 1991).

Damanpour (1991), identified 13 determinants of innovation on an organizational level, from reviewing previous studies, as follows:

Specialization:	This provides a broader knowledge base and increase the cross-fertilization of ideas.
Functional Differentiation:	Coalitions of professionals form differentiated units elaborate upon, introduce changes in the units' technical systems and influence changes in their administrative systems.
Professionalism:	This increases boundary-spanning activity, self-confidence, and a commitment to move beyond the status quo.

Formalization: Flexibility and low emphasis on work rules facilitate innovation. Low formalization permits openness and encourages new ideas and behaviours.

Centralization: The concentration of decision-making authority prevents innovative solutions, while the dispersion of power is necessary for innovation.

Managerial Attitude Toward Change: Managers' favourable attitude toward change leads to an internal climate conducive to innovation.

Managerial Tenure: The longevity of managers in their jobs provides legitimacy and knowledge of how to accomplish tasks, manage political processes, and obtain desired outcomes.

Technical Knowledge Resources: The greater the technical knowledge resources, the more easily can new technical ideas be understood and procedures for their development and implementation be attained.

Administrative Intensity: A higher proportion of managers facilitates intensity of innovation because the successful adoption of innovations depends largely on the leadership, support, and coordination of managers.

Slack Resources: These allow an organization to pursue innovations, absorb failure, bear the costs of instituting innovations, and explore new ideas in advance of an actual need.

External Communication:	Environmental scanning and extra-organizational communication professional activities of members can bring innovative ideas.
Internal Communication:	This facilitates dispersion of ideas within an organization and increases their amount and diversity, which results in cross-fertilization of ideas. Also it creates an internal environment favourable to the survival of new ideas.
Vertical Differentiation:	Hierarchical levels increase links in communication channels, making communication between levels more difficult and inhibiting the flow of innovative ideas.

Damanpour (1996), added two more determinants, namely *structural complexity* and *size.* These were defined as follows:

Structural Complexity:	This refers to the number of locations at which work is performed, the number of jobs or services performed; or the number of hierarchical ranks performing different tasks. Other dimensions of differentiation in organizations are spatial, occupational, hierarchical, and functional.
Size:	One of the most important factors affecting the structure and processes of an organization, large organizations have more slack resources for new projects and diversification, greater challenges and more opportunities for growth among their employees, and

	more control over the external environment. They also are more bureaucratic and less flexible; are unable to change and adapt quickly; and tend to have impersonal work environments.

In 1997, Balachandra and Friar (1997), have added *Market type (i.e. existing versus new)*, and *Technology type (i.e. innovativeness of the technology).* These are defined as follows:

Market Type:	When a new product is introduced, there should be a strong market in order for it to succeed. Although market strength is a composite factor, its estimation is contextual, because some components for estimating market strength may contribute positively in some situations but negatively in others. The main contextual feature is whether the new product is entering an established market or is an innovative product for which there is no established market.
Technology Type:	The success of a new product depends on technology factors and on the innovativeness of the technology. The precise relationship between innovativeness and commercial success however is a matter of dispute.

A later study, conducted by Pittaway et al. (2004), argued that, network relationships with suppliers, customers, and intermediaries (e.g. professional and trade associations) are important factors affecting innovation performance and productivity. Networks can endure and evolve over the years and as a result they go through periods of conflict between partners, which can (and usually do) lead to the failure of the network. Networks may also display internal conflicts, and conflict with other alternative networks (Pittaway, et al., 2004).

In a more recent study, Anderson et al. (2014) identified and/or restated some determinants at the organisational level by systematically reviewing the existing literature. These are (Anderson, Potocnik, & Zhou, 2014):

Management-Related Factors: Human Resource (HR) practices were found to have a mixed effect, with some arguing that the provision of training, employee involvement practices, use of performance based pay systems, flexible working hours, job variety and autonomy, and human resource flexibility engender higher levels of innovation. The role of *management support* in organizational innovation in terms of the CEO's *transactional and transformational leadership, management support,* and *top managers' favourable attitude towards innovation* was found to have a positive effect on innovation.

Knowledge Utilisation and Networks: Knowledge search and *spillover* (transfer*), knowledge stock*, and *social network* had overall mixed effects, while the *absorptive capacity* of an organisation (Cohen & Levinthal, 1990) and *intellectual capital,* were found to have positive effect.

Structure and Strategy: *Decentralised, more complex structures,* and structures with *harmonisation* or *commitment to low power*

	differentiation, and low formalization have a positive effect on innovation. In terms of strategy, the *formalization* and the *structural integration had* a negative effect on innovative practices.
Size:	The size of a firm and its innovativeness are positively linked which is not surprising since larger organisations are more likely to have more assets of different classes (finances, personnel, expertise, etc.) to devote to innovation.
Resources:	The *availability of resources* was found to have no effect on the innovativeness of a firm. The *diversity* and *quality* of the resources were found to have a positive effect, while the results on *slack resources* were mixed.
Culture and Climate:	A *climate supportive of innovation* is favourable to organizational-level innovation; a *climate that favours r personal initiative and psychological safety* enhances the relationship between process innovativeness and firm performance. The *national culture*, and *empowerment* were found to have mixed effects.
External Environment:	Market *competition* was found to have a positive effect on the innovative activity of a firm, while mixed effects were found for the *geographic distribution of R&D activity*, as well as for *environmental uncertainty*,

turbulence, *dynamism*, *urbanization*, *community wealth*, *population growth*, and the *unemployment rate*.

Innovation Diffusion: The *diffusion process* was found to have mixed effects on further innovation.

Corporate Entrepreneurship as Innovation: Entrepreneurship as *a process of human creativity, financial resources, and technological capital, can enhance new product development processes and new institutional forms and foster new ventures and successful innovations.*

It is apparent from the above that some determinants are common, such as the size of an organisation, the resources and the market structure and competition.| others differ, depending in part on the classification criterion used.

A regression analysis by Bhattacharya and Bloch (2004) examined how firm size, market structure, profitability and growth influence innovative activity in small to medium sized Australian manufacturing businesses. They found that size, R&D intensity, market structure and trade shares were conducive to further innovative activity for the full sample and for high-tech firms. For low-tech industries, fewer variables were significant (Bhattacharya & Bloch, 2004).

2.3.3 Determinants of Innovation at the National Level

In addition to within organisations, innovation can take place at the level of the wider nation. In this sub-section I look at whether and how can organisational innovation scale up to the national level and/or how organisational and national innovation interact. Porter and Stern (2001) suggested that a nation's competitiveness depends on the capacity of its industry to innovate and upgrade. Companies gain advantage over the world's best competitors as a result of pressure and challenge, while they also benefit from having strong domestic rivals, aggressive home-based suppliers, and demanding local customers. For example, Israeli firms, who have a striking innovative output, are benefiting by the environment of innovation, including strong university-industry linkages, as well as a large pool that includes highly trained scientists and engineers (Kuan, 2004). Similarly, the United States had attracted innovation in pharmaceuticals in the 1990s, while Sweden and Finland have had extraordinary rates of innovation in wireless technology (Porter & Stern, 2001). In the authors' view, as the basis of competition has shifted towards the creation and assimilation of knowledge, the role of the nation (and hence public policy) has grown (Porter, 1990).

In one of the earliest studies, Patel and Pavitt (1994) identified national institutions, their incentive structures and their competencies, as the determinants of the rate and direction of national innovation (in terms of technology created). In more detail the authors identified and defined the following (Patel & Pavitt, 1994):

Institutions:	*1. Business firms*, and especially those investing in change-generating activities;
	2. Universities and similar institutions, providing basic research and related training;

3. A mixture of *public* and *private institutions*, providing general education and vocational training, and;

4. Governments, financing and performing a variety of activities that both promote and regulate technical change.

Incentives:	*Government support for basic research* (given non-appropriability and non-depletability) is accepted in all countries. However, less attention had been placed on *firm-based training* (including training in change-generating activities) when employees are mobile between firms. The balance between the incentive of temporary monopoly profits for *innovation*, and the pressure of competition for *imitation.* The inadequate nature of such incentives in the previously centrally planned economies was a major reason for their lack of technological accumulation. *International differences* in the rate and direction of technological activities amongst advanced market economies, and most importantly the local supply of *skills*, specific local *demands*, and the pressure of *competition*.

Competencies: One major reason for international differences in growth and trade performance is the existence of international technology gaps i.e. international differences in technological competence resulting from differences in the volume and sectoral pattern of R&D and related activities.

The above is closely linked both to NIS and the "diamond". But it goes further in identifying the role of competences and incentives that both the NIS and diamond-based approaches seem to downplay.

While their original work was not linked to NIS, more recently, Furman, et al. (2002) have tried to link the diamond to the NIS and other economic literature. They have also developed the notion of National Innovative Capacity (NIC) which they defined as *[a] country's potential-as both an economic and political entity-to produce a stream of commercially relevant innovations*, which depends on the overall both on the technological sophistication of an economy and its labour force, as well as on the *investments and policy choices made by the government and the private sector*. The authors based their framework on three different theories: Romer's (1990) endogenous growth theory; Porter's (1990) cluster-based theory of national industrial competitive advantage; and Nelson's (1993) research on national innovation systems. Drawing from Romer's (1990) work, their framework proposed that the innovative performance is determined by the following set of influences, (Furman, Porter, & Stern, 2002):

$$\dot{A}_{j,t} = \delta_{j,t}(X_{j,t}^{\mathrm{INF}}, Y_{j,t}^{\mathrm{CLUS}}, Z_{j,t}^{\mathrm{LINK}}) H_{j,t}^{\mathrm{A}\lambda} A_{j,t}^{\phi} \qquad (2\text{-}1)$$

Where:

$\dot{A}_{j.t}$ is the flow of new-to-the-world technologies, per county *(j),* per year *(t)*;

$H_{j.t}^{A}$ is the total level of capital and labour resources allocated to the ideas sector of the economy;

$A_{j,t}$ is the total stock of knowledge held by an economy at a given point in time to drive future production;

X^{INF} is the level of cross-cutting resource commitments and policy choices that constitute the common innovation infrastructure;

C^{CLUS} is the specific environments for innovation in the industrial clusters of a country; and

Z^{LINK} is the strength of linkages between common infrastructure and the industrial clusters of the nation.

The equation assumes that the elements forming the NIC are complementary, i.e. the marginal boost to ideas production from increasing one factor is increasing in the level of all the other factors, As a result, the determinants of the framework were divided into three categories: (i) innovation-supporting infrastructure (i.e. the common pool of institutions, resources, and policies), (ii) a country's industrial clusters, and (iii) the linkages and interaction between the two. In so doing the authors brought together organisational, sectoral, institutional and national determinants of innovation, including policy related determinants.

In the case of the first category, two major determinants identified were an economy's aggregate level of technological sophistication, and the amount of the total available scientists and engineers that can be dedicated to the production of new technologies. The authors expanded this concept to include the extent to which an economy invests in higher education and public policy choices (e.g. patent and copyright laws), the extent of R&D tax credits, the nature of antitrust laws, the rate of taxation of capital gains, and the openness of the economy to international competition (Furman, Porter, & Stern, 2002).

Regarding the second category, they argued that firms - influenced by their microeconomic environment – are the main actors who develop and commercialize innovation, and hence, the NIC depends on the microeconomic environment present in a nation's industrial clusters. A number of cluster specific determinants were identified, including investments, and policies which influence the extent to which a country's industrial clusters compete on the basis of technological innovation. These clusters can be complementary to one another, both due to knowledge spill-overs and other interrelationships (Furman, Porter, & Stern, 2002).

Public policy was argued to have a significant role in shaping a country's national innovative capacity. Apart from increasing the level of R&D resources available to the economy, other policy choices shape human capital investment, innovation incentives, cluster circumstances, and the quality of linkages. Every country that had increased their estimated level of innovative capacity over the last quarter century (i.e. Japan, Sweden, Finland, Germany) have implemented policies that foster human capital investment in science and engineering (for example by establishing and investing resources in technical universities) as well as greater competition on the basis of innovation (e.g. through the adoption of R&D tax credits and the gradual opening of markets to international competition) (Furman, Porter, & Stern, 2002).

Finally, the relationship between the common innovation infrastructure and industrial clusters was said to be mutually reinforcing: for a given cluster innovation environment, innovative output will tend to increase with the strength of the common innovation infrastructure and vice versa. These strengths are translated into specific innovative outputs, hence shaping the realized rate of national R&D productivity. Linkages can be assisted by various types of institutions, such as universities, cluster trade associations, and informal alumni networks. In the absence of strong linking mechanisms, the authors observed that upstream scientific and technical activity may spill over to other countries more quickly than opportunities can be exploited by domestic industries (Furman, Porter, & Stern, 2002).

Despite the emphasis on the role of firms, Furman et al., (2002) focused on the cluster level, not the firm level as such, and also on public policy. It is worth noting that competences and incentives mentioned by Patel and Pavitt (1994) can be both organisational level and cluster and more macro level, hence it is important to maintain these as part of the analysis of the determinants of innovation and NIS. Unlike Patel and Pavitt (1994), Furman et al., (2002) have not paid sufficient attention to competences and incentives.

A large number of empirical studies have tried to test for the importance of different determinants of innovation. In 1996, a study conducted by Malebra et al., (1996) concluded that the patterns of innovative activities differ systematically across technological classes[2] but are remarkably similar across countries for each technological class. They examined the patterns of innovative activities at the technological and country levels, using patent data for 49 technological classes in six countries (USA, Japan, Germany, France, United Kingdom and Italy) (Malebra & Orsenigo, 1996). This statement was later supported by other studies – see Breschi, et al., (2000), and Carlsson, (2006).

2.3.4 Eco-innovation and public policy

Given the importance of country level and technological class in the remainder of this chapter the focus will be on the determinants of a particular class, that of eco-innovation (environmental innovation) and a particular key aspect of country-level factors, that of public policy. Eco-innovation is defined as "*the introduction of any new or significantly improved product (good or service), process, organisational change or marketing solution that reduces the use of natural resources (including materials, energy, water and land) and decreases the release of harmful substances across the whole life-cycle*" (European Commission, 2016). The OECD, based on their definition of innovation (OECD, 2005), identified three dimensions based on which eco-innovation can be understood and analysed, being its *targets* (the main focus), its *mechanisms* (methods for introducing changes in the target) and its *impacts* (the

[2] In order for international comparisons to be feasible, sector classifications (such as comparisons of productions, and employment) are important. These sectors are defined by typical products, which however are broad in nature, while their production and function are based on technologies. The said technologies (as well as sectors) are classified for ease in comparisons into five broad categories, being electrical engineering, instruments, chemistry, mechanical engineering, and other fields (Schmoch, 2008).

effects on environmental conditions). Renewable energy is part of the scope of the general eco-innovation concept (OECD, 2009).

In one of the earliest studies, Green et al. (1994) identified the *existence and anticipation of environmental regulation*, *expanding market share* of green products, and *cost savings* as the main determinants of eco-innovation by surveying UK firms (Green, McKeenin, & Irwin, 1994). In a similar study, focusing on the US manufacturing firms, conducted by Florida (1996), the author identified the *environmental regulation, corporate citizenship,* and factors related with the *industrial performances* (Florida, 1996).

On the empirical front, Lanjouw and Mody (1996) have found a strong correlation between *pollution abatement expenditures* and the *rate of patenting* for several countries (Lanjouw & Mody, 1996). Jaffe and Palmer (1996) used *R&D expenditures* and *patents application* as measures of innovative activity and data on regulatory compliance costs to study whether changes in regulatory stringency are associated with more or less innovative activity by US regulated industries. They concluded that (lagged) environmental compliance expenditures had a significant positive association with R&D expenditures, but that there was no relationship between compliance costs and inventive output (as measured by successful applications) (Jaffe & Palmer, 1996). The *regulatory stringency* (as measured by pollution abatement and control expenditure) was also identified as key determinant by Brunnermeier et al. (2003), alongside the role of the international competition (Brunnermeier & Cohen, 2003).

Newell et al. (1999) considered the effect of both *energy prices* and energy-efficiency *standards* on the average efficiency of a group of energy-using consumer durables (i.e. room air conditioners, central air conditioners, and gas water heaters). They showed that over time, changes in energy prices induce both the production and commercialization of new models and the elimination of old models from the USA market. In contrast, the imposition of environmental standards leads to a drop of those products which are energy-inefficient (Newell, Jaffe, & Stavins, 1999). Popp (2002) analysed the inducement effect of changing *energy prices* and *technological availability* on energy-efficient and environmentally-friendly innovations by using data on US patents and patent citations between 1970 and 1994. Using a knowledge stock (see Popp, 2002) to proxy for the supply-push determinant of innovation and energy prices as proxy for demand-pull determinant, he concluded that both demand-side and supply-side factors have an important role in the inducement of innovation (Popp, 2002).

De Vries et al. (2005) identified *policy stringency* as a determinant of eco-innovation by examining European patents on sulphur dioxide abatement technologies (De Vries & Withagen, 2005). However, Frondel et al. (2008), when surveying OECD countries, found a significant positive correlation between *policy stringency* (as well as *technology standards* and *regulatory compliance*) with the introduction of end-of-pipe technologies[3], but not with clean technologies. Innovations in clean technology tended to be more market driven and motivated by *cost savings* (Frondel, Horbach, & Rennings, 2008).

The *certification* of environmental management systems was found by Rehfeld et al. (2007) to have a significantly positive effect on environmental product innovations. By examining a dataset of the German manufacturing sector (at firm level), they also found that *environmental policy* seemed to be a driver for product innovations, and finally that technology-push (R&D) and market pull also have a positive effect on environmental product innovations (Rehfeld, Rennings, & Ziegler, 2007). Wagner (2007) found the implementation level of environmental

[3] *Any device and/or treatment system applied to storm-water, combined wastewater, municipal wastewater and/or industrial wastewater at the outlet of a collection system prior to a receiving water body. The majority of wastewater treatment systems including sanitary and combined wastewater treatment plants and many storm-water treatment schemes such as detention basins are end-of-pipe systems* (US EPA, 2016).

management systems to have a positive effect on environmental process innovations, by surveying and using patent data on German manufacturing firms (Wagner, 2007).

Horbach (2008) examined two panel databases on German firms and concluded that *improvement of the technological capabilities by R&D* is very important for environmental innovation as well as that an increase in the *expected future demand* fosters environmental innovations. Environmental *regulation* and environmental *management tools* are highly relevant determining factors (Horbach, 2008).

In 2010, Braun et al. (2010) found that (eco-) innovation is strongly driven by knowledge spill-overs, especially those occurring at the national level. By investigating two major renewable energy technologies - wind and solar - across a panel of 21 OECD countries over the period 1978 to 2004, they concluded that the technologies under examination exhibit distinct innovation characteristics: both are stimulated by intra-sectoral spill-overs, but respond differently to inter-sectoral spill-overs, which are only influential in the case of wind technology. They also found that public R&D stimulates innovation, particularly in solar technologies (Braun, Schmidt-Ehmcke, & Zloczysti, 2010).

Public policy has been found to be an important determinant of innovation in general and RE innovation in particular. The importance of public policy in eco-innovation specificity is related to what is called the "double externality" problem. Eco-innovations produce two types of positive externalities, i.e. usual knowledge externalities in the research and innovation phases; and externalities in the adoption and diffusion phases due to the positive impact on the environment. The beneficial environmental impact of environmental innovations makes their diffusion always socially desirable. This implies the existence of a twofold market failure; first in the lack of incentives for firms to invest in environmental innovation since the private return on R&D in environmental technology is less than its social return, and second in the lack of incentives for that lead firms to under-invest in environmental R&D and innovation. This double source of market failure justifies the needs of policy instruments and the existence of what Rennings (2000) calls the "regulatory push-pull" effect (Oltra, 2008). The authors classified the eco-innovation determinants in three categories, *supply-side, demand-side,* and *policy-regulatory*. These are summarised below, in Table 6:

Table 6: Determinants of eco-innovation

Regulation and Policy Determinants	Implementation of environmental policy instruments: economic and regulatory instruments Existence and anticipation of environmental regulations Regulatory design: stringency, flexibility, time frame
Supply Side Determinants	Cost savings, productivity improvements Organizational innovations: environmental management systems, extended producer responsibility R&D activities Industrial relationships, supply chain pressure, networking activities
Demand Side Determinants	Environmental consciousness and consumers' preferences for environmentally friendly products Expected increase in market share or penetration of new market segments
	Source: Oltra, (2008)

Given the role and importance of public policy both in theory and the existing evidence, the benefits of measuring eco-innovation can be described as five-fold (Arundel & Kemp, 2009):

- Helping policy makers to understand, analyse, and benchmark the overall trend of eco-innovation activity (increasing, decreasing, transitions in the nature of eco-innovation such as from end-of-pipe towards cleaner production and increased recycling and reuse); as well as trends in specific product categories (such as wind turbines).
- Helping policy makers to identify drivers and barriers to eco-innovation. This information can inform the design of effective policies and framework conditions such as pollution taxes.
- Raising awareness of eco-innovation among stakeholders and encourage companies to increase eco-innovation efforts based on an analysis of the benefits for companies, sectors and nations.

- Helping society to decouple economic growth from environmental degradation.
- Making consumers aware of differences in the environmental consequences of products and life styles

2.4 Concluding Remarks

In this chapter I discussed the definition and key determinants of innovation, paying attention to at organisational and wider levels. Innovation can take place at the individual, organisational, cluster, and national levels and that these four levels are closely linked. In particular, Patel and Pavitt's (1994) have identified organisations and their competences as well as incentives as important sources of innovation. Furman, et al., (2002) have employed Porter's diamond to synthesise firm, regional (cluster) and national level determinants. Their definition of national innovative capacity helps bring together national, cluster and organisational factors. Within each level of analysis, the literature has identified key determinants, important among these being firm size, strategy, structure and competencies. Public policy was also found to be important determinant of innovation, particularly of the GPT type.

A number of studies were also surveyed that focused on the determinants of (eco-) innovation. In this case too, public policy as well as supply-side and demand-side factors were found to be important. In all the findings point to the importance of country level and technology class factors, public policy, demand and supply factors , and linkages.

In the remainder of this thesis I account for most of those key variables, at the national level (my focus in this thesis) in that I look at public policy, I employ both demand and supply side instruments and look at different country and technology related factors. I was less able to account for linkages as data on this is very limited, and is a common limitation in the literature. That said, the use of market share that shows market concentration hence, all other things being equal suggests fewer linkages, accounts to limited degree for that variable too. In line with literature, I focus on a particular type of innovation (that is innovation in RETs) and a particular type of public policy, that of industrial policy (IP) and its (demand and supply side) instruments. As already noted RE can be seen as a type of GPT and in this sense it provides an excellent context for the analysis of the idea that IP can be important in fostering RE innovation. In addition, I develop and test for a number of other important hypotheses, that have not been adequately explored in literature.

Chapter 3
Empirical Protocol and Methodology

In this chapter, I discuss the choice of methodology focusing on the empirical protocol employed in this thesis. In terms of methodology, I employed an econometric investigation. In effect this involves testing with primary or secondary data the Hypotheses developed on the basis of a conceptual framework based upon and developing extant literature. Testing the Hypotheses involves first the development of an equation (see below) and then checking if these are borne out by the data. . This involves in turn using an extant or building an appropriate data base, identifying the most likely factors that help predict changes in the dependent variable, identify best proxies for all variables, select and employ an econometric technique that is best for the purpose, identify and address any problems related to the econometric estimation, and explain and interpret the results and their limitations.

As it has already been explained, in IP there is very little econometric research. Robust econometric findings therefore can help complement and hence triangulate findings from qualitative or empirical case-based techniques.

As already noted in the case of this thesis, the key dependent variable is innovation in the RE sector (and in particular RE technologies) and the key independent variables are RE policies and RE policy instruments. Below I explain the choice of the key variables, the proxies used, the data set, and the estimating technique. Additional control variables used in various chapters are explained within the relevant chapters themselves and the same applies for the presentation and analysis of the results.

Starting with the data collection, for all variables (including the control variables) data was collected for all the OECD countries, between 1990 and 2014. The 34 OECD countries are: Australia; Austria; Belgium; Canada; Chile; Czech Republic; Denmark; Estonia; Finland;

France; Germany; Greece; Hungary; Iceland; Ireland; Israel; Italy; Japan; Korea; Luxembourg; Mexico; the Netherlands; New Zealand; Norway; Poland; Portugal; the Slovak Republic; Slovenia; Spain; Sweden; Switzerland; Turkey; the United Kingdom; and the United States. The OECD was chosen based on the diversity of the countries, and therefore the diversity of the RE policy instruments (further explained below), while including the whole EU, widely perceived as a leader in the area of RE policy making and innovation. The year 1990 was taken as the starting point of this analysis to capture the effects before and after the Kyoto Protocol signing and ratification, which initiated the redirection of innovative activities towards RE (Rawlins & Allal, 2003). The end date had to be 2014 due to data restrictions related to patenting activity (although data do exist, it takes a few years for all the filed patents to show). Therefore, as advised by the OECD (2005) I avoid the use of data for the last three years.

The resulting comprehensive data base is employed in full in Chapter 5. In Chapter 4 I commence with a subset that focuses on the leading countries in terms of public policy towards RE, namely those of the 'old' EU (the EU15). This is in order to focus on the frontier of extant practice and allow gradual comparisons. The focus on the EU 15 also restricts the years to 1995 and 2014 (the year of the 4th enlargement). Then in Chapter 5, I first employ the full sample and then use sub samples for North and South EU. This is to allow for regional variations between old and enlarged EU, between the EU and the OECD as a whole and between North and South EU countries. In chapter 6, the full sample is restricted to 24 countries because of emergent lack of data that resulted from fine tuning the data set to identify particular REP instruments and RETs (few countries had very few to permit meaningful econometric investigation).

3.1 Dependent Variable (DV): Patenting Activity on the RE Sector

A challenge in the literature is how to measure/proxy the main (dependent) variable (DV) i.e. RE innovation. Innovation can be measured both by means of input measures (such as R&D expenditure), and output (yield)-oriented measures which account for the results of the innovation process (Groba & Breitschopf, 2013). In line with the literature reviewed, most studies on this topic rely on patents as a measure of RE innovations. In this dissertation, innovation will also be measured using patent statistics related to RETs, in part because of data availability but also for reasons of comparability with other studies.

Figure 3: Overview of measures of inputs (determinants) and outputs of innovation

Measures of input (determinants)

- Dummies for specific policy implementation
- Level of energy influenced by policy
  - Energy tax level and prices
  - Emission price
- Public and private R&D spending
- Number of scientific personnel
- Strength of intellectual property protection
- Education/training expenditure
- Pollution Abatement Cost and Expenditures (PACE)

Measures of Output

- Private R&D spending
- Patent applications and citations
- Trade or market shares in R&D/knowledge-intensive industries
- Prices or cost development

Source: Groba & Breitschopf, 2013

According to OECD (2011), a patent is an intellectual property right that is related to technical inventions. It can be granted to a firm, individual or public body by a national patent office. For an application to be successful, certain criteria must be met, i.e. the novelty of the invention, being capable of industrial application as well as involving a (non-obvious) inventive step (OECD, 2001). Certain advantages and disadvantages can be identified with regards to the use of patents. In terms of advantages, patent data include disaggregated information on both the nature of the innovation and the applicant; hence, they provide alternative indicators of innovation and technology diffusion (Groba & Breitschopf, 2013). Furthermore, patents are closely related to invention while covering a broad range of technologies, often in ranges were other data sources are limited (OECD, 2001).

Although patent statistics are a very common empirical approach, they have been criticised in terms of their efficacy in proxying innovation and also for potential biases (Nelson, 2009). Nelson, in his study on assessing various measures of knowledge diffusion by comparing patent data on recombinant DNA technology, identified errors of omission and over-representation of measures, as well as potential biases (Nelson, 2009). In one of the most closely related studies to the present one by Johnstone et al (2008), the limitations of patent statistics were also highlighted. Three main issues were raised. First, that using unweighted patent counts attributes the same importance to patents that were not as successful as others. Second is the existing variation in the propensity to patent across countries and sectors as a result of the level of protection afforded by the patent, as well as the possibility of protecting monopoly rights. Third is the uncertainty of comparing information as a result of the differences in patent regimes for different countries (Johnstone et al., 2008). In addition, the various changes in the legislation of patent make it difficult to analyse trends over time.

Despite the aforementioned limitations and criticisms, patent data are the most commonly used proxy of innovation and many argue that despite limitations, they should not be dismissed as a statistical indicator (OECD, 2001; Johnstone, Haščič, & Popp, 2008; Nesta, Vona, & Nicolli, 2014; Dang & Motohashi, 2015). Importantly, Dang and Motohashi (2015) found that patent count is correlated with both R&D input and financial output, rendering patent statistics a good proxy for innovation. In addition, patents are *granted for* "inventive technologies with commercial promise" (i.e. innovation) (Smith K. , 2004, p. 159); hence, suggesting a close link with the definition of innovation. Last but not least, the availability of data, and their long history of records (patents are the only innovation indicator extending back over centuries), and the classification of technologies into a detailed and slow-to-change system (Smith K. , 2004) renders patents a suitable proxy for innovation.

I collected data from the 2016 online free version of the European Worldwide Patent Statistical Office (EPO) database (PATSTAT). In line with the extant literature (Johnstone, Haščič, & Popp, 2008; Nesta, Vona, & Nicolli, 2014) the International Patent Classification (IPC) system was used, because it allows distinguishing between inventions across different RE technological fields in Biomass, Geothermal, Hydro, Solar, and Wind. When searching for patents, there are two possible errors that can occur, i.e. the inclusion of irrelevant patents, and the exclusion of relevant ones. However, contrary to other 'environmental' technologies, RETs have the advantage to largely minimise said errors, because their definition of relevant patent classifications makes it easier to identify the relevant patents (Johnstone et al., 2008). It should be clarified that the patents used refer to electricity generation wherever that is appropriate. In some instances, there is cross-use of patented technologies in sectors other than electricity but that comes in addition to electricity and not instead of. Furthermore, in some occasions there are technologies (such as in the case of upstream biomass) where the relevant patent refers to fuel production and processing.

Patent Cooperation Treaty (PCT) patent applications in the international phase were considered and filed directly at the International Bureau of the World Intellectual Property Organisation (WIPO). Arguably, this also helps account for patents which are perceived to be more impactful, by virtue of the fact that they have been filed in multiple countries at once. The patents were assigned to a country on the basis of the address of the inventor. In the case where there were more than one assigned inventors' country addresses, the patent was attributed to both countries.. Table 8, summarises the IPC codes used in this thesis, obtained from Johnstone et al., (2008). I note that not all IPCs returned results.

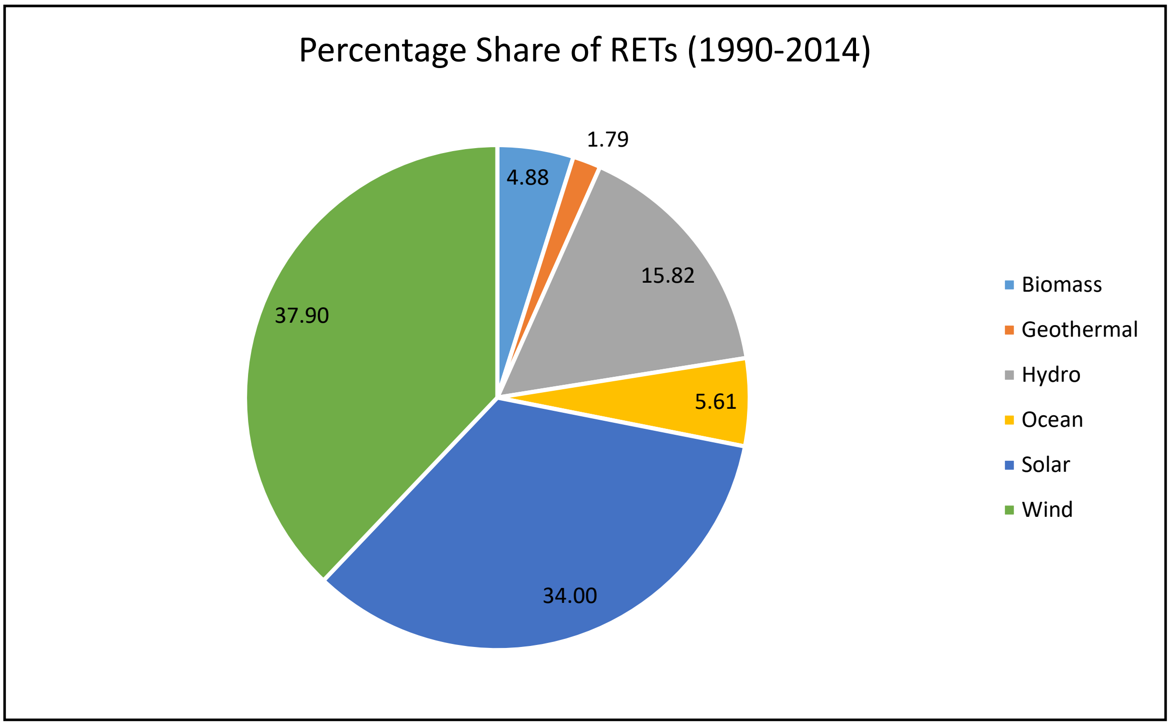
Table 7: International Patent Classes per Renewable Energy Technology

	Name	Class	Sub-Classes
WIND	Wind motors with rotation axis substantially in wind direction	F03D	1/00-06
	Wind motors with rotation axis substantially at right angle to wind direction	F03D	3/00-06
	Other wind motors	F03D	5/00-06
	Controlling wind motors	F03D	7/00-06
	Adaptations of wind motors for special use;	F03D	9/00-02
	Details, component parts, or accessories not provided for in, or of interest apart from, the other groups of this subclass	F03D	11/00-04
	Electric propulsion with power supply from force of nature, e.g. sun, wind	B60L	8/00
	Effecting propulsion by wind motors driving water-engaging propulsive elements	B63H	13/00
SOLAR	Devices for producing mechanical power from solar energy	F03G	6/00-08
	Use of solar heat, e.g. solar heat collectors	F24J	2/00-54
	Machine plant or systems using particular sources of energy -sun	F25B	27/00B
	Drying solid materials or objects by processes involving the application of heat by radiation -e.g. sun	F26B	3/28
	Semiconductor devices sensitive to infra-red radiation -including a panel or array of photoelectric cells, e.g. solar cells	H01L	31/042
	Generators in which light radiation is directly converted into electrical energy	H02N	6/00
	Aspects of roofing for the collection of energy –i.e. solar panels	E04D	13/18
	Electric propulsion with power supply from force of nature, e.g. sun, wind	B60L	8/00
GEOTHERMAL	Other production or use of heat, not derived from combustion -using natural or geothermal heat	F24J	3/00-08
	Devices for producing mechanical power from geothermal energy	F03G	4/00-06
	Electric motors using thermal effects	H02N	10/00
OCEAN	Adaptations of machines or engines for special use -characterized by using wave or tide energy	F03B	13/12-24
	Mechanical-power producing mechanisms -ocean thermal energy conversion	F03G	7/05
	Mechanical-power producing mechanisms -using pressure differentials or thermal differences	F03G	7/04
	Water wheels	F03B	7/00
BIOMASS	Solid fuels based on materials of non-mineral origin -animal or vegetable	C10L	5/42-44
	Engines operating on gaseous fuels from solid fuel -e.g. wood	F02B	43/08
	Liquid carbonaceous fuels -organic compounds	C10L	1/14
	Anion exchange -use of materials, cellulose or wood	B01J	41/16
			Source: Johnstone et al., 2008

The data obtained from PATSTAT returned a fair number of duplicates. The reason for this (in the case of this thesis) were that since divisions and country of origin were included, patents with more than one of these parameters appeared more than once. It was therefore necessary to manually remove the data obtained from PATSTAT in order to keep their unique values. I note that a patent can be filled under more than one IPC class since it can be applicable to more than one technologies and hence, appear twice (or more) with different IPCs. Such patents were included in the analysis.

3.1.1 Overview

Figure 4: Percentage Sharing of RET Patenting Activity

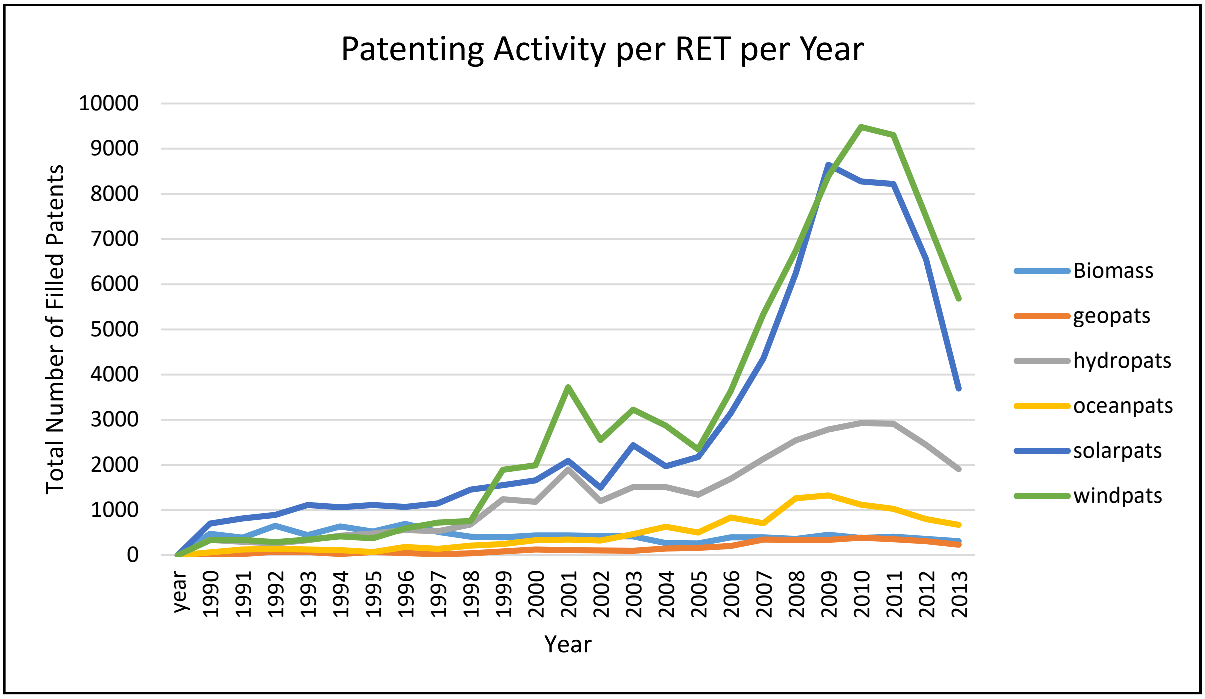


Source: Author after data from PATSTAT, 2016

A total of 217,393 patent counts were obtained from PATSTAT, using the aforementioned SQL code and IPC classes. Of these, 10,603 were filed under Biomass; 3,892 under Geothermal; 34,393 under Hydro; 12,200 under Ocean; 73,916 under Solar; and 82,389 under Wind. The percentage share of the patent activity is shown in *Figure 4*.

It can be seen that Wind technologies have the highest patenting activity (circa 38%); followed by solar (34%); hydro (circa 16%); ocean (circa 6%); biomass (circa 5%); and geothermal (circa 2%). This is not a surprise though. Hydropower, biomass, and geothermal technologies are considered "well-established" since they rely on widely used turbine systems contributing a significant share of the world's primary energy supply (IEA, 2006). This can be better seen in the graph below (Figure 5) that shows the trend of patent activity over the years under examination (1990-2014).

Figure 5: RET Patenting Activity per Year



Source: Author after data from PATSTAT, 2016

It can be seen that the patenting activity related to biomass and geothermal technologies seems to have remained constant throughout the years examined – although some increase can be seen after 2006 in the patenting activity of the geothermal technologies. This is not the case for the hydro technologies, which have been steadily increasing and peaked after 2005. Wind, has been gradually increasing after 1998, and peaked after 2005, and especially in 2010. Ocean and solar, have all both peaked after 2005 (solar), and 2007 (ocean). This has also coincided with the ratification of the Kyoto Protocol, which took place in 2005, and initiated the redirection of innovative activities towards renewables (Rawlins & Allal, 2003).

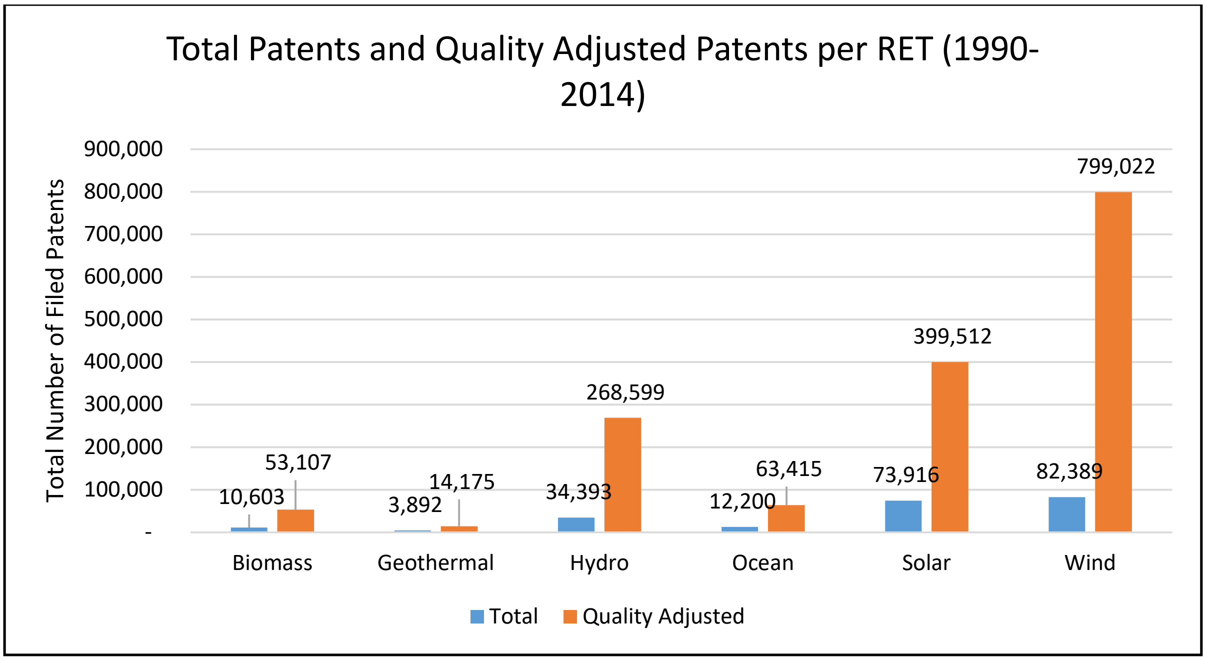
In order to avoid some of the limitations of using patents as an indicator of innovation, two additional indices were constructed by the author, one adjusting for quality, and one related to how many patents have been granted per annum and per RET. The quality adjustment indicator was given by the ratio of the citations per year for a specific patent over the total count of citations:

$$Q.A. = \frac{number\ of\ citations\ for\ a\ specific\ patent\ _{t,Te}}{total\ citations_{t,Te}}$$

Where, *t = year (1990, …, 2014);* and *Te = Technology*

This index was then divided with the number of patents per year, hence providing a better idea of the patenting activity. The following graph (Figure 6) shows the difference between the total RET patents filed, and adjusted for quality:

Figure 6: Total RET Patenting Activity and Total RET Patenting Activity Adjusted for Quality

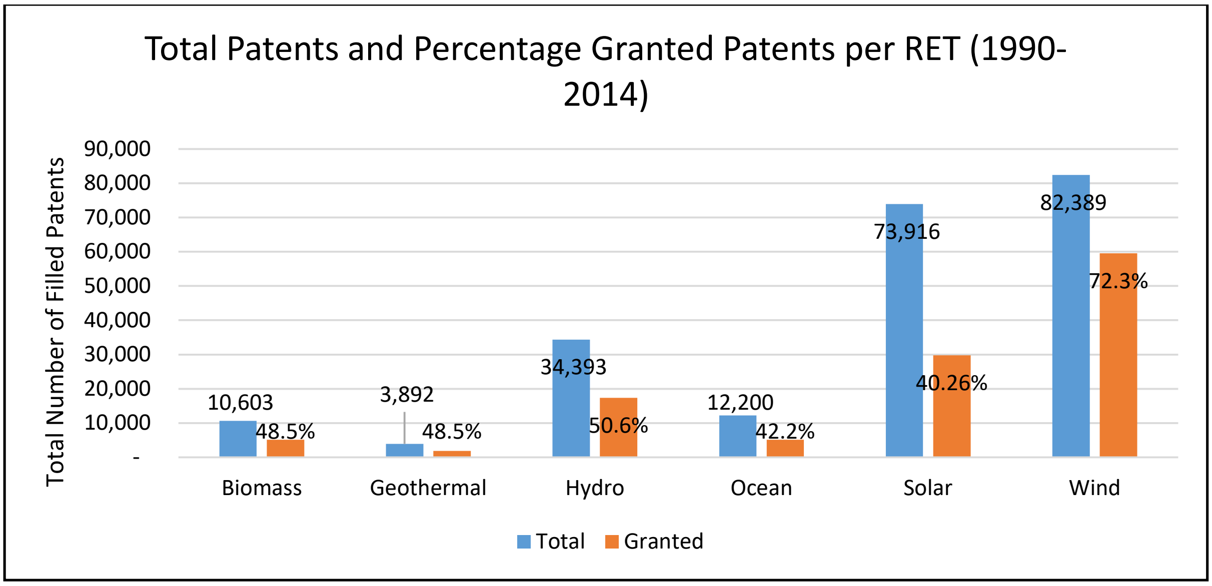


Source: Author after data from PATSTAT, 2016

When adjusting for quality, the distribution of patenting activity per RET remains the same, however, it can be seen that the resulting amount indicates the patenting quality of some RETs is better than others. This is especially the case for hydro, solar, and wind.

The second indicator, related to the patents that were granted, was constructed using data extracted from PATSTAT and relates to the patents that were granted per RET per year. Not all filed patents are getting granted, and not all granted patents get citations, thus the two indicators cannot be used in conjunction. The following graph (Figure 7) shows the total number of patents filed, as well as the total number of patents granted, and their percentage.

