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INNOVATION AND ENVIRONMENTAL STRINGENCY:

A CROSS COUNTRY ANALYSIS

Advisor:

Prof. Cédric SCHNEIDER

Department of Economics

Master of Science Thesis of:

Silvia REZZONICO

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Summary

The Porter Hypothesis, in contrast with mainstream micro-economic theory, claims that under certain circumstances strict environmental policy can provide positive incentive mechanisms, which may eventually foster innovation, growth and competitiveness.

This work tries to empirically test this hypothesis, by analyzing the relationship between stringency of environmental regulation, and environmental innovation.

Stringency of regulation is measured indirectly by the yearly change in greenhouse gas emission levels. This is based on the intuition that increasing emission levels will be associated with laxity of environmental stringency, whereas decreasing emission levels will signal deeper engagement in environmental policy.

Environmental innovation, instead, is measured by successful patent applications in selected patent classes, explicitly identifying "clean energy technologies". The selection was based on a recent, fully retroactive reclassification scheme operated by the European Patent Office, that has introduced patent class Y02, referring to "Technologies or Applications for Mitigation or Adaptation against Climate Change".

The analysis was conducted in selected OECD countries over a time span of 18 years (from 1990 until 2007); the findings appear to be in line with Porter's hypothesis and seem to confirm that the more stringent regulation, the higher the degree of innovative activity. Additionally, results provide support to the claim that market based instruments are more effective in spurring innovation.

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1. Introduction

Over the last few decades, the topic of sustainable development has received increasing attention from several sides, including civil society but also the political and business worlds. Over time, companies have also become increasingly aware of the social and environmental pressures facing business; after the publication of the Brundtland Report in 1987 [1] and following international events such as the Earth Summit in Rio de Janeiro (1992) and the adoption of the Kyoto Protocol (1997) [2], sustainable development has become one of the foremost issues facing the world.

The interest in the topic of sustainable development has generated an international debate, focusing on the relationship between environmental protection and business concerns. Such relationship has traditionally been seen in terms of a trade-off built around the idea that environmental regulation constitutes an extra cost for firms, which will negatively affect productivity and competitiveness. Therefore, while often acknowledging the need for higher environmental engagement to preserve our planet and publicly demonstrate higher corporate social responsibility (McKinsey, 2010), managers have been striving to implement strategies aimed at minimizing the diversion of resources to environmental management, keeping profit maximization as their primary concern.

The approach that considers environmental protection as a cost is founded in mainstream micro-economic theory and it originates from the assumption that optimal allocation of resources can be naturally achieved

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[1] In 1987, the World Commission on Environment and Development (WCED) published a report, titled "Our common future". The document became known as the "Brundtland Report", after the Commission's chairwoman, Gro Harlem Brundtland. The report developed guiding principles for sustainable development and laid the foundations of the subsequent 1992 Earth Summit. *Source: http://www.un-documents.net/wced-ocf.htm*

[2] Informally known as the "Earth Summit", the United Nations Conference on Environment and Development (UNCED) of Rio de Janeiro witnessed the creation of the "United Nations Framework Convention on Climate Change". The treaty was aimed at stabilizing greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous interference with the climate system. The treaty included provisions for updates (called "protocols") that would set mandatory emission limits. The principal update is the Kyoto Protocol, which has become much better known than the UNFCCC. itself. *Source: http://unfccc.int/*

by markets through the price mechanism, thus generating a "first best" equilibrium solution. Only when markets alone are unable to reach efficient solutions are regulators called to intervene and correct such inefficiencies (Morgan, Katz, & Rosen, 2006).

In the case of environmental protection, the identified market failure is determined by the presence of negative externalities, which are linked to the very nature of resources such as clean air or water. Because ownership rights on these "environmental goods" are often poorly defined, economic agents tend to use *excessive amounts* of these resources at zero cost, generating pollution levels above the social optimum and simply leaving the real burden on society as a whole (Ambec & Lanoie, 2008).

Since the price system is not effective in conveying correct information to the markets, government intervention – through mechanisms spanning from regulation and taxation to pollution quotas or permits (Magat, 1979) - is needed to bring markets back to the socially optimal equilibrium level. With government intervention being considered a "second best" solution, a natural implication is that any kind of state regulation is believed to constitute a cost for firms, correcting their excessive depletion of resources and increasing their accountability.

This general paradigm, which essentially embraces the concept of environmental management as a cost minimization exercise aimed at regulatory compliance, has however been challenged in more recent times by an article written by Michael E. Porter (1991), then further elaborated by Porter and van der Linde (1995/a). In the paper, the two scholars bring forth the idea that raising environmental standards at country level can lead to win-win situations, where both social welfare and private net benefits of firms can be increased. In what has become to be known as the "Porter hypothesis", the authors even imply that imposing tougher regulation and establishing stricter environmental standards can, under certain circumstances, actually represent an incentive to innovation, and eventually lead to a competitive advantage at country level.

Porter (1991) claims that "*strict environmental standards do not inevitably hinder competitive advantage against foreign rivals*". More specifically, he points to the fact that "*the environment-competitiveness debate has been framed incorrectly*"; he notes that, by definition, equilibrium analyses performed under "traditional" frameworks are essentially static in nature, while in the real world companies are faced with *dynamic competition*, and need to deal with a wide range of pressures coming from competitors, customers and regulators (Porter & van der Linde, 1995/a). In particular, Porter stresses the fact that pollution is often a form of economic waste and inefficiency, and that regulation can represent an opportunity