Figure 7: Total patents and percentage granted per RET between 1990-2014



Source: Author

Once again, wind technologies have the highest potential of being granted, with 72.3% of the total filed patents having been granted. This is followed by geothermal, as one may have expected, biomass, ocean, and finally solar, with the lowest percentage. Arguably this is because wind is one the earliest RETs (first generations) while at the same time, some mechanical parts can be used for other purposes (e.g. rotors), while solar is a relatively new RET, with high potential for emerging inventors (as seen from the total patents filed – second to wind technologies). Finally, of the total patents filed across all RETs, only 54.7% was granted, as seen in the following table (Table 9) that summarises the overview of the total patenting activity:

Table 8: Summary of Patenting Activity per RET and Total

RET	Total Patents Filed	Percentage of Total	Quality Adjusted (QA)	% of Total QA	Total Patents Granted	% of Total Granted	% that was Granted
Biomass	10603	4.88	53107	3.32	5140	4.33	48.48
Geothermal	3892	1.79	14175	0.89	1889	1.59	48.54
Hydro	34393	15.82	268599	16.81	17353	14.60	50.46
Ocean	12200	5.61	63415	3.97	5148	4.33	42.2
Solar	73916	34.00	399512	25.00	29763	25.05	40.27
Wind	82389	37.90	799022	50.01	59524	50.10	72.25
Total	**217393**		**1597831**		**118817**		**54.66**
Source: Author							

The data collected were further classified based on the RET, the country, and the year, as presented below.

3.1.2 Biomass

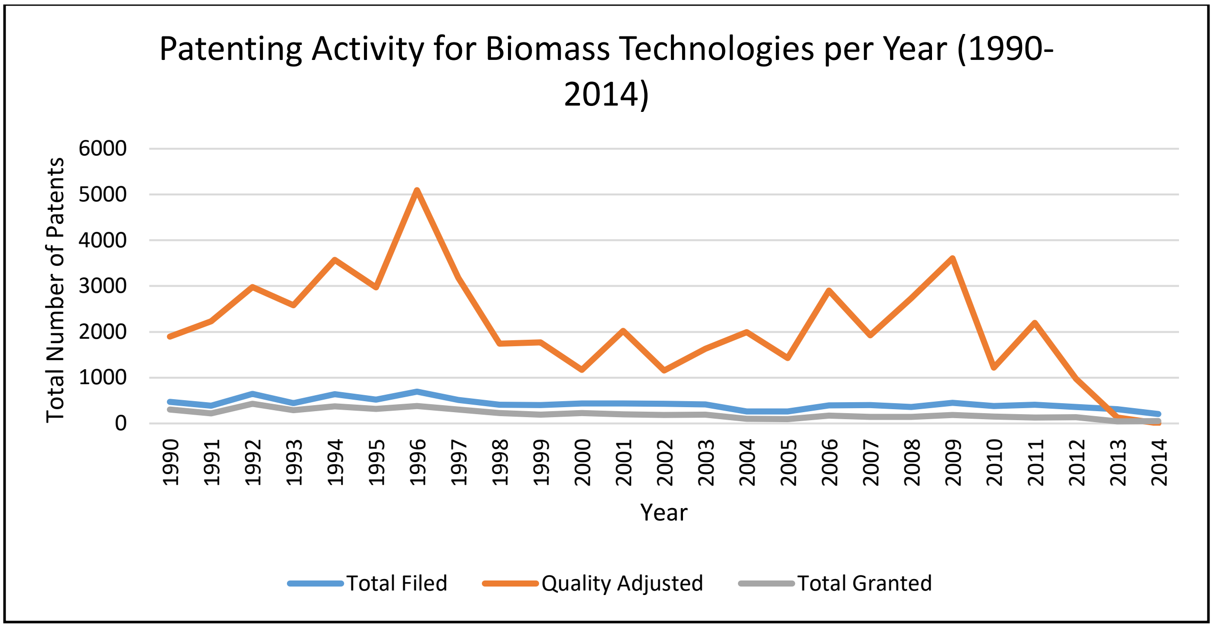
The aforementioned IPC codes resulted in a total of 10,603 filed patents related to biomass technologies. The three countries with the highest patenting activity were the United States with a total 3,860 patents filed between 1990 and 2014, followed by Germany with 1,921 patents, and the United Kingdom with 1,603. However, the number drastically decreases immediately after with France ranking fourth with only 472 patents, and Turkey, Chile, and Slovenia being the last three with 6, 4, and 3 patents respectively throughout the years examined. As it can be seen in Table 10, the first three countries account for almost 70% of the total patenting activity among all 34 OECD members.

When adjusted for their quality, the top three countries remain the same and in the same order, however, following these, the ranking changes, with Netherlands being now ranked in the fourth place, France being sixth after Korea, and the last three being Slovenia, Chile, and Latvia with 0 quality adjusted patents. The same is the case when taking into consideration the patents granted; the first three countries are the same, but the last three are now Israel, Slovenia, and Chile.

When examining the time trend (Figure 8), it can be seen that for the total filed and the total granted patents are almost identical, and relatively smooth, with no peaks, but slightly declining. This implies that most of the filed patents were granted and it is also evident from examining the actual data; there were a total of 470 patents filed in 1990, of which 300 were granted, the highest patenting activity took place in 1996 with 693 filed patents of which 377 were granted, and gradually decreased following, to 205 total filed patents in 2014 of which only 52 were granted.

The quality adjusted time trend (Figure 8) shows a different story: the quality of the patents was steadily increasing from 1990 until 1996 when it peaked, but gradually decreased following that and until 2002. It started to increase again after 2002, with fluctuations until 2009, when it drastically declined, having 0 quality patents in 2014.

Figure 8: Patenting Activity for Biomass Technologies per Year (1990-2014)



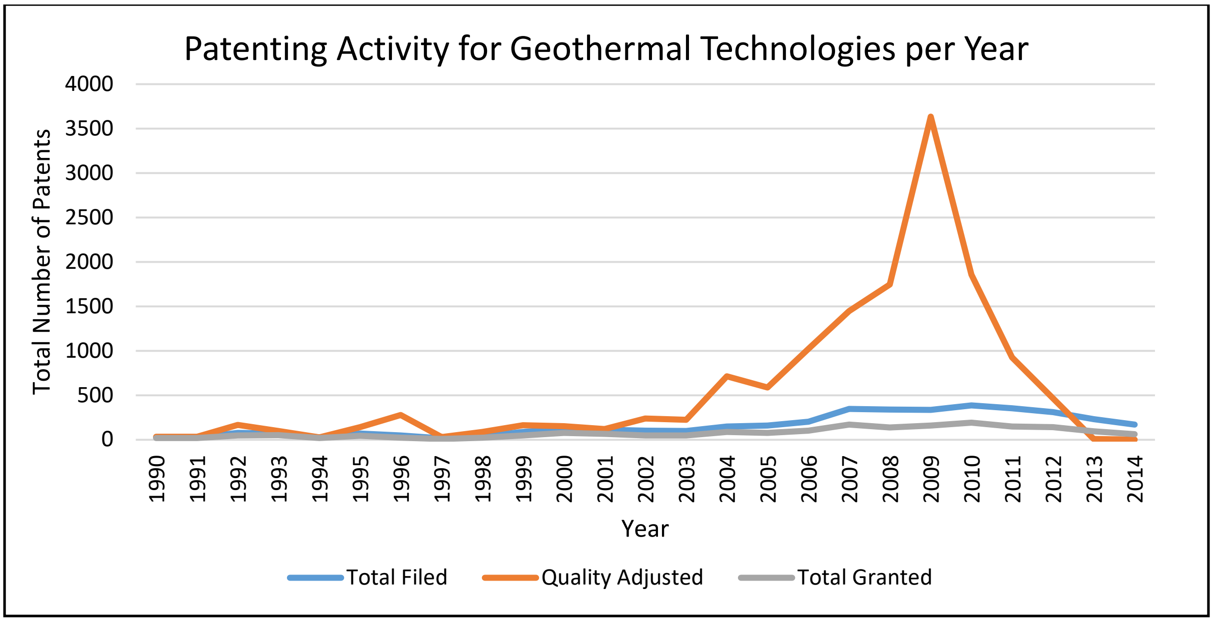
Source: Author

3.1.3 Geothermal

The aforementioned IPC codes resulted in a total of 3,892 filed patents related to geothermal technologies. The three countries with the highest patenting activity were again the United States with a total 1,006 patents filed between 1990 and 2014, followed by Germany with 691 patents, and Korea with 657. Similarly, to biomass technologies the number drastically decreases immediately after with Japan and Switzerland ranking fourth with only 174 patents each, and Portugal, Mexico, and Slovenia being the last three with 1, 0, and 0 patents respectively throughout the years examined. As it can be seen in Table 10 the first three countries account for almost 60% of the total patenting activity among all 34 OECD members.

When adjusted for their quality (Figure 9), the top three countries remain the same and in the same order like in the case of biomass, however, after these, the ranking does not change, and the last three remain the same all with 0 quality adjusted patents (the last six countries all have 0 quality patents). When taking into consideration the patents granted the order changes. Although the United States remains in the first place with a total of 470 out of the 1,006 filed patents having been granted, Korea takes the lead with 456 out of 657 filed patents having been granted, followed by Germany with 298 out of 691 having been granted. Portugal having its one patent filed granted, is not among the last three, but Chile is.

Figure 9: Patenting Activity for Geothermal Technologies per Year (1990-2014)



Source: Author

When examining the time trend (Figure 9), it can be seen that the total number of filed patents related to geothermal technologies, along with the quality adjusted, and the granted patents per year, are almost collinear, implying that most of the patents filed were granted, and of high quality. This is also evident from examining the data, with 17 patents being granted out of 27 filed in 1990, peaking in 2010 with 189 granted patents out of the 385, before dropping to 170 in 2014, with 61 having been granted. It can be seen that between 2003 and 2009, the quality of the patents drastically increased, but declined equally drastically after that year.

3.1.4 Hydro

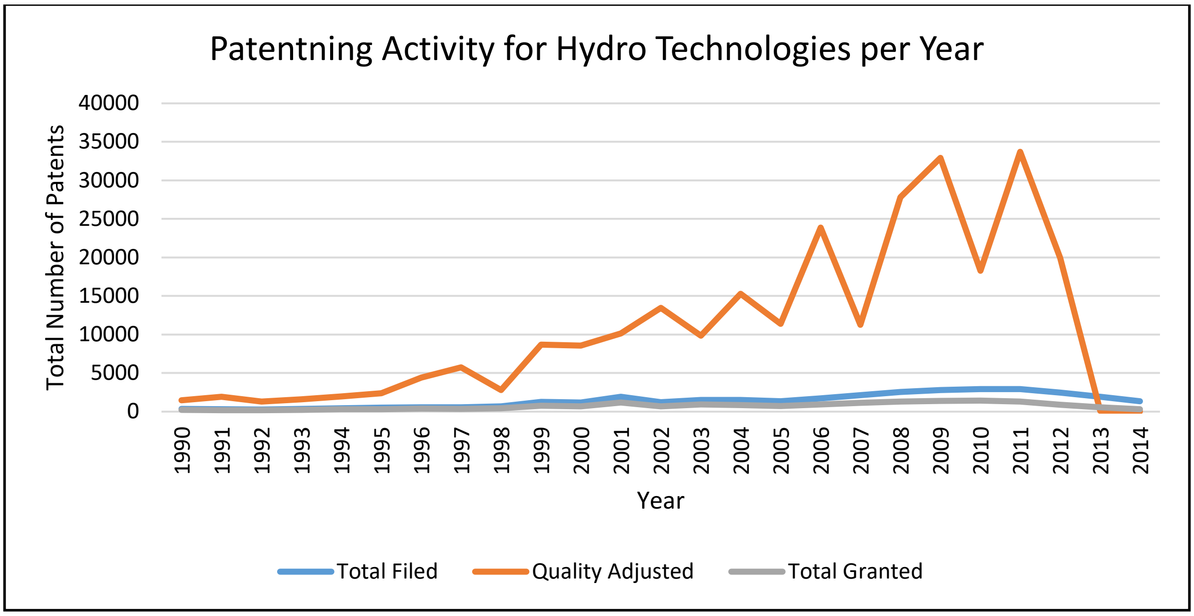
The aforementioned IPC codes resulted in a total of 34,393 filed patents related to hydro technologies. The three countries with the highest patenting activity were again the United States with a total of 8,486 patents filed between 1990 and 2014, followed by Germany with 7,290 patents, and Korea with 3,266. Contrary to the previous technologies the number decreases smoothly, with Japan ranking fourth with 2,973 patents, and the United Kingdom ranking fifth with 1,796. The countries with the lowest patenting activity are New Zealand with

31, Estonia with 28, and Slovenia being the last with 24, throughout the years examined. As it can be seen in Table 10 the first three countries account for almost 55% of the total patenting activity among all OECD members.

When adjusted for their quality, the top three countries remain the same but not in the same order with Germany having better quality patents, followed by the United States and Korea. Similarly, New Zealand and Estonia, are no longer on the bottom, meaning despite having the least patent counts, these are of better quality. The lowest ranking countries are now Turkey with 11 quality patents, Slovenia with 9, and Latvia with 5. Regarding the granted patents, the top-ranking countries are the same, with the United Sates having 4,639 granted patents, Germany 3,572, and Korea 1,697. That is not the case for the low-ranking countries though, with bottom three now being Chile with 12 out of 43 having been granted, New Zealand with 9 out of 31, and Mexico with 8 out of 55.

When examining the time trend (Figure 10), it can be seen that the total number of filed patents related to hydro technologies, along with the granted patents per year, are almost collinear, implying that most of the patents filed were granted. Indeed, circa 50% of the patents filed were granted, the highest percentage after wing technologies (see Table 9). Their quality, despite the fluctuations, constantly increases, especially after 1999, until its peak in 2012 when it radically decreases.

Figure 10: Patenting Activity for Hydro Technologies per Year (1990-2014)



Source: Author

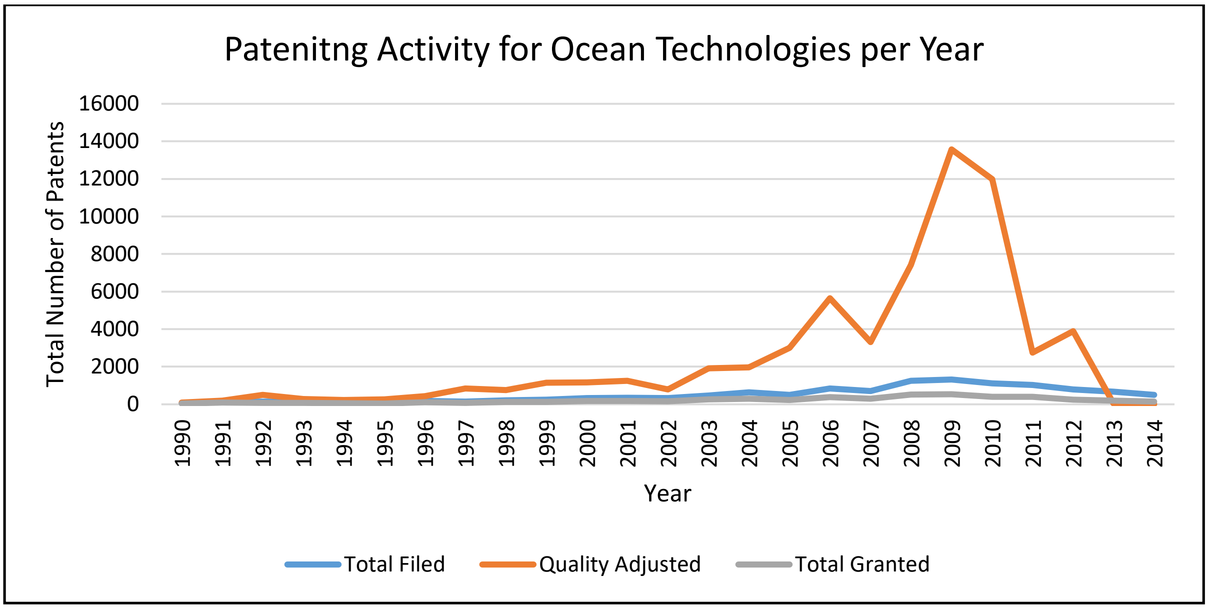
3.1.5 Ocean

With regards to the Ocean technologies, the aforementioned IPC codes resulted in a total of 12,200 patent counts. Once again, the United States have the highest patenting activity, with 2,538 total filed patents, followed by Korea with 2,114, and the United Kingdom with 1,223. As with the hydro technologies, the rest of patenting activity decreases gradually, with the last three countries being Latvia with 11 counts, Slovenia with 5, and Luxembourg with 3. As it can be seen in Table 10, the first three countries account for almost 48% of the total patenting activity among all OECD members.

When adjusted for their quality, the order changes, with Korea producing patents of the highest quality, followed by the United States, and Germany, while the United Kingdom is now fourth. Latvia and Luxembourg are also producing patents of the lowest quality, but second to last is now Hungary instead of Slovenia. Regarding the granted patents, the top-ranking countries are the same, with the United States having 1,243 granted patents, Korea 846, and the United Kingdom 513. That is not the case for the low-ranking countries though, with the bottom three now being Hungary with 2 out of 15 having been granted, Mexico with 0 out of 71, and Luxembourg with 0 out of 3.

When examining the time trend (Figure 11), it can be seen that the total number of filed patents related to ocean technologies, along with the granted patents per year, are almost collinear, especially until 2007. Circa 40% of the patents filed were granted (see Table 9). In terms of their quality, despite the fluctuations, it constantly increases, especially after 2002, until its peak in 2009 when it decreases again.

Figure 11: Patenting Activity for Ocean Technologies per Year (1990-2014)



Source: Author

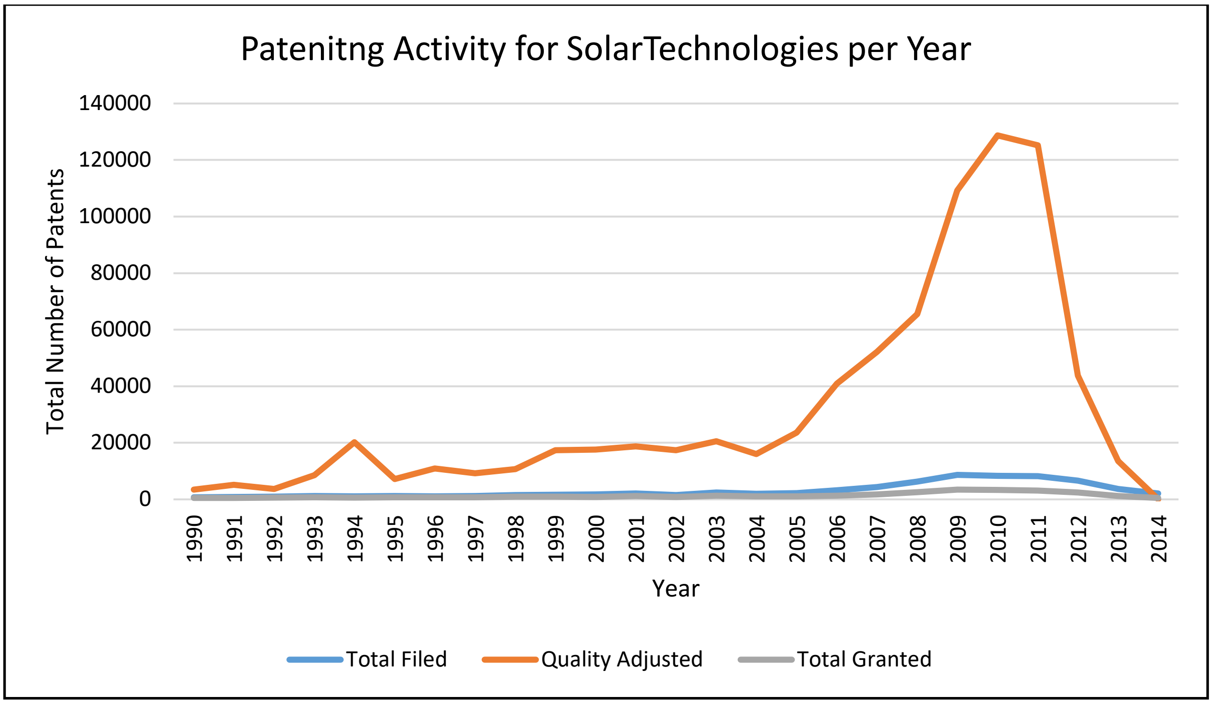
3.1.6 Solar

Regarding the Solar technologies, the aforementioned IPC codes resulted in a total of 73,916 patent counts. Again, the United States have the highest patenting activity, with 15,759 total filed patents, followed by Germany with 15,399, and Korea with 8,825. As with the previous technologies, the rest of patenting activity decreases gradually, with the three countries with the least counts being Chile with 54 counts, Estonia with 22, and Latvia with 17. As it can be seen in Table 10, the first three countries account for 54% of the total patenting activity among all members, and if Japan is included, that ranks fourth with 7,464 solar patent counts, the percentage increases by 10% to 64%. The lowest ranking countries are Chile with 54 counts, Estonia with 22, and Latvia with 17.

When adjusted for their quality, the order changes, with Germany topping the list, followed by the United States, and Korea. The aforementioned countries with the lowest patenting activity also have the lowest quality. Regarding the granted patents, the top-ranking countries are the same, with Germany having 6,918 granted patents, the United Sates 6,478, and Korea 4,936. Similarly, for the case for the low-ranking countries, Latvia has 16 granted patents, Estonia 15, and Chile 7.

When examining the time trend (Figure 12), it can be seen that the total number of filed patents related to solar technologies, along with the granted ones per year, are almost collinear, especially until 2007. Circa 40% of the patents filed were granted (see Table 9). In terms of their quality, despite the fluctuations, it constantly increases, especially after 2004, until its peak in 2010 when it decreases again.

Figure 12: Patenting Activity for Solar Technologies per Year (1990-2014)



Source: Author

3.1.7 Wind

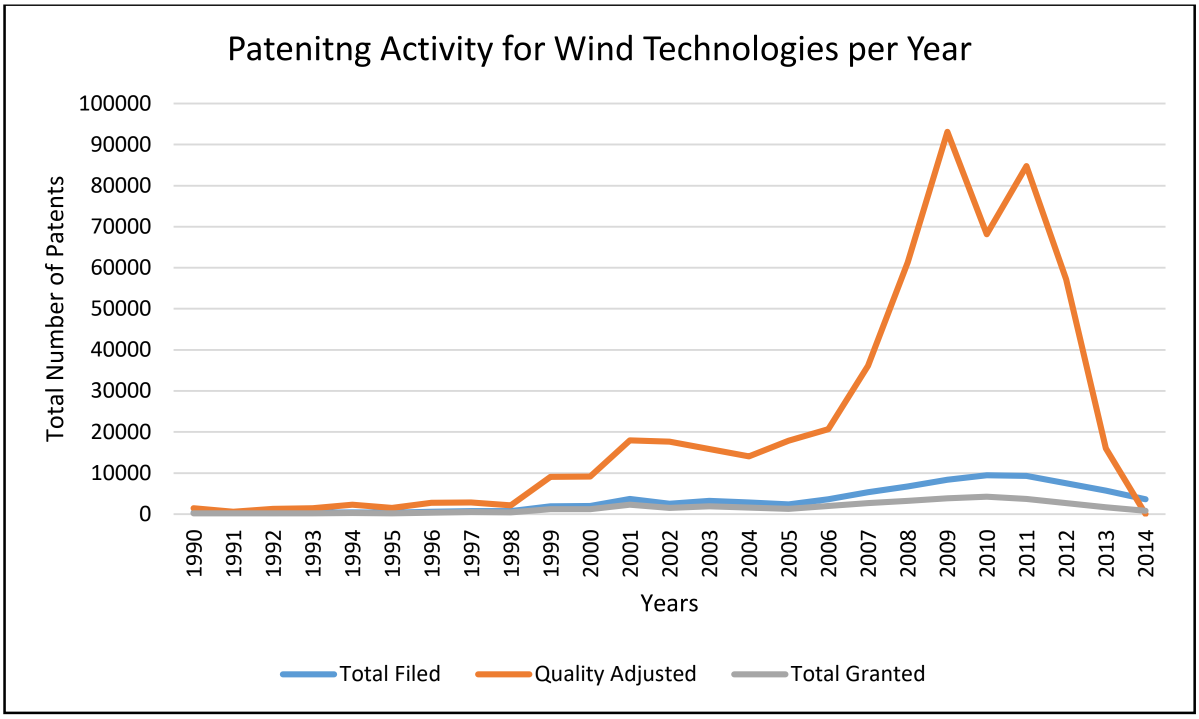
Finally, regarding the Wind technologies, the aforementioned IPC codes resulted in a total of 82,389 patent counts. In this case, Germany has filed for the most patents, with a total of 22,788 counts, by the United States with 13,626, and Denmark with 9,462. These countries account for circa 56% of the total patenting activity, while if Korea is added (ranking fourth after Denmark) this increases to almost 67% (see *Table 10*). Following the first four countries, the patenting activity drastically drops, much like in the case of Biomass activity, with the three countries with the least counts being Estonia with 58 counts, Slovenia with 25, and Chile with 19.

When adjusted for their quality, Germany remains in the first place in producing patents of the highest quality, followed by the United States, and Korea instead of Denmark, which now ranks fourth. The countries with the lowest patenting activity also have the lowest quality, but with Poland taking the place of Estonia in the last place, with 0 quality patents out of the 1,014.

Regarding the granted patents, the top-ranking countries are the same as with when adjusted for quality, with Germany having 11,307 granted patents, the United Sates 6,435, and Korea 4,803. The last three countries, however, are now New Zealand with 17 granted patents out of 95, Mexico with 16 out of 84, and Chile with 6 out of 19.

When examining the time trend (Figure 13), it can be seen that the total number of filed patents related to wind technologies, along with the granted ones per year, are again almost collinear, especially until 2007 implying that most of the patents filed were granted. Indeed, circa 72% of the patents filed were granted (see Table 9). In terms of their quality, despite the fluctuations, it constantly increases, especially after 1998, until its peak in 2009 when it decreases again.

Figure 13: Patenting Activity for Wind Technologies per Year (1990-2014)



Source: Author

Table 9: Percentage share per country and per technology

Country	Biomass	Geothermal	Hydro	Ocean	Solar	Wind
Australia	0.42	1.23	1.27	3.47	2.52	0.67
Austria	1.25	2.03	1.91	0.43	2.10	1.03
Belgium	0.96	0.15	0.32	0.17	0.68	0.71
Canada	1.35	4.32	3.11	3.28	2.04	1.74
Chile	0.04	0.05	0.13	0.39	0.07	0.02
Czech Republic	1.38	1.05	0.60	0.44	0.61	0.21
Denmark	0.25	0.10	4.01	2.28	0.63	**11.48**
Estonia	0.10	0.28	0.08	0.14	0.03	0.07
Finland	0.94	1.05	0.41	1.82	0.42	0.56
France	4.45	3.88	4.18	4.75	6.11	2.91
Germany	**18.12**	**17.75**	**21.20**	8.07	**20.83**	**27.66**
Greece	0.35	0.15	0.24	0.70	0.44	0.30
Hungary	0.31	0.59	0.21	0.12	0.48	0.24
Ireland	0.43	0.13	0.59	1.77	0.28	0.20
Israël	0.08	2.06	0.62	1.16	1.60	0.32
Italy	1.37	1.13	2.00	2.14	2.44	1.59
Japan	2.90	4.47	8.64	3.39	10.10	5.90
Korea	3.66	**16.88**	**9.50**	**17.33**	**11.94**	11.00
Latvia	0.07	0.08	0.15	0.09	0.02	0.22
Luxembourg	0.07	0.03	0.40	0.02	0.23	0.29
Mexico	0.15	0.00	0.16	0.58	0.30	0.10
Netherlands	4.23	1.77	1.69	1.62	1.78	2.09
New Zealand	0.18	0.13	0.09	0.21	0.20	0.12
Norway	0.55	1.44	1.54	4.38	0.57	1.32
Poland	1.16	1.98	0.90	0.72	0.70	1.23
Portugal	0.07	0.03	0.15	0.98	0.24	0.18
Slovak Republic	0.10	0.21	0.28	0.16	0.16	0.11
Slovenia	0.03	0.00	0.07	0.04	0.09	0.03
Spain	0.50	0.87	1.90	3.74	4.12	3.96
Sweden	1.33	2.93	1.84	2.92	0.76	1.55
Switzerland	1.63	4.47	1.70	1.28	3.19	0.80
Turkey	0.06	0.15	0.24	0.60	0.47	0.21
United Kingdom	**15.12**	2.75	5.22	**10.02**	2.52	4.63
United States	**36.40**	**25.85**	**24.67**	**20.80**	**21.32**	**16.54**

Note: *In bold, the three countries with the higher percentage share per technology*

Source: Author

3.1.8 Summary

Overall, it can be seen that the United States, Germany, Korea, and the United Kingdom are ranked in the top places regardless of the nature of the technologies and the same countries are while Latvia, Slovenia, and Estonia occupy the bottom of the rankings. Reasons that may help explain this include RD&D budget allocations towards RETs, the overall patenting activity, as well as the overall economic state of the countries. An additional reason, which is also the focus of this thesis, is the extent to which the existence or not, of public industrial policy instruments may foster the innovative activity of a country. The following sub-chapter will present the data collected related to public policy instruments, for the same countries, and for the same time span.

3.2 Independent Variable (IV): RE Policy (and Policy) Instruments

As mentioned in Chapter 2, public industrial policy has been found to be an important determinant of innovation and particularly for RE. Given their importance, and for the purposes of this thesis, three key groups of policy instruments were selected to be the independent variable. Using the International Energy Agency (IEA)/International Renewable Energy Agency (IRENA) Joint Policies and Measures Database (IEA/IRENA, 2014), an advanced search was performed with the specifications presented in Table 11, for 34 countries and between 1990-2014. This resulted in a total of 226 policy instruments operated that relate to the RE in the electricity sector, the focus of this thesis. Table 11 summarises the specifications used in order to extract the relevant REPs from the IEA/IRENA (2014) database.

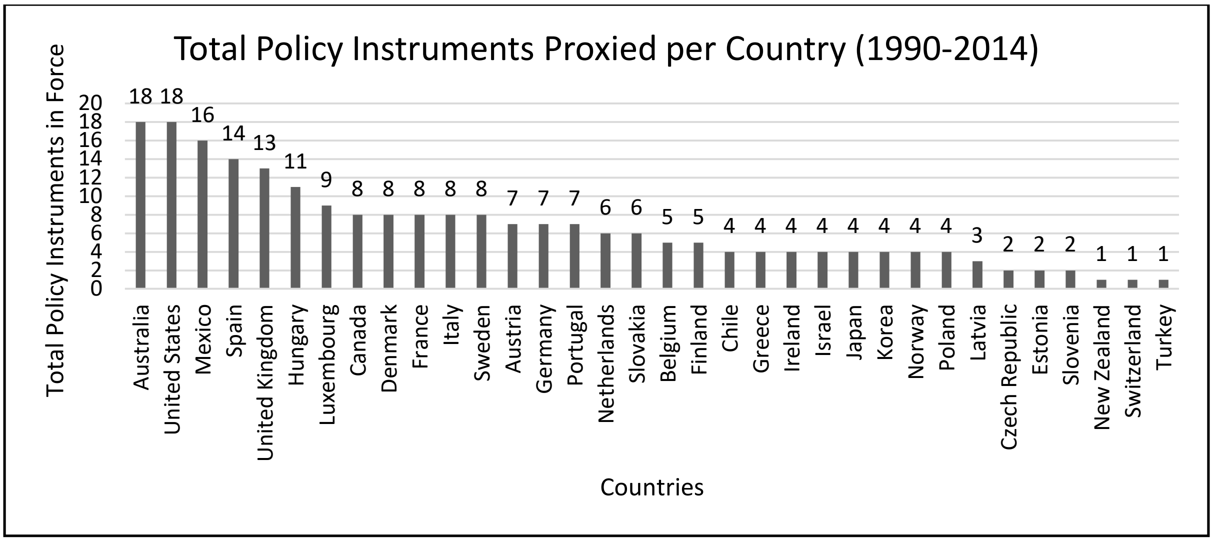
Table 10: Specifications of the Renewable Energy Policies

Country	OECD Countries
Policy Type	Economic Instruments
	Policy Support
	Regulatory Instruments
	Research, Development and Deployment (RD&D)
Renewable Energy Policy Target	Bioenergy
	Geothermal
	Multiple Renewable Energy Sources
	Hydropower
	Ocean
	Solar
	Wind
Sector	Electricity
Effective between	1990-2014
Jurisdiction	National
Policy Status	Ended
	In Force
	Planned
	Superseded
Size Plant	Large
	Small
	Source: Author after IEA/IRENA, 2014

Figure 14 shows the total number of policy instruments per country for the years under examination. It can be seen that, Australia and the United States have had the most policy instruments introduced throughout the time span examined (18 each), followed by Mexico (16). Switzerland and Turkey have had only one policy instrument each between the aforementioned years. From the total policy instruments introduced, not all were in force throughout the years examined. For this reason, data on policies were proxied depending on the total number of instruments in force per year and per country, as shown below:

$$IV \begin{cases} 0 = no\ instruments\ in\ force \\ 1 = one\ instrument\ in\ force \\ 2 = two\ instruments\ in\ force \\ 3 = three\ instruments\ in\ force \\ \dots \\ n = n\ instruments\ in\ force \end{cases}$$

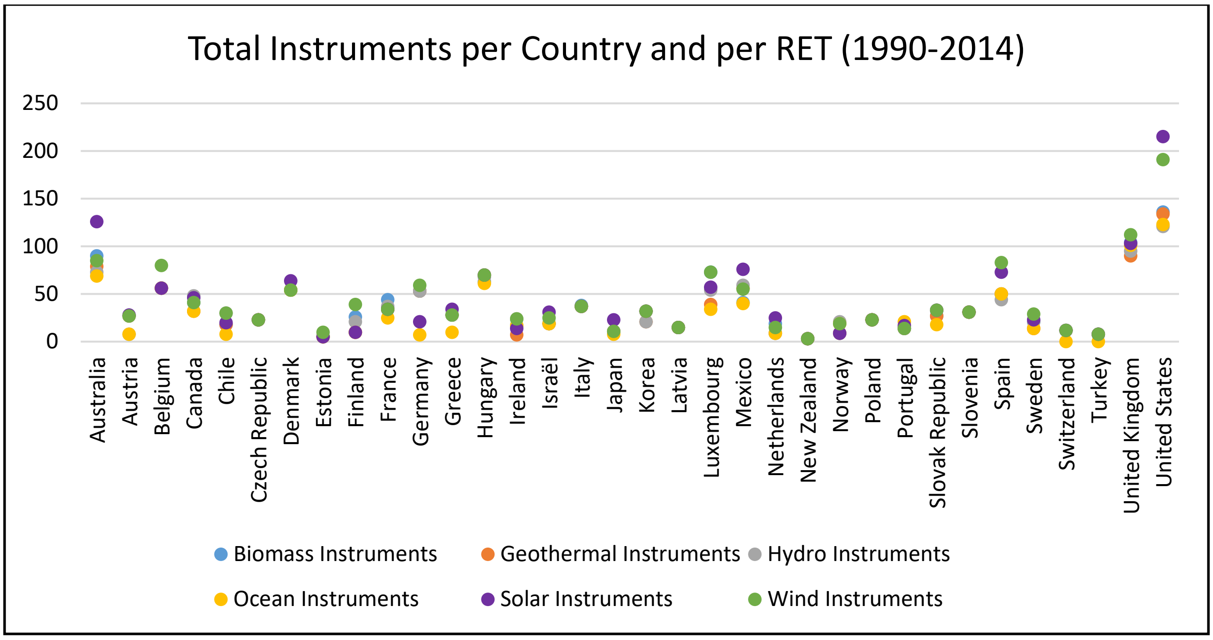
Figure 14: Total Policy Instruments Proxied per Country between 1990 and 2014



Source: Author

Secondly, not all instruments target all, or the same RETs. Therefore, the aforementioned policies were further classified depending on the technology they are targeting, resulting in six categories, one for each technology (biomass, geothermal, hydro, ocean, solar, and wind). In the case were one instrument was targeting more than one RET, this was attributed to both (or more). Based on the above two, the following graph summarizes the total instruments per country and per RET proxied:

Figure 15: Total Instruments per Country and per RET between 1990 and 2014



Source: Author

As noted in Chapter 2, there is not a uniform classification of instruments types. This is problematic in that it renders findings from different studies that use different classifications difficult to compare[4]. Drawing on earlier work on innovation, (see for example Rosenberg, 1974; Nelson, 2009; and Nemet, 2009), Rogge & Reichardt (2016) have emphasised the importance of a consistent terminology and went on to propose that in terms of purpose served, three types of instruments help provide a comprehensive classification that also aids comparability of results. These are technology-push, demand-pull, and systemic instruments (Rogge & Reichardt, 2016).

[4] For example, Johnstone et al. (2008), as well as Nesta et al. (2014) distinguished instruments in R&D; investment incentives; tax incentives; tariff incentives; voluntary programs; obligations; and, tradable certificates (Johnstone, Haščič, & Popp, 2008; Nesta, Vona, & Nicolli, 2014). Marques et al. (2013), classified instruments in terms of education and outreach, financial incentives - subsidies, policy processes, public investment, R&D, regulatory, tradable permits, and voluntary agreements (Marques & Fuinhas, 2012). Mabee and Saddler (2007), identified five groups, being feed-in tariffs, green certificates, tendering systems, and tax and investment incentives (Mabee & Saddler, 2007). Kim et al., (2015), distinguished instruments in public R&D, tariff incentives, renewables obligation, environmental taxes, and public investment (Kim K. & Kim, 2015). Few studies have distinguished among demand-pull and technology-push (Horbach, Rammer, & Rennings, Determinants of eco-innovations by type of environmental impact - The role of regulatory push/pull, technology push and market pull, 2012; Costantini, Crespi, Martini, & Pennacchio, 2015; Guerzoni & Raiteri, 2015) with later work adding systemic instruments as well (Cantner, Graf, Herrmann, & Kalthaus, 2016).

Technology-push are policy instruments aiming to foster technological change in RE from the supply side (the innovators), while demand side policies aim to foster RE innovation by increasing the demand for it (Nemet, 2009). Examples of technology-push include government-sponsored R&D and tax credits for companies to invest in R&D. Proponents of technology-push assume that advances in scientific understanding determine the rate and direction of innovation. This has been criticised in terms of ignoring changes in economic conditions (e.g. prices) that affect the profitability of an innovation, as well as ignoring feedback within the stages of the innovation process (Nemet, 2009). In addition, the technology-push idea has been argued to be dependent on the exploitable “technological opportunities” and the “strength of science’’ in each sector (Rosenberg, 1974; Klevorick, et al., 1995; Nelson A. J., 2009). Moreover, firms need to invest in scientific knowledge in order to develop their “capacity to absorb”[5] knowledge and leverage the opportunities that emerge from advanced technologies (Rosenberg, 1990; Cohen & Levinthal, 1990; Nemet, 2009). As a result, it has been argued that the instruments promoting technology-push are unlikely to be as effective as demand-pull ones and they should be considered a complement to demand-pull instruments (Nemet, 2009; Mazzucato, 2013).

The demand-pull perspective sees demand as a driver of the rate and direction of innovation, arguing that demand factors increase the market for and improve the incentive of firms to innovate. Examples of demand-pull instruments include tax credits and rebates for consumers of new technologies and taxes on competing technologies. In the absence of interactions, one could expect demand-side instruments to exert a stronger influence on RE innovation than technology-push ones (Nelson A. J., 2009)[6].

[5] Absorptive capacity is defined as “an ability to recognize the value of new information, assimilate it, and apply it to commercial ends” (Cohen & Levinthal, 1990, p. 128), and it depends on prior related knowledge and diversity of background.

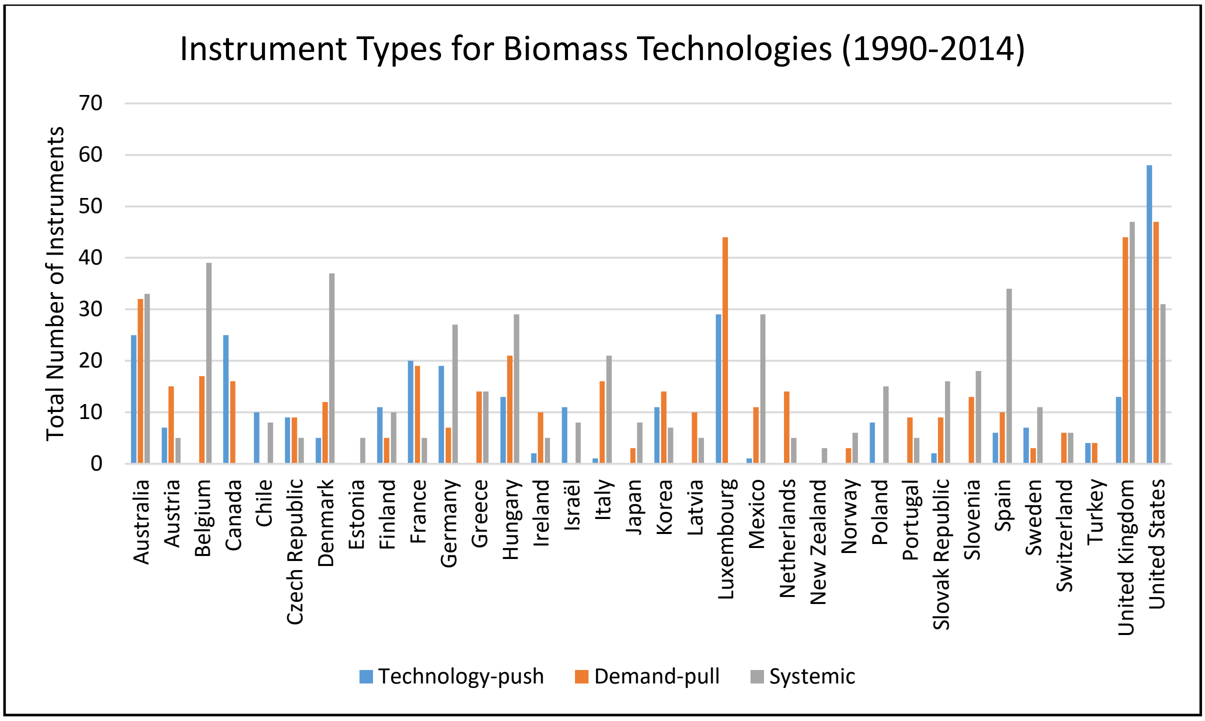
[6] Nelson (2009) in his study concluded that “the array of demand-side policies that stimulated several billions of dollars of investment in wind power projects does not appear to have had any positive effects on invention of valuable wind power

Smits et al., (2004) have argued that systemic instruments act at the level of the innovation system as a whole instead of specific parts of innovation systems. Their aim is to align the instrument mix to the needs of the actors involved. They aim to promote collaboration and knowledge transfer, like for example cooperative R&D programs, and clusters or infrastructure provisions (Smiths & Kuhlmann, 2004). Some previous scholars have seen systemic instruments as novel means that can stimulate technological innovation for sustainability (Smiths & Kuhlmann, 2004; Wieczorek & Hekkert, 2012).

Based on the above, policy instruments were classified into the aforementioned three main categories, by systematically reviewing the descriptions of each individual policy, in accordance to the examples provided in the literature (see Rogge and Reichardt, (2016, d Groba & Breitschopf, 2013). This description of the policy was provided by the IEA database, and in the few cases where it was not, related literature was consulted – mainly the original policy documents. This resulted in 18 total categories, three instrument types, for each one of the six RETs. The following graphs summarise the findings on an aggregated annual level, per country and per RET.

patents" (Nelson A. J., 2009, p. 705). This highlights the need to analyse both the aggregate and more specific RET-related relationships.

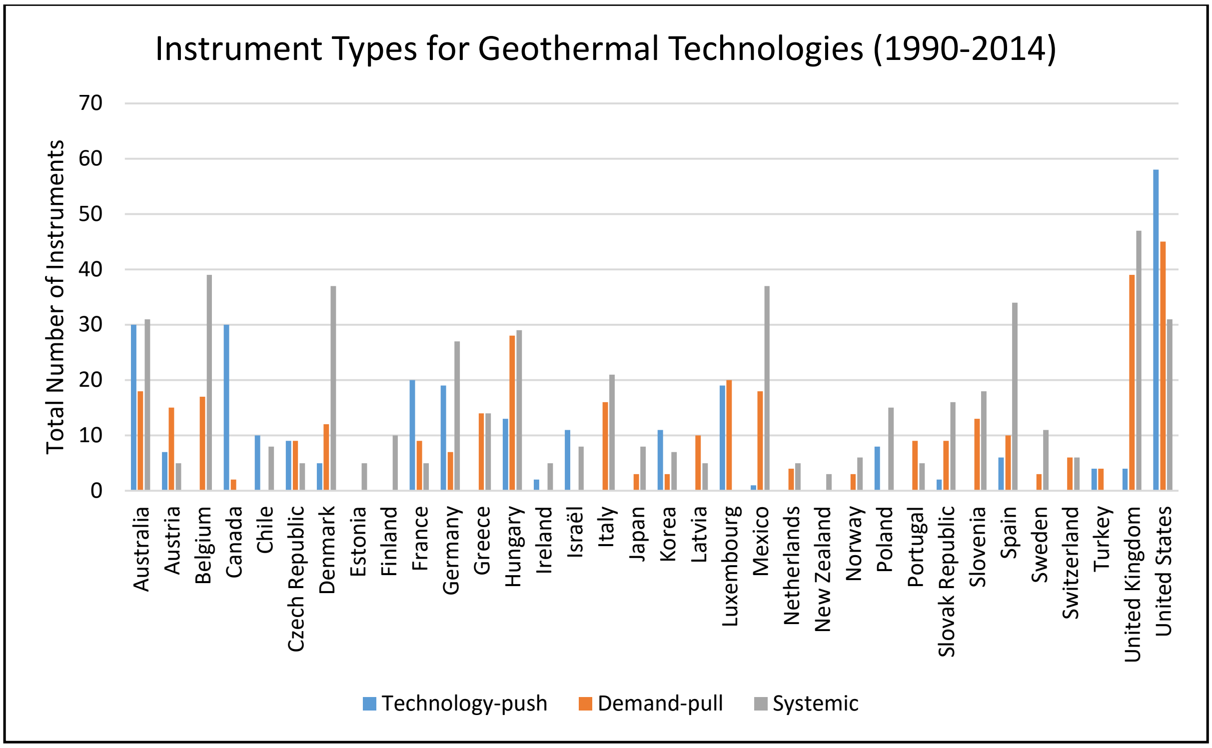
Figure 16: Instrument Types for Biomass Technologies (1990-2014)



Source: Author

Regarding the biomass technologies (Figure 16), a total of 297 technology-push instruments have been in force throughout the years examined, 437 demand-pulls, and 497 systemic ones. In biomass, demand-pull instruments dominate technology-push ones. This makes sense, as biomass is a first-generation RET, which means that advances in its technology are more difficult since its progress is really all about coal-substitution in solid-fuel fired power stations. As a result, governments try to increase the demand for it. For example in the EU biomass is considered a renewable energy source and it is used to extend the life-span of older coal-fired power stations (Pérez-Jeldres, et al., 2017). The practice is not without controversy for a range of broader sustainability issues related to biomass substitution in nature and harmful combustion emissions (The Guardian, 2017).

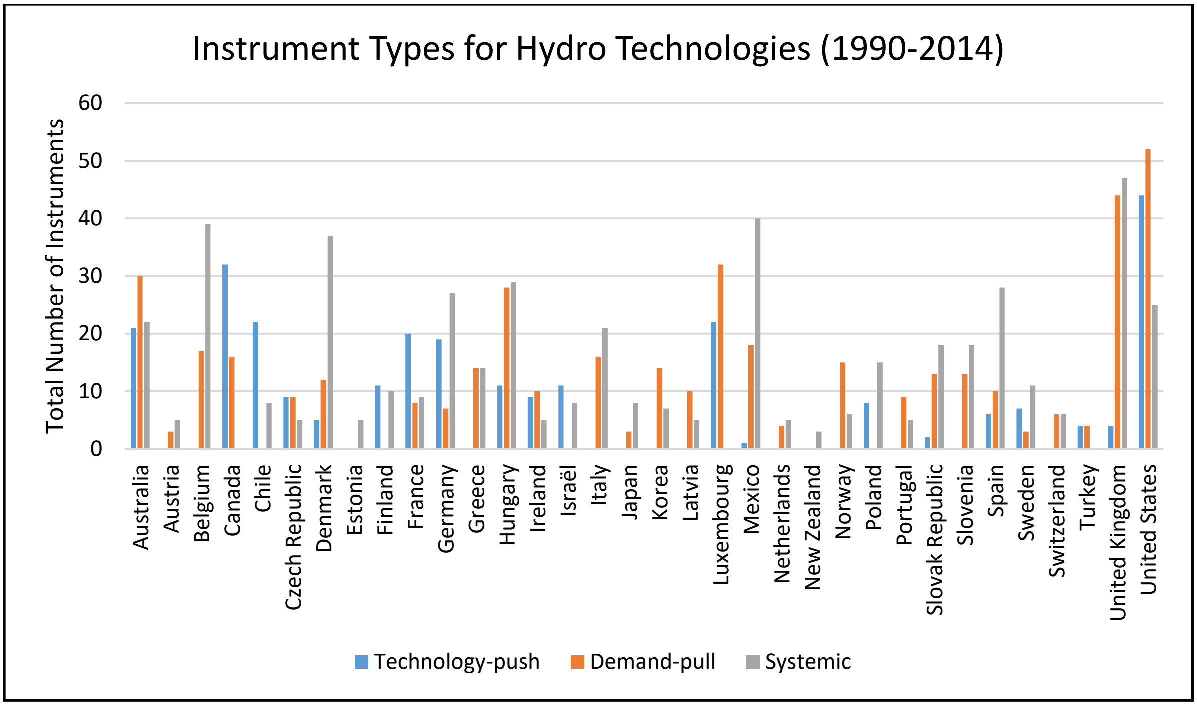
Figure 17: Instrument Types for Geothermal Technologies (1990-2014)



Source: Author

When it comes to geothermal technologies (Figure 17), a total of 269 technology-push instruments have been in force, 346 demand-pull, and 503 systemic ones. Similar to biomass, geothermal technologies are also first-generation ones, hence the prevalence of demand pull instruments.

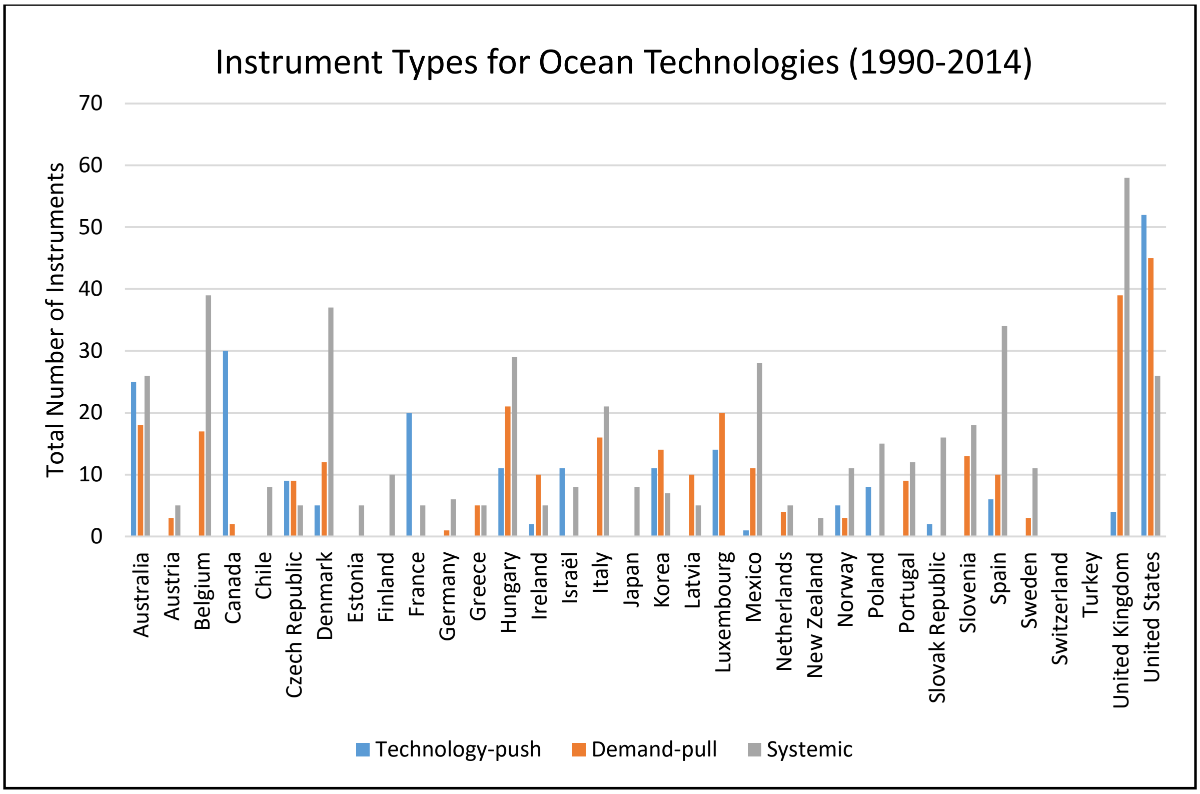
Figure 18: Instrument Types for Hydro Technologies (1990-2014)



Source: Author

In hydro (Figure 18), demand-pull instruments are more than the technology-push ones (420 as opposed to 491), for the reasons explained above. A total of 491 systemic instruments have been in force throughout these years.

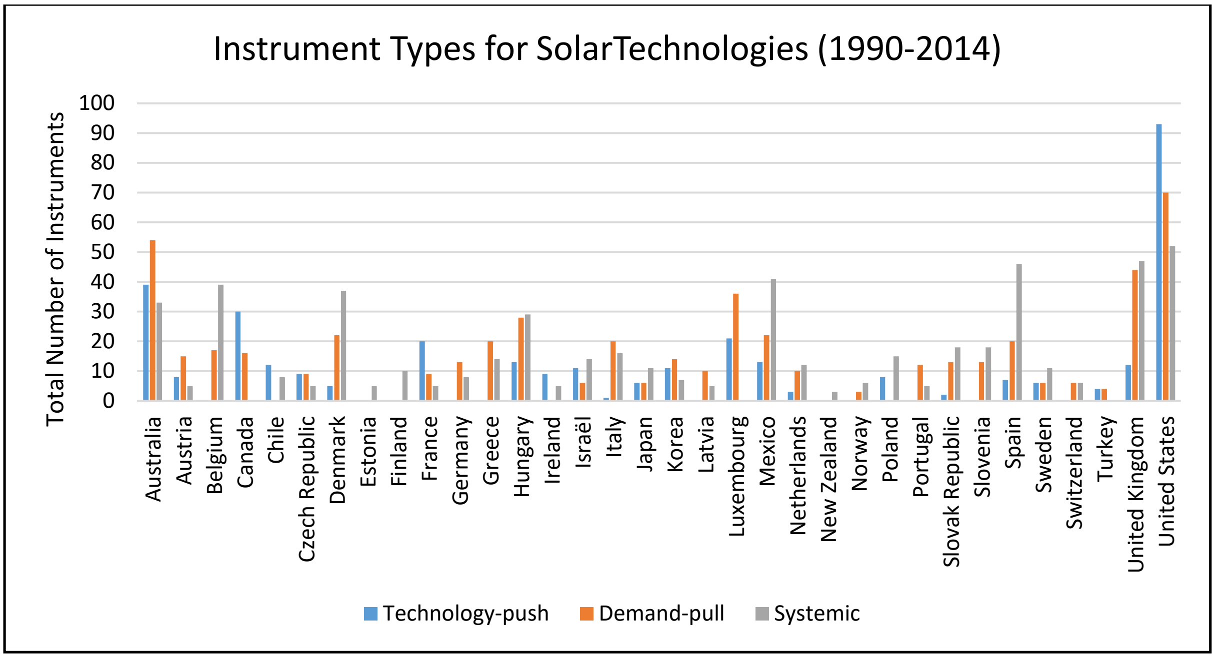
Figure 19: Instrument Types for Ocean Technologies (1990-2014)



Source: Author

With ocean technologies being a third-generation RET, the story is different. Technology-push instruments and demand-pull ones are relatively equal (216 and 295 respectively). A total of 471 systemic instruments were also identified being in force.

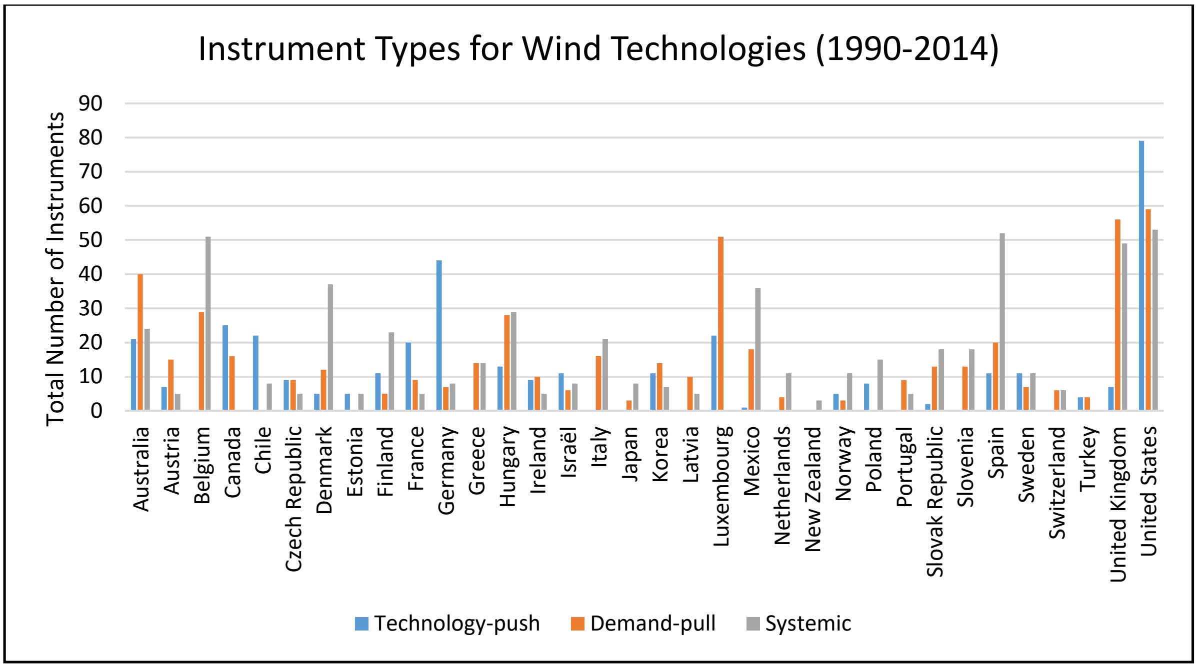
Figure 20: Instrument Types for Solar Technologies (1990-2014)



Source: Author

A total of 343 technology-push instruments were in force related to solar technologies (Figure 20), 518 demand-pull ones, and 536 systemic. Much like the ocean technologies, combined solar are a third-generation technology, albeit not a new one. This implies that although some technological expertise did exist, new incentives towards its technological advancement should be made – hence the relatively high number of technology-push instruments. However, since the public is already aware of the existence of this technology, but not of its new advances, demand and awareness should be fostered which could explain the high number of demand-pull and systemic instruments.

Figure 21: Instrument Types for Wind Technologies (1990-2014)



Source: Author

Finally, wind technologies (Figure 21) are a special case. This is because, despite being a RET, the technological advancements do not necessarily apply to that technology only, but over a spectrum of technologies, including but not limited to RETs (for example the rotors used). This was also the case with patent counts, with the highest activity and granted patents. One should therefore expect a relatively high number of technology-push instruments, but a higher number of demand-pull ones. Indeed, there were a total of 363 technology-push instruments in force between 1990 and 2014, and 506 demand-pull ones. A total of 556 systemic instruments were in force during the same years.

3.2.1 Summary

RE policy instruments can be an important determinant of RE innovation. Using the IEA/IRENA (2014) database, a total of 226 policy instruments related to RE, for the OECD member countries under examination, and for the years 1990-2014, were collected. These were then classified into multiple sub-categories, depending on the country, the targeting RE, and their type, as explained. This, along with the patent data presented in sub-chapter 1.1, allows for an extensive panel database, which allows for the examination of a number of hypothesis, as presented and supported by theory in the chapters to follow.

3.3 Econometric Model and Estimating Procedure

In line with the aforementioned discussion and as already noted at the beginning of this chapter, an econometric model has been employed for testing for the hypotheses presented in the next chapters. As it can be seen in Figure 22, there are multiple methodologies depending on the purpose and data of the study. In the case of this thesis, the aim is to explore the relationship among variables, while data come in the form of measurements. As mentioned previously, apart from the main independent variable (or explanatory/predictor), additional chapter-specific control variables are to be employed. This in return implies that "Multiple Regression" analysis should be used (Corston & Coleman, 2000). A regression analysis is a simple method aiming to investigate the functional relationships among variables. An equation is used to express the relationship between the dependent (or response) variable (DV) and one or more independent variables. In its linear form, the above equation becomes as follows (Chatterjee & Hadi, 2012), while "multiple" implies more than one independent variable:

$$y = a + b_{1,t}x_{1,t} + b_{2,t}x_{2,t} + \cdots + b_{n,t}x_{n,t} + \varepsilon \quad (3\text{-}1)$$

Where, in the case of this dissertation:

y_i: Innovations related to RE technologies (*INNOV)*

a: Intersection with y-axis at x=0 (constant)

x: REPs

b: Coefficients of the independent variables

ε: Error term (residuals)

t: is a time subscript

Specifically, the use of repeated observations on the same cross-section of a variable, such as individuals, households, cities, or as in this case countries over time constitutes panel data (or longitudinal data) (Wooldridge, 2001) and requires an appropriate technique for panel data analysis. Panel data differ from time-series data and cross-sectional data, in the sense that the first observes only one entity over time (e.g. max temperature), and the latter multiple entities at one point in time. Panel data is therefore a combination of the two (Chatterjee & Hadi, 2012). What is more, the use of patent data as a proxy for innovation implies count variables, which is defined as a non-negative integer-valued random variable (Wooldridge, 2001).

In addition, count data can be econometrically examined either by using the Poisson Regression Model (PRM), or the Negative Binomial Regression Model (NBRM) (Greene, 1994). These methods are used in order to estimate the number of occurrences of an event (Johnstone, Haščič, & Popp, 2008) which, in the case of this chapter the event count is the patenting activity, using the PRM can result in biased results when there are a lot of zero values as well as over-dispersion (i.e. when the variance exceeds the mean – the case in this thesis). This can be overcome by using the NBRM which introduces unobserved heterogeneity across the Poisson means (Costantini, et al., 2015). The main way however, to choose between the two, is by examining the variance and the mean of the dependent variable. The variance of the dependent variables was found in all cases to be larger than the mean (as shown in the Table 12 below), implying over-dispersion.

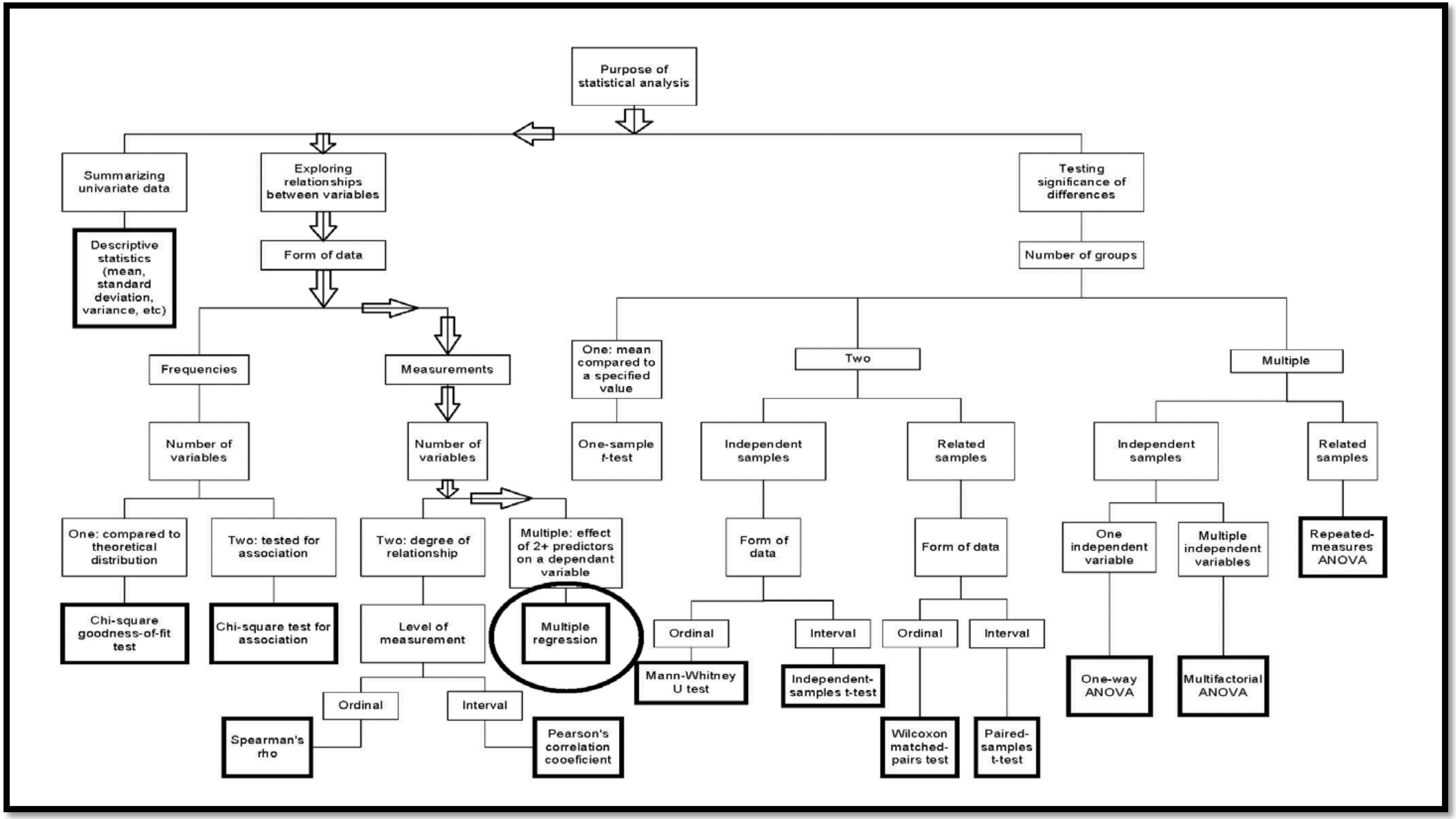
Table 11: Comparison of the Variance and Mean Values of the Basic Variables

Variable		Variance	Mean
Dependent: Patenting Activity	**Total**	388,771.20	255.76
	Biomass	1,175.06	12.47
	Geothermal	173.59	4.58
	Hydro	9,323.34	40.46
	Ocean	1,180.72	14.35
	Solar	52,155.85	86.96
	Wind	74,133.95	96.93
Independent: Policy Instruments	**Total**	46.26	4.08
	Technology-Push	5.79	1.18
	Demand-Pull	10.95	1.64
	Systemic	6.65	1.26
			Source: Author

Based on the above, the NBRM method was employed, which allows the variance to be greater than the mean, while scaling the standard errors (Hilbe, 2011; Wooldridge, 2001).

To sum up, in this chapter I have outlined the overall methodology employed in order to address my research question, and test the various theory-derived hypotheses in each subsequent chapter. I focused on data, econometric methods and the selection or creation, measurement and proxy employed for the dependent variable (RE innovation) and the independent ones (RE policy instruments). Discussion of control variables instead was left for each particular each specific chapter. In addition and for reasons provided in each chapter, there are small variations in the method and data in specific chapters, mostly motivated by comparability data considerations. Based on the above, the next chapter looks at the impact of European IP instruments and their interactions on RE innovation.

Figure 22: Selection of appropriate statistical procedure



Source: Corston & Coleman, 2000; Arrows added by the Author

Chapter 4
Industrial policy for renewable energy: The innovation impact of European policy instruments and their interactions[7]

4.1 Introduction

This chapter examines the impact of renewable energy policies as well as three renewable energy policy instruments (demand-pull, technology-push and systemic) discussed in the previous chapter and their interactions, on renewable energy innovation. The chapter focuses on the 15 European Union countries (Austria, Belgium, Denmark, Germany, Greece, Spain, France, Ireland, Italy, Luxembourg, Netherlands, Portugal, Finland, Sweden, and the United Kingdom) for the period 1995–2014. These 'old' EU members are widely perceived as leaders in this area. In particular, the EU has aimed to develop EU-wide RE and innovation policies to deliver the requisite targets with some degree of success (EC COM 130 final/2, 2014). Looking at a wider set of countries for this case of the aggregate effects, would run the risk of diluting the potency of the results by including countries with smaller or minimal activity on RE and RE policy. The period chosen is between 1995 and 2014, because that was when the fourth enlargement of the EU that took place, which saw Austria, Finland, and Sweden (four leading countries on RE and RE policy) accede to the EU.

Following a critical literature survey, a conceptual framework and hypotheses are developed, which are then tested by employing a unique and comprehensive data set. It is found that RE policies as a whole as well as demand-pull and technology-push instruments affect RE innovation positively and significantly. The impact of interactions between instruments on RE energy innovation is also positive and significant, but that in the case of specific pairs of

[7] This chapter is based on the published paper by Pitelis, A. T. (2018), with the same title and DOI: 10.1177/1024529418768491 on the Competition and Change Journal

instrument interaction the outcome is contingent on the specification used. Reasons are discussed for these findings, implications for public policy, as well as limitations and opportunities for further research.

As mentioned in the introduction of this thesis, the use of fossil fuels as a primary energy source has been associated with environmental and climate challenges (Stern, 2006). In this context, a transition to RETs is widely regarded by the international community and national governments to be essential in addressing environmental degradation (Jacobsson & Bergek, 2003). It is widely held however that it is unlikely for the required transition to take place through market forces alone. The development, diffusion, and deployment of RETs is said to face a number of barriers (Beck & Martinot, 2004), and market failures (Wustenhagen, et al., 2007; Arnold, et al., 2014). Such failures in turn can require suitable government intervention in support of RE sources (Mazzucato, 2013; Helm, 2010; Atkinson & Stiglitz, 1980).

Public policy intervention can take place at the international, national or regional and province levels. International cooperation is often deemed as important to address problems of free riding, for example, countries not being diligent enough to foster requisite change for cost and/or competitiveness considerations (Bailey et al, 2015). Important public policy intervention at the inter-national level aimed to redirect innovative efforts towards RE has been initiated by the Kyoto Protocol (Rawlins & Allal, 2003). Such international agreements can function as a constraint or incentive for national policy makers to adopt RE policies to reach agreed targets. Key questions however, are not only whether and how national governments can foster RE innovation but also through what types of policies and policy instruments.

If markets alone could solve the problem of transition to RE, no international agreements and no government intervention would be required. Additionally, if government policies are not effective, or they create more problems than they solve (Atkinson & Stiglitz, 1980), the case for RE policies weakens. In order to address the above, a theory is needed as to why or when public policy can be necessary, effective and useful. Many scholars have argued that public policy is indeed required to solve market failures and that the relationship between markets and governments is complementary and symbiotic; hence, public sector intervention can be of the essence in fostering RE transitions even in the absence of pervasive market failures. In this argument governments can help create and indeed co-create markets (Pitelis and Teece, 2009), with the RE market being a key candidate and paradigm (Mazzucato, 2013; Weber & Rohracher, 2012; Rennings, 2000; Atkinson & Stiglitz, 1980). Others however, have argued that governments too fail and that such failures weaken the case for interventionist public policy (Helm, 2010).

A large literature body has addressed the extent to which RE policy fosters RE by focusing on the impact of RE policy on RE innovation. On balance this has shown that public policy fosters RE innovation (Jaffe & Palmer, 1996; Johnstone, et al., 2008; Nesta, et al., 2014). However, for public authorities, it is also important to know which type of intervention (policies and policy instruments) work and how do these interact (Sorrell, 2003; Sijm & van Dril, 2003). These issues need to be further examined to help ascertain the role of the policy instrument mix and provide useful information for public policy makers (Landini, et al., 2017).

The aim of this chapter is to examine the relationship between public policy towards RE and RE innovation, at the aggregate level of all RE policies and all RETs, as well as at the level of three types of RE policy instruments and their interactions. Despite recognition of the importance of RE policy, and the existence of different types of RE policy instruments and their interactions (Boots, et al., 2001; Gunningham & Sinclair, 1998; Simões, et al., 2005; Oikonomou & Jepma, 2008; del Rio, et al., 2013), there exists little agreement on a common classification of the instruments concerned and little empirical evidence in the context of a common conceptual and empirical framework. These are important gaps that this chapter aims to contribute in filling.

The conceptual framework employed in the RE literature often goes little further than the recognition of market failures as a basis for RE policy, while the link to industrial policy (IP) is rarely made. This is rather paradoxical as RE is an industry where substantial public policy intervention (industrial policy) takes place, as mentioned in Chapter 2. Moreover, despite the interest in industrial policy and strategy (Bailey, et al, 2015), there is very little empirical-econometric work in support of its alleged positive effects. The focus on IP in the RE sector helps address this literature[8] gap.

In the next section, a conceptual framework is developed and three hypotheses are proposed. I then test these. First, I examined the impact of overall RE policies, followed the impact of three types of RE policy instruments and their interactions on RE innovation. For testing purposes, a unique database has been constructed by the author, as explained in Chapter 3 – with focus on EU15 and for a period of 19 years (1995-2014). The results support the three hypotheses.

The remainder of the chapter is structured as follows: The next section focuses on the background, conceptual and empirical literature and proposed hypotheses of the chapter, section three describes the empirical protocol, section four presents and discusses the results, and section five provides concluding remarks, limitations and opportunities for further research.

---

[8] It is appreciated that different RETs can have different effects; hence, focus on specific RETs is also important. These will be examined in the next chapter. Similar considerations apply for the role of sub-national units such as regions and cities. These are important (s. Coenen & Truffer, 2012; Hodson & Marvin, 2010), but are beyond the scope of this chapter, given the lack of data at such a disaggregated level.

4.2 Background to the Study and Hypotheses

Background

The basis for an EU wide RE policy was set by the White Paper for a Community Strategy and Action Plan Energy for the future: Renewable sources of energy, in which a number of targets were proposed, including doubling the use of RE in the EU gross energy consumption (European Commission, 1997). Others include the Renewable Electricity Directive 2001/77/EC (an EU Directive is a form of legislative act, directed to the member states, and can be used to establish common (social) policies). It is up to the individual member states to form their laws to achieve the goals proposed (European Union, 2016). While the directive mentioned is not a policy, but a framework, the 2009 Renewable Energy Directive 2009/28/EC, established an overall policy for the production and promotion of energy from renewable sources (CIEEM, 2015). It required all EU member states to ensure that 20% of their gross final energy consumption, and 10% for transportation comes from RE. A further 20% reduction of green-house gas (GHG) emission (compared to 1990 levels) was also suggested. The objectives proposed in the directive were legally binding (as opposed to indicative targets) (European Commission, 2009), which sought a 21% of total electricity to be produced by renewable sources by 2010 (European Commission, 2001; Scarlat, et al., 2015), and the introduction of emissions trading in 2005. The last two were based on environmental regulation (Art. 175 (1) EC) (Langsdorf, 2011). According to the latest communication from the European Commission to the European Parliament, the EU is close to achieving its 2020 target of 20% reduction (with half of the member states having already achieved their targets). A steady increase in the use of RE has been observed which if sustained, could allow the EU to achieve its target of increasing the use of RE by 20% (EC COM 130 final/2, 2014).

Most EU national governments have adopted specific RE policies and policy instruments in order to satisfy the aforementioned objectives. As recently noted by Christensen et al. (2016) further development of innovation policy should include addressing what the most relevant instruments are, and how these are most appropriately designed and combined. Among other challenges, this requires deciding on the right taxonomy (Martin, 2016). In the above context, it is interesting to see the extent to which IP in the RE sector is a success or not and in particular what types of IP instruments (and any interactions between them) are more effective. This adds to the literature in meaningful ways, not least by providing econometric evidence on the effectiveness of IP which is lacking (Bailey, et al, 2015).

In order to answer this and develop the conceptual framework and hypotheses one should look into the extant theory and evidence on these matters.

Literature and Hypotheses

As mentioned in Chapter 2, the discussion about the nature and importance of innovation dates at least as far back as in the work of Joseph A. Schumpeter (1934), who defined technological change as new combinations pertaining to the organisation of production and distinguished among three different aspects of innovation; invention, innovation, and diffusion (Schumpeter, 1934). Since then, innovation has been widely seen as a desirable generator of positive knowledge spill-overs, which help engender systemic benefits. Like all 'externalities' (factors whose economic impact is not reflected on market prices), however, it is widely believed that innovation is subject to market failures, making it likely that in the absence of supporting measures and policies, it will be undersupplied (Stoneman, 1995; Varian, 2003; Mazzucato, 2013). In addition to knowledge externalities in the research and innovation phases, RE innovations can engender positive externalities in the adoption and diffusion phases. The undersupply of RE innovations, can result from the lack of incentives for firms to invest in RE innovation since the private return on R&D in RETs is lower than its social return. This helps justify the need for public policy intervention (Rennings, 2000; Oltra, 2008)[9]. Moreover, innovation does not automatically guarantee that the development it fosters will be sustainable. For sustainable development, innovations in RE are required as they may facilitate the transition to RE. This renders important the question of the determinants of innovation that help foster RE transitions and sustainable development.

There are two main theoretical perspectives concerning the determinants of innovation at the national level. One is the economics-based endogenous growth theory of Romer (1990) and the other is Nelson's (1993) research on national innovation systems (NIS), based on institutionalist economics (Furman, et al., 2002). Drawing on these, Furman et al. (2002) proposed that national innovative performance is determined by a broad set of complementary influences which include institutional and policy-related factors, industry and cluster-related factors and their interactions. Furman et al. (2002) argued that public policy has a significant role in shaping a country's national innovative capacity (for a detailed review of the innovation determinants see Chapter 2). This view is shared by the NIS approach which moreover emphasises complementarities between different actors and institutions of innovation. In the IS framework, innovation is seen as a complicated evolutionary process "distributed in a system of multiple socio-economic agents whose behaviour and interactions are governed not only by market forces but to a greater extent by non-market institutions" (Bleda & del Río, 2013, p. 1039)[10]. This view is complemented by arguments of scholars such as Arnold, et al.

[9] Other barriers to transition to RE include market power, information asymmetries, externalities, network effects, and infrastructure (Arnold, et al., 2014). Beck and Martinot (2004), also identified a number of barriers related to the deployment and diffusion of RETs, including the absence of up-front financing and/or the necessary equipment (REN21, 2015) and grid access (Fouquet, 2013). Therefore, given pervasive barriers to RE innovation and other market failures, government intervention has been deemed necessary in addressing failures and in satisfying the targets set by said accords.

[10] Market and systemic failure-based rationales are sometimes seen as two contrasting theoretical positions. The former is often considered as a valid, albeit insufficient justification for policy intervention, which needs to

(2014), Mazzucato, (2013), Rennings (2000) and others who suggest that solving market failures with complementary public and private policies is a good way through which we can achieve the requisite transition to RE. A challenge however, is how exactly and what type of RE public policy and instruments can be more potent in helping achieve the targets (Wustenhagen, et al., 2007; Beck & Martinot, 2004; Sterk, et al., 2007).

Moreover, while it is widely recognised that markets alone cannot guarantee requisite transition to RE, there is also an understanding that government policies too can lead to failures (Atkinson & Stiglitz, 1980). These result from errors in targeting and implementation, lobbying by interest groups, and rent seeking (the pursuit of self-interest that can lead to corruption) of government officials, (Helm, 2010; Jaffe, et al., 2005; Atkinson & Stiglitz, 1980). Despite acknowledging government failures, there seems to be a degree of consensus in the literature that at the aggregate level RE policies will have a positive effect on RE innovation (Lanjouw & Mody, 1996; Brunnermeier & Cohen, 2003; Popp, 2006; De Vries & Withagen, 2005; Wagner, 2007; Dechezleprêtre & Glachant, 2014; Böhringer, et al., 2014). This however is a matter for empirical investigation and this is the aim in the rest of this chapter. [11].

An important advantage of econometric investigation is that it helps gauge the extent to which RE policies have a positive and significant effect on RE innovation, after having controlled for other determinants. Hence it is mostly through an econometric investigation that the added value of REPs, or their "additionality", namely "the difference between the presumed

---

be complemented by arguments from the systemic failure perspective. The latter is sometimes considered a more general approach than the market failure one, in that it recognises that there exist government and wider systemic failures that need to be accounted for (Bleda & del Río, 2013). In this context the concept of "additionality" becomes important (see below).

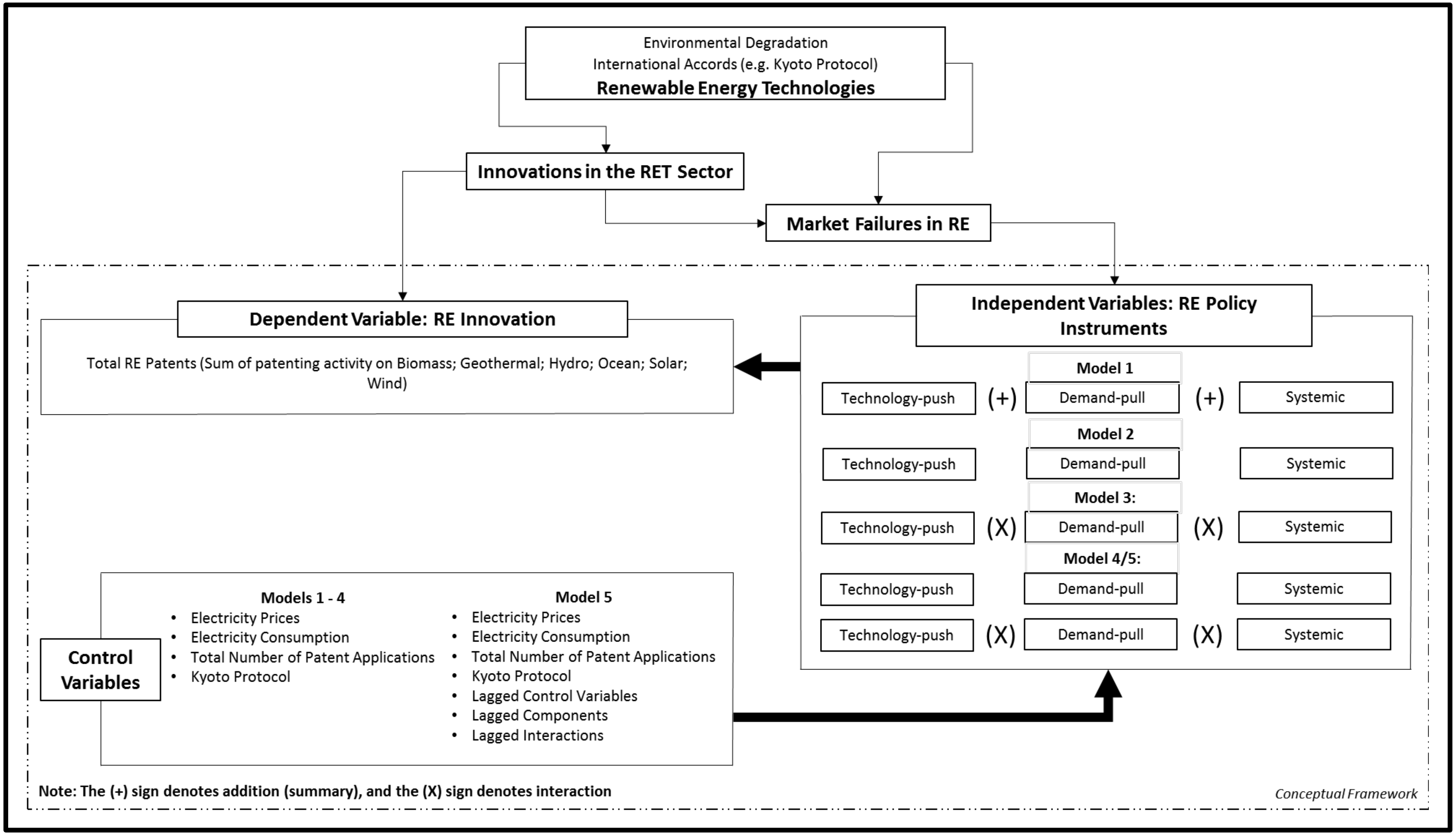
[11] While aggregate empirical analysis cannot show the exact causes of government failures, it helps find if on balance such failures are offset by the advantages of government intervention in solving market failures and "crowding in" (being complementary to) as opposed to "crowding out" (substituting for) private investments in RETs (Mazzucato, 2013).

underinvestment in RTD by firms and the actual joint investment by firms and public agencies in RTD prompted by the public programmes" (Luukkonen, 2000, p. 712) can be assessed. The aforementioned discussion is summarised in a schematic way in Figure 23. In brief the Figure suggests that in the context of pervasive market failures, international agreements such as the Kyoto Protocol operate as a constraint and incentive for governments to adopt RE policies and RE instruments (government intervention) aimed at fostering RE innovation. These are in addition to other reasons governments may have to adopt RE policies; thus, innovation in RE becomes the dependent variable and RE policy instruments become the main independent variables. RE innovation is also affected by various other factors which are used as control variables.

The above discussion leads to formulation of the first hypothesis in the following way.

Hypothesis 1: RE policy has a positive and significant effect on RE innovation.

Figure 23: Background to the study and conceptual framework schematic



Source: Author

The basis of the second hypothesis lies in the fact that public authorities can use a number of different instruments in order to promote RE. However, there is not a uniform classification of instruments types. This is problematic in that it renders findings from different studies that use different classifications hard to compare[12]. Drawing on earlier work on innovation, (see for example Rosenberg, 1974, Nelson, 2009, and Nemet, 2009), Rogge & Reichardt (2016) have argued for a consistent terminology and went on to propose that in terms of purpose served, three types of instruments, namely technology-push, demand-pull, and systemic, are in line with extant theory and can help with comparability (Rogge & Reichardt, 2016) (these are explained in detail in Chapter 3).

Hence, the second hypothesis takes the following form.

Hypothesis 2: Technology-push and demand-pull policy instruments have a positive and significant effect on RE innovation.

Furthermore, RE policy instruments may interact with each other, as noted before. The role of an interaction variable is akin to that of moderating variables, which are deemed important when the impact of an independent variable on the dependent one is based on a third variable, known as the moderator; and the fit between the independent variable and the moderator is

[12] For example, Johnstone et al. (2008), as well as Nesta et al. (2014) distinguished instruments in R&D; investment incentives; tax incentives; tariff incentives; voluntary programs; obligations; and, tradable certificates (Johnstone, et al., 2008; Nesta, et al., 2014). Marques et al. (2013), classified instruments in terms of education and outreach, financial incentives - subsidies, policy processes, public investment, R&D, regulatory, tradable permits, and voluntary agreements (Marques & Fuinhas, 2012). Mabee and Saddler (2007), identified five groups, being feed-in tariffs, green certificates, tendering systems, and tax and investment incentives (Mabee & Saddler, 2007). Kim et al., (2015), distinguished instruments in public R&D, tariff incentives, renewables obligation, environmental taxes, and public investment (Kim K. & Kim, 2015). Few studies have distinguished among demand-pull and technology-push (Horbach, et al., 2012; Costantini, et al., 2015; Guerzoni & Raiteri, 2015) with later work adding systemic instruments as well (Cantner, et al., 2016).

what determines the dependent one (Venkatraman, 1989)[13.] In the case of policy instruments, their interactions have been argued to be potentially important in that there may exist synergies, overlaps or clashes between instruments (Michelsen, 2005; Mundaca & Neij, 2010; Sorrell, 2003; Rogge & Reichardt, 2016).

The exact type and significance of interactions can depend on numerous factors that cannot be known in advance. These include context, design and technology type (s. Costantini, et al., 2015; Cantner, et al., 2016), as well as different lag structures. Cantner et al. (2016), for example identified differences between different examined RETs[14].

In one of the first studies conducted by Gunningham and Sinclair (1998), the authors concluded that the combination between different regulatory instrument combinations was important and that different combinations had different effects (Gunningham & Sinclair, 1998).

This leads to the third hypothesis.

Hypothesis 3: The interaction between demand-pull, and technology-push policies on the one hand and systemic policies on the other, have a positive and significant effect on RE innovation.

[13] In a formal representation, the relationship between two or more variables *X* and *Y*, is a function of the level of *Z*, i.e. $Y=f(X, Z, X \cdot Z)$ where in this case, Y = RE innovation, X = RE policy instrument types, and Z = the contextual variable that fits with the different instrument types (Venkatraman, 1989). In essence, a moderator, is the interaction effect of the two variables.

[14] Technology-push and systemic instruments seemed to work better in wind power, while demand-pull instruments worked better in the case of photovoltaics. Systemic instruments interactions increased interaction- especially in the wind power, and were found to be complementary to demand-pull in fostering collaboration (Cantner, et al., 2016). It should be noted, however, that Cantner, et al. (2016) focused on RE inventor networks (as opposed to RE innovation as in this chapter), making their results not directly comparable those of this chapter.

Empirical Evidence

Below the existing empirical evidence in terms of two major categories is summarised: first studies on the overall impact of REPs and REP instruments on total RE innovation as well as on different RETs; and second, studies that looked into interactions between REP instruments. In the first category two classifications are made, between general studies, those focusing on specific RETs and those that examine the role of different institutional settings.

Evidence on the Impact of REPs on RE Innovation

Johnstone et al. (2008) analysed a panel of 25 countries over the period of 1978-2003. By employing a Poisson regression analysis and with patent counts as their dependent and the RE policies as their independent variable, the authors concluded that RE policy plays a significant role in determining patent applications, and also that different types of policy instruments are effective for different RE sources (Johnstone, et al., 2008). Marques and Fuinhas, (2012) examined the extent to which public policies towards RE are effective, using Panel Corrected Standard Errors estimator (PCSE) over the whole spectrum of RE technologies. They used the contribution of renewables to total energy supply as their dependent variable, and aggregated and disaggregated RE policies as their independent (Marques & Fuinhas, 2012). They concluded that policies of incentives/subsidies (incl. feed-in tariffs) (demand-pull instruments) and policy processes (systemic instruments) are significant drivers of improved RE use.

In terms of the impact of REPs on specific RETs, Lee and Lee (2013) also supported the idea that REPs have a positive effect on RE innovation, by having explored patterns of innovation and of evolution in energy technologies (incl. solar, photovoltaic, biomass, wind, tidal (ocean), and geothermal), focusing in particular on similarities and differences across technologies. They employed two different techniques (static portfolio and dynamic portfolio analysis) and patent data over the period 1991-2010, and concluded that customised policies are likely to be required for each technology (Lee & Lee, 2013).

Hoppmann et al. (2013), conducted comparative case studies to a sample of nine firms globally, producing solar photovoltaic modules, complemented by in-depth interviews with sixteen top photovoltaic industry experts. They concluded that demand-pull policies have a greater impact when they target more mature technologies (Hoppmann, et al., 2013). Dechezleprêtre et al. (2014), examined the influence of both domestic and foreign REPs on innovation activity in wind power using patent data from 1995 to 2005 for OECD countries. They distinguished between demand-pull policies and technology-push policies and concluded that public R&D expenditures (technology-push instruments) only affect domestic inventors, contrary to demand-pull ones.

Costantini et al. (2015) explored the differentiated impact of demand-pull and technology-push instruments in shaping technological patterns in the biofuels sector. Their empirical analysis was based on a database containing patents in the field of biofuels as the dependent variable, for 32 countries (incl. some EU) using a negative binomial regression analysis (NBR). They concluded that demand-pull and technology-push factors are important drivers of innovation in the biofuels sector. In addition, technology exploitation activities in first generation technologies were mainly driven by quantity and price-based demand-pull policies. In contrast, the pace of technology exploration efforts in advanced generation biofuels was shown to react positively to price based demand-pull incentives and to technology-push policy (Costantini, et al., 2015).

In the third sub-category, Nesta, et al. (2014), examined the effect of various RE policies on innovation for different levels of competition. In line with Johnstone et al. (2008) the authors employed a Poisson regression analysis, with patent data as the dependent variable and the RE

Policy Index (sum of all implemented policies - as in Johnstone et al. (2008) - expressed as dummies), and the Product Market Regulation Index - PMR index for electricity and gas as the independent variable. They found that RE policies are more effective in forecasting green innovation in countries with deregulated energy markets and that public support for RE is crucial only for the generation of high-quality green patents while competition enhances the production of green patents regardless of their quality (Nesta, et al., 2014).

Evidence on the Role of Interactions

In 2003, the INTERACT project explored the relationships between the EU ETS and other climate policy instruments. A basic distinction in this study was the internal and external interaction. The former referred to two or more climate policy instruments while the latter to a climate and a non-climate policy instrument (environmental or energy policy). A typical example is an emission trading scheme and a carbon tax that affects the same participants, while for the second case an emissions trading scheme that targets electricity generators and an energy tax at the point of consumption, irrespective of the carbon content of the energy used (Sorrell, 2003; Sijm, 2003). Furthermore, an important division in the same study at the level of governance was horizontal and vertical interaction. Horizontal referred to the same level of governance (e.g., EU ETS and EU labelling for energy efficiency appliances) while vertical to different levels (e.g., RE Certificate System (RECS) with TGC in one-member state). Other types of policy interactions distinguished in this study were operational, sequencing and trading (Sorrell, 2003).

In a similar vein, Oikonomou (2004) in the EU SAVE project ‘‘White and Green’’, analysed the issue of compatibility between different policy types and types of interactions. Simões et al. (2005), assessed the overlap between energy and environmental policy instruments in place among electricity systems. She concluded that a tangled web of policies exists, which in some cases pushes towards complementary objectives but that most of the times these are antagonistic. The most relevant conflicts are between hidden subsidies provided to energy supply infrastructures and environmental command-and-control regulation. Although there are policy instruments acting both on the supply and the demand side, this was found not to foster the integration of supply and demand-side policy instruments (Simões, et al., 2005).

Later studies have focused mainly on the interactions of various policy instruments with the EU-ETS (OECD, 2011a; Kautto, et al., 2012), on interactions between climate change and other environmental policies and the tax (fiscal) system (Goulder, 2013) or like in del Rio's (2014) study, on the theoretical and methodological framework for assessing the success of complex policy mixes. This was in order to identify conflicts between individual instruments and other elements within those mixes. Del Rio (2014) concluded that instruments may lead to conflicts, complementarities or synergies with regards to one criterion when the addition of one instrument to another leads to reductions, adding or magnifying the impact of the combination of both instruments (del Rio, 2014).

Guerzoni et al. (2015), concluded that supply-side subsidies (technology-push instruments) are not as effective as suggested in the previous literature when controlling for the interaction with other policies and also that innovative public procurement (a demand-pull instrument) seem to be more effective that other tools. Overall, technology policies were found to exert the highest impact when they interacted with other policies (Guerzoni & Raiteri, 2015).

Assessment of Evidence

Overall, and with the exception of Cantner et al. (2016) and Guerzoni et al. (2015), studies on instrument interactions have mainly focused on qualitative methods, by focusing on: specific aspects of instruments such as the scope, operations, implementation, timing (s. Sorrell, 2003), mechanism, target stakeholder (s. Simoes, 2005) and objective (Sorrell, 2003; Simoes, 2005); on specific RETs (s. Kautto et al, 2011 who focused on biomass. Moreover, they have done so by employing mostly qualitative methodologies, including possible scenarios (Boots et al., 2001; Sijm, 2001) and optimal designs (best-case scenarios) (Boots et al., 2001), case studies (s. Sorrell, 2003), literature reviews (Oikonomou, 2008; Goulder, 2013) and other (Kautto et al, 2011 (literature review and interviews); Boots, 2003 (conclusions reached by discussion). This renders further econometric work on this topic very important.

In addition to the limited empirical evidence on this matter, existing studies have focused on different types of RE technologies, such as for example Johnstone et al. (2008) and Nesta et al. (2014) on Biomass, Geothermal, Ocean, Solar, Waste-to-energy, and Wind; Hoppmann et al. (2013) on PV modules; and Dechezleprêtre et al. (2014) on wind energy. Furthermore, there is lack of consistency in the RE policy instruments examined; therefore, making the comparison of results difficult. For public authorities, it is important to know which types of instruments are more effective in achieving the required targets, both in general and with regards to fostering particular types of technologies and with particulate types of instruments.

In conclusion, there are various literature gaps and limitations that pertain mostly to the underlying theory (particularly that of industrial policy), the limited econometric evidence, and the comparability between the results.

4.3 Description of the empirical protocol and results

Empirical method, Sample, and Estimated equation

In order to test the three hypotheses econometrically, data on the EU15 Member States were used in the time-span between 1995 and 2014. Five different models were employed, as follows:

In Model 1 the first hypothesis is examined, i.e. the effects of REP instruments at the aggregate level, on the overall RE innovation activity, using the sum of all RE patent counts as the DV, and sum of all instrument types as the Independent Variable (IV). A standard model setting was considered, in the following form:

$$\sum RE\ Innovation_{i,t} = \beta_1\left(\sum REP\ Instr._t\right) + \beta_2\left(Elec\ Prices_{i,t}\right) + \beta_3\left(Total\ Pat_{i,t}\right) + \beta_4\left(Elec\ Cons_{i,t}\right) + \beta_5\left(Kyoto_{i,t}\right) + \varepsilon_{i,t} \tag{4-1}$$

Where, *i = values per country* and *t = year (1995, …, 2014).*

In Model 2 the effects of the three types of RE policy instruments on RE innovation at the aggregate level (second hypothesis) is examined, i.e. sum of all RE patent counts as the DV, and sum of each type of instrument as the IV. A standard model setting is again considered, in the following form:

$$\sum RE\ Innovation_{i,t} = \beta_1\left(Tech\ Push_{i,t}\right) + \beta_2\left(Dem\ Pull_{i,t}\right) + \beta_3\left(Systemic_{i,t}\right) + \beta_4\left(Elec\ Prices_{i,t}\right) + \beta_5\left(Total\ Pat_{i,t}\right) + \beta_6\left(Elec\ Cons_{i,t}\right) + \beta_7\left(Kyoto_{i,t}\right) + \varepsilon_{i,t} \tag{4-2}$$

Where, *i = values per country* and *t = year (1995, …, 2014).*

In Model 3 the interaction terms[15] are introduced in order to assess their effects (third hypothesis). The sum of all RE patent counts is used as the DV, and REP instruments interaction as the IV. Again, a standard model setting was considered, in the following form:

[15] As noted by scholars such as Schoonhoven (1981) and Venkatraman (1989), when there is a relationship between two variables (in this case these are the policy instruments types) that can predict a third one, the role of the *interaction* between the two variables should be considered

$$\sum RE\ Innovation_{i,t} = \beta_1(Tech\ Push * Systemic_{i,t}) + \beta_2(Dem\ Pull * Systemic_{i,t}) + \beta_3(Tech\ Push * Dem\ Pull_{i,t}) + \beta_4(Tech\ Push * Dem\ Pull * Systemic_{i,t}) + \beta_5(Elec\ Prices_{i,t}) + \beta_6(Total\ Pat_{i,t}) + \beta_7(Energy\ Cons_{i,t}) + \beta_8(Kyoto_{i,t}) + \varepsilon_{i,t} \qquad (4\text{-}3)$$

[16]

Where, *i = values per country* and *t = year (1995, …, 2014).*

Model 4, is a variation of Model 3, its form therefore will be the addition of Eq. (2) and Eq. (3). It examines the effect of the aforementioned interaction terms alongside their component variables (the three types of RE policy instruments) on RE innovation. A standard model setting was again considered, where the sum of all RE patents is used as the DV, and the sum of each type of instrument as well as the REP instruments interactions as the IV.

Given some differences in the results when instrument interactions were examined in isolation, versus alongside their components, Model 4 was rerun with the first lag of all independent variables (Model 5). The aim here was to test for the extent to which any observed differences between the two variants of Model 4 could be attributable to different lag structures.

As mentioned in the third chapter, the use of data for various countries over various years implies the need for analysing panel data; while the use of patent data as a proxy for innovation implies count variables.

The following sections describe the various variables employed in the estimations, a summary of which can be found in Table 13. The descriptive statistics of all main variables are reported in Table 14.

[16] The asterisk symbol (*) denotes interaction variables.

Dependent Variable: RE Innovation

As mentioned in the methodology chapter, patent data from the latest (2016) online free version of European Worldwide Patent Statistical Office (EPO) database (PATSTAT, 2016) were collected, using the International Patent Classification (IPC) system for Biomass, Geothermal, Hydro, Ocean, Solar, and Wind. PCT patent applications in the international phase were considered, and filed directly at the International Bureau of the World Intellectual Property Organisation (WIPO). The patents were assigned to a country on the basis of the address of the inventor. The date of the patent is the earliest priority date.

Overall, a total of 102,830 patent counts were used, with most coming from Germany, followed by Denmark and the United Kingdom, as shown in Figure 24, below. Figure 25, shows the annual trend of the patenting activity. As compared to the overall EU RE patenting activity (EU27 for the same years – 1995-2014), the aforementioned member states account for 98.3%, while for the same time-span and for the overall OECD members, EU15 accounts for 49.9%.

Table 12: Summary of Variables and Variables' abbreviations (in brackets)

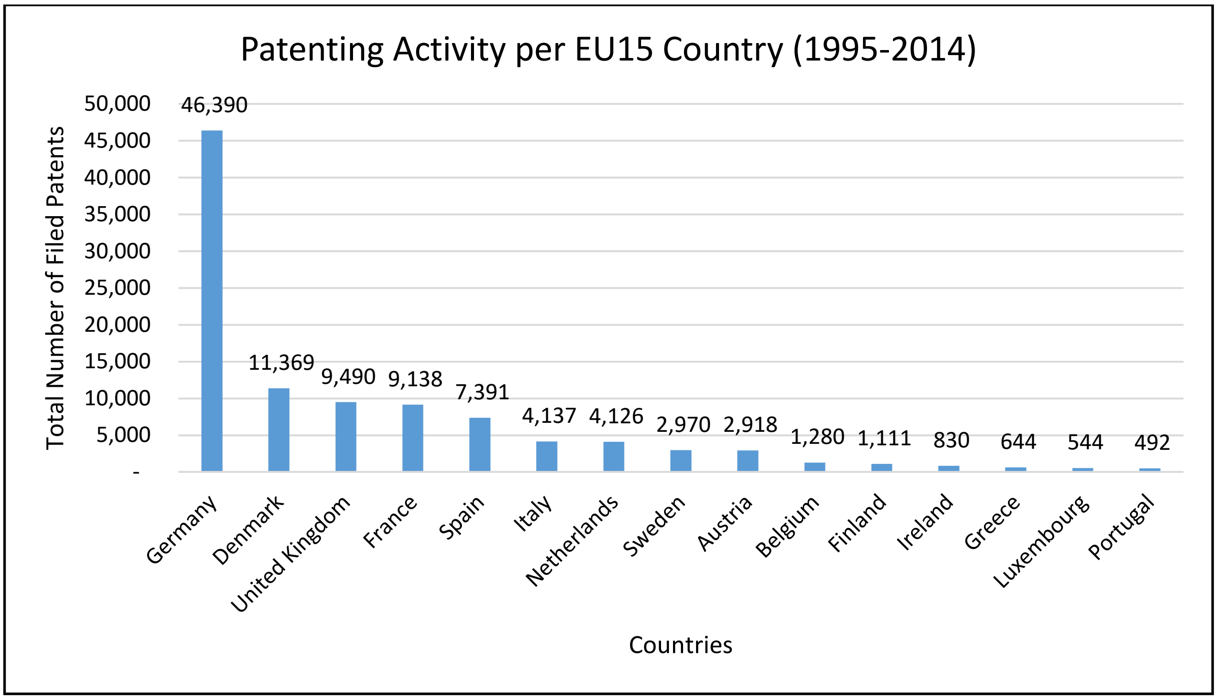
Name	Definition	Unit	Notes	Variable	Source
Patents ($RE\ Innovation$)	Total patent counts filed per country per year, filed under the PCT	Count Values	Data were collected using International Patent Classification, for Bioenergy; Geothermal; Hydroelectricity; Ocean Energy; Solar Energy; Wind Energy	Dependent	PATSTAT (2016) (European Patent Office)
Policy Instruments ($REP\ Instr$; $Tech\ Push$, $Dem\ Pull$, $Systemic$)	The IEA/IRENA Global Renewable Energy Policies and Measures Database provides information on policies and measures taken or planned to encourage the uptake of renewable energy in all IEA and IRENA Member countries and signatories.	Count Values	OECD Countries; All Policy Types; All RE Policy Target; Only Electricity Sector; Effective between 1974-2015; All Jurisdictions; All Policy Statuses; Large and Small Plant Sizes	Independent	IEA/IRENA (2014) Joint Policies and Measures Database
Electricity Consumption ($Elec\ Cons$)	The IEA Electricity Information: OECD Electricity and Heat Supply and Consumption (GWh, TJ) database provides electricity and heat balance data for 35 OECD countries	TWh	Data was collected for EU15 member states. Both observed and calculated balances were collected and averaged.	Control	OECD (2016)
Electricity Prices ($Elec\ Prices$)	End-use energy prices in US dollars converted using average exchange rates per energy unit (MWh), by sector (industry, households and electricity generation).	Thousand US$ (2015 constant prices)	Data refers to electricity prices. Prices for electricity generation were not available, therefore industry and households' prices (US$/MWh) were averaged. These were then divided by 1000000 to get them in	Control	IEA Energy Prices and Taxes: End-use energy prices and taxes in US dollars, 1978-2016 Preliminary Edition

Name	Definition	Unit	Notes	Variable	Source
			million US$, and divided by the 2015 GDP deflator.		
Total Patents $(Total\ Pat)$	Total patent application counts across all technology fields (estimated total patents for latest years), filed under the PCT	Count Values	Data were available for both applicants' and inventors' country of residence - mean values of both were taken	Control	OECD (2016)
Kyoto Protocol $(Kyoto)$	The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change, which commits its Parties by setting internationally binding emission reduction targets. The Kyoto Protocol was adopted in Kyoto, Japan, in 1997 and entered into force in 2005.	Dummy	0 for all years prior to 2005; 1 for the following ones	Control	Author
GDP Deflator	The GDP implicit deflator is the ratio of GDP in current local currency to GDP in constant local currency. The base year varies by country.	Ratio (current to constant price GDP)	Values were divided by 100. 2015 was my selected base year	Construction Indicator	World Bank National Accounts data, and OECD National Accounts data files (2016)
					Source: Author

Table 13: Descriptive Statistics of Variables

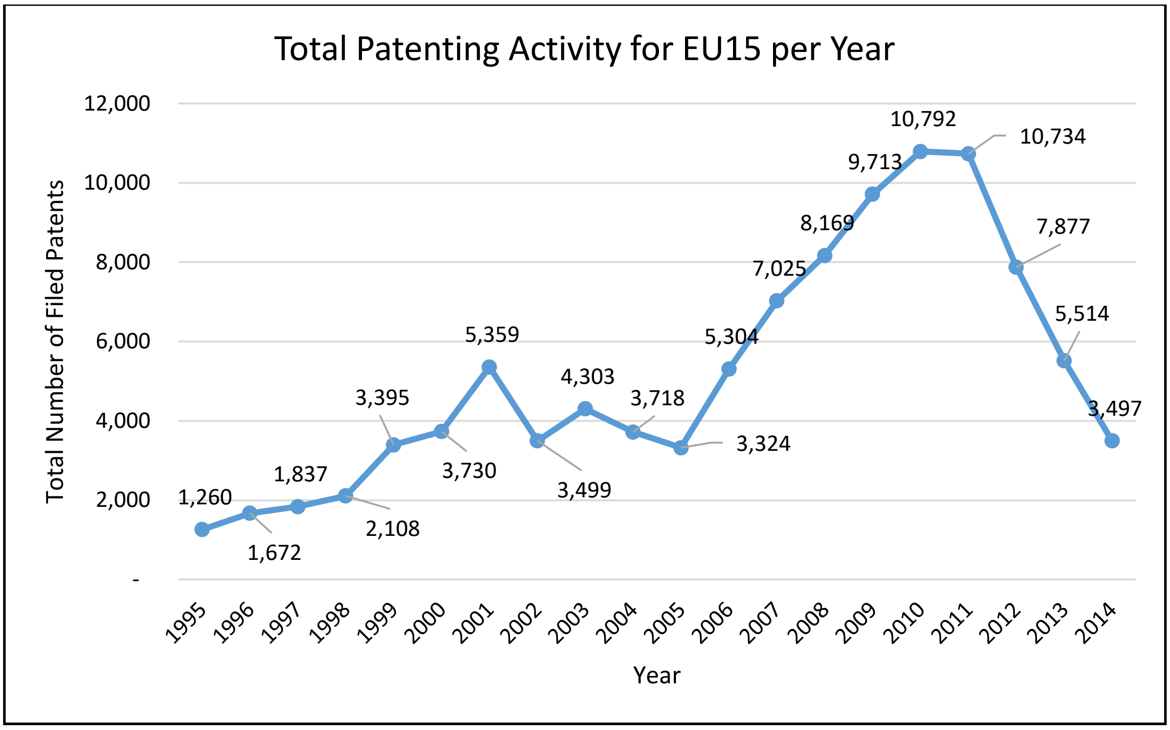
Variable Name	Observations	Mean	Std. Deviation	Min	Max
RE Patents $(RE\ Innovation)$	300	324.77	657.61	0	4547
RE Policies (all) $(REP\ Instr)$	300	5.48	6.56	0	30
Tech. Push Policy Instruments $(Tech\ Push)$	300	1.22	1.84	0	7
Dem. Pull Policy Instruments $(Dem\ Pull)$	300	2.47	3.41	0	14
Systemic Policy Instruments $(Systemic)$	300	1.79	2.88	0	14
Kyoto Dummy $(Kyoto)$	300	0.5	0.5	0	1
Electricity Prices $(Elec\ Prices)$	300	0.0001225	0.0000613	0	0.0002999
Electricity Consumption $(Elec\ Cons)$	300	159782.9	157050.9	4905	547284
Total Patents $(Total\ Pat)$	300	2656.98	3817.84	6.24	18611.81
					Source: Author

Figure 24: Patenting Activity per EU15 Country (1995-2014)



Source: Author

Figure 25: Total Patenting Activity for EU15 per Year



Source: Author

Independent Variable: RE policies and RE Policy Instruments

For the purpose of this chapter, data on RE policies were used from the International Energy Agency (IEA) database for all EU members for the years 1995-2014, as explained in Chapter 3, and classified into technology-push, demand-pull, and systemic.

Control Variables

Inducing green innovation is not only a matter of public policies. There is, therefore, need to control for factors other than policies, which may foster innovation. In line with the literature, it is expected that the price of electricity would amplify the incentives for innovation in renewable energy (Johnstone, et al., 2008). It is assumed that these prices are exogenous; given that RE sources have in the past and up until recently contributed fairly small shares towards the overall electricity production (World Bank, 2010) (although many countries have now reached their targets e.g. Denmark and Germany). Values per year and per country for end-use electricity prices in US dollars were obtained from the IEA Energy Prices and Taxes database. These were converted in constant 2015 US$ using average exchange rates per energy unit (MWh), by sector (industry, households and electricity generation).

Additionally, the total number of patent applications across the whole spectrum of technological areas per year, per country filed in the PCT was also included as a control variable. This variable accounts for the overall propensity of a country to innovate, while taking into consideration only patents filed in the PCT (Johnstone, et al., 2008; Nesta, et al., 2014). Furthermore, returns on innovation are affected by the potential market for this innovation. In the case of RE this is best reflected in trends for electricity consumption. A large growing market for electricity should increase incentives to innovate with respect to renewable energy technologies. Data on household and industry sector electricity consumption was obtained from the IEA/OECD Database, in GWh.

Finally, the models were augmented by including a dummy variable set to unify for years after the Kyoto protocol came into force in 2005, to capture changes in expectation on both the context for future policy and the global market size for renewable energy (Nesta, et al., 2014). Year dummies were also included in order to reduce the impact of any aggregate trends. Significant coefficients show the importance of such effects in particular years, and it is sometimes suggested that even in the case of non-significance, the direction of the relationship can be important (Grotenhuis & Thijs, 2015). In Model 5, one year lags of all (non - dummy) independent variables were used to check for any specific lagged effects, as opposed to using an all-inclusive LDV (s. Blundell, et al., 1995).

4.4 Empirical results and discussion

The following table (Table 15) summarises the main results of the NBRM in which the main variables of interest for the first three Models (as explained in the previous section) are presented. Regarding the first Model, RE innovation is found to be positively and significantly affected by RE policy. This supports the first Hypothesis.

Model 2 shows that demand-pull and technology-push instruments have a positive and significant effect on RE innovation. The findings on demand-pull are similar to those of the extant literature, such as Marques et al. (2012), Wangler (2013), Peters et al. (2012) and partly Johnstone et al. (2010) (only for the case of tradable certificates). Constantini, et al. (2015) also found that demand-pull policies are dominant (in the biofuels sector). Systemic instruments were found to be insignificant when examined on their own. This lack of significance of systemic instruments when acting in isolation is explicable in terms of the argument that systemic policy instruments are aimed to support and align the instrument mix, i.e. support the other instruments, demand-pull and/or technology-push (Smiths & Kuhlmann, 2004); hence, the results are partly in line with what was expected.

Regarding the interaction terms in Model 3, when examined in isolation it was found that technology-push and demand-pull instruments interact positively with systemic ones. This is in line with the literature, as systemic instruments are meant to act in support for other instruments. Cantner et al. (2016), have also found that systemic instruments interact positively with demand-pull (Cantner, et al., 2016). The interaction between demand-pull and technology-push was found to be negative. This supports the idea that demand-pull and technology-push policies can have different effects and targets and the two may well be incompatible.

Finally, it can be seen that the interaction between all three instruments has a negative and significant effect on RE innovation. Howlett et al. (2013) pointed out that instruments in a mix are consistent when they reinforce each other, and inconsistent when they work against each other in achieving a policy target (Howlett & Rayner, 2013; Kern & Howlett, 2009). Therefore, a negative interaction among policy instruments could signify an inconsistent mix (Sorrell, 2003). Indeed, and as mentioned earlier, while the EU has aimed at developing EU-wide RE and innovation policies, most EU governments, have adopted nation-specific RE policies and instruments, providing an extra source of potential inconsistency of the instrument mix. Michalena and Hills (2012) who undertook a meta-analysis of the international scientific literature of the European RE generation found a total 54 challenges related to the implementation of RE technologies on a local basis. The authors concluded that the RE policies in the EU partially fail as they are limited in their scope in dealing with RE on a local basis (Michalena & Hills, 2012); thus, being inconsistent with their targets. Fouquet (2013), argued that policies aimed at the 2020 target appear to be successful but, there remain challenges like grid access, and that some member states are reconsidering their policies, which prejudice the ability of the EU to meet this target (Fouquet, 2013).

Table 14: Estimated coefficients of the NBRM for the first four models

Dependent Variable		Model 1: Total RE Patents	Model 1: Total RE Patents (after General to Specific)	Model 2: Total RE Patents	Model 2: Total RE Patents (after General to Specific)	Model 3: Total RE Patents	Model 3: Total RE Patents (after General to Specific)	Model 4: Total RE Patents	Model 4: Total RE Patents (after General to Specific)
Explanatory Variables	Total REP Instruments	0.0163286*** (0.000)	0.0166181*** (0.000)	-	-	-	-	-	-
	Technology-push	-	-	0.0222055† (0.058)	0.0306851† (0.070)	-	-	0.1521989*** (0.000)	0.1524736*** (0.000)
	Demand-pull	-	-	0.0171185 (0.134)	0.0223764* (0.027)	-	-	0.0683901*** (0.000)	0.0685266*** (0.000)
	Systemic	-	-	0.0080978 (0.461)	-	-	-	0.0495038* (0.030)	0.0498035* (0.026)
Interaction Variables	Technology-push * Demand-pull	-	-	-	-	0.0028954 (0.402)	-	-0.022023*** (0.000)	-0.022088*** (0.000)
	Technology-push * Systemic	-	-	-	-	0.0129876* (0.027)	0.0124924* (0.025)	-0.0196405* (0.024)	-0.0197401* (0.022)
	Demand-pull * Systemic	-	-	-	-	0.0022378† (0.067)	0.0022078† (0.063)	-0.0066984** (0.009)	-0.0067267** (0.008)
	Technology-push * Demand-pull * Systemic	-	-	-	-	-0.0015703* (0.025)	-0.0012859* (0.028)	0.0026381** (0.006)	0.0026496** (0.005)

Dependent Variable		Model 1: Total RE Patents	Model 1: Total RE Patents (after General to Specific)	Model 2: Total RE Patents	Model 2: Total RE Patents (after General to Specific)	Model 3: Total RE Patents	Model 3: Total RE Patents (after General to Specific)	Model 4: Total RE Patents	Model 4: Total RE Patents (after General to Specific)
Control Variables	Electricity Consumption	0.0074748*** (0.000)	0.0073985*** (0.000)	0.0075412*** (0.000)	0.0075314*** (0.000)	0.0074235*** (0.000)	0.0072967*** (0.000)	0.0073867*** (0.000)	0.0073816*** (0.000)
	Electricity Prices	-0.4859528 (0.434)	-	-0.6658229 (0.299)	-	-0.5392625 (0.404)		-0.0416782 (0.948)	
	Total Patent Applications	-0.000071*** (0.000)	-0.000074*** (0.000)	-0.000071*** (0.000)	-0.000077*** (0.000)	-0.000074*** (0.000)	-0.000073*** (0.000)	-0.000037* (0.020)	-0.000038* (0.020)
	Kyoto Dummy	0.129225 (0.380)	-	0.1562084 (0.292)	-	0.1832747 (0.219)		0.0214215 (0.877)	
Note: *p<0.05; **p<0.01; ***p<0.001; †p<0.1									

Table 15: Estimated coefficients of the NBRM for Model 5

	Dependent Variable	Model 5: Total RE Patents	Model 5: Total RE Patents (after General to Specific)
Explanatory Variables	Total REP Instruments	-	-
	Technology-push	0.0994381* (0.022)	0.0856244*** (0.000)
	Demand-pull	-0.0013922 (0.961)	-
	Systemic	0.0185584 (0.576)	-
Interaction Variables	Technology-push * Demand-pull	-0.0022102 (0.693)	-
	Technology-push * Systemic	-0.0079169 (0.488)	-
	Demand-pull * Systemic	0.0021029 (0.473)	-
	Technology-push * Demand-pull * Systemic	0.0002364 (0.856)	-
Control Variables	Electricity Consumption	0.0099927*** (0.000)	0.0061606*** (0.000)
	Electricity Prices	-0.5532112 (0.514)	-
	Total Patent Applications	-0.00000503 (0.919)	-
	Kyoto Dummy	-0.0254068 (0.872)	-
	Lagged Technology-push	-0.0009425 (0.983)	-
	Lagged Demand-pull	0.0799585** (0.004)	0.0580948*** (0.000)
	Lagged Systemic	0.0314545 (0.386)	-

Dependent Variable	Model 5: Total RE Patents	Model 5: Total RE Patents (after General to Specific)
Lagged Technology-push * Demand-pull	-0.0154224† (0.052)	-0.012961*** (0.000)
Lagged Technology-push * Systemic	0.0093841 (0.461)	-
Lagged Demand-pull * Systemic	-0.0100225 (0.027)	-
Lagged Technology-push * Demand-pull * Systemic	0.0003102 (0.828)	-
Lagged Energy Prices	1.043982 (0.294)	-
Lagged Electricity Consumption	-0.0025104 (0.322)	-
Lagged Total Patents	-0.000028 (0.372)	-
Note: *p<0.05; **p<0.01; ***p<0.001; †p<0.1		

In Model 4 all interactions alongside their individual components have been included. The results are interesting in that now all three instruments are positive and significant and only the interaction of all three instruments is positive and significant. The pairs of the three interactions instead are negative and significant. This could suggest that when components as well as interactions are included, the positive effects are fully captured by the components (and in this case by the interaction of all three components). One potential source of incompatibility that could explain the findings could involve different lag structures of the IVs. For this reason, Model 4 was rerun with all IVs lagged by one period (Model 5). The results are interesting (Table 16) in that now only technology-push is significant and positive at its level, while the demand-pull ones are positive when lagged by one period. The interaction between the two is negative as in Model 3. These findings suggest that lag effects can be a source of incompatibility between the various instruments and their interactions. In all models a general to specific specification was run that involved removing gradually the least significant variables in order to identify the model preferred by the data (Pesaran, 1974; Campos, Ericsson, & Hendry, 2005).

Quantitatively it was found that technology-push policies are slightly larger in all cases than demand-pull ones which in turn are larger than systemic, which in turn are larger than the effects of the interactions. In more detail, from Model 1, it can be seen that the expected number of RE Patents will increase by 1.7% (this is derived from the exponential of the constant, i.e. exp(0.0166181) when REP instrument also increase. From Model 2 however, it can be seen that not all instruments are equally potent with systemic instruments having no effect on RE patenting activity, while technology-push will increase RE patenting activity by 3.1%, and demand-pull instruments, by 2.3%. Model 3 indicates that the effect of the technology-push instruments increases by when they interact with the systemic instruments, and demand-pull instruments increase by 0.2%, when they interact with the systemic instruments. Model 4 indicates that technology-push instruments increase patenting activity by 16.5%, demand-pull instruments by 7.1%, and systemic instruments by 5.1%. While different specifications and lag structures can lead to some changes in the observed effects, on balance the findings for the key variables were fairly close in most specifications.

With regards to control variables, electricity prices are found to be of no statistical significance, (possibly suggesting that higher electricity prices do not provide an incentive for increased patenting activity). There are various reasons for this: first, that such prices can sometimes be influenced by public policy considerations to keep them low, (Cherni & Kentish, 2007); second, that RE contributes to electricity generation (14.3% of the final EU energy use in 2012 (EEA, 2016); third, that, certain REP instruments, and specifically that of feed-in tariffs, require grid companies to pay for electricity generated from renewable energies higher prices, as compared to those from fossil-fuel generated (Zhao & Jiarong, 1998).

The estimated coefficient of the total number of PCT filings is negative and significant, suggesting that total patenting propensity negatively affects the variation in RE patenting activity. It could be argued that the RE sector is less responsive to changes in the patenting propensity. This may relate to the issue of "lock-in", namely that countries that have a history in non-RE patents are "locked-in" these types of innovations; thus, having no impact on RE innovations (Beck & Martinot, 2004).

The Kyoto protocol dummy was also found to be insignificant. As noted, the Kyoto Protocol has increased the expected size of the global market for clean energy, redirecting the innovative efforts of the EU15 member states towards renewables. Such treaties usually create incentive frameworks for the diffusion of energy technologies, yet most are not designed to specifically foster energy technology innovation (Aguayo, et al., 2012). Only one other study had controlled for the Kyoto Protocol (s. Nesta et al. (2014) who also found it to be insignificant.

The coefficient of the final energy consumption has a positive and significant sign and is statistically significant at 1% in all Models. This is in line with the literature suggesting that RE innovations are more likely to take place when there exist a market for them. Previous studies argued that growing electricity consumption can be used to control for possible dimension of the possible market for RE (Johnstone et al., 2008; Nesta et al., 2014).

In terms of the year dummies, for Models 1 to 4 and from 1995 to 1998, the coefficients were found to be negative and significant. From 1996 to 2005, the coefficients were mostly insignificant and in most cases negative. In Model 5, the coefficients were mostly insignificant and varied in terms of their direction. From 2006 to 2013, the coefficients were in all Models positive and significant. This could be attributed to aggregate trend effects becoming more potent during that period. From a number of possible aggregate trend triggers, it is noted that it coincided with the adoption of the Kyoto protocol. Overall the use of year dummies seemed to be helpful and value adding.

4.5 Concluding Remarks

The effects of RE policy on RE innovation at the aggregate level have been examined but also in terms of three different policy instruments (technology-push, demand-pull, and systemic) and their interactions on RE innovation, in a cross-section of 15 EU countries[17] over the period 1995-2014. Building on existing literature a conceptual framework and Hypotheses have been developed. Evidence in support of all three hypotheses has been found.

This chapter's research adds to the literature in a number of ways. The first is related to the focus on the three types of instruments. This classification seems appropriate in terms of theory (Rosenberg, 1974; Nelson, 2009; Nemet, 2009; Rogge et. al., 2017) and has been adopted in some recent studies (Costantini, et al., 2015). The second relates to the examination of instrument interactions. It was found that RE policy has a positive and significant effect on RE innovation as a whole, and that RE policy instruments also have significant effect on RE innovation. It was also found that the interactions between instruments (especially those between technology-push and demand-pull on the one hand and systemic on the other) are positive and significant when analysed on their own. However, when examined alongside their components, it was found all component instruments as well as the interaction of all three to be positive and significant, while the interaction between the three individual pairs was negative and significant.

[17] It is worth noting that some recent scholars have started shifting their views of energy and sustainability transitions from a national level to a more city-centred approach (Coenen & Truffer, 2012; Hodson & Marvin, 2010; Knight, 2012), which could produce some useful insights when considering regional RE policies.

Reasons for these, including the possibility of different lag structures, have been examined, a suggestion supported by the results. Quantitatively it was found that the coefficients of technology-push were larger than those of demand-pull which in turn were found to be larger than those of systemic effects and of interaction effects. While reluctant to place much weight on precise quantitative effects given some sensitivity of results to lag structures and specifications, the results were found to be on balance robust in terms of the direction of the key relationships and in line with theory and the theory-informed Hypotheses of this chapter, albeit not with all specific suggestions by scholars. For example, the effects of the usually favoured demand side policies were found not to be larger than those of technology-push, while the two were not found to be complementary to each other. In general, the results supported the ideas that RE policy has a positive effect on RE innovation and that REP instruments can have different but important roles, and that interactions are important. Although the precise effects can depend on whether they are examined in isolation or alongside their individual components and the lag structures of the variables.

All the above have important implications for policy makers. They highlight that different instruments matter, their interactions matter and the way in which they interact and how they interact (for example alongside their component instruments or not) also matter. This is also the case for lag structures. Accordingly, much care should be taken to identify and leverage complementarities, while eschewing from potential inconsistencies and interactions. Such interactions between these instruments have not been properly taken into account in the existing literature, depriving policy-makers from a significant source of information (Magro & Wilson, 2013). Based on the above, it would appear that the optimal approach is for a government to employ policy instruments that complement, and are consistent with, each other, and that this is a matter for empirical design and can be contingent on each specific case. This in turn calls for further research, more disaggregated findings and triangulation, including case studies to support the quantitative econometric findings.

As with other studies, this research has limitations. The first limitation relates to the use of patent data as a proxy for innovation, which can be problematic. Nevertheless, in the absence of suitable and comparable alternative measures, it remains the most plausible and highly used indicator for this type of study. The second limitation relates to the fact that there are more determinants of RE innovation than accounted for in this chapter. However, a more comprehensive set of determinants than other studies was used, not least the separate instruments and their interactions. This and the consistency of the results with the literature and the Hypotheses render confidence in the findings. Overall the results seemed to be rather robust to various specifications used, and in line with theory and previous evidence.

To conclude in this chapter, I have sought to add to the literature in a number of novel ways, including the unique data base, the conceptual framework, the instrument types, the comprehensive coverage of possible relationships and their interactions. In the next chapter I aim to examine the extent to which Industrial Policy (IP) can help to pick wining RETs (an important longstanding concern in the IP literature). This is achieved by cross fertilising scholarly work on IP and RE.

Chapter 5
Can Industrial Policy Pick Winning Renewable Energy Technologies?[18]

As mentioned already, debates on IP have relied mainly relied on conceptual arguments and case examples with minimum econometric support. Research on public policy towards RE has employed econometric analyses but it has not cross fertilised adequately with IP debates, despite the RE industry having over the years being the recipient of substantial public support. A lasting debate in IP concerns whether government support to sectors and firms can help 'pick winners'. More recent developments have shifted attention to picking winning policies, policy instruments and/or technologies, especially General Purpose Technologies (GPTs). In this chapter, I submit that RE can qualify as GPT that consists of more specific RETs. Having developed theory and Hypotheses, econometric evidence for the impact of three IP policy instruments on different RETs is provided, followed by the unexplored role of country experience in mediating this relationship and for regional variations. Continuing from the previous chapter, I first test for the case of the EU. Going further, and in order to test for regional variations, I have controlled for North and South EU regions. This allows for better understanding on which policy instrument types work best per region. Last I employ an expanded more comprehensive sample that includes all OECD members. This is in order in order to test for regional variations between leaders and newcomers, as well as the old EU. And the new EU, EU north and south and EU versus the rest of the OECD. The expanded sample also allows us to extend the period under examination to between 1990 and 2014, as explained in Chapter 3. In addition, I examine whether the quality of the innovation outcomes is affected by IP.

[18] Based on the forthcoming paper by Pitelis, A. T., Chalvatzis, K., Vasilakos, N., and Pitelis C. N. (2019), in the Cambridge Journal of Regions, Economy and Society, with the same title.

5.1 Introduction

At the timing of writing this chapter, Europe together with most of the northern hemisphere are experiencing one of the hottest summers in their history (WorldWeatherAttribution, 2018), widely believed to be a result of ongoing anthropogenic climate change. It is also widely accepted that eliminating anthropogenic emissions especially those from energy use is the first step to climate change mitigation (Rockström, et al., 2017). To this end, there has hardly been a more opportune timing to explore the renewable energy (RE) transition and the role of public policy in fostering such a transition - the aim in this chapter.

The need for transition from non-RE sources to RE has long been recognised (Smil, 2010). That recognition has led to debates about the role of the relative advantages of markets and governments-public policy in bringing about desired change. In the process of growing from a nascent sector into a major contributor of power generation, RE has benefited from both direct public support (e.g. subsidies) and indirect one (e.g. training and awareness programmes). Despite that being a clear case of Industrial Policy (IP), namely policies and policy instruments that aim to direct industry towards achieving a particular desired objective (Bailey, et al, 2015), links between IP, RE and RETs have been underexplored. This is acknowledged by the European Union (EU), who has recently enriched its "New Industrial Policy Strategy" with the Launch of the EU clean energy industrial competitiveness and innovation forum for renewables (European Commission, 2017; European Commission, 2018).

IPs can be any type of government policy that affects industry, often delineated to those policies that seek specifically to improve manufacturing competitiveness, usually in its link and interactions with other sectors such as services and even agriculture (Pitelis, 2015). They can aim to substitute or complement market forces by reinforcing or counteracting the allocative and other effects that existing markets would otherwise bring about. In case of missing markets, IPs can also serve as market creation and co-creation devises – the creation of carbon markets being a case in point. They are sometimes seen as a *discovery process* where firms and governments learn about underlying costs and opportunities and engage in strategic cooperation. Both the government and the private sector have imperfect information. This engenders information externalities and implies that the two would benefit by engaging with each other. At the same time however, such an engagement can foster additional negative externalities such as regulatory capture, corruption and rent-seeking – the pursuit of rents from firms, sectors and/or policy makers (Rodrik, 2004). In this case instead of government policy solving market failures, it can help accentuate existing and/or create new ones.

The debate between market versus government failure has been central in IP discourse throughout its history (Pitelis, 1994). In brief, mainstream neoclassical economic theory would recommend public sector intervention only in cases of market failures (such as externalities, monopolistic restrictions and public goods), and provided that the public sector intervention does not cause more damage than it helps avoid. More recently scholars in the "new IP" tradition, have claimed that missing linkages and connections, filling gaps and learning can be important reasons for government IP interventions. Scholars such as Stiglitz (1989) have pointed to the ubiquity of market failures but have also highlighted causes and instances of government failures – hence leaving the question of the effectiveness of public IP not fully resolved. Importantly, the various arguments by the aforementioned IP scholars are rarely backed by econometric evidence.

In this chapter, the aim is to address this gap by looking at IP in the context of the RE sector. The exercise is important because the RE sector has been the recipient of public sector support and can serve as a first ambitious step to decarbonisation. Moreover, the RE sector lends itself to econometric work in part as a result of data availability. Despite that the link between IP and

RE has remained elusive (Pitelis, 2018). In this context, it is of particular interest to know what type of IP and policy instruments as well as which degree of targeting are likely to be more or less successful.

Traditionally the idea of targetting focuses to specific sectors and/or firms, see Bailey, Coffey, Gavris, & Thornley, 2018. Support for RE can in itself be seen as a form of targetting in that it privileges a particular sector. More recently, however the idea behind targetting and picking winners has been extended beyond that of sectors and firms, to picking winning policies and/or winning technologies (Helm, 2010). This form of targetting is relevant to RE since there is a range of technologies suitable for the exploitation of different RE sources. In the RE literature there have been a number of studies that have looked at different policy instrumernts as well as different RETs. None of these studies however has been conceptualised and/or formulated in the context of IP, and/or as a test of the picking winners view. Addresing this limitation is an intended contributions in this chapter.

In the above context, the aims of this chapter are as follows; apply the notion of targetted IP-picking winners to the case of different RE policy instruments and to specific RETs (in particular biomass, geothermal, hydro, wind, and solar), as well as to cross-fertilise IP and RE literature. In this context theory and Hypotheses are developed and provide econometric evidence (in particular by testing for the role of IP instruments in fostering RE and specific RETs). Three more innovations are made: The first is to explore the issue of “country experience” and hence “learning” as a factor that mediates the relationship between RE policy and RE innovation. The second is to control for regional variations. A third is to look at the extent to which public policy affects the quality of innovations. All these are conceptually plausible relationships to explore in the context of extant debates (see below) but have not been discussed before.

The remainder of this chapter is structured as follows: The next section focuses on theory and hypotheses development; section three describes the empirical model, method, data and variables; section four presents and discusses the results and section five provides concluding remarks, limitations and opportunities for further research.

5.2 Theory and Hypotheses Development

Industrial Policy (IP) and Renewable Energy (RE)

As noted, the use of fossil fuels as the primary source of energy worldwide has been associated with environmental and climate challenges. With international agreements such as the Kyoto Protocol (United Nations, 1998) and more recently the Paris Agreement (United Nations, 2015) many governments have been pursuing ambitious RE targets and pursuing decarbonisation pathways, with varied degrees of success (see Flamos, 2010; Honegger & Reiner, 2018; Viñuales, Depletze, Reiner, & Lees, 2016). Within liberalised power markets the realisation of such targets often requires public policies and actions that help to trigger corporate interest and leverage private funding for large-scale RE projects (The Research Council of Norway, 2017). While some suggest that such policies work only in the case of clear and pervasive market failures, and provided government failures are not as damaging, others point out to that government IP can be complementary to, and supporting of, market forces (Bailey, et al., 2015). Instead of crowding out private investment in this view, government policy and intervention can instead help crowd investment in (Holland, 2014).

History-wise IP has been argued to have had three generations; the *vertical* IP that focused on backward linkages as justification for picking winners, the *horizontal* IP that focused on across the board market failures as justification for economy-wide not targeted policies, and the *open market* IP that focused on missing linkages and connections (Kuznetsov & Sabel, 2011). The first phase took place between the 1940s and 1960s, the second between the 1970s and 1990s, and the third one from the 2000s to date. The reasons are varied and include developments in economic theory and changes in political ideas about the role of markets and governments (Warwick, 2013). To these a fourth more recent generation could be added, that of the market and business ecosystem co-creation view that focuses on the complementary roles of the private-public interface as regards particularly co-creating markets and supporting business ecosystems (Pitelis & Teece, 2016), alongside its cousin place-based approach that has a similar ecosystem focus while also emphasising the role of geography and place/space (Bailey, et al, 2018).

In the case of the vertical IP, the focus was sectoral and at the microlevel (Kuznetsov & Sabel, 2011), something that Burton (1983) had identified as *accelerative* IP. In particular Burton argued that IP have had two classes – *accelerative* and *decelerative.* The first most commonly known as "picking winners" aimed to "stimulate the birth rate of new business ventures" (Burton, 1983, p. 8) while the latter aimed at reducing the "death rate of senescent companies and industries" (ibid, p. 8). Regarding the picking winners approach, the main weakness was felt to be that it is almost impossible for a government to pick a winner – since there are no means of prediction, neither in standard economic theory nor by everyday experience. All the same, the picking winners approach had been used with a degree of success in Japan and other industrialising countries (Chang, 1993) while a variant of it employed by China is arguably bearing fruits (Pitelis, 2015). It is also arguably in part because of such succeses that following a long period of focus on "horizontal policies" that focused on education, infractruture and public sector efficiency, sectoral and targetting policies are now back with a vengeance (Bailey, et al., 2015).

In recent years, EU industrial and regional policy has employed the concept of "smart specialisation strategies" (3S thereafter). In this 3S view, sectors and specific regions can build on their extant comparative advantages to generate novel competitive ones in new areas of specialisation. This is said to entail a process of *discovery of local concentration and agglomeration of resources and competencies in novel domains of opportunity* (Foray, 2015). In line with the market failure argument, this view suggests that in many cases market and systemic failures lead to under-investment in such processes and activities by the private sector. In such cases the public sector can go beyond horizontal policies with the aim to assist regional players to identify, shape and take advantage of new opportunities (Foray, 2015). This, in turn can help regions to become more dynamic and more "sticky"-namely with unique and embedded advantages vis-a-vis other regions. In their essence, place-based IP and 3S-type approaches are about auditing and appreciating the nature and dynamics of the regional eco-system, and nurturing and leveraging potentially promising opportunities that can foster regional advantage. In addition to proximity within an eco-system, 'relational embeddedness' of firms and other regional actors within ecosystems, help create and diffuse new knowledge and foster innovation (Bailey et al, 2018).

Identifying suitable 3S-type cases requires strategic collaboration between private and public sector actors that involves sharing of information around potential opportunities and critical evaluation of policies. This entails policy learning in a process of an 'embedded autonomy' (Bailey, et al, 2018) – this practically means the exercise mutually beneficial collaboration without however this leading to collusion. This of course is easier said than done and depends among others on institutional, cultural and historical factors-hence the need to also look at both policy learning and regional variations.

In terms of EU RE, the basis for a Europe-wide RE policy was set by the *White Paper for a Community Strategy and Action Plan Energy for the future: Renewable sources of energy,* which sets out the EU strategy on RE and set a number of targets, including doubling the use of RE in the EU gross energy consumption (European Commission, 1997) The *Renewable Electricity Directives 2001/77/EC* and *2009/28/EC* (European Parliament, 2009), set RE targets for 2010 and 2020 (European Commission, 2001; Scarlat, et al., 2015), and the introduction of The Emissions Trading Scheme in 2005 (European Commission, 2015). More recently the European Commission (EC, 2017), has set out proposals for a new Directive for the promotion of the use of energy from renewable sources (European Commission, 2016).

As regards particular measures, and echoing the more general debate on IP and the specific RE policy instruments, some argued that technology blind instruments, like sector-wide subsidies, are adequate to foster innovation (Nordhaus, 2009). In this view, targeting specific RETs can distort the functioning of carbon markets and hinder efforts to decarbonise the economy (Moselle & Moore, 2011; Less, 2012), while the ensuing social costs might be higher than their benefits due to rent-seeking, transaction costs and information problems (Kalkuhl, Edenhofer, & Lessmann, 2012). Indeed, on one hand, it can be argued that targeting a particular RET for support can help achieve a policy target more effectively in that it facilitates better focus and allocation of often limited resources. On the other hand, however, targeting specific RETs involves the opportunity costs of not pursuing other actions, and increases the costs of any failures in that other potentially more effective measures have not been pursued. While public policy in general can involve the possibility of government failures, it is arguable that more targeted policies are likely to involve a higher possibility of failure both in identifying the target and in ensuring that targeting one technology does not have negative impact on other technologies. These problems are likely to be more acute the more targeted the policies are, leading to circumstances when governments trying to pick winners, may instead end up picking losers (Helm, 2010).

Other scholars have argued that a policy mix that incorporates support for specific RETs may still be preferable (Stern, 2006; Fischer & Newell, 2007; Kalkuhl et al., 2012). This is not least as it fosters learning. Questions and challenges remain, however, including what can be counted as a renewable form of energy – and therefore being eligible for support, and how does one choose the weights to be placed upon the different RETs (Helm, 2010). This, according to Helm has resulted in the 'renewables pork barrel' for lobbyists to compete for, and therefore a major problem in rent-seeking. Theory aside, in practice the current policy mix in the EU implements both general support and technology specific instruments. This renders the need for evidence all the more pressing.

In terms of extant evidence, in IP there is an abundance of case study-based anecdotal evidence (e.g. Chang et al., 2016) but very little in terms of econometrically-supported research. This is not the case in RE literature where econometric work is not uncommon. In such work general policies and policy instruments have been found on balance to have a positive and significant effect in fostering innovation in RE (Johnstone, et al., 2008; Nesta, et al., 2014; Pitelis, 2018). On the other hand, RE-related research has mostly failed to cross fertilise literature on IP and tends to be overly evidence (with limited theory) focused.

Important is also that despite significant progress with IP thinking, especially in its fourth generation of 3S, place-based and ecosystem-based IP, there remain many unresolved and even non-questioned issues. One is whether country experience and hence learning can moderate the degree of effectiveness of IP in general and targeted IP in particular. While learning is a critical part of the 3S approach and also the work on IP of Joseph Stiglitz, Giovanni Dosi and others (see Cimoli, Dosi, & Stiglitz, 2009) it has never to my knowledge been tested. Besides learning from cooperation as per the 3S view, countries can also learn from trying, failing and/or succeeding in terms of particular policies, instruments and targeting. All these promising ideas can benefit from empirical testing.

Another argument concerns regional variations. EU regions differ in terms of their RE-related advantages and experiences. A 3S-type view takes extant advantages as a basis. Accordingly, one would anticipate that there will exist regional variations in the degree of effectiveness of RE policies, not just because of learning but also because of history and path dependency as such (see Aghion, P. et al., 2012 for more on path dependency). One for example might hypothesise that 'Southern' countries that have been plagued with higher degree of market and government failures might tend to perform worse, ceteris paribus. This is precisely because of public-private cooperation and hence mutual learning failures and also because of prevalence of more traditional rent seeking, transaction costs regulatory capture and corruption-type cases (Pitelis, 2017). Despite a large body of literature on learning in policy diffusion (Stiglitz, 1989, Nelson, 1993, Rodrik, 2004) the idea has not to my knowledge been tested econometrically.

The last important question is about quality and it relates to whether challenges of targeting are not reflected (merely) in terms of failure to foster innovation, but (also or instead) in terms of fostering the wrong type of innovations- for example lower quality ones. The "picking winners" hypothesis critics have not entertained such a possibility to my knowledge which consequently has also not been tested before. It is however both a plausible deduction from a government failure-market distortion point of view, arguably worthy of further exploration and testing.

Hypotheses Building

Considering the mixed record of targeting sectors, the case for targeting RE needs justification. As already noted, in recent years the case for targeting has shifted from sectors to policy instruments and/or technologies, not to specific sectors as such. The debate concerning General Purpose Technologies can provide an answer. Bresnahan and Trajtenberg (1995) introduced the concept of “General Purpose Technologies” (GPTs), as in effect epoch-making ones. The authors proposed three criteria for a GPT: (1) being pervasive; (2) being capable of ongoing technical improvement; and (3) enabling complementary innovations in other sectors (Bresnahan & Trajtenberg, 1995). In other words, GPTs have economy-wide effects, can improve over time, and can help trigger a raft of further innovations. It is arguable that RE qualifies as a GPT. Its adoption can be applicable in virtually every economic activity-from construction to manufacturing, to agriculture (consider energy self -sufficient greenhouses). This is because of scale flexibility and the potential for electricity transmission. Specifically, almost all types of renewables come in various sizes either without any loss in technical efficiency; they achieve that either by modular design (solar PV) or by engineering configuration (small and large turbines for hydro, geothermal and wind energy). It is particularly this attribute of renewables that has given rise to distributed energy systems (Alstone, Gershenson, & Kammen, 2015; Parag & Sovacool, 2016), offering efficiency without the need for a large-scale grid, and making renewables applicable almost everywhere. Even beyond scale flexibility, the existing power grid and virtual power markets allow physical and logistical power transmission between producers and consumers. This enables large power consumers to sign private Power Purchase Agreements (PPAs) with wind or solar farms (see Google, Facebook etc.) or residential consumers to sign up for RE tariffs (Bird, et al., 2017). RE technologies also improve over time both in terms of their efficiency in energy generation and in terms of their own manufacturing - solar PV cost for example has gone down over twelve times during the last decade (LAZARD, 2017). Innovation and growth of RE applications has triggered further innovation in a range of adjacent sectors; for example, long-distance High Voltage Direct Current (HVDC) transmission systems were developed to take RE from remote offshore wind farms to urban consumption centres (Elliott, et al., 2016); smart grid applications were developed to facilitate grid services and power multi-directionality (Batista, Melício, & Mendes, 2017) and grid-scale batteries were developed to improve demand and supply timing with intermittent output renewables (Zafirakis, et al., 2016).

Pitelis and Teece (2016) have argued that as regards IP, it is plausible and in line with historical experience to suggest that public support is likely to be more effective when it targets GPTs. This is in part because it is easier to appreciate their significance, albeit imperfectly (consider electricity and the internet), and in part because private initiatives are unlikely to be forthcoming and or effective in such cases due to the scale of requisite investments and the uncertainty over any future returns (the internet being a case in point). According to the authors, on the other hand, private business may well in turn be best to capitalise and commercialise on these publicly funded GPTs/innovations (consider Microsoft) (Pitelis & Teece, 2016).

Moreover, in line with the more recent shift of attention, the focus here is on particular RE policy instruments. The debate on RE policy instruments is long standing but it is arguable that following a healthy and extensive debate over the years, the literature seems to have reached a consensus in terms of three key categories of RE policy instruments, namely technology-push (such as RD&D grants and loans, and tax incentives), demand-pull (such as feed-in tariffs, and subsidies), and systemic (such as tax and subsidy reforms, and education system) (see Pitelis, 2018, for more extensive discussion). The first group refer to those that impact on the supply side, in particular the willingness and capability of firms to innovate: the second impact on the demand for RE, in particular they boost demand for RE; the third are systemic instruments that operate at the economy-wide level and help boost the effectiveness of both technology-push and demand-pull.

Based on these arguments it is plausible to derive the following Hypothesis (H).

H1: *RE policy instruments have a positive effect on RE Technologies*

The basis of this hypothesis is that RETs as a whole are easier to target and support than particular firms; hence, on balance one would expect that RE policy instruments will have a positive and significant effect on RETs.

While overall positive, the impact of REP instruments on RETs is likely to be variable between different REP instruments and different RETs, for instrument, technology and country specific reasons. This leads to the second Hypothesis.

H2. *The effect of RE policy instruments on RETs varies between specific instruments and RETs.*

The first two hypotheses are similar to those from Chapter 4 but for the expanded sample. In addition, reflecting on the additional literature, my control variables are different. Overall, the expanded sample and the new control variables allow for comparisons between the findings of the two chapters, (specifically among the EU15, the whole of the EU, (that is the more experienced and the newcomers) and the OECD as a whole.

The next Hypothesis follows on from the above and submits that one factor that can help mediate the aforementioned relationship is country experience and hence learning. In particular, the more experienced a country will be in supporting RETs the more likely it will be to be successful. Hence, it is anticipated that more experienced countries will be more successful in terms of fostering RETs.

H3: *The impact of targeting particular RETs on RE innovation is mediated by a country's experience.*

The fourth hypothesis in effect states that not all regions are equally qualified to target effectively. Countries differ in terms of their capacity to design or implement RE policies. An apparently politically incorrect but pragmatically plausible argument is that the degree of development (including institutional and governance development) of a country serves as a proxy for its capability to design and implement RE policies. If so, one would expect the Southern regions (countries) of the EU to be less effective than the Northern ones, as a result of their legacy in failures by both the public and private sectors (see Pitelis, 2017). Hence

H4: *The efficacy of targeting RETs differs across regional blocks*

The fifth Hypothesis is essentially an extension of the argument that a government cannot pick winners but with a twist or two. First the focus is on technologies not firms or sectors. Second it suggests that any failures in picking winners is in terms of fostering lower quality of RE innovations. This is in line with both theory and practice (for example the prevalence of investments aimed at taking advantage of a particular government programmes). This would imply the need to adjust for quality of innovations emanating from public sector support. Accordingly

H5: *Public support for particular RETs impairs (has a negative effect on) the quality of the RET innovations*

It is worth noting that while the first two hypotheses have both been made and tested before in the RE literature (even if not sufficiently cross-fertilised and informed by advances in IP literature), the other three have not been tested and/or hypothesised before. This is arguably in part because of the failure to employ and develop theory and in part because of the requirement for a comprehensive data set and sophisticated econometric techniques. Below those limitations are addressed.

5.3 The Model and Variables

Following the specifications in Chapter 3, a panel consisting of all the OECD members for between 1990 and 2014 was constructed. Reasons for the choice of countries and time span have been explained in said chapter, while the reasons for going from the EU15 in Chapter 4, to OECD in this one, are given in the beginning of this chapter.

5.3.1 Dependent Variable: RE Innovation

Following the review in Chapter 3, the DV in this chapter is RE innovation proxied by patents. Overall, a total of 217,393 patent counts were obtained and proxied.

5.3.2 Independent Variable: RE policies and REP Instruments

For the purpose of this chapter, data on RE policies were proxied. Furthermore, in order to test for the third Hypothesis an additional index for experience and learning was created. It was also hypothesised that experience and learning can be proxied in terms of the extent of intervention (high and low policy intervention of countries) and used it to test for the impact of experience on the efficacy of targeting. Following that, two more regional dummies for the North and South European countries were created, in order to test the fourth hypothesis. Last, the quality of innovations was also examined (as explained in Chapter 3), in order to explore whether targeting impacts upon/distorts the innovation outcome.

5.3.3 Control Variables

RE innovation is likely to be affected by a raft of other factors, besides public policies. Therefore additional controls are in need for such other key factors. Returns on innovation are affected by the potential market for this innovation. In the case of RE this is best reflected in trends for electricity consumption. A large growing market for electricity should increase incentives to innovate with respect to RETs. Data on household and industry sector electricity consumption was obtained from the IEA/OECD database, in GWh. Both observed and calculated balances exist, which in this chapter were averaged. An index developed by the EuroSTAT (2016) related to the market share of the largest generator in the electricity market was employed. This is in order to control for market power. It is expected that this should have a negative effect on RE innovation, as the higher it is (tending to monopoly), the less the incentive to innovate will be as a result of the fear of appropriating the returns from innovations due to monopolistic restrictions (Teece, 1986). In addition, total Government Budget Allocations for R&D (GBARD) by socio-economic objective (SEO) was also included. This controls for the overall tendency of a government to support innovation. Its precise sign is hard to predict, in that while overall the more pro-innovation a government is, the more this is likely to incentivise RE innovations, on the other hand governments can also support non-RE innovations rendering the interactions tricky to hypothesise on an a priori bases. Data was extracted from the OECD database for the years under examination (1990-2014), and converted to constant 2010 USD prices and purchasing power parity by the authors. Finally, the model has been augmented by including a dummy variable set to unity for the years after the Kyoto protocol came into force in 2005, in order to capture changes in expectation on both the context for future policy and the global market size for RE (Nesta, et al., 2014).

In terms of procedure firstly the impact of RE policy instruments on RE innovation in the OECD and European countries as a whole were compared and contrasted.

In terms of IP intervention, the average annual number of REP policies implemented over the period 1990-2014 was taken and have created two groups on this basis, as follows:

High policy intervention group: countries that have implemented more than the average number of REP of all countries over the sample period (i.e. 4 REP per year).

Membership rule: $$\frac{\sum_{t=1990}^{2014}\sum_{i=1}^{5}\mathrm{REP_{it}}}{n} \geq \frac{\sum_{j=1}^{34}\sum_{t=1990}^{2014}\sum_{i=1}^{5}\mathrm{REP_{itj}}}{n} \quad (5\text{-}1)$$

Low policy intervention group: countries that have implemented less than the average number of REP of all countries over the sample period.

Membership rule: $$\frac{\sum_{t=1990}^{2014}\sum_{i=1}^{5}\mathrm{REP_{it}}}{\mathrm{n}} < \frac{\sum_{j=1}^{34}\sum_{t=1990}^{2014}\sum_{i=1}^{5}\mathrm{REP_{itj}}}{\mathrm{n}} \quad (5\text{-}2)$$

5.3.4 Methodology

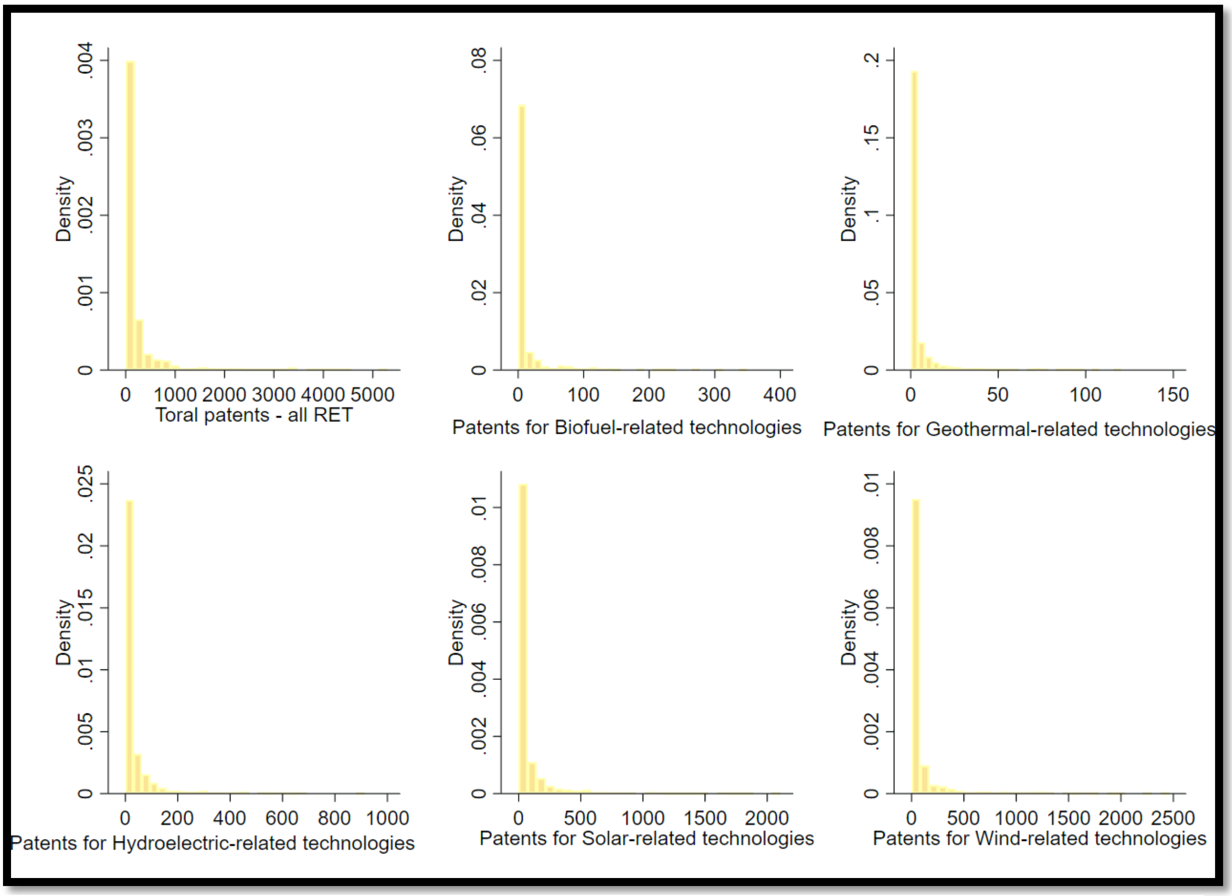
Considering the nature of the dependent variable (number of patent, which is a count variable), and as mentioned in Chapter 3, a conditional negative binomial model for panel data was employed which follows the classic model of Hausman, Hall and Grilliches (1984) and augments the basic negative binomial model to include fixed effects. Typically, negative binomial regressions are suitable for use with over-dispersed count variables -commonly when the conditional variance of the outcome variable exceeds the conditional mean, as is the case for all innovation measures that is used in this chapter. For instance, in the case of total non-quality adjusted patents, the conditional variance is found to be 6.8, which is greater than the corresponding conditional mean of 4.8. Figure 26 illustrates the distributional properties of the patent data by renewable technology.

The sample is drawn from the OECD database and it includes information on all 34 OECD countries, over the period 1990-2014. The model is designed to evaluate the effectiveness of policy support instruments on the innovation activity of five core renewable technologies: biomass, geothermal, hydroelectric, solar and wind related technologies. The dependent variable of the regression is, therefore, a vector of length 5, depicting patent counts by renewable technology. In particular, the core estimation model takes the following form:

$$RE\ Innovation_{i,\,t,Te} = \alpha + REP_{itj}\,\underline{\beta} + X_{itj}\underline{\gamma} + \ v_i + u_t + \varepsilon_{itj} \quad (5\text{-}3)$$

Where, “i” denotes the values per country, “t” the year (1990, …, 2014), and “j” the technology; “REP” is the vector of policy variables, “X” the vector of control variables, and “v” and “u” the country and time fixed effects respectively.

Figure 26: Distributional properties of patent data by renewable technology



Source: Author

In order to test for the quality of innovations, an index derived from the ratio of the citations over the average citation performance for that year/country for each technology was constructed and used. The importance of controlling for quality of innovation when assessing policy effectiveness has been raised in several recent papers (Flanagan and Uyarra, 2016; Blind, 2016; Athey and Imbens, 2017) but not tested in this context.

5.4 Results

Starting with all OECD countries (columns on the left of Table 17), it can be seen that the effects are quite varied and that policy instruments have different levels of success in stimulating innovation, depending on the instrument and technology. Overall, all five hypotheses were supported, and some very interesting findings a propos control variables (notably market concentration hindering RE innovation) were also derived. As evidence has been found for the first hypothesis for both EU (Chapter 4) as well as the extant literature, in this Chapter the focus was on the disaggregated variant only.

In more detail, REP instruments have different effects on RETs. As in this chapter additional control variables were used, the effects of RE policy instruments on RE innovation for the whole OECD were rerun, for comparability (within this chapter) reasons. It can be seen that in the case of Biomass, technology-push instruments have a positive and significant effect on innovation at 1%, and demand-pull have a positive and significant effect at 5%. Quantitatively this means that an increase in technology-push instruments will result in a 1.25% increase in the patenting activity, while an increase in the demand-pull ones, will result into a 1.18% increase. With regards to geothermal technologies, no policy instruments were found to be of significance. Hydro innovation was found to be fostered by both the technology-push instruments (positive and significant at 1%), and the demand-pull ones (positive and significant at 0.1%). Quantitatively, this translates into a 1.27% increase in the patenting activity from the technology-push instruments, and a 1.39% from the demand-pull ones. Solar technologies, were found to be fostered by only technology-push instruments, at a significance level of 5%. Finally, innovations in wind technologies are due to demand-pull instruments, at 0.1%, while a negative but significant level was also found for systemic instruments at 5%. In a quantitatively sense, these imply a 1.25% increase in the innovative activity as demand-pull instruments increase, while an increase in the systemic instruments will result in a 0.92% decrease. Differences between these findings and the results of the previous chapter can be attributed to the different control variables, and especially the total government budget allocations, which makes more sense for the cases to follow.

Regarding the control variables, marker concentration was found to be negative and significant for the cases of hydro (at 5%) and Solar (at 0.1). The negative sign implies that the greater the concentration the less is the incentives to innovate, as mentioned in the previous chapters, and quantitatively, these imply that an increase in concentration will decrease the innovative activity by 0.99% in both cases. The electricity market size, was found to be positive and significant for all RETs apart from solar, at 0.1% for biomass, hydro, and wind, and at 1% for geothermal. The dummy for the Kyoto protocol was also found to be positive and significant with the exception of biomass technology, at 0.1% for geothermal, solar, and wind, and at 1% for the hydro technology. Finally, the total government budget allocations were found to be insignificant in all but the case of wind technologies, were a negative but significant at 5% sign was found.

When it comes to the countries with high policy intervention however, the story is different. Technology-push instruments are only found to be positive and significant for the cases of geothermal and hydro technologies, both at 5%, while it was insignificant for the rest. Quantitatively, an increase in technology-push instruments will result in a 1.73% increase in the geothermal patenting activity, and a 1.36% increase in the case of hydro. Demand-pull instruments on the other hand, were found to be positive and significant at 0.1% for all cases except biomass, where it was positive and significant at 1%, which is also in line with the theory discussed in the previous chapters. On a quantitative manner, and increase in the demand-pull instruments will result in a 1.5% increase in the innovative activity for the case of biomass, 2.83% increase in the case of geothermal, 1.78% for the case of hydro, 1.38 for the case of solar, and 1.37% for the case of wind. Regarding the systemic instruments, they were found to be negative and significant in the cases of all RETs under examination, at 5% for biomass and 0.75% decrease in the patenting activity as systemic instruments increased, at 1% for geothermal and 0.7% decrease, at 1% for hydro and a 0.8% decrease, at 1% for solar and

0.88% decrease, and at 5% for wind and 0.89% decrease. These are again in line with the theory and expected.

Contrary to the previous case, market concentration was found to have no significant effects on the innovative activity of the RETs for the high intervention counties, while the same is true for the total government budget allocations. Regarding the electricity market size, it was found to be positive and significant in all cases except the solar technology, at a 0.1% for the case of biomass, 5% for geothermal and hydro, and 1% for wind. Finally, Kyoto protocol was found to be positive and significant for the cases of hydro at 5%, and for solar and wind at 1%.

Again, the results change when considering countries with low policy intervention. It seems that in these countries, technology-push instruments are more important than demand-pull ones in fostering innovation. Specifically, innovations in biomass technologies are fostered by technology-push instruments which were found to be positive and significant at 5% (implying a quantitatively increase of 1.26% in patenting activity), and for solar and wind at 1% (implying a 1.23% and 1.2% increase respectively). For hydro technologies, both technology-push, and demand-pull instruments were found to be positive and significant at 0.1% and 5% respectively, which in quantitative terms translate into a 1.36% and 1.22% increase in the patenting activity respectively. None of the RETs seem to be affected by the introduction of systemic instruments.

As expected, market concentration was found to be negative and significant but only for the cases of hydro (at 5%) and solar (at 1%) technologies, while the electricity market size have had an effect only in the cases of hydro (positive and significant at 5%) and wind (again, positive and significant at 5%). The Kyoto protocol dummy was found to be positive and significant at 0.1% in the cases of geothermal, solar, and wind, while it was of no significance for the cases of biomass and hydro. Finally, the total government budget allocations were found to be insignificant in all cases.

Overall, technology-push policy instruments had an overall positive and significant effect on innovation, except for geothermal and wind technologies. Similarly, demand-pull policy instruments were rather effective in boosting innovation for biomass, hydro and wind-related technologies, but not so for geothermal and solar. Systemic policy instruments had no significant effect on innovation outcomes for all but one technology (wind) - for which the effect was marginally negative. On balance the overall reflects are positive and in line with previous research that has employed aggregate RE policies as independent variable (Pitelis, 2018), hence supportive of the first Hypothesis. As the aggregate relationship masks the disaggregated effects here the focus was on the latter. The results lent support to the second Hypothesis.

Given that OECD is a group of countries with largely different approaches to regulatory policy, it is quite possible that pulling together all OECD data may average away some of the key effects that should be explained. This potential concern was addressed by splitting my dataset to two smaller groups: high policy intervention and low policy intervention member countries, following again the methodology that was described earlier in Chapter 3 (Table 17, columns on the right). The magnitude and significance of the estimated coefficients was now quite different: technology-push policy instruments were found to be largely ineffective in promoting innovation, when used by high intervention OECD countries; unlike demand-pull policy instruments which were found to be the most effective for this group. The exact opposite was true for low-intervention countries for which (demand)- technology- (pull) push policy instruments were found to be rather (in)effective. Systemic policy instruments did not have a significant positive effect for either of the two groups – in particular, the effect of these policy instruments is negative and significant for the high intervention group and positive but not significant for the low intervention group, across the entire spectrum of renewable technologies. This supports the third hypothesis.

The findings about policy instruments are in line with theory and earlier studies (Pitelis, 2018). As regards in particular the systemic ones, it is arguable that the finding of an insignificant effect is not very surprising. The very aim of systemic instruments is to support the efficacy of demand-pull and technology-push ones. In this context their effects are likely to be exhausted in terms of their impact on the other two. Differently put, the observed coefficients for systemic policies show the differential impact such policies may have in addition to that they have through the other two. It is this additional impact that is found to be insignificant.

Table 16: Results for the OECD Specification

	All OECD					High Intervention OECD					Low Intervention OECD				
Policy and control variables\Innovation intensity	Biofuel	Geo-thermal	Hydro	Solar	Wind	Biofuel	Geo-thermal	Hydro	Solar	Wind	Biofuel	Geo-thermal	Hydro	Solar	Wind
Technology-push PI	0.229**	0.219	0.240**	0.139*	0.086	0.231	0.548*	0.306*	-0.0524	-0.059	0.230*	0.0776	0.306***	0.210**	0.184**
	(-2.58)	(-1.52)	(-3.26)	(-2.39)	(-1.57)	(-1.21)	(-2.14)	(-2.36)	(-0.45)	(-0.61)	(-1.98)	(-0.4)	(-3.84)	(-3.13)	(-3.01)
Demand-pull PI	0.168*	0.215	0.329***	0.102	0.226***	0.405**	1.041***	0.577***	0.323***	0.316***	0.156	-0.0255	0.204*	-0.0036	0.0927
	(-2.1)	(-1.58)	(-4.57)	(-1.73)	(-4.1)	(-2.86)	(-4.55)	(-6.51)	(-3.46)	(-4.37)	(-1.52)	(-0.14)	(-2.18)	(-0.05)	(-1.1)
Systemic PI	-0.0527	-0.000604	-0.0187	-0.0278	-0.0832*	-0.276*	-0.350**	-0.217**	-0.123**	-0.111*	0.119	0.273	0.116	0.0902	0.0331
	(-0.72)	(-0.01)	(-0.40)	(-0.85)	(-2.41)	(-2.07)	(-2.91)	(-3.20)	(-2.65)	(-2.42)	(-1.11)	(-1.95)	(-1.74)	(-1.31)	(-0.56)
Market Concentration	-0.00612	0.00697	-0.00659*	-0.013***	-0.00609	-0.0151	0.0212	-0.00809	-0.0143	-0.00795	-0.00587	0.0165	-0.00950*	-0.0116**	-0.0053
	(-1.37)	(-1.00)	(-2.00)	(-3.82)	(-1.93)	(-1.40)	(-1.91)	(-1.69)	(-1.95)	(-1.47)	(-0.90)	(-1.5)	(-2.27)	(-2.81)	(-1.23)
Electricity Market Size	0.0000068***	0.0000061**	0.0000053***	1.42E-06	0.0000053***	0.0000079***	0.0000074*	0.0000038*	7.48E-07	0.000005**	0.0000011	0.0000026	0.0000048*	0.0000021	0.0000053*
	(-4.45)	(-3.21)	(-4.42)	(-1.14)	(-5.05)	(-3.96)	(-1.99)	(-2.31)	(-0.46)	(-3.05)	(-0.34)	(-0.71)	(-2.43)	(-0.88)	(-2.47)
Kyoto dummy	0.154	0.879***	0.242**	0.647***	0.450***	-0.0178	0.222	0.279*	0.413**	0.429**	0.27	0.940***	0.156	0.664***	0.386***
	(-1.2)	(-5.39)	(-2.65)	(-6.96)	(-5.64)	(-0.11)	(-1.13)	(-2.21)	(-2.6)	(-3.04)	(-1.57)	(-4.28)	(-1.37)	(-5.19)	(-3.74)
Total Government Budget Allocations	-0.0000373	-0.0000324	-0.0000407	0.0000039	-0.0000488*	-0.0000473	-0.0000415	-0.0000495	0.0000025	-0.0000363	0.000106	0.000019	0.0000148	-4.93E-06	-0.0000364
	(-1.34)	(-1.07)	(-1.90)	(-0.17)	(-2.50)	(-1.31)	(-1.04)	(-1.72)	(-0.09)	(-1.38)	(-1.64)	(-0.26)	(-0.38)	(-0.10)	(-0.78)

All specifications include country fixed effects and year dummies. t-values in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 17: Results for the OECD Specification, Adjusted for Quality

	High Intervention OECD					Low Intervention OECD				
Policy and control variables\Innovation intensity	Biofuel	Geo-thermal	Hydro	Solar	Wind	Biofuel	Geo-thermal	Hydro	Solar	Wind
Technology-push PI	0.448	0.319	0.998***	0.162	0.607**	0.188	-1.322*	-0.174	-0.204	-0.153
	(-1.56)	(-0.59)	(-3.43)	(-0.62)	(-2.81)	(-0.7)	(-1.97)	(-0.65)	(-0.81)	(-0.90)
Demand-pull PI	0.385	1.221*	1.037***	0.0758	0.451*	0.244	0.0943	0.0997	-0.416*	0.0147
	(-1.71)	(-2.45)	(-5.44)	(-0.38)	(-2.36)	-1.28	-0.27	-0.46	(-2.00)	-0.08
Systemic PI	-0.151	-0.48	-0.996***	-0.363**	-0.614**	-0.195	-0.362	-0.252	-0.133	-0.207
	(-0.75)	(-1.13)	(-6.06)	(-2.60)	(-3.00)	(-1.07)	(-1.50)	(-1.48)	(-0.74)	(-1.55)
Market Concentration	-0.00552	0.0535**	0.0156	-0.0133	-0.0114	-0.00104	0.0185	-0.0225***	-0.0142*	-0.0232***
	(-0.37)	(-2.78)	(-1.36)	(-1.09)	(-1.02)	(-0.12)	(-1.32)	(-3.68)	(-2.08)	(-3.57)
Electricity Market Size	0.0000123**	0.0000182***	6.82E-06	5.16E-06	0.00000716*	-6.78E-06	-2.75E-06	3.89E-06	2.28E-06	-2.48E-07
	(-3.02)	(-3.37)	(-1.86)	(-1.61)	(-1.97)	(-1.25)	(-0.42)	(-0.84)	(-0.5)	(-0.06)
Kyoto dummy	-0.113	0.163	-0.0521	0.137	0.173	-0.309	1.209**	-0.715**	-0.158	-0.448*
	(-0.37)	(-0.46)	(-0.19)	(-0.46)	(-0.8)	(-1.09)	(-3.2)	(-3.22)	(-0.60)	(-2.22)
Total Government Budget Allocations	-0.000176*	-0.000292**	-0.000183*	-0.0000613	-0.000192**	0.00019	0.000233	3.93E-06	0.0000082	0.000104
	(-2.23)	(-2.79)	(-2.17)	(-1.00)	(-2.95)	(-1.67)	(-1.78)	(-0.04)	(-0.08)	(-1.1)

All specifications include country fixed effects and year dummies. t-values in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 18 shows a similar set of estimations, but this time using a quality-adjusted measure of innovation. This quality adjustment enables for the evaluation of the effect of policy intervention on impactful innovation, rather than just the mere quantity of it. To the best of my knowledge this is the first chapter to take into consideration such differences when assessing OECD policy effectiveness in the current context. Since it has already been established from the earlier analysis that there are significant differences between high- and low- intervention OECD members, the focus of the estimations is on within rather than between groups. It is clear from the results that when controlling for quality of innovation many of the effects that were described earlier for either group became insignificant (although the signs of the coefficients remain largely unchanged). This means that the use of policy support instruments in the OECD over the sample period has been much less effective in encouraging impactful innovation in RE technologies than it had in stimulating activity per se. This supports the fifth hypothesis.

Statistically speaking, the findings are significantly different in both high and low policy intervention countries. With regards to the former, no policy instruments have had any significant effects, positive or negative on the innovation activity of the biomass technologies. In the case of geothermal, demand-pull instruments were found to be positive and significant at 5%, and with a quantitative impact of 3.39% increase in the innovative activity as the demand-pull instruments increase. Regarding hydro, both technology-push and demand-pull policy instruments were found to be positive and significant at 0.1%, and the systemic negative and significant at 0.1%. Quantitatively, this implies that as technology-push instrument increase, the innovative activity for hydro technologies will increase by 2.71%, by 2.82% as demand-pull increase, while the innovative activity will decrease by 0.37% as the systemic instruments increase. Systemic were the only instruments that have had a negative and significant effect on solar technologies at 1% (0.7% decrease). As with hydro, in wind too all instruments were found to be significant and positive for the technology-push and demand-pull ones (significant at 1% and 5% respectively) and negative for the case of systemic at 1%. Quantitatively, an increase in the technology-push instruments will result in a 1.83% increase in the patenting activity, an increase in the demand-pull instruments will result in 1.57% increase, and as the systemic instruments decrease, innovative activity will decrease by 0.54%.

Market concentration was found to be positive and significant at 1% in case of geothermal while it was of no significance for the remaining RETs. The electricity market size was found to be positive and significant in the cases of biomass (at 1%), geothermal (at 0.1%), and wind (at 5%), and insignificant for hydro and solar. The total government budget allocations were found to be negative and significant for all RETs (biomass and hydro at 5%, and geothermal and wind at 1%) but insignificant for the case of solar. The dummy for the Kyoto protocol have had no significant in any of the RETs examined.

In low policy intervention countries with a quality adjusted innovation activity, technology-push instruments were found to be significant but negative for the case of geothermal, at 5%, with a quantitative effect of 3.75% decrease, while demand-pull instruments were significant but again negative for the case of solar at 5%, and with quantitative effect of 0.66% decrease. No other policy instruments were found to be of statistical significance, and for none of the RETs.

The market concentration was found to be negative and significant for the cases hydro and wind at 0.1%, and for solar at 1%, which is in line with the theory, and the dummy for the Kyoto protocol was found to be positive and significant for the case of geothermal at 1%, and negative and significant for the cases of hydro and wind at 1% and 5% respectively. The size of the electricity market, as well as the total government budget allocations were found to be of no statistical significance.

Overall, the control variables were mostly in line with theory. In particular, market concentration was found to be negative and significant in the majority of cases, the electricity market size was found to be on balance positive and significant with varying degrees of significance, the dummy for the Kyoto protocol was found to be variable but often positive and significant, the total government budget allocations were found to be highly contingent and variable, and the same with the electricity market size and the dummy for the Kyoto protocol.

Next the sample was narrowed down to the EU member states only (Table 18), to evaluate the effect of the same policy instruments on EU energy innovation outcomes (with and without quality adjustments, like before). The argument for doing this is twofold: first, the EU as a group has been in the forefront of using policy support instruments to stimulate innovation in the renewable energy sector (Schubert, et al., 2016; Sahu, 2015). Second, the EU is a much more homogeneous group of countries than the OECD is from a regulatory perspective, which may make it easier to identify links between energy innovation and policy support. The results are very similar to the ones obtained in earlier analysis.

When examining the EU alone, results are comparable to the OECD, even when accounting for policy intervention, with only the significance levels changing. In this case however, it is interesting to examine the controls introduced for the North and South of Europe. It can be seen that in the Northern Europe and for countries with high policy intervention, biofuel and wind technologies are positive and significant at 1% and solar technology positive and significant at 0.1% implying that these countries are more likely to innovate in these technologies. In South Europe with policy intervention, the technologies more likely to innovate are solar (at 1%) and wind at 0.1%.

In the Northern Europe countries with low policy intervention, the results show that biomass and wind are the technologies that are less likely for innovation to occur (negative and significant at 1% and 5% respectively), and similarly, in the southern Europe solar (negative and significant at 0.1%) and wind (at 1%) are the RETs where innovation is less likely to take place.

Similarly, when adjusted for quality (Table 20), in the case of high policy intervention countries, results are similar to those found for the case of the whole OECD, with only the significance levels having changed. However, it is interesting to see that for low policy intervention countries no policy instruments were found to be of any significance. For high policy intervention countries in Northern Europe, the RETs more likely for innovation to take place are hydro, solar, and wind (positive and significant at 1%). For Southern Europe, these RETs are hydro (at 5%) and wind (1%). For low policy intervention countries, Northern Europe is more likely to innovate on biomass (positive and significant at 5%), while the Southern part of Europe is less likely to innovate on hydro, solar, and wind (positive and significant at 1%).

To sum up, the use of policy support has had an overall positive effect in terms of quantity of innovation, which, however, was watered down significantly when controlling for quality. In addition policy intervention is often more effective in northern than in southern member states – for both high and low intervention groups. These differences became more pronounced when adjusting for quality and they may partly reflect climatic and geological differences between north and south (for instance, the North of the EU is host to higher capacity of hydroelectric generation technologies than the South, which affects both the funding and intensity of innovation on these technologies). The results support the fourth Hypothesis.

Table 18: Results for the Europe Specification

	All Europe					High Intervention Europe					Low Intervention Europe				
Policy and control variables\Innovation intensity	**Biofuel**	**Geo-thermal**	**Hydro**	**Solar**	**Wind**	**Biofuel**	**Geo-thermal**	**Hydro**	**Solar**	**Wind**	**Biofuel**	**Geo-thermal**	**Hydro**	**Solar**	**Wind**
Technology-push PI	0.223*	0.215	0.226**	0.138*	0.101	0.24	0.576*	0.369***	-0.113	0.145	0.232*	0.0787	0.285***	0.178**	0.180***
	(-2.55)	(-1.55)	(-3.08)	(-2.36)	(-1.81)	(-1.75)	(-2.27)	(-3.33)	(-1.30)	(-1.66)	(-2.19)	(-0.5)	(-3.79)	(-2.83)	(-3.32)
Demand-pull PI	0.172*	0.214	0.363***	0.107	0.221***	0.275*	0.866***	0.577***	0.338***	0.333***	0.124	-0.0622	0.218*	0.00262	0.0213
	(-2.19)	(-1.58)	(-5.07)	(-1.81)	(-3.91)	(-2.01)	(-4.26)	(-6.53)	(-4.63)	(-5.06)	(-1.25)	(-0.37)	(-2.34)	(-0.03)	(-0.26)
Systemic PI	-0.0665	0.00649	-0.00813	-0.0252	-0.0696*	-0.281*	-0.388**	-0.169*	-0.139***	-0.166***	0.0595	0.257	0.130*	0.0978	0.0454
	(-0.90)	(-0.08)	(-0.18)	(-0.77)	(-2.00)	(-2.04)	(-3.08)	(-2.44)	(-3.38)	(-3.86)	(-0.56)	(-1.84)	(-2.06)	(-1.5)	(-0.78_
Market Concentration	-0.00713	0.00489	-0.00681*	-0.0125***	-0.00552	0.00108	0.0233*	-0.00427	-0.0131*	-0.00717	-0.0126	0.0126	-0.00832	-0.0107*	-0.000681
	(-1.60)	(-0.7)	(-2.06)	(-3.72)	(-1.73)	(-0.12)	(-2.06)	(-0.91)	(-2.44)	(-1.34)	(-1.82)	(-1.1)	(-1.96)	(-2.56)	(-0.16)
Electricity Market Size	0.00001***	0.000006**	0.00001***	1.43E-06	0.00001***	0.00001***	4.95E-06	0.000006**	2.2E-06	0.000005**	-2.02E-06	0.00001*	0.000008**	0.000009**	0.00001***
	(-4.54)	(-2.9)	(-4.42)	(-1.15)	(-5.09)	(-4.64)	(-0.86)	(-2.87)	(-1.28)	(-2.79)	(-0.47)	(-2.35)	(-3.03)	(-3.08)	(-4.06)
Kyoto dummy	0.13	0.830***	0.248**	0.637***	0.427***	-0.135	0.268		0.585***	0.526***	0.344*	0.731**		0.580***	0.401***
	(-1.03)	(-5.1)	(-2.64)	(-6.7)	(-5.21)	(-0.94)	(-1.35)		(-4.19)	(-3.96)	(-1.98)	(-3.19)		(-4.81)	(-4.11)
Total Government Budget Allocations	-3.93E-05	-3.48E-05	-0.000044*	3.94E-06	-0.000045*	-1.3E-05		-3.17E-05	1.87E-05	-1.23E-05	0.0000648		1.23E-05	0.000014	-2.33E-05
	(-1.42)	(-1.14)	(-2.05)	(-0.17)	(-2.54)	(-0.32)		(-1.01)	(-0.62)	(-0.42)	(-1.00)		(-0.32)	(-0.3)	(-0.53)
North of Europe						3.590**	13.07	1.177	2.054***	1.586**	-1.166**	-0.915	-0.535	-0.373	-0.644*
						(-2.85)	(-0.02)	(-1.68)	(-3.39)	(-3.07)	(-2.78)	(-1.15)	(-1.80)	(-1.26)	(-2.24)

	All Europe					High Intervention Europe					Low Intervention Europe				
Policy and control variables\Innovation intensity	**Biofuel**	**Geo-thermal**	**Hydro**	**Solar**	**Wind**	**Biofuel**	**Geo-thermal**	**Hydro**	**Solar**	**Wind**	**Biofuel**	**Geo-thermal**	**Hydro**	**Solar**	**Wind**
South of Europe						1.988	-1.423	1.133	1.897**	2.364***	1.817	-3.004	-1.315	-2.746***	-2.666**
						(-1.78)	(-0.86)	(-1.52)	(-2.84)	(-3.93)	(-0.93)	(-1.95)	(-1.52)	(-3.35)	(-3.16)

All specifications include country fixed effects and year dummies. t-values in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 19: Results for the Europe Specification, Adjusted for Quality

	High Intervention Europe					Low Intervention Europe				
Policy and control variables\Innovation intensity	**Biofuel**	**Geothermal**	**Hydro**	**Solar**	**Wind**	**Biofuel**	**Geothermal**	**Hydro**	**Solar**	**Wind**
Technology-push PI	0.505	0.585	0.609*	0.236	0.958***	0.251	-1.194	-0.359	-0.462	-0.271
	(-1.75)	(-1.21)	(-2.34)	(-0.97)	(-4.19)	(-0.87)	(-1.57)	(-1.32)	(-1.61)	(-1.53)
Demand-pull PI	0.431	1.162**	0.461*	0.0376	0.326*	0.273	0.196	0.0599	-0.26	0.0421
	(-1.77)	(-2.8)	(-2.08)	(-0.18)	(-2.31)	(-1.35)	(-0.53)	(-0.28)	(-1.22)	(-0.23)
Systemic PI	-0.221	-0.643	-0.589***	-0.405*	-0.613***	-0.0692	-0.305	-0.173	-0.109	-0.218
	(-1.04)	(-1.95)	(-3.75)	(-2.38)	(-3.80)	(-0.35)	(-1.31)	(-0.99)	(-0.62)	(-1.69)
Market Concentration	-0.00731	0.0639***	0.00742	0.00613	-0.00401	0.00511	0.0286	-0.0223***	-0.0190*	-0.0246***
	(-0.40)	(-3.52)	(-0.56)	(-0.45)	(-0.27)	(-0.54)	(-1.69)	(-3.47)	(-2.49)	(-3.66)
Electricity Market Size	0.0000122**	1.65E-05	0.00000808*	5.48E-06	0.00000812*	-9.33E-06	-8.85E-07	9.8E-06	3.74E-06	5.5E-06
	(-2.83)	(-1.35)	(-2.34)	(-1.69)	(-2.21)	(-1.48)	(-0.07)	(-1.87)	(-0.71)	(-1.17)
Kyoto dummy	-0.119	0.216	0.189	0.155	0.148	-0.326	1.192**	-0.815***	-0.248	-0.449*
	(-0.39)	(-0.61)	(-0.6)	(-0.51)	(-0.68)	(-1.13)	(-3.22)	(-3.87)	(-1.00)	(-2.31)
Total Government Budget Allocations (all categories)	-0.00015	-0.000237*	-7.8E-05	-0.0000122	-0.00013	0.000242	0.000332*	0.000106	0.000199	0.000168
	(-1.71)	(-2.26)	(-1.03)	(-0.18)	(-1.85)	(-1.86)	(-2.45)	(-0.96)	(-1.67)	(-1.69)
North of Europe	0.399	15.21	2.564**	2.029**	2.357**	1.226*	1.411	0.198	0.395	-0.0863
	(-0.35)	(-0.01)	(-3.26)	(-2.82)	(-2.91)	(-2.07)	(-1.56)	(-0.46)	(-0.81)	(-0.20)
South of Europe	1.067	-1.378	3.707*	0.647	2.714**	0.573	-1.245	-3.512**	-3.050**	-3.151**
	(-0.92)	(-0.35)	(-2.5)	(-0.85)	(-2.89)	(-0.3)	(-0.47)	(-3.01)	(-2.58)	(-3.05)

All specifications include country fixed effects and year dummies. t-values in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Overall the estimation results are statistically significant and free from the econometric problems that are often associated with count data estimators. Given moreover the novelty of different instruments and RETs a more detailed description might well be beyond the scope of this chapter which aimed at as developing and accessing some general novel ideas as opposed to the very specifics of each case. These would require further investigation and represent a major opportunity for further research

5.5 Summary, Conclusions and Discussion

In summary, in this chapter, I have:

1. Cross fertilised RE and IP
2. Developed the argument that RE can qualify as a GPT
3. Applied the concept of picking winners to policy instruments and RE Technologies
4. Provided fresh econometric evidence for IP
5. Explored regional variations
6. Adjusted RE innovation for quality of innovations

Based on the conceptual analysis, five Hypotheses have been developed and tested by employing a unique and comprehensive data set. Overall and on balance my Hypotheses were supported by the econometric evidence. More specifically, the results showed that

- IP instruments have a positive and significant effect on RETs with demand-pull ones being more potent, especially in high intervention countries.

- Targeting RETs is contingent upon country experience with more experienced countries being more effective.

- There exist regional disparities with Southern countries being less effective in fostering innovation in different RETs.

- Public policy support is found to induce innovation of lower quality.

In addition to the above there were some very interesting findings a propos control variables- notably market shares (that can be seen as a proxy for market power) hindering RE innovation. These are all fairly significant advances in a rather important field. All these have rather clear, strong and even self-evident policy implications-not least that policy experience and competence matter and that public policy interventions can help distort incentives and induce lower quality innovations.

There are limitations in this research which present opportunities for further research. These include the use of patent data with their limitations that I have already discussed. Other limitations include fine tuning my proxies for experience, quality and regional blocks (e.g. European OECD, non-Europe OECD). In addition, for the first Hypothesis I relied on the balance of the evidence on the impact of REP instruments on specific RETs as opposed to a regression with the aggregate effects of all REPs instruments on all RE innovation. That was in part because of earlier extant evidence on this (see Chapter 4 and Pitelis, 2018), and because the aggregated effect masks the nuances of the relationships.

In the next chapter I look at the impact of specific instruments on specific RETs. This is because there are policy instruments that can target one specific RET, and other that target multiple. This helps us select right instrument for the relevant RET, based on its effectiveness.

Chapter 6
Fostering Innovation in Renewable Energy Technologies: Choice of policy instruments and effectiveness

In this chapter, the effectiveness of different types of RE policy instruments (demand-pull, technology-push and systemic) on innovation have been tested for an array of RETs. The novelty in this chapter lies in examining the degree of policy instruments targeting, i.e. whether instruments are more effective when targeting one specific RET, or more.

6.1 Introduction

As already mentioned, the environmental and climate challenges relating to the use of fossil fuels, has motivated a number of governments to adopt REPs. These are currently an important feature of the global energy landscape (Kieffer & Couture, 2015), and have motivated debates about the role of public policy towards RE. .

At a practical level, the proliferation of REPs and REP instruments poses a number of challenges for scientific research. These include the adoption of widely agreed classifications but also the analysis of which policy instrument is more or less effective in impacting upon which particular RET. Common classifications permit better comparisons while identification of the instrument that is good for purpose (effective in fostering a particular RET) provides more detailed knowledge and hence helps with more informed policy making.

As already noted, an important question for policy makers, pertains to the optimal degree of targeting of RETs. On one hand, it can be argued that targeting a particular RET for support can help achieve a policy target more effectively. On the other hand, targeting specific RETs can involve higher costs and scope for failures, partly because of possible interaction effects with other policies (Pitelis, 2018). The issue of targeting has not featured in the RE literature but has been a staple of academic debate in the literature on IP and Industrial Strategy which is currently a topic of extensive debate and very high in the policy Agenda of the UK government (Rhodes, 2014; Bailey, et al., 2018).

In the context of this longstanding debate, public policy in general can involve the possibility of government failures, for example as a result of lobbying, rent-seeking and lock-ins (Bailey, et al., 2015). Specifically for the case of RE, some scholars have argued that targeting RE distorts the functioning of carbon markets and therefore hinders efforts to decarbonise the economy (Moselle & Moore, 2011; Less, 2012; Nordhaus, 2009). It is then arguable that more targeted policies are likely to involve a higher possibility of failure both in identifying the target and in ensuring that targeting one type of technology does not have a negative repercussion on other technologies. On the other hand, however, some scholars have argued that a policy mix that targets specific technologies to foster RE innovation, alongside carbon pricing policies, may be preferable (Stern, 2006; Grimaud & Lafforgue, 2008). However finding which particular RE instruments foster particular RETs requires empirical evidence. This is my intended contribution in this chapter.

In the above context, the aim of this chapter is to examine the extent to which RET specific policy instruments are more (or less) effective than RET-neutral ones, by examining their respective effects on RE innovation. A common classification of REP instruments (s. Chapter 3) will be adopted, focusing on all key RETs, that are *Biomass*, *Geothermal*, *Hydro*, *Solar*, and *Wind* energy technologies, for the electricity sector, and looking at a large sample of 21 countries that are actively involved in the adoption of REPs[19]. The reason for limiting of my sample to 21 countries, and for dropping one RET (Ocean Energy), was by data restrictions. In particular, the re-classification of the RE instruments into those that target multiple RETs and

[19] These are the following: *Australia, Austria, Belgium, Canada, Finland, France, Germany, Ireland, Israel, Italy, Japan, Korea, Mexico, Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, United Kingdom, and the United States.*

those that target just one RET, resulted in cases of countries with very few REP values that render their statistical analysis impossible. The same applied for the case of RETs. While the more restricted sample makes comparisons less straightforward, I note that this exercise has not been undertaken before and is necessary for reasons already explained. Future research is likely to encounter the same data restrictions hence allowing better comparisons with my results.

The remainder of the chapter is structured as follows: The next section focuses on the background and proposed hypotheses of the chapter; section three describes the model and variables; section four presents the results and their discussion; and section five concludes.

6.2 Background

AS discussed earlier in the thesis, the early 1990s witnessed a new wave of RE policies aimed at mitigating the impact to climate change. The UNFCCC triggered regular COP meetings, with a key meeting being COP3 (1997) where the Kyoto Protocol was adopted.

By way of example, in 2015, as many as 164 countries worldwide had adopted at least one type of policy associated with RE. Since their emergence in the 1970s, REPs have taken different forms, ranging from government announcements to legally binding obligations (Kieffer & Couture, 2015). The OECD distinguishes between two waves of REPs. The first wave took place in the aftermath of the two oil crises of the 1970s, which stimulated policy adoption in most developed countries, but was phased out in the early 1980s when the oil price started falling. The second wave, which is also the focus of this chapter, emerged in the early 1990s in response to the increased concerns for climate change mitigation (Nicolli & Vona, 2012). Different phases can also be observed in the adoption of policies as such. The first phase saw the adoption of RD&D (Research, Demonstration and Development) subsidies and grants. The second phase focused mainly on the use of market-based instruments (such as taxes, incentives, and tradable permits), which also resulted in policy diversification, since early adopted policies were kept in use jointly with new ones (Nicolli & Vona, 2012).

As aforementioned, it has been claimed that such policies, among others, help foster innovation, and in the specific case of this thesis, RE innovation. The idea however that environmental policy can help foster RE innovation is not new (see for example Porter & Van Der Linde, 1995). For the specific case of RE however, interest has emerged mostly over the last decade; see for example Johnstone et al. (2008); Chalvatzis, (2009); Popp et al. (2009); Nesta, et al. (2014); Pitelis, (2018).

As with the previous chapters, I employ the classification proposed in Chapter three. This draws on earlier leading contributions on innovation, (Rosenberg, 1974; Nelson, 2009; Nemet, 2009), and includes three types of instruments: technology-push, demand-pull instruments, and systemic. .

Few studies have addressed the effects of specific REPs on inducing innovation in RETs and none to my knowledge on a comprehensive account of the impact of specific REP instruments on specific RETs. As an example of one of the earlier studies in the literature, Loitera & Norberg-Bohmb (1999), reviewed the technological and policy history of the development of wind power in the United States. They found that demand-side policies are needed to encourage not only diffusion of wind energy, but innovation in the technology itself, as well as that weak demand-side policies for wind energy risks wasting the expenditure of public resources on research programs aimed at technological innovation. Wangler (2013), Peters, et al. (2012) and partly Johnstone, et al. (2008) (only for the case of tradable certificates), also found demand-pull instruments to have an important role in facilitating inventive activity. Marques and Fuinhas (2012), examined the extent to which public policies towards RE are successful over the whole spectrum of RE technologies and concluded that incentive and subsidy policies (including feed-in tariffs) (demand-pull instruments) and policy processes (systemic instruments) were significant drivers of the use of RE. Constantini, et al. (2015), found that demand-pull policies are dominant (in the biofuel sector). They suggested this is because other complementary technology-push support mechanisms are needed to increase the availability of scientific and technological capabilities and foster innovation. Palmer, et al. (2015) who examined the evolution of residential PV systems in Italy for 2006-2026, found that the feed-in tariff scheme (demand-pull instrument) had again a positive effect on their rapid growth, beyond an initial stage (Palmer, Sorba, & Madlener, 2015). Hoppmann, et al. (2013), who examined solar photovoltaic modules producing firms globally, also concluded that demand-pull policies have a greater impact when they target more mature technologies.

Lee and Lee (2013) explored patterns of innovation and evolution in energy technologies (including solar PV, biomass, wind, tidal and geothermal), particularly by focusing on similarities and differences across technologies. They concluded that customised policies are likely to be required for each technology. Hoppmann, et al. (2013), conducted comparative case studies to a sample of nine global solar PV producers and concluded that demand-pull policies have a greater impact when they target more mature technologies. Dechezleprêtre and Matthieu (2014), analysed the influence of domestic and foreign demand-pull policies (e.g., guaranteed tariffs, investment and production tax credits) in wind power across OECD countries on the rate of innovation in said technology. They concluded that wind technology improvements responded positively to policies both home and abroad.

Crespi, et al. (2015) used data from Eurostat and the OECD to empirically test for the role of policy in inducing the adoption of environmental innovation by firms. They concluded that policies are found to play a crucial role in supporting or even spurring the adoption of environmental innovations. They also differentiated between (i) typologies of policy instruments and (ii) typologies of innovations and found that the inducement effects depend on the type of instrument under scrutiny. In this way they provided empirical support to linking inducement effects of a policy and the specific type of environmental innovation, since the latter reacted differently to the array of policy instruments scrutinized. Costantini, et al. (2015) explored the differentiated impact of demand-pull and technology-push instruments in shaping technological patterns in the biofuels sector. They concluded that demand-pull and technology-push factors are important drivers of innovation in the biofuels sector.

Lindman and Söderholm (2016), analysed patent data for four western European countries over the period 1977–2009, with different model specifications and found that both public R&D support (technology-push policy) and feed-in tariffs (demand-pull policy) have positively affected patent application counts in the wind power sector. In addition, they argued that the impact of feed-in tariffs became more profound as the technology has matured, and the impact of public R&D support was greater if it is accompanied by feed-in tariffs. Nicolli and Vona (2016), studied the effect of REPs on innovation activity in different RETs for the EU countries and the years 1980 to 2007. They found that the inducement effect of REPs is heterogeneous and more pronounced for wind, which for the period of their study was the only technology with developed mature and high technological potential. In a broader sense, Grafström, et al. (2017) who examined the technological patterns (i.e. invention, innovation, and diffusion) of the European wind energy sector, also found the feed-in tariffs (demand-pull instruments) to be vital factors of said patterns (Grafström & Lindmand, 2017).

As it can be seen, currently literature provides some, albeit limited conclusions regarding to which type of policy instruments work better. Especially when it comes to the degree of targeting, as a result of the narrow focus of the studies, either in terms of the policy classification, the RETs and/or in terms of the countries examined. The policy classification adopted in this study allows for the examination of all policy instruments, not only examples (i.e. public R&D support for technology-push policies and feed-in tariffs for demand-pull policies) and alongside the selected RETs, it also allows to account for the degree of targeting (by distinguishing into two policy instruments, those that target only one RET, and those targeting at least two).

Based on the above two Hypotheses are tested:

***H*$_1$*:* *The impact of REP instruments on RE innovation is contingent on the instrument used*

and

***H*$_2$*:* *REP instrument that target specific RETs have a stronger effect on RE innovation of the targeted RETs*

6.3 Methodology and Data Description

Following the propositions in Chapter 3, a panel has been constructed to consist of 21 countries, from 1990 to 2014. All the countries in the sample have used and/or are currently using a range of policy instruments to support development of their RE sector. These also include some key members of the EU (*Austria, Belgium, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom)* widely perceived as a leader in the area of RE policy making and innovation. Year 1990 was used as the starting point as this is when the second wave of RE policy adoption took place, while it also captures the effects before and after the adoption of Kyoto Protocol, which helped redirect innovative activities towards renewables (Rawlins & Allal, 2003). Year 2014 was chosen as the end date of this analysis due to data availability. Table 21 provides a summary of the definitions and source of the main variables.

6.3.1 Measuring RE Innovation

For this chapter, patent data for the Biomass, Geothermal, Hydro, Solar, and Wind technologies were used. Overall, a total of 217,393 patent counts were obtained.

6.3.2 RE policies and REP Instruments

Policies can target one or more RETs, as well as one or more RE sector(s). For example, in 2000 the UK introduced the Renewable Energy Obligation, which targeted all RETs and was applicable across all sectors (e.g. electricity, heating and cooling, and transport). In the same year, the UK also introduced the Energy Crops Scheme, which targeted only biomass related technologies, and was only relevant to sectors related to power and heat. In a similar manner, in 1990 Germany introduced the Environment and Energy Saving Programme which provided loans specifically for onshore and offshore wind technologies, for biomass technologies related to power, heat, and transportation, and for solar technologies related to the heating sector. Germany's Integrated Climate Change and Energy Programme (2007) however, targeted all RETs across all sectors. For this chapter, collected data on RE policy instruments were used that only target the electricity sector, and five RETs[20].

In this chapter, the data on RE policy instruments collected were divided in two categories, those targeting multiple RETs, and those targeting one specific RET. They were also classified into *technology-push*, *demand-pull,* and *systemic*, by thoroughly reviewing the specifics of each individual policy, as explained in Chapter 3.

This is in line with the practice followed by other studies in the literature, which also use the total number of all implemented policies (s. Johnstone et al., 2008; Nesta et al., 2014). My

[20] These are: *biomass, geothermal, hydro, solar,* and *wind*

adopted classifications allowed for the treatment of the resulting variables as count variables, as they were not diverse in character.

6.3.3 Control Variables

Inducing green innovation is not just a matter of public policy. There is need therefore to control for factors other than policies, which may foster innovation. In line with the literature, returns on innovation are affected by the potential market for this innovation. In the case of RE this is best reflected in trends for electricity consumption. A large market for electricity should increase the incentives to innovate in RE. Data on household and industry sector electricity consumption was obtained from the IEA/OECD Database, in GWh. Both observed and calculated balances exist, which as in previous cases, they were averaged.

Another index developed by the EuroSTAT related to the market share of the largest generator in the electricity market was used. The expectation is that this should have a negative effect on RE innovation, as the higher the market concentration is, the less the incentive to innovate (Sandulli, et al., 2012). Data were obtained for most countries from the Eurostat database. As in Nesta, et al (2014), I used a dummy variable to pick up any effects of the Kyoto protocol, which came into effect in 2005.

A new indicator was also included, that of "renewable energy innovation intensity", which is the ratio of individual RET patenting activity over the total RET patenting activity. Finally, to remove the country-specific time invariant components from the error term, country dummies are used in the form of fixed effects. A vector of year dummies (u) was also used to pick up time effects (trend).

Table 20: Definitions of main variables

Name	Definition	Unit	Notes	Variable	Source
Patents	Total patent counts filed per country per year, filed under the PCT	Count Values	Data were collected using International Patent Classification, for Bioenergy; Geothermal; Hydroelectricity; Ocean Energy; Solar Energy; Wind Energy	Dependent	PATSTAT (European Patent Office)
Policy Instruments	The IEA/IRENA Global Renewable Energy Policies and Measures Database provides information on policies and measures taken or planned to encourage the uptake of renewable energy in all IEA and IRENA Member countries and signatories.	Count Values	OECD Countries; All Policy Types; All RE Policy Target; Only Electricity Sector; Effective between 1974-2015; All Jurisdictions; All Policy Statuses; Large and Small Plant Sizes	Independent	IEA/IRENA Joint Policies and Measures Database
Market Share	Market share of the largest generator in the electricity market	Percentage of the total generation	Data exist for most countries and from 1999 to 2015	Control	Eurostat
Kyoto Protocol	The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change, which commits its Parties by setting internationally binding emission reduction targets. The Kyoto Protocol was adopted in Kyoto, Japan, in 1997 and entered into force in 2005.	Dummy	0 for all years prior to 2005; 1 for the following ones	Control	Authors
Electricity Consumption	The IEA Electricity Information: OECD Electricity and Heat Supply and Consumption (GWh, TJ) database provides electricity and heat balance data for 35 OECD countries	GWh	Data were collected for EU15 member states. Both observed and calculated balances were collected and averaged.	Control	IEA/OECD
RE Innovation Intensity		Ratio		Control	Authors
					Source: Author

6.3.4 Methodology

As explained in the methodology chapter, count data – the case of this chapter – can be econometrically examined either by using the Poisson Regression Model (PRM), or the Negative Binomial Regression Model (NBRM) (Greene, 1994). For reasons explained in the aforementioned chapter, the NBRM has been adopted in this chapter too.

Three different models were employed, each with five different specifications (one for each RET examined) in order to assess the two hypotheses, as described below.

Model 1 examines the total RE Innovation per year per country as being equal to the three types of RE policy instruments i.e. the effects of technology-push, demand-pull, and systemic instruments on the overall RE innovation activity, a standard fixed effects model setting was considered, in the following form:

$$\begin{aligned} \sum RE\ Innovation_{i,t} &= \beta_1\left(\sum REP\ Tech.Push_{i,t}\right) + \beta_2\left(\sum REP\ Dem.Pull_{i,t}\right) \\ &+ \beta_3\left(\sum REP\ Systemic_{i,t}\right) + \beta_4\left(Market\ Share_{i,t}\right) + \beta_5\left(Kyoto_{i,t}\right) \\ &+ \beta_6\left(Electricity\ Consumption_{i,t}\right) + \beta_7\left(RE\ Inn.Intensity_{i,t,Te}\right) + v_i \\ &+ u_t + \varepsilon_{i,t} \end{aligned} \qquad (6\text{-}1)$$

Where, *i = values per country,* and *t = year (1990, …, 2014), and v and u are vectors of country and time dummies, respectively.*

Model 2 examines the effects of the three types of RE policy instruments on RE innovation on the multiple level, i.e. those policies that target more than one technology, but not necessarily all of them. RE patent counts per RET is the DV, and the sum of policy instrument per type and per technology is the IV. A standard model setting is again considered, in the following form:

$$
\begin{aligned}
&RE\ Innovation_{i,t,Te} \\
&\quad = \beta_1(M.Tech\ Push_{i,t,Te}) + \beta_2(M.Dem\ Pull_{i,t,Te}) \\
&\quad + \beta_3(M.Systemic_{i,t,Te}) + \beta_4(Market\ Share_{i,t,Te}) \\
&\quad + \beta_5(Kyoto_{i,t,Te}) + \beta_6(Electricity\ Consumption_{i,t,Te}) \\
&\quad + \beta_7(RE\ Inn.Intensity_{i,t,Te}) + v_i + u_t + \varepsilon_{i,t,Te}
\end{aligned}
\tag{6-2}
$$

Where, *i = values per country, t = year (1990, …, 2014),* and *Te=Technology. M implies "multiple".*

Model 3 examines the effects of the three types of RE policy instruments on RE innovation when targeting one specific RET. RE patent counts per RET is the DV, and the sum of policy instruments per type and per technology is the IV. A standard model setting is again considered, in the following form:

$$
\begin{aligned}
&RE\ Innovation_{i,t,Te} \\
&\quad = \beta_1(Tech\ Push_{i,t,Te}) + \beta_2(Dem\ Pull_{i,t,Te}) \\
&\quad + \beta_3(Systemic_{i,t,Te}) + \beta_4(Market\ Share_{i,t,Te}) + \beta_5(Kyoto_{i,t,Te}) \\
&\quad + \beta_6(Electricity\ Consumption_{i,t,Te}) \\
&\quad + \beta_7(RE\ Inn.Intensity_{i,t,Te}) + v_i + u_t + \varepsilon_{i,t,Te}
\end{aligned}
\tag{6-3}
$$

Where, *i = values per country, t = year (1990, …, 2014),* and *Te=Technology.*

6.4 Empirical Results and Discussion

A summary of the main estimation results can be found in Tables 22 and 23.

Table 21: NBRM Results for Model 1 and Model 2

	Model 1	Model 2 Specification				
		(1)	(2)	(3)	(4)	(5)
	Total RE Patents	Biomass Patents	Geothermal Patents	Hydro Patents	Solar Patents	Wind Patents
Total Technology-Push Instruments	0.0153 (-0.58)					
Total Demand-Pull Instruments	0.113*** (-6.71)					
Total Systemic Instruments	-0.0316* (-2.00)					
Multiple Technology-Push Instruments (Biomass)		0.212 (-1.73)				
Multiple Demand-Pull Instruments (Biomass)		0.236** (-2.88)				
Multiple Systemic Instruments (Biomass)		-0.151* (-1.99)				
RE Innovation Intensity (Biomass)		3.931*** (-10.78)				
Multiple Technology-Push Instruments (Geothermal)			0.361 (-1.6)			
Multiple Demand-Pull Instruments (Geothermal)			0.399** (-2.91)			
Multiple Systemic			-0.138 (-1.68)			

	Model 1	Model 2				
		Specification				
		(1)	(2)	(3)	(4)	(5)
	Total RE Patents	Biomass Patents	Geothermal Patents	Hydro Patents	Solar Patents	Wind Patents
Instruments (Geothermal)						
RE Innovation Intensity (Geothermal)			18.38*** (-11.19)			
Multiple Technology-Push Instruments (Hydro)				0.265* (-2.43)		
Multiple Demand-Pull Instruments (Hydro)				0.410*** (-4.62)		
Multiple Systemic Instruments (Hydro)				-0.122* (-2.11)		
RE Innovation Intensity (Hydro)				2.441*** (-7.35)		
Multiple Technology-Push Instruments (Solar)					0.167 (-1.83)	
Multiple Demand-Pull Instruments (Solar)					0.145 (-1.92)	
Multiple Systemic Instruments (Solar)					-0.0535 (-1.34)	
RE Innovation Intensity (Solar)					3.038*** (-9.92)	

	Model 1	Model 2 Specification				
		(1)	(2)	(3)	(4)	(5)
	Total RE Patents	Biomass Patents	Geothermal Patents	Hydro Patents	Solar Patents	Wind Patents
Multiple Technology-Push Instruments (Wind)						0.221** (-2.6)
Multiple Demand-Pull Instruments (Wind)						0.326*** (-5.2)
Multiple Systemic Instruments (Wind)						-0.181*** (-4.19)
RE Innovation Intensity (Wind)						3.459*** (-12.02)
Market Share	-0.0109*** (-3.32)	-0.00599 (-1.33)	-0.00302 (-0.52)	-0.00883** (-2.62)	-0.0177*** (-4.51)	-0.00866* (-2.40)
Kyoto Protocol Dummy	0.175* (-2.1)	-0.0587 (-0.46)	0.670*** (-4.35)	0.158 -1.69	0.443*** (-4.01)	0.343*** (-3.99)
Electricity Consumption	0.00000325*** (-4.74)	0.00000575*** (-7.8)	0.00000578*** (-5.75)	0.00000439*** (-6.46)	0.00000302*** (-3.86)	0.00000232** (-2.75)

All specifications include country fixed effects and year dummies. t-values in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 22: NBRM Results for Model 3

Model 3

	Specification				
	(1)	(2)	(3)	(4)	(5)
	Biomass Patents	**Geothermal Patents**	**Hydro Patents**	**Solar Patents**	**Wind Patents**
Technology-Push Instruments (Biomass only)	0.315 (-1.9)				
Demand-Pull Instruments (Biomass only)	0.179* (-2.19)				
Systemic Instruments (Biomass only)	-0.224 (-1.27)				
RE Innovation Intensity (Biomass)	3.861*** (-10.64)				
Technology-Push Instruments (Geothermal only)		0.574 (-1.85)			
Demand-Pull Instruments (Geothermal only)		0.421** (-2.94)			
Systemic Instruments (Geothermal only)		-0.122 (-0.68)			
RE Innovation Intensity (Geothermal)		18.90*** (-11.65)			
Technology-Push Instruments (Hydro only)			0.115 (-0.77)		

Model 3

	Specification				
	(1)	(2)	(3)	(4)	(5)
	Biomass Patents	Geothermal Patents	Hydro Patents	Solar Patents	Wind Patents
Demand-Pull Instruments (Hydro only)			0.530*** (-5.5)		
Systemic Instruments (Hydro only)			-0.0916 (-0.76)		
RE Innovation Intensity (Hydro)			2.456*** (-7.44)		
Technology-Push Instruments (Solar only)				0.145 (-1.26)	
Demand-Pull Instruments (Solar only)				0.242** (-2.86)	
Systemic Instruments (Solar only)				-0.1 (-1.35)	
RE Innovation Intensity (Solar)				2.951*** (-9.79)	
Technology-Push Instruments (Wind only)					0.121 (-1.21)
Demand-Pull Instruments (Wind only)					0.376*** (-5.81)
Systemic Instruments (Wind only)					-0.154* (-2.31)

Model 3

	Specification				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
	Biomass Patents	**Geothermal Patents**	**Hydro Patents**	**Solar Patents**	**Wind Patents**
RE Innovation Intensity (Wind)					3.245***
					(-11.48)
Market Share	-0.00481	-0.00244	-0.00977**	-0.0169***	-0.00868*
	(-1.02)	(-0.44)	(-2.78)	(-4.21)	(-2.41)
Kyoto Protocol Dummy	-0.0488	0.651***	0.108	0.393***	0.232**
	(-0.38)	(-4.46)	(-1.17)	(-3.57)	(-2.63)
Electricity Consumption	0.00000589***	0.00000599***	0.00000466***	0.00000312***	0.00000302***
	(-7.86)	(-6.43)	(-6.55)	(-3.98)	(-3.51)

All specifications include country fixed effects and year dummies. t-values in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

As expected, the aggregated effect of policy instruments varies according to their type. Specifically, the technology-push instruments have an insignificant effect on the overall RE innovation which is in line with the extant literature and theory (Pitelis, 2018; Nemet, 2009; Rosenburgh, 1979). Demand-pull policies however, have a positive effect on RE innovation, significant at 1%, which quantitatively means that the expected number of RE patents will increase by 1.12% when demand-pull instruments also increase. Systemic instruments are found to have a significant but negative effect on RE innovation, which is also in line with the existing literature and theory, since systemic instruments are aimed to support and align the existing instrument mix, i.e. support the demand-pull and/or technology-push (Smiths & Kuhlmann, 2004). Hence when acting in isolation, it is expected to have a negative effect when significant, and an insignificant effect otherwise. The same result hold true in the second set of estimations presented in Table 22; i.e. the one examining policy instruments targeting multiple

RETs, as well as in the third set of estimations (Table 22 – Model 3), i.e. the one examining policy instruments targeting one specific RET.

In terms of control variables, the market share is found to be negative and significant, in both models (at 1%). This is in line with the theory, since the higher it is, the lower the need for competitive advantage (Sandulli, et al., 2012); hence the incentive to innovate is reduced. Instead of innovation, electricity suppliers often deploy consumer-facing strategies to increase their market share (Rutter, et al., 2017). The dummy for the Kyoto protocol was found to be positive and significant in both models (at 5%), suggesting that RE patenting activity can be influenced by constraints and incentives provided by international accords and that the Kyoto protocol has indeed had noticeable impact. Finally, electricity consumption was found to be positive and significant (at 1%) suggesting that RE innovations are more likely to take place when there exists a market for them[21].

In the case of biomass technologies, technology-push instruments have an insignificant effect on driving innovative activity regardless of whether they concern policy instruments that target multiple RETs or only biomass technologies. In both model specifications, demand-pull policy instruments have had a positive and significant effect. However, in the second model, where multiple RETs were targeted, the significance was higher (at 1%) than when only biomass technologies were targeted (significant at 5%). An explanation for this can be the fact that in the first scenario, systemic instruments are significant (5%) but have a negative effect on the biomass innovative effect, while in the latter, their effects are insignificant. In quantitative

[21] Previous studies argued that growing electricity consumption can be used to control for possible dimension of the possible market for RE (Johnstone et al., 2008; Nesta et al., 2014). Despite efficiency gains electricity consumption is expected to grow as it substitutes other forms of energy in deep decarbonisation scenarios (IPCC, 2014). For example, even if slowly electricity already claims a share of transport energy supply with the growing use of electric vehicles. At a market, rather than national level, electricity share of individual utilities is threatened by active consumers at industrial (Zafirakis, et al., 2014) or household levels (Pothitou, et al., 2017) who invest in energy generation and management technologies.

terms, the aforementioned translate in a 1.27% increase in the innovative activities of biomass technologies as demand-pull policy instruments increase in the first case, and a 1.2% increase in the second.

In terms of the control variables, only electricity consumption is found to be of significance and positive in both models. Market share and the Kyoto protocol seem to not have an impact on the biomass innovative activity. In the case of market share, this can be because biomass belongs to the first-generation, already mature technologies (IEA, 2006). Essentially, technologies for power generation from solid biomass are very similar to those widely used for coal. Linked to that is that very often biomass has been used either in coal and biomass co-firing power stations or in retired coal-fired stations which were converted to biomass only. Therefore, some of the largest biomass facilities are in fact operated by market incumbents who have previously burnt coal.

Similarly, for both models geothermal technologies are significantly impacted by only demand-pull instruments (at 1%). However, as systemic instruments are insignificant in both models, an increase in the constant of the demand-pull policies is observed in the second model, implying that the instruments targeting a specific RET have a greater effect on their innovative activity. This corresponds to a 1.49% increase in the innovative activity as demand-pull policies increase in the first case, and 1.52% increase in the second case.

Market share has no effect on the innovative activity of geothermal technologies. As with biomass technologies, geothermal is also a first-generation technology which has reached maturity (IEA, 2006) by using tried and tested turbine systems. Kyoto protocol and energy consumption are positive and significant in both model specifications at 1%.

Hydro and wind technologies differ from the biomass and geothermal, in the sense that both specifications have all instruments, i.e. technology-push, demand-pull and systemic, significant. In hydro, technology-push instruments are positive and significant at 5%, with a quantitative increase of 1.3% in their innovative activity as these policy instruments increase. Demand-pull instruments are positive and significant at 1%, with a qualitative increase of 1.51% in their innovative activity as these policy instruments increase. Systemic instruments are negative and significant at 1%. Technology-push instruments for wind technologies are positive and significant at 1%, and demand-pull instruments at 1%. Quantitatively, the first will result in 1.25% increase in innovative activity, and the latter in 1.39% increase. Systemic instruments are negative and significant at 1%.

However, as policy instruments become more targeted (model 3) (Table 23), the effects of policy instruments change. For hydro technologies only demand-pull instruments are positive and of statistical significance at 1%, with a quantitative impact of 1.7%. This is also partially true for wind technologies, which in the second case have a higher constant for demand-pull instruments, which translates in a quantitative impact of 1.46%, while maintaining the same significance, at 1%, and sign. Contrary to hydro, systemic instruments for wind technologies are negative but significant at 5%.

In terms of control variables, energy consumption is positive and significant, at 1%, for both wind and hydro energy. Market share is negative and of statistical significance as expected, at 1% in the case of hydro technologies and 5% in the case of wind energy. Kyoto protocol was only of statistical significance (and positive) in the case of wind, at 1%. Clearly, for most regions hydro power is established and heavily reliant on specific geography. Wind energy, on the other hand is a challenger technology that removes incumbent market share (Green &

Vasilakos, 2011) and has been greatly benefitted by the advancement of the climate change agenda.

Solar energy technology is completely different from the above examined technologies. In the first case it can be seen that no policy instruments are of statistical significance while in terms of control variables, the market share is negative and significant at 5%, the Kyoto protocol dummy is positive and significant at 1%, and the electricity consumption positive and significant at 1%. However, when policy instruments target specifically solar technologies, demand-pull instruments have a positive and significant effect of 1% and a quantitative impact of 1.27%. A possible explanation for this is that solar energy is a second-generation technology which despite the fact that it undergoes rapid development when policy instruments allow for a choice in the RET to be employed, other technologies may be chosen. In terms of the control variable, the market share is negative and significant at 5%, the Kyoto protocol dummy is positive and significant at 1%, and the electricity consumption positive and significant at 1%.

6.5 Concluding Remarks

This chapter examined the effects of RE policy on RE innovation for the case of technology-push, demand-pull, and systemic policy instruments on RE innovation, in a cross-section of 21 countries over the period 1990-2014. Existing literature has been used to build the hypotheses which evidence supports.

The research adds to the literature in a number of ways. Firstly, it adds to the weight of evidence found by recent studies that have employed the same classification of policy instruments (Costantini et al., 2015; Pitelis, 2018). I found that the choice of policy instruments matters and this varies depending on the particular RET.

Three different models were used to examine the effects of the three different types of policy instruments on renewable energy innovation, the policy instrument targeting more than one RET (but not necessarily all), and policy instruments targeting one specific RET. Model 1 was in accordance to the first hypothesis, namely that the impact of REP on the RE innovation varies between the instruments used. In the second model, I found that the different types of policy instruments have different effects on the innovative activity of RETs. Demand-pull policy instruments were found to be positive and significant in all cases with the exception of solar energy technologies - for which technology no instrument type had any effect, something that can be explained in terms of the technology's maturity. Technology-push instruments were significant only for the cases of hydro and wind energy technologies, while systemic were found to be significant for the cases of biomass, hydro, and wind energy technologies, but negative in all other cases. By observing the third model, it was concluded that when it comes to targeting one specific technology, only demand-pull policies seem to be effective – something that was also true for the case of solar energy technologies. This was further supported by the existing literature as well as previous studies.

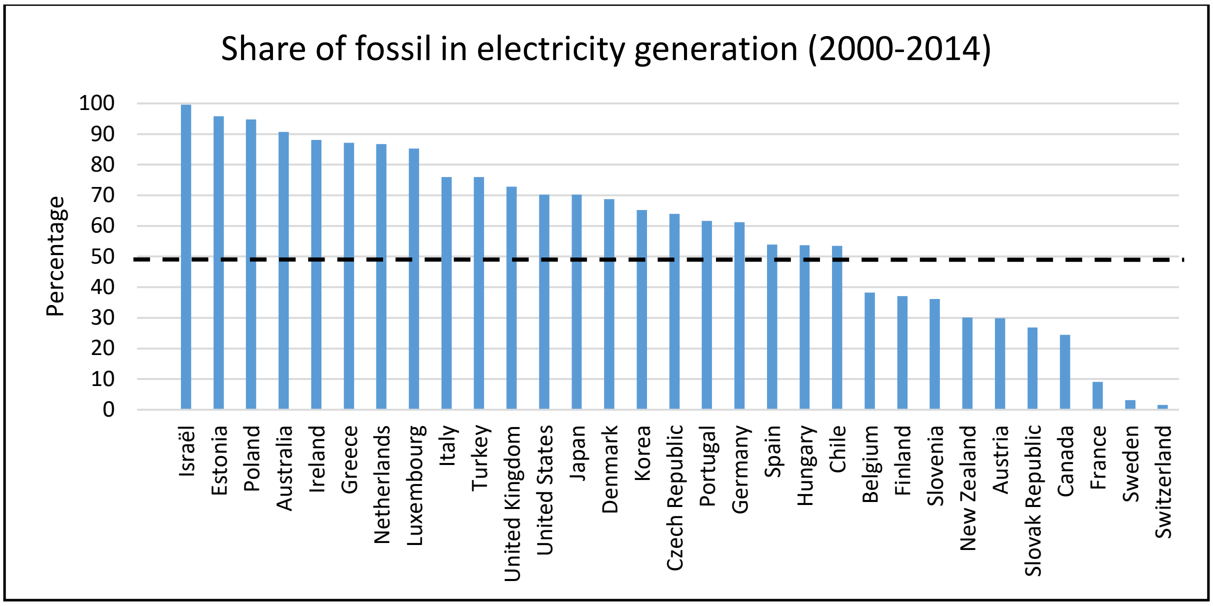
In terms of policy implications, it is apparent that different technologies require different types of policy instruments to induce innovation. It seems that demand-pull policies are stronger. This can be because of their horizontal nature (namely that they impact upon all). Another reason could be their strong design (like feed-in tariffs in Germany) alongside being introduced earlier; thus, creating a degree of path-dependency. The results also show that the Kyoto protocol has had minimal to no effect on RE innovation. Such treaties, usually create incentive frameworks for the diffusion of energy technologies, yet often they are not designed to foster the commercialisation of energy technology innovation (Aguayo, et al., 2012).

Chapter 7
The Interrelationship Between Subsidies to Fossil Fuels and to Renewable Energy Sources in the OECD

7.1 Introduction

As noted earlier in the thesis, the need for energy transition from fossil fuel-based sources of energy to RE has long been recognised (Smil, 2010). However, despite the talk and public support to RE over the past years, the composition of energy sources between RE and non-RE remains almost unchanged. Quantitatively, in 2015, 86.3% of the world's total primary energy supply came from fossil fuels (including nuclear power), relatively unchanged from 87.6% in 1973. In the OECD countries, in 2016 fossil fuels contributed 89.8% to the total primary energy supply (including nuclear power, down from 95.4% in 1973) (IEA, 2017). While better than that for the world as a whole, this is hardly dramatic. What is more, according to the *International Energy Outlook* (2016), the projected contribution of fossil fuels to the global energy use in 2040 is anticipated to be as high as 78% (US Energy Information Administration, 2016). Narrowing this down to the case of the OECD, the years under examination of this chapter (2000-2014), and for the case of electricity generation, the following figure (Figure 27) shows the share of fossil fuels in electricity generation. It can be seen that in most countries electricity is still produced using mainly fossil fuels, in some cases nearly 100%.

Figure 27: Share of fossil-fuels in electricity generation (2000-2014)



Source: Author using OECD data

From the various possible reasons for the apparently paradoxical relative stability in the composition of energy sources, one is the potential imperfect substitutability between them. Clearly if new energy sources are poor substitutes, advances in RE are unlikely to translate into RE adoptions in practice. Another reason that has gained a degree of notoriety concerns the persistence of public support to fossil fuels. Indeed, one might expect that with all the discussion and public sector support to RE, public sector support to fossil fuels would be on the decline. Paradoxically however, support to RE has been going hand in hand with support to fossil fuels leading scholars and international organisations to suggest that this could hamper efforts to transition to clean energy (European Commission, 2016, p. 17).

While the issue of substitutability between energy sources has received interest by leading scholars, the argument that public support to fossils fuels will hamper energy transitions, has been taken as self-evident and has generated to my knowledge little scholarly debate. However, the relationship between subsidies to RE and to fossil fuels is more nuanced. In theory the two types of support can be substitutes, unrelated or even complements. Evidently, the impact on energy transition will depend on the exact relationship; one that has never been tested before. The aim of this chapter is to explore this idea both conceptually and econometrically.

In particular, the next section first discusses extant debates about the relationship (degree of substitutability) between energy sources. Following on from this focuses on the totally unexplored question of the relationship between subsidies to fossil fuels and subsidies to RE. The relationship is conceptualised and Hypotheses are developed that pertain to three possibilities – substitutability, complementarity, or independence. The next section discusses the methodology, data, and econometric results. The last section provides conclusions and discussion.

7.2 The 'Paradox' and the Role of Public Policy

Substitutability between energy sources and Public Policy

According to one observer, "industrial economies have been locked into fossil fuel-based energy systems through a process of technological and institutional co-evolution driven by path-dependent increasing returns to scale" (Unruh, 2000, p. 817). Below some reasons are explored that have been advanced in order to explain the apparent paradox of slow progress towards a more RE-based composition of energy sources.

Acemolgu, Aghion, Bursztyn and Hemous (2012) constructed a model which emphasized three factors that can affect the direction of technological change at the sectoral level; the price effect (i.e. higher prices encourage innovation); the market size (i.e. bigger market such as demand, encourage innovation); and the direct productivity effect (i.e. innovation is more likely to take place in technologies with higher productivity or existing stock of knowledge (Acemoglu, et al. 2012). They applied this analysis to the case of energy and concluded that in the case where the clean and 'dirty' technologies[22] are strong substitutes, the market size and initial productivity advantage of dirty technologies will direct innovation towards these. They also found that a high macroeconomic elasticity of substitution between clean and dirty technologies constituted a crucial condition for green growth and depended on the substitution between clean and dirty fuels and substitution between fuels and other inputs. Pelli (2012) extended the aforementioned study by Acemoglu, et al. (2012) to include multiple sectors. With regards to the electricity sector, a number of assumptions were made in order to calibrate the non-US elasticities from the US elasticities, and found that for the electricity sector, the calibrated elasticities were circa 0.51. Papageogiou, et al. (2016) also built on Acemoglu, et al. (2012) framework. The authors used a novel panel of cross-country sectoral data and examined the elasticity of substitution between clean and dirty energy inputs, which was found to be about 1.8, implying that "long-term clean growth of the electricity sector is technologically feasible" (Papageorgiou, Saam, & Schulte, 2017, p. 21). They also found evidence for substitutability between RETs and fossil fuels.

By developing a dynamic model in which the energy demand is covered by both renewable and fossil-fuel energy, Lanzi and Sue Wing (2010) examined the direct technical change in the energy sector. Using panel data for the OECD member countries, and assuming a steady-state model of directed technical change, they examined the relationship between the relative patenting activity for both clean and dirty energy production and the relative fossil fuel prices. They concluded that RE and fossil-fuel technologies are good substitutes in electricity production (Lanzi, et al., 2010), a conclusion that was also reached by Baker and Shittu (2006).

[22] 'Dirty' technologies are defined as those associated with high GHG pollution (such as coal power plants), while clean technologies are alternative technologies that can replace them (such as solar energy) (Dechezleprêtre, et al., 2017)

Aghion et al. (2012) also built on the Acemoglu, et al. (2012) framework in order to study whether firms in the automobile sector will invest (or not) more on clean (such as electric and hybrid) as opposed to dirty (such as internal combustion engine) technologies, based on the carbon taxes and the firms' past knowledge stocks (Aghion, et al., 2012). In the same year, Popp and Newell (2012) conducted a study in which they examined the trade-offs between clean and dirty innovation. By examining the patenting activity of large publicly traded firms, they concluded that such firms will switch their research on alternative energies based on market incentives, i.e. the more profitable the research on alternative energy gets, the more such firms will innovate. However, no evidence was found that this is also the result of such firms being financially constrained.

The assumption that RE and energy from fossil fuels are substitutes have resulted to the notion that higher energy prices and taxes foster innovation in RETs. This however would be the case "[…] *provided it* [renewable energy], *can be stored and transported efficiently, would be highly substitutable with energy derived from fossil fuels. This reasoning would suggest a (very) high degree of substitution between dirty and clean inputs, since the same production services can be obtained from alternative energy with less pollution*" (Acemoglu, Aghion, Bursztyn, & Hemous, 2012, p. 135).

An important reason why the composition of energy sources changes so slowly can be that energy sources are not complete substitutes or at least they are perceived not to be. In cases of full lack of substitutability for example, higher availability of alternative RE sources of energy are unlikely to have an appreciable effect on the composition of energy use. In this context, the question of substitutability is important. In the literature this question has acquired some prominence in the late 1970s, arguably as a response to the need to understand how the economy reacts to the oil crisis (see for example Atkinson and Halvorsen, 1976; Griffin, 1977;

and Pindyck, 1979). The focus of these early studies was on the extent to which coal, gas, and electricity can substitute for oil. Later studies focused mainly on substitution elasticity estimates. Jones (1995) analysed interfuel substitution in the U.S. industrial sector and found that "excluding fuels used for non - energy purposes yields larger estimates of the price elasticities for coal and oil and indicates generally greater potential for interfuel substitution than when using aggregate data" (Jones, 1995, p. 459). Steinbuks (2010), classified fuel use for the provision of energy into different manufacturing processes and found that fuels aiming at heating accounted for more than two thirds of the total energy consumption in manufacturing. In these processes, positive shares of all four energy inputs (petroleum, coal, gas, electricity) were observed, while other processes required specific fuels (Steinbuks, 2010).

A potentially important reason concerning the composition of energy sources is public policy, in particular taxes and subsidies. Both can impact on incentives to consumers and producers and hence have the potential to engender changes in the said composition.

In the context, Lazkano and Pham (2016) distinguished among the different fossil fuel technologies and evaluated the role of fossil fuel tax and R&D subsidies in directing the innovation activity from fossil fuel to RETs focusing on the electricity sector. By employing a global firm-level electricity patent database for the years between 1978 and 2011, they concluded that the overall impact of taxing the fossil fuels on RE innovation depended on the type of fossil fuel. In more detail, they found that taxing coal reduces innovation in both fossil fuel and RE technologies, while the impact of taxing natural gas was statistically insignificant. They also suggested that if natural gas is taxed while research on RETs is sufficiently subsidised, innovation activity on the electricity sector can be shifted from fossil fuels to renewables. Although, a coal or a carbon tax that may increase coal price, is likely to have a negative effect on RE innovation. The authors have also claimed that electricity is a distinct sector since electricity must be consumed at the same time as it is produced. It is therefore of great importance to adjust the electricity supply as soon as possible in order to meet the demand. In order to overcome this, electricity producers produce a base electricity load which meets the minimum demand, while peak electricity loads are added to meet excess demand. While this power generation model is gradually challenged by the emergence of large-scale electricity storage it remains the dominant paradigm. This makes RETs an imperfect substitute to fossil-fuel technologies since the electricity is supplied intermittently (this is especially the case for wind and solar technologies), and in such cases where is not (see for example the hydropower technologies which are able to provide base-load) are geographically dependent and their capacity expansion is usually limited. This also implies the following: firstly, RETs are not a suitable substitute for fossil-fuels; secondly that RETs are still unable to replace coal-based technologies for the production of base loads, and finally that electricity generated from RETs relies on coal-firing plants to meet the electricity demand (Lazkano, et al., 2016).

To summarise, it is apparent that the degree of substitutability between energy sources is not perfect and in this context the role of taxes and energy prices have a distinct upper limit. This can in part explain why the composition of energy sources has been so difficult to shift.

The Relationship between Subsidies

Another factor potentially explaining the slow transition concerns the fact that direct support to RE sources (subsidies) has been going hand in hand with support to fossil fuels. According to a joint paper from the International Monetary Fund, and the University of California that estimated fossil fuel subsidies along with the economic and environmental benefits from reforming them, it was found that in 2013 and 2015 6.5% of global GDP was spent on such subsidies (Coady, et al., 2016). In a similar report by the International Energy Agency (2016), for 2015, fossil fuel subsidies amounted to 325 billion USD (from almost 500 billion USD in

2014), while for the same year subsidies for RE sources was 150 billion USD. For 2000-2015, 70% of the total capital investments in energy supply went to fossil fuels (IEA, 2016). As of 2016, fossil fuel support in the OECD countries had flattened to around 82 billion annually, however the main reason was argued to be the low oil price rather than policy reforms (OECD, 2018). As noted by the European Commission, such support initiatives are "particularly problematic, as they disadvantage clean energy and hamper the transition to a low-carbon economy" (European Commission, 2016, p. 17).

The aforementioned argument takes as a given fact that the relationship between subsidies is one of (perfect) substitutability. While in the context of fixed budgets it appears reasonable to assume that if the public sector supports dirty energy that will imply less support to RE, this need not always be the case as over time, budgets may change. Importantly, for reasons addressed below, the relationship between fossil fuels and RE subsidies can be negative (substitutability), unrelated (independence) and even positive (complementarity). Additionally, the degree of substitutability or complementarity can vary. These arguments are explored, and possibilities in turn.

The case for substitutability between subsidies is predicated on the idea that with fixed budgets for energy support, whatever goes to one source is taken away from the other. In this context subsidies to dirty sources would imply an equal amount taken away from clean energy; hence, the two types of subsidies would be perfect substitutes. However, budgets need not be fixed. Governments can shift resources between categories and indeed they can create new funding through taxation or borrowing. If so the two types of subsidies can be independent from each other – for example any addition to RE subsidies can be funded by increasing the share of the total budget allocated to energy. This would imply independence between the two types.

A third possibility, is fully underexplored and arguably more interesting. This is when the two types of subsidies are complementary. As already noted this has not been hypothesised before but it is quite possible and even theoretically plausible. For instance, when government subsidises dirty energy, it may feel compelled to also increase support to RE. The reasons can vary from moral considerations and interest in RE as such, to consumer support for clean energy; thus, potential votes for the incumbent government. On the other hand, suppliers of dirty energy are usually large corporates with market power and many resources, including lobbyists to hand. They are likely to demand support stating their own arguments in favour (often raising doubts about the negative environmental impact of their energy sources). With resources to also fund political parties, and one has an explanation as to why many governments still subsidise fossil fuels while also preaching for, and indeed, supporting clean energy. In broader terms it could be argued that if policy makers go for votes in support of clean energy, then they will increase the subsidies for RE, while if they are "captured" by special corporate interest groups representing dirty sources, they will subsidise fossil fuels. If the latter is more subsidised, they may feel pressure to increase the former as well in order to compensate, implying complementarity. In fact, in public economics the so-called Wagner's law (the argument that the share of the government spending to GDP increases over time, is based on precisely this type of arguments (Mueller, 2003).

In both cases of substitutability and complementarity, the degree matters too. This can range from very low to very high. In the case of substitutability, the relation can take values between zero (no substitutability) and one (perfect substitutability). In the case of complementarity, the upper limit is theoretically not bound, although in practice one would not expect it to be higher than one (implying a one to one-dollar increase in subsidies for the two respective sources). As the factors that impact on the relationship can operate in different directions, in practice the observed relationship will tend to be the outcome of the respective strength of all extant forces hence not possible to determine on a priori grounds.

What can be hypothesised conceptually however is that, similarly to the case of taxes examined above, in the case of subsidies to the relationship can vary according to the type of fossil fuel subsidised. For example, subsidies for coal could exhibit a higher degree of substitutability than those to natural gas, in case the former is seen as dirtier hence more likely to emanate from a government with a lower degree of environmental sensitivities.

It follows that the case for perfect substitutability between subsidies is far from being a foregone conclusion. The policy implications that emanate from the actual precise relationship could not be overemphasised. Taking the case of complementarity for example, support to fossil fuels could even be regarded as good news for RE producers in that it would also increase support to RE. The precise relationship is mostly an empirical matter. Yet there has been to my knowledge no study to test this.

Based on the above my aim is to test for the following four Hypotheses:

H1a: Higher subsidies to fossil fuels lead to lower subsidies to RE (substitutability)

H1b: Higher subsidies to fossil fuels lead to higher subsidies to RE (complementarity)

H1c: Higher Subsidies to fossil fuels lead to no change in subsidies to RE (independence)

H2: The relationship between subsidies for fossil fuels and RE is mediated by the type of fossil fuel technology.

The aim of the next section is to test the aforementioned Hypotheses.

7.3 Empirical Protocol

An econometric model has been employed to test the aforementioned Hypotheses. Both dependent and the key independent variable are subsidies to RE and to fossil fuels respectively, measured through government budgets on Research, Development and Demonstration (RD&D) allocated to the respective energy sources. While there are two R&D indicators, the aforementioned, as well as the Government Budget Allocations for Research and Development (GBARD), the latter covers only basic and applied research and experimental development (i.e. R&D), while the former (i.e. RD&D) includes "demonstration" (such as prototyping, field tests, or lab trials) (Sun & Kim, 2017).

Data were collected for all OECD countries (except Chile, Israel, Latvia, Mexico, and Slovenia, as no data existed for these countries) and for the years between 2000 (additional data on fossil fuel subsidies exist, as explained below, but for 2000 onwards) and 2014.

7.3.1 Dependent Variables: RD&D Allocations on Renewable Energy Technologies

Data on RD&D allocations on the OECD database and on RETs exist for biomass, geothermal, hydroelectricity, ocean energy, solar energy, wind energy, as well as an additional category for "unallocated" (RE) budgets. For the case of this chapter, data were collected for all RETs, but (i) for the case of biofuels only data related to applications for heat and electricity were collected, as the focus is on electricity (and not for example on transportation), and (ii) "unallocated" RE budgets were completely exempt since the focus of the thesis is specifically on six RETs (i.e. biomass, geothermal, hydro, ocean, solar, and wind), while "unallocated" may also include sectors other than electricity. Overall, a total of 29,311.85 million 2015 USD and PPP were allocated on RETS during the years under examination in the OECD member countries. Table 24 shows the total RD&D budgets for RETs as a total:

Table 23: Total RD&D Allocations for the RETs under examination

Country	Total RD&D for RETs
United States	10,482.58
Japan	2,702.84
Germany	2,377.76
France	1,598.73
Korea	1,432.07
Italy	1,215.27
Canada	1,208.96
United Kingdom	1,116.10
Netherlands	1,075.76
Spain	963.53
Australia	881.62
Denmark	670.04
Sweden	645.74
Switzerland	575.86
Finland	525.05
Norway	436.88
Austria	396.54
Poland	254.99
Ireland	129.40
Belgium	119.63
Hungary	105.15
Slovak Republic	102.35
New Zealand	96.23
Czech Republic	92.20
Turkey	52.90
Portugal	35.36
Estonia	12.41
Luxembourg	5.89
Greece	0.00
	Source: Author after OECD data

As it can be seen, the United States allocate the by far the most on RD&D for RETs, almost four times more than the following country, Japan. Overall, the United States account for almost 36% of the total allocations, followed by Japan with approximately 9%, and Germany with circa 8%. These countries account for 53.1% of the total allocation, while the first ten countries account for 82.5%. Greece has allocated no budgets at all on RETs over the time span examined.

7.3.2 Independent Variables: RD&D Allocations on Fossil Fuels

As with the RETs, additional data on RD&D allocations for fossil fuels were collected from the same database, countries, and years. Data existed and collected for different fossil fuel technologies, namely, oil and gas (as one indicator), coal, CO_2 capture and storage[23], nuclear fusion, and nuclear fission[24]. Similarly to budget allocations collected for the RETs, these too were converted into million 2015 USD and PPP. Unsurprisingly, a total of 95,566.19 million 2015 USD and PPP were allocated for RD&D for fossil fuel technologies, almost three times more than for RETs. Table 25 summarises the total allocations per country:

Table 24: RD&D Allocations in Million US$ (2010 prices and PPP) per Fossil Fuel Technology and per Country

Country	RD&D - Oil and gas	RD&D - Coal	RD&D - CO_2 capture and storage	RD&D - Nuclear fission	RD&D - Nuclear fusion
Australia	434.79	322.08	759.92	104.32	0.91
Austria	13.19	5.28	3.97	2.59	61.99
Belgium	3.32	0.00	4.36	473.58	53.74
Canada	1,359.19	780.30	1,259.96	2,071.32	41.48
Czech Republic	10.81	22.41	7.68	231.36	1.97
Denmark	31.38	3.72	9.25	24.89	18.04
Estonia	3.02	2.45	1.01	0.86	0.00
Finland	31.56	73.61	0.00	176.15	45.29
France	1,971.82	1.80	464.72	8,854.46	709.17
Germany	31.11	232.82	117.45	926.18	2631.48
Greece	0.00	0.00	0.00	0.19	0.00
Hungary	14.10	1.30	0.00	20.30	0.00
Ireland	2.90	0.75	0.05	0.15	5.42
Italy	192.28	182.31	39.97	647.93	812.01
Japan	2,820.33	999.19	828.63	3,1694.82	2,846.78
Korea	308.28	248.55	233.64	2,020.02	41.66
Luxembourg	0.00	0.00	0.02	0.00	0.00
Netherlands	146.21	15.20	130.93	185.35	111.96

[23] Although classified as a fossil fuel technology by the OECD, its purpose is to reduce carbon emissions to the atmosphere from fossil fuels. It "is considered a crucial strategy for meeting CO_2 emission reduction targets" (Leung, Caramanna, & Maroto-Valer, 2014) but not without controversy over its suitability to deliver results timely.

[24] Nuclear fission is defined as "the splitting of a heavy nucleus into two lighter ones and is the standard process providing nuclear energy. Nuclear fusion is "the joining of two nuclei to form on heavier nuclei" (Murtanu, 2016) and has never been used for sustained power generation in laboratory or commercial settings.

Country	RD&D - Oil and gas	RD&D - Coal	RD&D - CO_2 capture and storage	RD&D - Nuclear fission	RD&D - Nuclear fusion
New Zealand	51.11	3.28	3.84	0.00	0.00
Norway	665.29	0.00	815.85	144.87	0.00
Poland	119.87	243.44	66.29	55.16	[25]
Portugal	2.28	3.21	2.84	0.09	14.60
Slovak Republic	0.00	7.42	1.24	22.18	26.00
Spain	23.22	44.71	18.02	168.33	274.09
Sweden	0.00	1.74	5.15	62.26	25.10
Switzerland	136.96	0.00	16.09	319.62	289.56
Turkey	23.45	18.47	0.75	3.30	0.15
United Kingdom	30.99	68.62	353.67	241.80	544.32
United States	1,094.70	6,876.82	2,254.72	5,817.48	5,659.32
					Source: Author after OECD data

In terms of allocations for oil and gas, Japan accounts for almost 30% of the total, followed by France with circa 21%, Canada with approximately 14%, and the United States with 11.5%. Those four countries, account for 76.1% of the total allocations. The United States allocate the most on RD&D on coal, accounting on its own for almost 68% of the total allocations. Japan follows with approximately 10%, and Canada with circa 8%. Overall, the first three countries account for 85.2% of the total coal allocations. When it comes to CO_2 capture and storage, the United States comes first again, allocating the most, with 30.5% of the total allocations. Canada follows with 17%, Japan and Norway with 11%, and Australia with 10%. Overall, these countries account for 80% of the total CO_2 capture and storage allocations.

Regarding the nuclear fission, Japan allocates the most with 58% of the total allocations coming from there. France follows with 16% and United States with 11%. These three countries contribute a total of 85.4% of the total allocations. United States once again allocate the most when it comes to nuclear fusion, accounting for almost 40% of the total budget allocations.

[25] Data not available

Japan follows with 20%, and Germany with 18%. The first three countries account for 78% of the total allocations.

Overall, Japan allocated the most when it comes to fossil fuels, accounting for 41%. United States follows, allocating almost half of what Japan does, with approximately 23%, of the total allocations, and France with 12.5%. It is interesting to see that the first three countries are of different geographic areas. It is also interesting to see that when comparing the budget allocations for RETs and fossil fuels, all countries allocate more on the latter than the former. Japan, allocates 14.5 times more on fossil fuels, while France allocates 7.5 times more, Canada 4.6, Belgium 4.5, Norway 3.7. An interesting case is that of Greece, which allocates nothing on RETs, but it does allocate on fossil fuels (albeit a small fraction, and only on nuclear fission).

7.3.3 Control Variables

Subsidies to RE are influenced by a number of other factors than subsidies to fossil fuels. Based on the literature discussed earlier in this chapter, a number of control variables have been included in the estimation model.

Firstly, fossils are the main fuel for electricity generation. It can therefore be assumed that, in case the incumbent electricity provider monopolises the market, more subsidies will be placed in support of fossil fuels. The first control variable is therefore a newly developed index by EuroStat related to the market share of the largest generator in the electricity market (*Market Share*). It is a percentage of the total of the total generation of the largest generator in the electricity market, and it is expected to have a negative effect on RE subsidies. A dummy variable set to unity for years after the Kyoto protocol came into force in 2005 was included, in order to capture changes in expectation on both the context for future policy and the global market size for renewable energy (Nesta, et al., 2014) (*Kyoto*).

It has also been claimed that the price of electricity amplifies the incentives for innovation in renewable energy (Johnstone, et al., 2008). Therefore, it can be assumed that a government would allocate more budgets in RETs RD&D, to amplify said incentives. It is assumed that these prices are exogenous; given that RE sources have in the past and up until recently contributed fairly small percentages towards the overall share of electricity production (World Bank, 2010). Data on end-use energy by sector (industry, households and electricity generation) were collected from the IEA database (*Electricity Prices*). In a similar manner, a large growing market for electricity should increase incentives to innovate with respect to RE technologies, which is best reflected in trends for electricity consumption. As a result, it can be argued that the higher the electricity consumption, the higher the propensity to innovate on RETs, and hence for a government to invest more on RD&D for RETs. Data on household and industry sector electricity consumption was obtained from the IEA/OECD database, in GWh. Both observed and calculated balances exist, which were averaged (*Electricity Consumption*).

Additionally, the total RD&D budget allocations across the whole spectrum of all sectors per year and per country were also included as a control variable. This variable accounts for the overall propensity of a country to allocate budgets in RD&D (*Total RD&D Budgets*). Additional data on GBARD were also collected and used, for similar reasons. GBARD data are classified by socio-economic objective, and in this case, the energy objective was employed (*GBARD*). Data on direct fossil fuel budgetary transfers were also collected from the OECD/IEA iLibrary (2018). These data only account for a small part of the overall data on transfers (the rest is data on tax expenditures, and outside the reach of this chapter), and come from three areas, "(i) support for energy purchases by low-income households; (ii) government expenditure on research, development and demonstration projects, both through government laboratories and through grants to non-governmental bodies; and (iii) transfers to help redeploy resources in declining fossil-fuel industries, namely coal" (OECD, 2013). Data are available for coal, natural gas, petroleum, and electricity, and for the years 2000 onwards (hence the starting date of this chapter). Data per year were aggregated due to data limitations and treated as a single indicator, after being converted into constant Million USD 2015 and PPP for uniformity reasons (*Other Fossil Fuel Subsidies*). Finally, the model specifications were augmented by including the lagged by one-year dependent variable, which is equivalent to controlling for persistency in past activities (Blundell, et al., 1995) (*Lagged DV*).

7.3.4 Methodology

Since the data of this chapter is not count data as with the previous cases, a different estimation model was used. While the principle is the same as the one of the previous chapters (as explained in Chapter 3), an Ordinary Least Square (OLS) regression model for panel data was used. Contrary to the rest however, to decide between fixed-effects and random-effects, one must use the Hausman specification test. In brief, the Hausman specification test "[…] compares an estimator $\hat{\theta}_1$ that is known to be consistent with an estimator $\hat{\theta}_2$ that is efficient under the assumption being tested. The null hypothesis is that the estimator $\hat{\theta}_2$ is indeed an efficient (and consistent) estimator of the true parameters. If this is the case, there should be no systematic difference between the two estimators. If there exists a systematic difference in the estimates, there is reason to doubt the assumptions on which the efficient estimator is based" (STATA, n/a, p. 3). What this means in this case is that if the systematic difference is statistically significant (indicated by the probability of chi squared (x^2) being statistically significant), the fixed-effects model should be preferred. In this case, the Hausman test showed no statistical significance (Prob > x^2 = 0.2124) and therefore the random effects model was preferred.

In order to test for the first three hypotheses, a standard model setting was considered, in the following form (specification 1):

$$\sum RE\ Subsidies_{\,i,t} = \beta_1\left(\sum Fossil\ Fuel\ RD\&D\ Subsidies_{\,i,t}\right) + \beta_2(Market\ Share_{i,t}) + \beta_3(Kyoto_{i,t}) + \beta_4(Electricity\ Prices_{i,t}) + \beta_5(Total\ RD\&D\ Budgets_{i,t}) + \beta_6(Electricity\ Concumption_{i,t}) + \beta_7(Other\ Fossil\ Fuel\ Subsidies) + \beta_8(Lagged\ DV_{i,t}) + \beta_9(GBARD_{i,t}) + \varepsilon_{i,t} \tag{7-1}$$

Where, *i = values per country* and *t = year (2000, …, 2014).*

In order to test for the fourth hypothesis, a standard model setting was again considered. Two different specifications were examined, each time disaggregating the independent variable more, i.e. in the first case (specification 2), the total fossil fuel subsidies were disaggregated into two variables, into total fossil fuel allocations except nuclear, and one for nuclear, and in the second case (specification 3), a complete disaggregation of the fossil fuel allocation, as follows:

Specification 3:

$$\sum RE\ Subsidies_{i,t} = \beta_1(RD\&D\ Subsidies\ for\ Oil\ and\ Gas_{i,t}) + \beta_2(RD\&D\ Subsidies\ for\ Coal_{i,t}) + \beta_3(RD\&D\ Subsidies\ for\ CO^2\ Capture\ and\ Storage_{i,t}) + \beta_4(RD\&D\ Subsidies\ for\ Nuclear\ Fission_{i,t}) + \beta_5(RD\&D\ Subsidies\ for\ Nuclear\ Fusion_{i,t}) + \beta_6(Market\ Share_{i,t}) + \beta_7(Kyoto_{i,t}) + \beta_8(Electricity\ Prices_{i,t}) + \beta_9(Total\ RD\&D\ Budgets_{i,t}) + \beta_{10}(Electricity\ Concumption_{i,t}) + \beta_{11}(Fossil\ Fuel\ Subsidies) + \beta_{12}(Lagged\ DV_{i,t}) + \beta_{13}(GBARD_{i,t}) + \varepsilon_{i,t} \tag{7-2}$$

Following that, for each specification, the elasticities were also calculated. In a linear function form, like in this case (see chapter 3), the elasticity is given by the following equation:

$$\in = \frac{dY}{dX}\frac{X}{Y} = b\,\frac{X}{Y} \tag{7-3}$$

Where, "b" is the change in "Y" from a unit increase in "X".

The descriptive statistics of all the main variables are reported in the following table (Table 26):

Table 25: Descriptive Statistics of all variables

Variable	Obs.	Mean	Std. Dev.	Min	Max
RD&D Budget Allocations on Renewable Energy Technologies	365	80.30679	184.0123	0	2,442.68
Total RD&D Budget Allocations on Fossil Fuels	363	267.4203	618.9738	0	4,650.6
RD&D Budget Allocations (excl. nuclear)	363	76.94609	228.9653	0	3,717.16
RD&D Budget Allocations on Nuclear	366	188.9139	489.5285	0	2,872.18
RD&D Budget Allocations on Oil and Gas	343	27.7616	53.69259	0	280.77
RD&D Budget Allocations on Coal	337	30.14697	180.7782	0	3141.37
RD&D Budget Allocations on CO_2 Capture and Storage	343	21.57452	57.65521	0	497.17
RD&D Budget Allocations on Nuclear Fission	353	153.7385	450.2544	0	2746
RD&D Budget Allocations on Nuclear Fusion	335	42.43328	92.70548	0	538.14
Market Share	284	52.78486	25.26739	15.3	100
Kyoto Protocol	435	0.666667	0.4719473	0	1
Energy Prices	435	0.0001143	0.0000625	0	0.0002999
Total RD&D Budget Allocations	362	602.0853	1264.567	1.93	10863.6
Electricity Consumption	435	309998.7	692183.6	5421	3921940
Fossil Fuel Subsidies	344	2.61E+10	1.22E+11	0	1.51E+12
Lagged DV	340	79.02341	186.0737	0	2442.68
Energy GBAORD	382	458.5255	699.4411	0	5202.715
					Source: Author

7.4 Empirical Results

Table 27, summarizes the results of all specifications as mentioned earlier in this chapter. As expected, at the aggregated level, subsidizing fossil fuels affect negatively and significantly (at 0.1%) RD&D budget allocations on RETs. The first hypothesis is therefore supported, implying substitutability between the variables. Quantitatively, the subsidies of RETs will decrease by 0.79% (this is derived from the exponential of the constant, i.e. exp(-0.2362383)) as more budgets are allocated on fossil fuels.

Regarding the second specification, again, the aggregated variables of RD&D subsidies on fossil fuels excluding nuclear, and on nuclear, were both found to have a negative and significant effect on RETs innovation, both at 0.1%. Again, the first hypothesis is found to be true, with subsidies on fossil fuels, substituting those on RETs. Quantitatively, the findings imply that as higher budgets are allocated on RD&D related to fossil fuels (excluding nuclear), RD&D budgets on RETs will decrease by 0.84%, while if they are allocated on nuclear, this will decrease RETs budgets by 0.75%.

The final specification is interesting, as it totally disaggregates the fossil fuel technologies; thus, allowing to effectively assess which subsidised fossil fuel technologies affect RETs the most. It can be seen that among all technologies, oil and gas subsidies have a negative and significant effect on RETs at 0.1%. Quantitatively, a reduction of 0.72% in subsidizing the RE sector is caused by investing on RD&D on oil and gas. Budget allocation on coal was found to be negative, but insignificant. As mentioned by Lazkano et al. (2016), coal-based technologies are yet to be replaced by RETS, while RETs still rely on coal-firing plants to meet the electricity demand. This may also imply the issue of "lock-in", namely that countries that have a history in investing on advancing coal, are "locked-in" in these types of innovations; hence, having no statistical impact on RE (Beck & Martinot, 2004).

Subsidising CO_2 capture and storage seem to have a positive but insignificant effect on RETs allocations. Indeed, and as mentioned before, although classified as a fossil fuel technology by the OECD, its recent advance is to reduce carbon emissions to the atmosphere from fossil fuels. It has however, been used in the past and continued to be used today as means to increase the lifespan of conventional oil fields by increasing their internal pressure and facilitating increased oil production. Although the net reductions of emissions depend on the fraction of carbon captured, a power plant equipped with CO_2 capture and storage could reduce carbon emissions by 80%-90% (IPCC, 2005). It can be argued therefore that despite being a fossil fuel technology, it does not undermine RET allocations as they serve the same purpose. This is the only fossil fuel technology where the third hypothesis (of independence) is supported.

With regards to subsidies to the two nuclear technologies, both were found to have a negative and significant effect on RD&D allocations on RETs (at 1% in the case of fission, and 0.1% in the case of fusion). Quantitatively, subsidising nuclear fission has a greater effect on RETs budgets, reducing them by 0.86%, as compared to the 0.73% reduction caused by subsidizing nuclear fusion. Further questions are relevant to nuclear fission indirect subsidies such government support for nuclear waste management, insurance underwriting for nuclear accidents and nuclear power station decommissioning. Despite these indirect support mechanisms for nuclear fission being fairly widespread, there is little in the way of data detailing national budgets allocation.

In terms of the control variables, the electricity market share, as well as energy price, and the fossil fuel subsidies (in the form of budgetary transfers) were found to be statistically insignificant for all the specifications examined, while the dummy for the Kyoto protocol was found to be positive and significant at 5% only in the first specification.

The total RD&D budget allocations was found to be positive and significant at 0.1%, which implies that RD&D budget allocations positively affect the allocations on RETs. This is also the case for electricity consumption which was also found to be positive and significant at 0.1% for all specifications. Previous allocations (captured by the lag by one year of the dependent variable) were also found to be positive and significant for all specifications, but their effect varied among specifications; at 1% in the first specification, at 5% in the second, and at 0.1% in the third.

Table 26: Estimated coefficients of the regression analysis for all specifications

Dependent Variable: RD&D Budget Allocations on Renewable Energy Technologies		Specification 1	Specification 2	Specification 3
Independent Variables	Total RD&D Budget Allocations on Fossil Fuels	-0.2362383*** (0.000)		
	RD&D Budget Allocations on Fossil Fuels (excl. nuclear)		-0.1718357*** (0.000)	
	RD&D Budget Allocations on Nuclear		-0.2866117*** (0.000)	
	RD&D Budget Allocations on Oil and Gas			-0.3223004*** (0.000)
	RD&D Budget Allocations on Coal			-0.5103654 (0.058)
	RD&D Budget Allocations on CO_2 Capture and Storage			0.0977072 (0.134)
	RD&D Budget Allocations on Nuclear Fission			-0.1503488** (0.002)
	RD&D Budget Allocations on Nuclear Fusion			-0.3208568*** (0.000)
Control Variables	Market Share	0.0741351 (0.512)	0.1909758 (0.144)	-0.0548383 (0.610)
	Kyoto Protocol	11.23931* (0.047)	10.37383 (0.066)	5.094946 (0.243)
	Energy Prices	-66,210.4 (0.140)	-7,7431.05 (0.066)	20,064.786 (0.612)
	Total RD&D Budget Allocations	0.2002876*** (0.000)	0.2023008*** (0.000)	0.1143754*** (0.000)
	Electricity Consumption	0.0000901*** (0.000)	0.0001031*** (0.000)	0.0001027*** (0.000)
	Fossil Fuel Subsidies	-9.17e-10 (0.067)	-8.85e-10 (0.076)	-5.18e-10 (0.161)
	Lagged DV	0.1938937** (0.005)	0.1744546* (0.011)	0.2447495*** (0.000)
	Energy GBAORD	0.0098859 (0.462)	0.0201205 (0.167)	0.0606469*** (0.000)
Legend: ** p<0.05; ** p<0.01; *** p<0.001*				

The following table summarises the elasticities of the main independent variables for all specifications:

Table 27: Estimated Elasticities

Elasticities			
Dependent Variable: RD&D Budget Allocations on Renewable Energy Technologies	**Specification 1**	**Specification 2**	**Specification 3**
Total RD&D Budget Allocations on Fossil Fuels	-0.62		
RD&D Budget Allocations (excl. nuclear)		-0.12	
RD&D Budget Allocations on Nuclear		-0.54	
RD&D Budget Allocations on Oil and Gas			-0.13
RD&D Budget Allocations on Coal			-0.04
RD&D Budget Allocations on CO2 Capture and Storage			0.023
RD&D Budget Allocations on Nuclear Fission			-0.23
RD&D Budget Allocations on Nuclear Fusion			-0.18
			Source: Author

7.5 Discussion

To sum up, in this chapter the role of subsidies to fossil fuels on subsidies to RETs was examined. This was done by collecting data on six RETs (i.e. biomass, geothermal, hydro, ocean, solar, and wind) and summed together, thus placing the focus on those specific six technologies which are the focus of this thesis. Similarly, data on different fossil fuels were collected (i.e. oil and gas, coal, CO_2 capture and storage, nuclear fusion, and nuclear fission) thus allowing to examine the effect at both aggregated as well as a disaggregated level. Support for the first hypothesis was found in almost all cases implying substitutability between fossil fuel budget allocations and RETs allocations. On the totally disaggregated specification (third), it was found that budget allocations on coal and CO_2 Capture and Storage were statistically insignificant, implying independence.

Although the hypotheses, and therefore the effects can be argued to be obvious, the results – and especially those of the last specification – allow for a number of conclusions to be drawn. These in return have some very important implications for policy makers. It is highlighted that the different fossil fuel technologies have different effects on RE, and should not be treated as a single indicator, as in most previous studies. Overall, it was found that when treated as a single indicator, fossil fuel RD&D budgets have a negative and significant effect on RE allocations. However, on the complete disaggregated scenario, it can be seen that subsidies on coal and CO_2 Capture and Storage were statistically insignificant. This is important in the sense that it supports the notion that there is currently a "lock-in" in coal technologies, and with the RETs being currently perceived unable to meet both base and peak load, as well as having RETs that rely on coal infrastructure to operate (see biomass), allocating budgets might still be of the essence. Based on these, it would appear that the optimal approach is for a government to allocate more budgets on RETs, while cutting on gas and oil, and nuclear. Subsidies should still be allocated on coal with CO_2 capture and storage (abated carbon), for the former because under current conditions it is still needed, and for the latter as it appears to be an important way to reduce and meet the emission targets, without lessening the innovation activity of RETs.

Like with the previous chapters, this too has limitations. The first relates to the relatively short time span of the data. As explained, additional fossil fuel subsidies are in place which however are only available from 2000 onwards, and it is a variable that cannot be excluded. The second relates to the fact that there are more determinants of RE subsidies than accounted for in this chapter. That said, while the key ones have been employed, the lagged DV is likely to have captured much of the impact of some potentially missing variables. These and the consistency of the results with the literature and the Hypotheses render confidence in their value. Moreover, and overall the results seemed to be robust to the three specifications used, and in line with theory and previous evidence.

Clearly more work is required to complement the findings. In particular, as regards the determinants of subsidies, more control variables should be employed, however these were out of the scope of this thesis. The precise reason why coal is found to be relatively insignificant has been explained, however why it fails and/or exceeds may be country dependent and hence, more in depth qualitative analysis to complement the econometric findings should be done. What is more, policy makers could benefit from the examination of the effects of RD&D allocations on fossil fuel on specific RETs.

Chapter 8
Summary, Conclusions and Policy Implications

The aim of this chapter is to provide a summary, conclusions and policy implications, as well as to look at limitations and opportunities for further research. The key research question is firstly explored followed by looking at each chapter's main aims and contribution.

The key research question was whether public policy towards RE can help foster a transition of energy sources from fossils to RE. The question is predicated on the understanding that:

1. Fossil fuels contribute to climate change;
2. Transition to RE energy sources is inhibited by market failures;
3. Innovations in RE can help foster the adoption of RE sources;
4. Public policy towards RE may help facilitate RE innovations; and
5. There are numerous factors that can help public policy makers improve the degree of success of their interventions and that requires further research.

Existing literature has some evident limitations, such as the lack of cross-fertilization between literature on industrial policy and RE, the lack of a uniform classification of the policy instruments, the often limited scope of the studies, and the absence of an econometric evaluation of the coexistence (interactions) of various policy instruments. Key innovations of this thesis are discussed in each chapter but more generically these include:

1. The cross-fertilization of the literature on industrial policy and renewable energy policy
2. The development of new theory and hypotheses and their testing
3. The adoption of a uniform classification of policy instruments
4. The use of interaction effects, i.e. their effects when multiple instruments are in place (Chapter 4)

5. The examination of the effects of RE instruments on specific renewable energy technologies (Chapter 5)
6. Their effects when targeting one specific technology, as opposed to targeting more than one (Chapter 6)
7. The effects of subsidies of fossil fuels on renewable energy subsidies
8. The examination of regional variations
9. The examination of the role of policy experience
10. Data-base. Data and method specific novelties
11. Other chapter-specific novelties

In the above context in Chapter 1 (Introduction) the problem of climate change and the contribution of fossils-based energy to that is discussed. Then in the second chapter entitled "Theoretical Framework: Determinants of Innovation and the Role of Public Industrial Policy", the main focus is on the role of innovation in fostering positive change in general and in RE in particular, as well as on how public industrial policy may help solve market failures and foster innovation in RE sources. Then, in Chapter 3 entitled "Empirical Protocol and Method", the main variables were described, and suitable methodologies were reviewed, giving reasons for the ones employed in this thesis.

In Chapter 4, entitled "Industrial policy for renewable energy: The innovation impact of European policy instruments and their interactions" the focus has been on the impact of renewable energy policies as well as the three renewable energy policy instruments (demand-pull, technology-push and systemic) and their interactions on renewable energy innovation in 15 European Union countries for the period 1995-2014. Following a critical literature survey, a conceptual framework and hypotheses were developed and tested by employing a unique and comprehensive data set. It was found that renewable energy policies as a whole as well as demand-pull and technology-push instruments affect RE innovation positively and significantly. The impact of interactions between instruments on RE innovation is also positive and significant, but that in the case of specific pairs of instrument interaction the outcome is contingent on the specification used. Reasons were discussed for these findings, implications for public policy, as well as limitations and opportunities for further research.

This chapter’s research added to the literature in a number of ways. The first is related to the focus on the three types of instruments. This classification seems appropriate in terms of theory (Pitelis, 2018), and has been adopted in some recent studies (Costantini, et al., 2015). The second relates to the examination of instrument interactions. It was found that RE policy will on average positively affect RE innovation as a whole (i.e. increase it), and that RE policy instruments also have significant effect on RE innovation. It was also found that the interactions between instruments (especially those between technology-push and demand-pull on the one hand and systemic on the other) have a positive effect on RE innovation when analysed on their own, implying that they are likely to increase it. However, when examined alongside their components, it was found all component instruments as well as the interaction of all three had again had a positive effect, though the interaction between the three individual pairs had had a negative effect, implying that they are likely to supress the innovative activity when all are in effect.

Reasons for these findings were examined, including the possibility of different lag structures, a suggestion supported by the results. The findings highlight that different instruments matter, as well as their interactions matter and the way in which they interact and how they interact (for example alongside their component instruments or not). This is also the case for lag structures. Accordingly, much care should be taken to identify and leverage complementarities, while eschewing from potential inconsistencies and interactions. Such interactions between these instruments have not been properly taken into account in the existing literature, depriving policy-makers from a significant source of information (Magro & Wilson, 2013). Based on this, it seems that the optimal approach is for a government to employ policy instruments that complement, and are consistent with each other, and that this is a matter for empirical design and can be contingent on each specific case. This in turn calls for further research, more disaggregated findings and triangulation, including the use of case studies to support the quantitative econometric findings.

In the fifth chapter entitled "Can Industrial Policy Pick Winning Renewable Energy Technologies?" it was argued that debates on Industrial Policy (IP) have relied on conceptual arguments and case examples with limited econometric support. While research on public policy towards RE has employed econometric analyses a cross fertilization between the two has failed to adequately be combined with IP debates. A lasting debate in IP concerns whether government support to sectors and firms can help "pick winners". More recent developments have shifted attention to picking winning policies, policy instruments and/or technologies, notable General Purpose Technologies (GPTs). Having developed theory and Hypotheses, econometric evidence was provided for the impact of three IP policy instruments on different RETs. Following that, the unexplored role of country experience in mediating this relationship and for regional variations in OECD and EU was examined, as well as North and South EU regions. In addition, the extent to which the quality of the innovation outcomes is affected by IP was also explored. Findings lent support to the theory-derived Hypotheses.

More specifically novelties in this chapter include:

1. Cross fertilisation of RE and IP literatures;
2. Developed the argument that RE can qualify as a GPT;
3. Applied the concept of picking winners to policy instruments and RE Technologies;

4. Provided fresh econometric evidence for IP;
5. Explored regional variations; and
6. Adjusted RE innovation for quality of innovations.

Based on the conceptual analysis, five Hypotheses were developed and tested. Overall and on balance the Hypotheses were supported by the econometric evidence, and showed that:

- IP instruments on average are likely to foster the innovative activity of RETs with demand-pull ones being more potent, especially in high intervention countries.
- Targeting RETs is contingent upon country experience with more experienced countries being more effective.
- There exist regional disparities with Southern countries being less effective in fostering innovation in different RETs.
- Public policy support is found to induce innovation of lower quality.

In addition to the above there were some very interesting findings regarding the control variables-notably the market share (that can be seen as a proxy for market power) hindering RE innovation. These are all significant advances in an important field. All these have clear and strong policy implications-mainly that the policy experience and competence matter and that public policy interventions can help twist incentives and cause lower quality innovations.

In chapter 6, entitled "Fostering Innovation in Renewable Energy Technologies: Choice of policy instruments and effectiveness", the effectiveness of different types of policy instruments on innovation for different RETs was evaluated. More specifically, data on the innovation activity and performance were collected and analysed for 21 OECD countries over the period 1990-2014 – which were then used to assess and compare the effect of different instruments on different renewable technologies. The results showed that demand-pull policy instruments have been the most effective of all in fostering innovation activity; and that their level of effectiveness increased when they were used to target specific RETs. More specifically, three different models were employed to examine the effects of the three different types of policy instruments on RE innovation, policy instruments targeting more than one RET (but not necessarily all), and policy instruments targeting one specific RET; first model examined the aggregated effect of policies on RETs, serving as a base case. It was found that the different types of policy instruments have different effects on the innovative activity of RETs and that demand-pull policy instruments were positive and significant in all cases with the exception of solar energy technologies - for which technology no instrument type had any effect. Technology-push instruments were significant only for the cases of hydro and wind energy technologies, while systemic were found to be significant for the cases of biomass, hydro, and wind energy technologies, but negative in all other cases. The third model, showed that when it comes to targeting one specific technology, only demand-pull policies seem to be effective – something that was also true for the case of solar energy technologies. This was further supported by the existing literature as well as previous studies. In terms of policy implications, different technologies were found to require different types of policy instruments to foster innovation. Demand-pull policies are stronger possibly because of their horizontal nature (namely that they impact upon all). Another reason is their strong design (like feed-in tariffs in Germany) alongside being introduced earlier; thus, creating a degree of path-dependency.

In the seventh chapter entitled "The Interrelationship Between Subsidies to Fossil Fuels and to Renewable Energy Sources in the OECD" the role of subsidies to fossil fuels on subsidies to RETs was examined. The key claim of this chapter was that while the issue of substitutability between energy sources has been widely examined, the argument that supporting fossils fuels will hamper energy transitions, has been taken as self-evident. However, the relationship between subsidies to renewable energies and to fossil fuels is more nuanced. In theory the two types of support can be substitutes, unrelated or even complements, and the impact on energy transition will depend on the exact relationship. Only if there is strong substitutability transition to RE is hindered. And the degree of substitutability (if any) can depend on different types of fossils and RE technologies. In this context, having developed Hypotheses, data were collected on six RETs (i.e. biomass, geothermal, hydro, ocean, solar, and wind) and summed together; thus, placing the focus on those specific six technologies which are the focus of this thesis. Similarly, data on different fossil fuels were collected (i.e. oil and gas, coal, CO_2 capture and storage, nuclear fusion, and nuclear fission) thus allowing to examine the effect at both aggregated as well as a disaggregated level. Three different specifications were examined, each time disaggregating the independent variable more, i.e. in the first case the total fossil fuel technologies were considered, in the second the total fossil fuel subsidies were disaggregated into the total fossil fuel allocations except nuclear, and one for nuclear, and in the third, a complete disaggregation of the fossil fuel subsidies into oil and gas, coal, CO_2 capture and storage, nuclear fission, and nuclear fusion. It was found that in the first two specifications, substitutability existed between fossil fuel subsidies and renewable energy. The third specification showed that substitutability existed in the cases of oil and gas, and for both cases of nuclear.

The following table (Table 29), summarises all the hypotheses set in each chapter, as well as the respective conclusions/findings:

Table 28: Summary of hypotheses and key results

	Hypotheses	Conclusions/Findings
Chapter 4: Industrial policy for renewable energy: The innovation impact of European policy instruments and their interactions	Hypothesis 1: RE policy has a positive and significant effect on RE innovation.	RE innovation is found to be positively and significantly affected by RE policy
	Hypothesis 2: Technology-push and demand-pull policy instruments have a positive and significant effect on RE innovation.	(1) Demand-pull and technology-push instruments have a positive and significant effect on RE innovation, (2) Systemic instruments were found to be insignificant when examined on their own.
	Hypothesis 3: The interaction between demand-pull, and technology-push policies on the one hand and systemic policies on the other, have a positive and significant effect on RE innovation.	(1) When examined in isolation it was found that technology-push and demand-pull instruments interact positively with systemic ones, (2) The interaction between demand-pull and technology-push was found to be negative, (3) the interaction between all three instruments has a negative and significant effect on RE innovation, (4) When tested along their individual components, all three instruments are positive and significant and only the interaction of all three instruments is positive and significant, but when different lag structures of the independent variables were included, (5) only technology-push is significant and positive at its level, while the demand-pull ones are positive when lagged by one period.
Chapter 5: Can Industrial Policy Pick Winning Renewable Energy Technologies?	Hypothesis 1: REP instruments positively affect RE technologies.	Overall positive and significant effect across most RETs. Policy intervention has been effective in stimulating more innovation activity in RET.
	Hypothesis 2: The effect of REP instruments on RETs varies between specific instruments and RETs.	Technology-push policy instruments have been more effective in fostering innovation in biofuel, hydro and solar -related technologies. Demand - pull policy instruments have been more effective in stimulating innovation in biofuel, hydro, and wind-related technologies. Systemic policy instruments are found to have a significant effect only when controlling for quality of innovation.

	Hypotheses	Conclusions/Findings
	Hypothesis 3: The impact of targeting particular RETs on RE innovation is mediated by a country's experience.	Experience in practicing industrial policy matters. When distinguishing between "high" and "low" policy intervention groups of countries, we find consistently that REP are more likely to have a significant (and more sizeable) effect when used in the "high intervention" group.
	Hypothesis 4: The efficacy of targeting RETs differs across North-South EU regions.	Policy intervention is more effective in northern than in southern EU member states. This result holds for both "high" and "low" intervention groups. These differences become even more pronounced when controlling for quality of innovation.
	Hypothesis 5: Public support for particular RETs impairs (negatively affects) the quality of the RET innovations.	The use of policy support instruments in the OECD over the sample period has been much less effective in encouraging impactful innovation in RE technologies than it had in stimulating activity per se.
Chapter 6: Fostering Innovation in Renewable Energy Technologies: Choice of policy instruments and effectiveness	Hypothesis 1: The impact of REP instruments on RE innovation is contingent upon the instrument used	The aggregate effect of policy instruments varies according to their type. Specifically, the technology-push instruments have an insignificant effect on the overall RE innovation, while demand-pull policies have a positive effect.

	Hypotheses	Conclusions/Findings
	Hypothesis 2: REP instrument that target specific RETs have a stronger effect on RE innovation of the targeted RETs	(1) In the case of biomass technologies, technology-push instruments have an insignificant effect on driving innovative activity regardless of whether they concern policy instruments that target multiple RETs or only biomass technologies. Demand-pull policy instruments have had a positive and significant effect. (2) Geothermal technologies are significantly impacted only by demand-pull instruments, (3) Hydro and wind technologies were affected significantly by all policy instruments in the case of multiple-targeting REPs, but in the case they only targeted one then for hydro and wind technologies only demand-pull instruments were significant. (4) For Solar energy, in first case (multiple-targeting REPs) no policy instruments were significantwhile in the second case, demand-pull instruments are significant (5)
Chapter 7: The Interrelationship Between Subsidies to Fossil Fuels and to Renewable Energy Sources in the OECD	Hypothesis 1a: Higher subsidies to fossil fuels lead to lower subsidies to RE (substitutability)	Hypotheses 1 and 2 were supported. That is the relationship between subsidies to fossil fuels and RETs is one of substitutability (H1a) , except in the case of oil and gas where independence was observed (H1c). In the case of CO2 capture and storage I found complementarity (hence supporting Hypothesis 2).
	Hypothesis 1b: Higher subsidies to fossil fuels lead to higher subsidies to RE (complementarity)	
	Hypothesis 1c: Higher Subsidies to fossil fuels lead to no change in subsidies to RE (independence)	
	Hypothesis 2: The relationship between subsidies for fossil fuels and RE is mediated by the type of fossil fuel technology.	

The results especially those of the last specification allow for a number of conclusions to be drawn with important implications for policy makers. It was highlighted that the different fossil fuel technologies have different effects on RE, and should not be treated as a single indicator, as in most previous studies. Overall, it was found that when treated as a single indicator, fossil fuel RD&D budgets have a negative and significant effect on RE allocations. However, on the complete disaggregated scenario, it can be seen that subsidies on coal and CO_2 Capture and Storage were statistically insignificant. This is important in the sense that it supports the notion that there is currently a "lock-in" in coal technologies, and with the RETs being currently perceived unable to meet both base and peak load, as well as having RETs that rely on coal infrastructure to operate (see biomass), allocating budgets might still be of the essence. Based on these, the optimal approach is for a government seems to be the allocation of larger budgets on RETs, while cutting on gas and oil, and nuclear. Subsidies could still be allocated on coal with CO_2 capture and storage (abated carbon) because it appears to be an important way to reduce and meet the emission targets, without lessening the innovation activity of RETs.

As with other studies, this thesis has limitations. The first limitation relates to the use of patent data as a proxy for innovation which is often seen as an imperfect proxy. That said, in the absence of suitable and comparable alternative measures, it remains the most plausible and highly used indicator for this type of studies. The second limitation relates to the fact that there may be more determinants of RE innovation than accounted for in this thesis. However, a more comprehensive set of determinants than other studies was used, not least the separate instruments and their interactions. Other limitations relate to the relatively short time span of the data in Chapter 7. As explained, additional fossil fuel subsidies are in place which however, are only available from 2000 onwards, and it is a variable that cannot be excluded. Another relates to the fact that there are more determinants of RE subsidies than accounted for in that specific chapter. That said, while the key ones have been employed, the lagged DV is likely to have captured much of the impact of some potentially missing variables. Other limitations include the proxies for experience, quality and regional blocks (e.g. European OECD, non-Europe OECD) in Chapter 5.

A more general limitation of the findings (and most related literature) is a failure to account for the cost of RE policies and also for the opportunity cost of supporting RE as opposed to allocating resources in other worthy (or less worthy) projects. In this context the literature as a whole suffers from a challenge to show the full cost-benefit calculus of RE support. In addition, in many cases public policies also support fossil fuels. It would be interesting to see how can this impact on support to RE.

Despite limitations, the various innovations of the thesis alongside the consistency of the results with the literature and the Hypotheses lend confidence in the findings. Overall the results seemed to be robust to various specifications used, and in line with theory and previous evidence. Another key strength is the data base which is likely to be the most or one of the most comprehensive ones available.

The findings of this thesis have important implications for policy makers as it was shown that different policy instruments matter, as well as their interactions and how they interact. Such interactions among these instruments have not been adequately taken into account before. In addition to this, it was shown that different technologies require different types of policy instruments in order to induce innovation. Furthermore, policy experience and competence also matter, and public policy interventions can help distort incentives and induce lower quality innovations. In terms of the renewable energy technologies as such, it was shown that different technologies require different types of policy instruments in order to induce innovation. It seems that those instruments that aim to promote the demand are overall better, and also, that it is better to target one specific technology instead of multiple. Evidence was also found that subsidizing for fossil fuel technologies, undermines the subsidies on renewable energy technologies. Based on the above, it would appear that the optimal approach is for a government to employ policy instruments that complement, and are consistent with, each other.

Overall some limitations notwithstanding, I believe that my analysis and evidence helped make some important contributions to this very important and topical issue. . The aim is to continue researching this very important issue and hope to motivate others to also do so.

References

Acemoglu, D., Aghion, P., Bursztyn, L., & Hemous, D. (2012). The Environment and Directed Technical Change. *American Economic Review, 102*(1), 131-166.

Aghion, P., Dechezleprêtre, A., Hemous, D., Martin, R., & Van Reenen, J. (2012). Carbon Taxes, Path Dependency and Directed Technical Change: Evidence from the Auto Industry. *NBER Working Paper Series 18596*.

Aguayo, F., Gallagher, K., Hekkert, M., JIANG, K., Mytelka, L., Neij, L., . . . Wilson, C. (2012). Chapter 24: Policies for the Energy Technology Innovation System (ETIS). In T. B. Johansson, A. Patwardhan, N. Nakicenovic, & L. Gomez-Echeverri (Eds.), *Global Energy Assessment* (pp. 1665-1743). Cambridge: Cambridge University Press.

Aiken, M., Bacharach, S. B., & French, J. L. (1980). Organizational Structure, Work Process, and Proposal Making in Administrative Bureaucracies. *Academy of Management Journal, 23*, 631-652.

Alstone, P., Gershenson, D., & Kammen, D. M. (2015). Decentralized energy systems for clean electricity access. *Nature Climate Change, 5*(4), 3-5.

Anderson, N., Potocnik, K., & Zhou, J. (2014). Innovation and Creativity in Organizations: A state-of-the-science review, prospective commentary, and guiding framework. *Journal of Management, 40*(5), 1297-1333.

Arbib, J., & Seba, T. (2017). *Rethinking Transportation 2020-2030.* U.S.: A RethinkX Sector Disruption Report.

Archibugi, D., Cesaratto, S., & Sirilli, G. (1991). Sources of Innovative Activities and Industrial Organisation in Italy. *Research Policy, 20*, 299-313.

Arnold, E., Farla, K., Kolarz, P., & Potau, X. (2014). *The Case for Public Support of Innovation: At the sector, technology and challenge area levels.* London: Crown.

Arundel, A., & Kemp, R. (2009). *Measuring Eco-innovation.* Maastricht: Working Paper Series #2009-017 .

Athey, S., & Imbens, G. W. (2017). The state of applied econometrics: Causality and policy evaluation. *Journal of Economic Perspectives, 31*(2), 3-32.

Atkinson, A. B., & Stiglitz, J. E. (1980). *Lectures on Public Economics* (2nd (2015) ed.). Oxford: Princeton University Press. Retrieved 2015

Atkinson, S., & Halvorsen, R. (1976). Interfuel Substitution in Steam Electric Power Generation. *Journal of Political Economy, 84*(5), 959-978.

Bailey, D., Coffey, D., Gavris, M., & Thornley, C. (2018). Sector-targeting Policies for National Competitiveness: Exploring the Tensions with Place-based Industrial Policy. *Conference - Back on the Agenda? Industrial Policy Revisited.* Cambridge.

Bailey, D., Cowling, K., & Tomlinson, P. (Eds.). (2015). *New Perspectives on Industrial Policy for a Modern Britain.* Oxford: OUP Oxford.

Bailey, D., Pitelis, C. N., & Tomlinson, P. R. (2018). A place-based developmental regional industrial strategy for sustainable capture of co-created value. *Cambridge Journal of Economics*, DOI: 10.1093/cje/bey019.

Baker, E., & Shittu, E. (2006). Profit-maximizing R&D in Responce to a Random Carbon Tax. *Resource and Energy Economics, 28*, 160-180.

Balachandra, R., & Friar, J. H. (1997). Factors for Success in R&D Projects and New Product Innovation: A Contextual Framework. *IEEE Transactions on Engineering Management, 44*(3), 276-287.

Baron, R. (2016). *Energy Transition after the Paris Agreement: Policy and Corporate Challenges.* Paris: OECD Publishing.

Batista, N. C., Melício, R., & Mendes, V. M. (2017). Services enabler architecture for smart grid and smart living services providers under industry 4.0. *Energy and Buildings, 141*, 16-27.

Beck, F., & Martinot, E. (2004). Renewable Energy Policies and Barriers. In C. J. Cleveland (Ed.), *Encyclopedia of Energy* (pp. 365-383). Boston: Elsevier.

Bhattacharya, M., & Bloch, H. (2004). Determinants of Innovation. *Small Business Econonmics*, 155-162.

Bird, L., Heeter, J., O'Shaughnessy, E., Speer, B., Cook, O., Jones, T., . . . Nilson, E. (2017). *Policies for Enabling Corporate Sourcing of Renewable Energy Internationally: A 21st Century Power Partnership Report (No. NREL/TP-6A50-68149).* Golden, CO (United States): National Renewable Energy Lab.(NREL).

Bleda, M., & del Río, P. (2013). The market failure and the systemic failure rationales in technological innovation systems. *Research Policy, 42*, 1039-1052.

Blind, K. (2016). The impact of regulation on innovation. In J. Edler, P. Cunningham, A. Gok, & P. Shapira (Eds.), *Handbook of Innovation Policy Impact* (pp. 450-48). Edward Elgar Publishing.

Block, F., & Keller, M. R. (2011). Where Do Innovations Come From? Transformations in the U.S. economy, 1970-2006. *Working Papers in Technology Governance and Economic Dynamics no. 35*, 1-31.

Blundell, R., Griffith, R., & van Reenen, J. (1995). Dynamic count data models of technological innovation. *Economic Journal, 105*, 333-344.

Böhringer, C., Cuntz, A., Harhoff, D., & Otoo, E. A. (2014). *The Impacts of Feed-in Tariffs on Innovation: Empirical Evidence from Germany.* CESifo Group Munich: CESifo Working Paper Series 4680.

Boots, M., Schaeffer, G., De Zoeten-Dartenset, C., Mitchell, C., Anderson, T., Morthorst, P. E., . . . Cadenas, A. (2001). *The interaction of tradable instruments in renewable energy and climate change markets - Final Report (ECN-C-01-048).* Netherlands: Energy research Centre of the Netherlands.

Braun, F. G., Schmidt-Ehmcke, J., & Zloczysti, P. (2010). Innovative Activity in Wind and Solar Technology: Empirical Evidence on Knowledge Spillovers Using Patent Data. *DIW Berlin Discussion Paper No. 993*.

Breschi, S., Malebra, F., & Orsenigo, L. (2000). Technological Regimes and Schumpeterian Patterns of Innovation. *The Economic Journal, 110*, 388-410.

Bresnahan, T., & Trajtenberg, M. (1995). General purpose technologies 'Engines of growth'? *Journal of Econometrics, 65*(1), 83-108.

Brunnermeier, S. B., & Cohen, M. A. (2003). Determinants of Environmental Innovation in US Manufacturing Industries. *Journal of Environmental Economics and Management 45:2*, 278-293.

Burton, J. (1983). *Picking Losers...? The political economy of industrial policy.* London: Institute of Economic Affairs - Hobart Paper 99.

Campos, J., Ericsson, N. R., & Hendry, D. F. (2005). General-to-Specific Modeling: An Overview and Selected Bibliography. In J. Campos, D. F. Hendry, & N. R. Ericsson, *General-to-Specific Modeling.* Cheltenham: Edward Elgar Publishing.

Cantner, U., Graf, H., Herrmann, J., & Kalthaus, M. (2016). Inventor networks in renewable energies: The influence of the policy mix in Germany. *Research Policy 45*, 1165-1184.

Carlsson, B. (2006). Internationalization of Innovation Systems: A survey of the literature. *Research Policy, 35*(1), 56–67.

CCC. (2016). *Switching to low-carbon fuels*. Retrieved July 19, 2018, from Committee on Climate Change: https://www.theccc.org.uk/tackling-climate-change/reducing-carbon-emissions/what-can-be-done/low-carbon-fuels/

Chalvatzis, K. J. (2009). Electricity generation development of Eastern Europe: A carbon technology management case study for Poland. *Renewable and Sustainable Energy Reviews, 13*(6-7), 1606-1612.

Chang, H. J. (1993). The political economy of industrial policy in Korea. *Cambridge Journal of Economics, 17*(2), 131-157.

Chang, Y. C., & Chen, M. N. (2016). Service regime and innovation clusters: An empirical study from service firms in Taiwan. *Research Policy*, in press.

Chatterjee, S., & Hadi, A. (2012). *Regression Analysis by Example* (Fifth ed.). New Jersey: Wiley.

Cherni, J. A., & Kentish, J. (2007). Renewable energy policy and electricity market reforms in China. *Energy Policy, 35*(7), 3616-3629.

Christensen, C. (1997). *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail.* Harvard: Harvard Business Review Press.

CIEEM. (2015). *EU Environmental Legislation and UK Implementation.* Hampshire: Chartered Institute of Ecological and Environmental Management.

Cimoli, M., Dosi, G., & Stiglitz, J. E. (Eds.). (2009). *Industrial Policy and Development: The Political Economy of Capabilities Accumulation.* Oxford: Oxford University Press.

CISL. (2014). *Climate Change: Implications for the Energy Sector - Key Findings from the Intergovernmental Panel on Climate Change Fifth Assessment Report.* Cambridge : The University of Cambridge Institute for Sustainability Leadership .

Climate Action. (2015). *COP - What's it all about?* Retrieved June 06, 2016, from COP21Paris: http://www.cop21paris.org/about/cop21

Coady, D., Parry, I., Sears, L., & Shang, B. (2016). How Large Are Global Fossil Fuel Subsidies? *World Development*, 11-27.

Coenen, L., & Truffer, B. (2012). Places and Spaces of Sustainability Transitions: Geographical Contributions to an Emerging Research and Policy Field. *European Planning Studies, 20*(3), 367-374.

Cohen, W. M., & Levinthal, D. A. (1990). Absorptive Capacity: A New Perspective on Learning and Innovation. *Administrative Science Quarterly, 35*(1), 128-152.

Conte, A. (2007). *The Evolution of the Literature on Technological Change Over Time: A Survey.* Germany: Max Planck Institute of Economics: Papers on Entrepreneurship, Growth and Public Policy.

Corston, R., & Coleman, A. (2000). *A Crash Course in SPSS for Windows.* Oxford: Blackwell.

Costantini, V., Crespi, F., Martini, C., & Pennacchio, L. (2015). Demand-pull and technology-push public support for eco-innovation: The case of the biofuels sector. *Research Policy, 44*(3), 577-595.

Crossan, M. M., & Apaydin, M. (2010). A Multi-Dimensional Framework of Organizational Innovation: A Systematic Review of the Literature. *Journal of Management Studies 47:6*, 1154-1191.

Daft, R. L. (1978). A Dual-core Model of Organizational Innovation. *Academy of Management Journal, 21*, 193-210.

Damanpour, F. (1987). The Adoption of Technological, Administrative, and Ancillary Innovations: Impact of organizational factors. *Journal of Management, 13*, 675-688.

Damanpour, F. (1991). A Meta-Analysis of Effects of Determinants and Moderators. *The Academy of Management Journal, 34*(3), 555-590.

Damanpour, F. (1996). Organizational Complexity and Innovation: Developing and Testing Multiple Contingency Models. *Management Science, 42*(5), 693-716.

Dang, J., & Motohashi, K. (2015). Patent statistics: A good indicator for innovation in China? Patent subsidy program impacts on patent quality. *China Economic Review, 35*, 137-155.

De Vries, F. P., & Withagen, C. (2005). Innovation and Environmental Stringency: The case of sulphur dioxide abatement. *CentER Discussion Paper Series No. 2005-18.*

Dechezleprêtre, A., & Glachant, M. (2014). Does Foreign Environmental Policy Influence Domestic Innovation? Evidence from the Wind Industry. *Environmental and Resource Economics, 58*(3), 391-413.

Dechezlepretre, A., & Martin, R. (2010). *Low Carbon Innovation in the UK: Evidence from Patent Data.* London: Centre for Climate Change Economics and Police.

Dechezleprêtre, A., Martin, R., & Mohnen, M. (2017). Knowledge spillovers from clean and dirty technologies. *Centre for Climate Change Economics and Policy Working Paper No. 151*, 1-113.

del Rio, P., Klessmann, C., Winkel, T., & Gephart, M. (2013). *Interactions between EU GHG and Renewable Energy Policies – how can they be coordinated?* Spain: European IEE project beyond2020 (work package 7, deliverable 7.2).

Dewer, D., & Dutton, J. E. (1986). The Adoption of Radical and Incremental Innovations: An empirical Analysis. *Management Science, 32*, 1422-1433.

Dosi, G. (1988). Sources, Procedures, and Microeconomic Effects of Innovation. *Journal of Economic Literature*, 1120-1171.

Dosi, G., & Teece, D. J. (1998). Organizational Competencies and the Boundaries of the Firm. In R. Arena, & C. Longhi (Eds.), *Markets and Organisations* (pp. 281-302). Berlin: Springer-Verlag.

EC COM 130 final/2. (2014). *Taking stock of the Europe 2020 strategy for smart, sustainable and inclusive growth.* Brusseld: European Commission.

Edison, H., bin Ali, N., & Torkar, R. (2013). Towards innovation measurement in the software industry. *The Journal of Systems and Software*, 1390-1407.

Edquist, C., & Lundvall, B. A. (1993). Comparing the Danish and Swedish systems of innovations. In R. R. Nelson (Ed.), *National Innovation Systems.* New York: Oxford University Press.

EEA. (2014). *Energy support measures and their impact on innovation in the renewable energy sector in Europe.* Luxembourg: European Environment Agency .

EEA. (2016). *Renewable energy in Europe 2016: Recent growth and knock-on effects (Report No 4/2016) .* Luxembourg: Publications Office of the European Union.

EIA. (2010). *Annual Energy Outlook 2011.* DOE/EIA-0383: Energy Information Administration.

Ellabban, O., Abu-Rub, H., & Blaabjerg, F. (2014). Renewable Energy Resources: Current status, future prospects and their enabling technology. *Renewable and Sustainable Energy Reviews, 39*, 748-764.

Elliott, D., Bell, K. R., Finney, S. J., Adapa, R., Brozio, C., Yu, J., & Hussain, K. (2016). A comparison of AC and HVDC options for the connection of offshore wind generation in Great Britain. *IEEE Transactions on Power Delivery*, 798-809.

Enerdata. (2017). *Electricity domestic consumption*. Retrieved July 19, 2018, from Enerdata: https://yearbook.enerdata.net/electricity/electricity-domestic-consumption-data.html

ETH. (2014). *Expert statement on the impact of the German Renewable Energies Act (EEG) on innovation and climate protection: In response to the annual report of the "Expert Commission Research and Innovation" to the German Chancellor.* Zurich: Chair of Sustainability and Technology.

Ettlie, J. E., Bridges, W. P., & O'Keefe, R. D. (1984). Organization Strategy and Structural Differences for Radical Versus Incremental Innovation. *Management Science, 30*, 682-695.

European Commission. (1997). *Energy for the future: renewable sources of energy. White paper for a community strategy and action plan, COM(97) 599 final.* Luxembourg: European Commission.

European Commission. (1997). *Energy for the future: renewable sources of energy. White paper for a community strategy and action plan, COM(97) 599 final.* European Commission.

European Commission. (2001). *Directive 2001/77/EC.* Luxembourg: European Commission.

European Commission. (2001). *Directive 2001/77/EC.* European Commission.

European Commission. (2009). *Directive 2009/30/EC amending Directive 98/70/EC and Directive 1999/32.* Luxembourg: European Commission.

European Commission. (2014). *European Commission Decision C (2014)4995 - HORIZON 2020 Work Programme 2014-2015 - Part 19: General Annexes.* Brussels: European Commission.

European Commission. (2015). *EU ETS Handbook.* Belgium: Climate Action. Retrieved from Europa/European Commission.

European Commission. (2016). *Glossary of terms used in the Eco Innovation Observatory*. Retrieved August 27, 2016, from http://www.eco-innovation.eu/index.php?option=com_glossary&letter=E&id=1&Itemid=126

European Commission. (2016). *Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the promotion of the use of energy from renewable sources (recast) COM/2016/0767 final/2 - 2016/0382 (COD.* Belgium: European Comission.

European Commission. (2016). *Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - Energy prices and costs in Europe.* Brussels: European Commission.

European Commission. (2016, May 02). *What are Technology Readiness Levels (TRLs) and to which Horizon 2020 call topics are they applicable?* . Retrieved March 08, 2017, from European Commission: https://ec.europa.eu/research/participants/portal/desktop/en/support/faqs/faq-2890.html

European Commission. (2017, December 14). *New Industrial Policy Strategy*. Retrieved June 01, 2018, from European Commission: https://ec.europa.eu/commission/news/new-industrial-policy-strategy-2017-sep-18_en

European Commission. (2018, August 1). *Launch of the EU Clean Energy Industrial Competitiveness and Innovation Forum for renewables*. Retrieved August 20, 2018, from Europa/European Commission: https://ec.europa.eu/info/news/launch-eu-clean-energy-industrial-competitiveness-and-innovation-forum-renewables-2018-jan-08_en

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

European Union. (2016). *Regulations, Directives and other acts*. Retrieved October 17, 2016, from https://europa.eu/european-union/law/legal-acts_en

EuroStat. (2016). *Your key to European statistics.* Brussels: European Commission.

Fischer, C., & Newell, R. G. (2008). Environmental and technology policies for climate mitigation. *Journal of Environmental Economics and Management 55 (2)*, 142-162.

Fischer, C., & Preonas, L. (2010). Combining policies for renewable energy: is the whole less than the sum of its parts? *International Review of Environmental and Resource Economics, 4 (1)*, 51-92.

Flamos, A. (2010). The Clean Development Mechanism - catalyst for wide spread deployment of renewable energy technologies? or misnomer? *Environment, Development and Sustainability, 12*(1), 89-102.

Flanagan, K., & Uyarra, E. (2016). Four dangers in innovation policy studies–and how to avoid them. *Industry and Innovation, 23*(2), 177-188.

Florida, R. (1996). Lean and green: the move to environmentally conscious manufacturing. *California Management Review, 39*(1), 80-105.

Foray, D. (2015). *Smart specialisation: Opportunities and challenges for regional innovation policy.* London: Routledge.

Fouquet, D. (2013). Policy Instruments for Renewable Energy - From a European perspective. *Renewable Energy 49*, 15-18.

Freeman, C. (1982). The Economics of Industrial Innovation. *Freeman, Christopher, The Economics of Industrial Innovation (1982). University of Illinois at Urbana-Champaign's Academy for Entrepreneurial Leadership Historical Research Reference in Entrepreneurship. Available at SSRN: https://ssrn.com/abstract=14961*. Retrieved from https://ssrn.com/abstract=1496190

Freeman, C. (1987). *Technology Policy and Economic Performance. Lessons from Japan.* London: Pinter.

Frondel, M., Horbach, J., & Rennings, K. (2008). End-of-pipe or cleaner production? An empirical comparison of environmental innovation decisions across OECD countries. In N. Johnstone (Ed.), *Environmental Policy and Corporate Behaviour.* OECD.

Furman, J. L., Porter, M. E., & Stern, S. (2002). The determinants of national innovative capacity. *Research Policy, 31*, 899-933.

Garcia, R., & Calantone, R. (2002). The Critical Look at Technological Innovation Typology and Innovativeness Terminology: A Literature Review. *The Journal of Product Innovation and Management, 19*, 110-132.

Goulder, L. H. (2013). Climate change policy's interactions with the tax system. *Energy Economics 40*, S3 - S11.

Grafström, J., & Lindmand, A. (2017). Invention, Innovationm and Diffusion in the European Wind Power Sector. *Technological Forecasting and Social Change*, 179-191.

Green, L., McKeenin, A., & Irwin, A. (1994). Technological Trajectories and R&D for Environmental Innovation in UK Firms. *Future, 26*, 1047-1059.

Green, R., & Vasilakos, N. (2011). The economics of offshore wind. *Energy Policy, 39*(2), 496-502.

Greene, W. H. (1994). *Accounting for Excess Zeros and Sample Selection in Poisson and Negative Binomial Regression Models.* New York: Stern School of Business .

Griffin, J. (1977). nterfuel Substitution Possibilities: a Translog Application to Intercountry Data. *International Economic Review, 18*(3), 755-770.

Groba, F., & Breitschopf, B. (2013). *Impact of Renewable Energy Policy and Use on Innovation: A literature review.* Berlin: Deutsches Institut für Wirtschaftsforschung: Discussion Papers 1318.

Grotenhuis, M. T., & Thijs, P. (2015). *Dummy variables and their interactions in regression analysis: examples from research on body mass index.* Retrieved March 05, 2018, from arXiv: https://arxiv.org/ftp/arxiv/papers/1511/1511.05728.pdf

Guerzoni, M., & Raiteri, E. (2015). Demand-side vs. supply-side technology policies: Hidden treatment and new empirical evidence on the policy mix. *Research Policy 44*, 726-747.

Gunningham, N., & Sinclair, D. (1998). *Designing smart regulation.* Paris: OECD/Intemational Energy Agency.

Hansen, S. O., & Wakonen, J. (1997). Innovation, A Winning Solution? *International Journal of Technology Management, 13*, 345-358.

Hausman, J., Hall, B. H., & Griliches, Z. (1984). Econometric Models for Count Data With an Application to the Patents-R&D Relationship. *Econometrica, 54*, 909-938.

Helm, D. (2010). Government Failure, Rent-Seeking, and Capture: the design of climate change policy. *Oxford Review of Economic Policy, 26*(2), 182-196.

Herrmann, J. K., & Savin, I. (2017). Optimal Policy Identification: Insights from the German electricity market. *Technological forecasting and social change*, 71-90.

Hilbe, J. M. (2011). *Negative Binomial Regression* (2nd ed.). Cambridge: Cambridge University Press.

Hodson, M., & Marvin, S. (2010). Can cities shape socio-technical transitions and how would we know if they were? *Research Policy, 39*, 477-485.

Holland, S. (2014). *Europe in Question - and what to do about it.* London: Spokesman Books.

Honegger, M., & Reiner, D. (2018). The political economy of negative emissions technologies: consequences for international policy design. *Climate Policy, 18*, 306-321.

Hoppmann, J., Peters, M., Schneider, M., & Hoffmann, V. H. (2013). The two faces of market support - How deployment policies affect technological exploration and exploitation in the solar photovoltaic industry. *Research Policy 42*, 989-1003.

Horbach, J. (2008). Determinants of Environmental Innovation - New Evidence from German Panel Data Sources. *Research Policy, 37*(1), 163-173.

Horbach, J., Rammer, C., & Rennings, K. (2012). Determinants of eco-innovations by type of environmental impact - The role of regulatory push/pull, technology push and market pull. *Ecological Economics 78*, 112-122.

Howlett, M. P., & Rayner, J. (2013, 05 30). *Patching vs Packaging: Complementary Effects, Goodness of Fit, Degrees of Freedom And Intentionality in Policy Portfolio Design.* Lille: ESEE Meetings.

IEA. (2006). *Renewable Energy: RD&D Priorities.* Paris: OECD/IEA.

IEA. (2006). *Renewable energy: RD&D priorities, insights from the IEA technology programmes.* Paris: International Energy Agency.

IEA. (2016). *Global Renewable Energy Policies and Measures Database.* Paris: IEA/IRENA .

IEA. (2016). *World Energy Outlook 2016.* Paris: OECD/IEA.

IEA. (2017). *Key World Energy Statistics.* Paris: International Energy Agency Publications.

IEA. (2017a, April). *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2017.* Retrieved July 15, 2018, from U.S. Energy Information Administration: https://www.eia.gov/outlooks/archive/aeo17/pdf/electricity_generation.pdf

IEA. (2017c). *CO2 Emissions From Fuel Combustion 2017.* Paris: International Energy Agency.

IEA/IRENA. (2014). *IEA/IRENA Joint Policies and Measures Database* . Retrieved July 13, 2014, from International Energy Agancy: http://www.iea.org/policiesandmeasures/renewableenergy/

IPCC. (2005). *IPCC Special Report on Carbon Dioxide Capture and Storage.* Cambridge: Cambridge University Press.

IPCC. (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press.

IRENA. (n/a). *Innovation for the Energy Transition*. Retrieved January 19, 2017, from International Renewable Energy Agency: http://www.irena.org/innovationtechnology/Innovation-for-Energy-Transition

Jacobsson, S., & Bergek, A. (2003). Transforming the Energy Sector: The Evolution of Technological Systems in Renewable Energy Technology. In K. Jacob, M. Binder, & A. Wieczorek (Eds.), *Governance for Industrial Transformation* (pp. 208-236). Berlin: Environmental Policy Research Centre.

Jaffe, A. B., & Palmer, K. (1996). Environmental Regulation and Innovation: A panel data study. *Review of Economics and Statistics*, 610-619.

Jaffe, A. B., Newell, R. G., & Stavins, R. N. (2005). A Tale of Two Market Failures: Technology and Environmental Policy. *Ecological Economics, 54*(2-3), 164-174.

Johnstone, N., Haščič, I., & Popp, D. (2008). Renewable Energy Policies and Technological Innovation: Evidence based on patent counts. *Environmental and Resource Economics 45:1*, 133-155.

Jones, C. T. (1995). A Dynamic Analysis of Interfuel Substitution in U.S. Industrial Energy Demand. *Journal of Business & Economic Statistics, 13*, 459-465.

Kalkuhl, M., Edenhofer, O., & Lessmann, K. (2012). Learning or lock-in: Optimal technology policies to support mitigation. *Resource and Energy Economics, 34 (1)*, 1-25.

Karnitschnig, M. (2014). Germany's Expensive Gamble on Renewable Energy. *The Wall Street Journal*, 12-13.

Kautto, N., Arasto, A., Sijm, J., & Peck, P. (2012). Interaction of the EU ETS and national climate policy instruments - Impact on biomass use. *Biomass and Bioenergy 38*, 117-127.

Kern, F., & Howlett, M. (2009). Implementing transition management as policy reforms: a case study of the Dutch energy sector. *Policy Sciences, 42*, 391-408.

Kieffer, G., & Couture, T. D. (2015). *Renewable Energy Target Setting.* Abu Dhabi: IRENA.

Kim K., & Kim, Y. (2015). Role of policy in innovation and international trade of renewable energy technology: Empirical study of solar PV and wind power technology. *Renewable and Sustainable Energy Reviews, 44*, 717-727.

Kimberly, J. R., & Evanisko, M. (1981). Organizational Innovation: The influence of individual, organizational, and contextual factors on hospital adoption of technological and administrative innovation. *Academy of Management Journal, 24*, 689-713.

Klessmann, C., Held, A., Rathmann, M., & Ragwitz, M. (2011). Status and Perspectives of Renewable Energy Policy and Deployment in the European Union - What is needed to reach the 2020 targets? *Energy Policy 39*, 7637-7657.

Klevorick, A. K., Levin, R. C., Nelson, R. R., & Winter, S. G. (1995). On the sources and significance of interindustry differences in technological opportunities. *Research Policy, 24*(2), 185-205.

Knight, E. (2012). The Economic Geography of Financing Clean Energy Technologies. *Competition and Change, 16*(2), 77-90.

Kuan, J. S. (Ed.). (2004). *Global Transfer Pricing Solutions: 2005.* Massachusetts: WorldTrade Executive, Inc.

Kuznetsov, Y., & Sabel, S. (2011). *New Open Economy Industrial Policy: Making Choices without Picking Winners.* The World Bank.

Landini, F., Lee, K., & Malerba, F. (2017). A history-friendly model of the successive changes in industrial leadership and the catch-up by latecomers. *Research Policy, 46*(2), 431-446.

Langsdorf, S. (2011). *EU Energy Policy: From the ECSC to the Energy Roadmap 2050.* Brussels: Green European Foundation.

Lanjouw, J. O., & Mody, A. (1996). Innovation and the International Diffusion of Environmentally Responsive Technology. *Research Policy 25:4*, 549–571.

Lanzi, E., & Sue Wing, I. (2010). Directed Technical Change in the Energy Sector: An Empirical Test of Induced Directed Innovation. *Paper presented at the SURED Conference, ETH Zurich*.

LAZARD. (2017). *LAZARD's Levelised Cost of Energy Analysis - Version 11.0.* Retrieved August 26, 2018, from LAZARD: https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf

Lazkano, I., & Pham, L. (2016). Do Fossil-Fuel Taxes Promote Innovation in Renewable Electricity Generation? *NHH Dept. of Economics Discussion Paper No. 16/2016*, 1-69.

Lee, K., & Lee, S. (2013). Patterns of technological innovation and evolution in the energy sector: A patent-based approach. *Energy Policy*, 415–432.

Less, S. (2012). *Greening the economy - not "green economy".* London: Policy Exchange.

Lundvall, B. A. (Ed.). (1992). *National Systems of Innovations.* London: Pinter.

Luukkonen, T. (2000). Additionality of EU framework programmes. *Research Policy, 29*, 711-724.

Mabee, W. E., & Saddler, J. N. (2007). *Forests and Energy in OECD Countries.* OCED: Food and Agriculture Organization of the United Nations.

Magro, E., & Wilson, J. R. (2013). Complex innovation policy systems: Towards an evaluation mix. *Research Policy, 42*, 1647-1656.

Malebra, F., & Orsenigo, L. (1996). Schumpeterian patterns of innovation are technology-specific. *Research Policy, 25*(3), 451-478.

Mankins, J. C. (1995). *A White Paper: Technology Readiness Levels.* Washington: NASA.

Marino, K. E. (1982). Structural Correlations of Affirmative Action Compliance. *Journal of Management, 8*, 75-93.

Marques, A. C., & Fuinhas, J. A. (2012). Are public policies towards renewables successful? Evidence from European countries. *Renewable Energy 44*, 109-118.

Martin, B. R. (2016). R&D policy instruments – a critical review of what we do and don't know. *Industry and Innovation, 23*(2), 157-176.

Mazzucato, M. (2013). *The Entrepreneurial State: Debunking Public vs. Private Sector Myths.* London: Anthem Press.

Metcalfe, J. S. (1995). The economic foundations of technology policy: equilibrium and evolutionary perspectives. In P. Stoneman (Ed.), *Handbook of Economics of Innovation and Technological Change.* Oxford: Blackwell.

Michalena, E., & Hills, J. M. (2012). Renewable Energy Issues and Implementation of European Energy Policy: The missing generation? *Energy Policy 45*, 201-216.

Michelsen, C. (2005). *Exploring policy space: Interactions between policy instruments on household energy efficiency.* http://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=1325690&fileOId=1325691: IIIEE.

Moselle, B., & Moore, S. (2011). *Climate Change Policy - Time for Plan B.* London: Policy Exchange.

Mueller, D. C. (2003). *Public Choice III.* Cambridge: Cambridge University Press.

Mundaca, L., & Neij, L. (2010). *A Meta-Analysis of Bottom-Up Ex-Ante Energy Efficiency Policy Evaluation Studies.* http://www.iepec.org/conf-docs/papers/2010PapersTOC/papers/033.pdf: International Energy Program Evaluation Conferences.

Nelson, A. J. (2009). Measuring Knowledge Spillovers: What patents, licenses and publications reveal about innovation diffusion. *Research Policy 38*, 994-1005.

Nelson, A. J. (2009). Measuring Knowledge Spillovers: What patents, licenses and publications reveal about innovation diffusion. *Research Policy, 38*, 994-1005.

Nelson, R. R. (Ed.). (1993). *National Innovation Systems: A Comparative Analysis.* New York: Oxford University Press.

Nelson, R. R., & Rosenberg, N. (1993). Technical innovation and national systems. In R. R. Nelson (Ed.), *Technical innovation and national systems.* New York: Oxford University Press.

Nemet, G. F. (2009). Demand-pull, technology-push, and government-led incentives for non-incremental technical change. *Research Policy 38*, 700-709.

Nesta, L., Vona, F., & Nicolli, F. (2014). Environmental policies, competition and innovation in renewable energy. *Journal of Environmental Economics and Management 67:3*, 396-411.

Newell, R., Jaffe, A., & Stavins, R. (1999). The induced innovation hyphothesis and energy-saving technological change. *Quarterly Journal of Economics, 114*(3), 941-975.

Nicolli, F., & Vona, F. (2012). *The Evolution of Renewable Energy Policy in OECD Countries: aggregate indicators and determinants.* France: OECD.

Niosi, J. (2002). National systems of innovations are "x-efficient" (and x-effective): Why some are slow learners. *Research Policy, 31*(2), 291-302.

Niosi, J., Saviotti, P. P., Bellon, B., & Crow, M. (1993). National systems of innovations: in search of a workable concept. *Technology in Society, 15*, 207-227.

Nord, W. R., & Tucker, S. (1987). *Implementing Routine and Radical Innovation.* Lexington, MA: Lexington Books.

Nordhaus, W. D. (2009). Designing a friendly space for technological change to slow global warming. *Snowmass Conference on Technologies to Combat Global Warming.* CO: Snowmass.

OECD. (1991). *The Nature of Innovation and the Evolution of the Productive System, Technology and Productivity - The Challenge for Economic Policy.* Paris: OECD Publishing.

OECD. (2001). Using Patent Counts for Cross-Country Comparisons of Technology Outputs. *STI Review No. 27*, 129-146.

OECD. (2005). *Oslo Manual - Guidelines for Collecting and Interpreting Innovation (3d Ed.).* OECD Publishing.

OECD. (2009). *Sustainable Manufacturing and Eco-Innovation: Framework, Practices and Measurement.* France: OECD.

OECD. (2011b). *Demand-side Innovation Policies.* Luxembourg: OECD Publishing.

OECD. (2013). *Introduction: Inventory of Estimated Budgetary Support and Tax Expenditures for Fossil-Fuels.* Paris: OECD Publishing.

OECD. (2015a). *Adapting to the Impacts of Climate Change - Policy Perspectives.* Paris: OECD Publishing.

OECD. (2015b). *The Economic Consequences of Climate Change.* Paris: OECD Publishing.

OECD. (2016b). *.Stat/iLibrary.* Paris: OECD.

OECD. (2018). *OECD Companion to the Inventory of Support Measures for Fossil Fuels 2018.* Paris: OECD Publishing.

Oikonomou, V. (2004). *A qualitative analysis of white, green certificates and EU CO2 allowances. Phase II of the White and Green projec (draft report).* Utrecht: Utrecht University.

Oikonomou, V., & Jepma, C. J. (2008). A framework on interactions of climate and energy policy instruments. *Mitigation and Adaptation Strategies for Global Change 13*, 131-156.

Oltra, V. (2008). *Environmental Innovation and Industrial Dynamics: the contributions of evolutionary economics.* France: Cahiers du GREThA n° 2008-28 .

Palmer, J., Sorba, G., & Madlener, R. (2015). Modelling the diffusion of residential photovoltaic systems in Italy: An agent-based simulation. *Technological forecating and social change, 99*, 106-131.

Papageorgiou, C., Saam, M., & Schulte, P. (2017). Substitution between Clean and Dirty Energy Inputs: A Macroeconomic Perspective. *Review of Economics and Statistics, 99*(2), 281-290.

Parag, Y., & Sovacool, B. K. (2016). Electricity market design for the prosumer era. *Nature Energy, 1*(4), 16-32.

Patel, P., & Pavitt, K. (1994). National Innovation Systems: Why They Are Important, And How They Might Be Measured And Compared. *Economics of Innovation and New Technology, 3*(1), 77-95.

PATSTAT. (2016). *Worldwide Patent Statistical Database .* Munich: EPO-PATSTAT.

Pavitt, K. (1984). Sectoral Patterns of Technical Change: Towards a taxonomy and a theory. *Research Policy, 13*(6), 343-373.

Pelli, M. (2012). The Elasticity of Substitution between Clean and Dirty Inputs in the Production of Electricity. *Discussion paper, Universita della Svizzera Italiana*.

Pérez-Jeldres, R., Cornejo, P., Flores, M., Gordon, A., & García, X. (2017). A modeling approach to co-firing biomass/coal blends in pulverized coal utility boilers: Synergistic effects and emissions profiles. *Energy, 120*(1), 663-674.

Pesaran, M. H. (1974). On the General Problem of Model Selection. *Review of, 41*(2), 153-171.

Peters, M., Schneider, M., Griesshaber, T., & Hoffmann, V. H. (2012). The impact of technology-push and demand-pull policies on technical change – Does the locus of policies matter? *Research Policy (41)*, 1296-1308.

Pindyck, R. (1979). Interfuel Substitution and the Industrial Demand for Energy: An International Comparison. *Review of Economics and Statistics, 61*(2), 169-179.

Pitelis, A. T. (2018). Industrial policy for renewable energy: The innovation impact of European policy instruments and their interactions. *Competition and Change, 22*(3), 227–254.

Pitelis, A. T. (2018). Industrial Policy for Renewable Energy: The innovation impact of European policy instruments and their interactions. *Competition and Change*, Forthcoming.

Pitelis, C. N. (1994). Industrial Strategy: For Britain, in Europe and the World. *Journal of Economic Studies, 21*(5), 3-92.

Pitelis, C. N. (2015). DIP-ly Speaking: Debunking 10 Myths and a Business Strategy-Informed Developmental Industrial Policy. In D. Bailey, K. Cowling, & P. Tomlinson (Eds.), *New Perspectives on Industrial Policy for a Modern Britain* (pp. 17-40). Oxford: Oxford University Press.

Pitelis, C. N. (2017). Europe in question and the question of Europe-an(d) capitalism: a review of Stuart Holland's 'Europe in Question. *Cambridge Journal of Economics, 41*(6), 1721–1739.

Pitelis, C. N., & Teece, D. (2016). Dynamic Capabilities, Developmental Industrial Strategy and The Strategic SCA of Nations. 1-42. Retrieved from https://ssrn.com/abstract=2749110

Pitelis, C. N., & Teece, D. J. (2009). The (new) nature and essence of the firm. *European Management Review, 6*(1), 5-15.

Pitelis, C. N., & Teece, D. J. (2010). Cross-border market co-creation, dynamic capabilities and the entrepreneurial theory of the multinational enterprise. *Industrial and Corporate Change, 19*(4), 1247-1270.

Pittaway, L., Robertson, M., Munir, K., & Denyer, D. (2004). *Networking and Innovation: A Systematic Review of the Evidence.* Lancaster : Lancaster University Management School Working Paper 2004/016.

Popp, D. (2002). Induced innovation and energy prices. *American Economic Review, 91*(1), 160-180.

Popp, D. (2006). International Innovation and Diffusion of Air Pollution Control Technologies: The effects of NOX and SO2 regulation in the US, Japan, and Germany. *Journal of Environmental Economics and Management 51:1*, 46-71.

Popp, D., & Newell, R. (2012). Where does energy R&D come from? examining crowding out from energy R&D. *Energy Economics, 34*(4), 980-991.

Porter, M. E. (1990). The Competitive Advantage of Nations. *Harvard Business Review*, 73-93.

Porter, M. E., & Stern, E. (2001). Innovation: Location Matters. *MIT Sloan Management Review, 42*(4), 28-36.

Rawlins, M., & Allal, H. (2003). *Renewable Energy Technologies and Kyoto Protocol Mechanisms.* Belgium: European Commission: EUR 20871.

Rehfeld, K., Rennings, K., & Ziegler, A. (2007). Integrated Product Policy and Environmental Product Innovations: An Empirical Analysis. *Ecological Economics,, 61*(1), 91-100.

REN21. (2015). *Renewables 2015: Global Status Report.* France: RE21.

Rennings, K. (2000). Redefining innovation - eco-innovation research and the contribution from ecological economics. *Ecological Economics, 32*, 319-332.

Rhodes, C. (2014). *SN/EP/6857 - Industrial policy, 2010 to 2015.* Lonodn: UK Parliament - House of Commons.

Rockström, J., Gaffney, O., Rogelj, J., Meinshausen, M., Nakicenovic, N., & Schellnhuber, H. J. (2017). A roadmap for rapid decarbonization. *Science, 355*(6331), 1269-1271.

Rodrik, D. (2004). Industrial Policy for the Twenty-First Century. *KSG Working Paper No. RWP04-047*, 1-58. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=617544

Rogge, K., & Reichardt, K. (2016). Policy mixes for sustainability transitions: An extended concept and framework for analysis. *Research Policy, 45*(8), 1620-1635.

Romer, P. (1990). Endogenous technological change. *Journal of Political Economy, 98*, S71-S102.

Rosenberg, N. (1974). Science, Invention and Economic Growth. *Economic Journal, 84*(333), 90-108.

Rosenberg, N. (1982). *Inside the Black Box: Technology and Economics.* Cambridge: Cambridge University Press.

Rosenberg, N. (1990). Why do firms do basic research (with their own money)? *Research Policy, 19*(2), 165-174.

Rutter, R., Chalvatzis, K. J., Roper, S., & Lettice, F. (2017). Branding Instead of Product Innovation: A Study on the Brand Personalities of the UK's Electricity Market. *European Management Review*.

Sahu, B. K. (2015). A study on global solar PV energy developments and policies with special focus on the top ten solar PV power producing countries. *Renewable and Sustainable Energy Reviews, 43*, 621-634.

Sandulli, F. D., Fernandez-Menendez, J., Rodriguez-Duarte, A., & Lopez-Sanchez, J. I. (2012). Testing the Schumpeterian hypotheses on an open innovation framework. *Management Decision, 50*(7), 1222-1232.

Scarlat, N., Dallemand, J.-F., Monforti-Ferrario, F., Banja, M., & Motola, V. (2015). Renewable energy policy framework and bioenergy contribution in the European Union – An overview from National Renewable Energy Action Plans and Progress Reports. *Renewable and Sustainable Energy Reviews, 51*, 969-985.

Schoonhoven, C. B. (1981). Problems with contingency theory: Testing assumptions hidden within the language of "theory". *Administrative Science Quarterly, 26*, 349-377.

Schubert, S. R., Pollak, J., & Kreutler, M. (2016). *Energy policy of the European Union.* London: Palgrave/Macmillan International.

Schumpeter, J. A. (1934). *The Theory of Economic Development.* Cambridge (Mass.): Harvard Univerity Press.

Schumpeter, J. A. (1942). *Capitalism, Socialism, and Democracy.* London and New York: Routledge.

Sijm, J. P., & van Dril, A. W. (2003). *The Interaction Between the EU Emissions Trading Scheme and Energy Policy Instruments in the Netherlands.* Netherlands: ECN-C--03-060 - Interaction in EU Climate Policy (INTERACT.

Simões, I., Huppes, G., & Seixas, J. (2005). A tangled web: assessing overlaps between energy and environmental policy instruments in place along electricity systems. In S. Attali, & K. Tillerson (Eds.), *Energy Savings: What Works and Who Delivers? ECEEE Summer Study Proceedings V 1-3.* Sweden: European Council for an Energy-Efficient Economy.

Smil, V. (2010). *Energy Transitions: History, Requirements, Prospects.* Oxford: Praeger.

Smith, B. L., & Barfield, C. E. (1996). *Technology, R&D, and the Economy.* Washington, DC: The Brookings Institution.

Smith, K. (2004). Chapter 6: Measuring Innovation. In J. Fagerberg, D. C. Mowery, & R. R. Nelson, *The Oxford Handbook of Innovation* (pp. 148-178). Oxford: Oxford University Press.

Smiths, R., & Kuhlmann, S. (2004). The Rise of Systemic Instruments in Innovation Policy. *International Journal of Foresight and Innovation Policy 1*, 4-32.

Sorrell, S., Boemare, C., Betz, R., Haralampopoulos, D., Konidari, P., Mavrakis, D., . . . Walz, R. (2003). *Interaction in EU Climate Policy - final report to DG research under the framework V project*

'Interaction in Climate Policy'. University of Sussex, Brighton: Science and Technology Policy Reseach.

STATA. (n/a). *hausman - Hausman Specification test.* Retrieved June 16, 2017, from stata.com: https://www.stata.com/manuals13/rhausman.pdf

Steinbuks, J. (2010). Interfuel Substitution and Energy Use in the UK Manufacturing Sector. *Cambridge Working Paper in Economics - EPRG Working Paper 1015*, 1-28.

Sterk, W., Dienst, C., Harmeling, S., & Schüwer, D. (2007). *Renewable Energy and the Clean Development Mechanism: Potential, barriers and ways forward - A guide for policy-makers.* Berlin: Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) - Public Relations Division.

Stern, N. (2006). *The economics of climate change: The Stern review.* Cambridge, UK: Cambridge University Press.

Stiglitz, J. E. (1989). Markets, Market Failures, and Development. *The American Economic Review 79 (2)*, 197-203.

Stoneman, P. (Ed.). (1995). *Handbook of the Economics of Innovation and Technological Change.* Oxford: Wiley-Blackwell Publishers.

Sun, I., & Kim, S. Y. (2017). Energy R&D towards Sustainability: A Panel Analysis of Government Budget for Energy R&D in OECD Countries (1974–2012). *Sustainability*.

Teece, D. J. (2010). Business Models, Business Strategy and Innovation. *Long Range Planning, 43*(2-3), 172-194.

The Economist. (2014, January 25). *European Climate Policy: Worse than useless.* Retrieved February 19, 2014, from The Economist: http://www.economist.com/news/leaders/21595002-current-policies-are-mess-heres-how-fix-them-worse-useless

The Guardian. (2017, December 14). EU must not burn the world's forests for 'renewable' energy. *The Guardian*. Retrieved from https://www.theguardian.com/environment/2017/dec/14/eu-must-not-burn-the-worlds-forests-for-renewable-energy

The Research Council of Norway. (2017, January 11). *Horizon 2020 - Public-Private Partnerships (PPPs).* Retrieved July 15, 2018, from The Research Council of Norway: https://www.forskningsradet.no/prognett-horisont2020/PublicPrivate_Partnerships_PPPs/1254023914755?d=Touch

Tidd, J., Bessant, J., & Pavitt, K. (1997). *Managing Innovation. Integrating Technological, Market and Organisational Change.* Chichester: Wiley.

Turkenburg, W. C. (2000). Chapter 7: Renewable Energy Technologies. In U. N. Programme, *Energy and the Challenge of Sustainability* (pp. 218-272). New York: UNDP.

UNFCCC. (2015). *The Paris Agreement.* Paris: United Nations.

United Nations. (1998). *Kyoto Protocol to the United Nations Framework Convention on Climate Change.* Bonn, Germany: United Nations.

United Nations. (2015). *Paris Agreement.* Bonn, Germany: United Nations.

Unruh, G. C. (2000). Understanding carbon lock-in. *Energy Policy 28*, 817-830.

US Energy Information Administration. (2016). *International Energy Outlook 2016.* Washington: US Energy Information Administration.

Varian, H. L. (2003, March 23). *Economics of Information Technology.* Retrieved December 22, 2016, from http://people.ischool.berkeley.edu/~hal/Papers/mattioli/mattioli.pdf

Venkatraman, N. (1989). The Concept of Fit in Strategy Research: Toward Verbal and Statistical Correspondence. *The Academy of Management Review, 14*(3), 423-444.

Wagner, M. (2007). *The Link between Environmental Innovation, Patents, and Environmental Management.* Copenhagen: DRUID Working Papers, n°07-14.

Wangler, L. U. (2013). Renewables and innovation: did policy induced structural change in the energy sector effect innovation in green technologies. *Environmental Planning Management 56*, 211-237.

Warwick, K. (2013). Beyond Industrial Policy: Emerging issues and new trends. *OECD Science, Technology andIndustry Policy Papers, No. 2, OECD Publishing*, 1-57.

Weber, M. K., & Rohracher, H. (2012). Legitimizing research, technology and innovation policies for transformative change: Combining insights from innovation systems and multi-level perspective in a comprehensive 'failures' framework. *Research Policy, 41*(6), 1037-1047.

Weitzman, M. (2007). A Review of The Stern Review on the Economics of Climate Change. *Journal of Economic Literature, Vol. XLV*, 703–724.

Wooldridge, J. M. (2001). *Econometric Analysis of Cross Section and Panel Data.* London: The MIT Press.

World Bank. (2010). *World Development Report: Development and Climate Change.* Washington: The International Bank for Reconstruction and Development/The World Bank.

World Bank. (2016). *DataBank.* Washington: World Bank Group.

WorldWeatherAttribution. (2018, July 28). *Heatwave in northern Europe, summer 2018*. Retrieved August 05, 2018, from World Weather Attribution: https://www.worldweatherattribution.org/attribution-of-the-2018-heat-in-northern-europe/

Wustenhagen, R., Wolsink, M., & Burer, M. J. (2007). Social acceptance of renewable energy innovation: An introduction to the concept. *Energy Policy, 35*, 2683-2691.

Zafirakis, D., Chalvatzis, K. J., Baiocchi, G., & Daskalakis, G. (2016). The value of arbitrage for energy storage: Evidence from European electricity markets. *Applied Energy, 184*, 971-986.

Zhao, J., & Jiarong, A. (1998). *Study of China's Economic Incentive Policies for Renewable Energy Development.* China: China Environmental Sciences Publishing House.

Zmud, R. W. (1982). Diffusion of Modern Software Practices: Influence of centralization and formalization. *Management Science, 28*, 1421-1431.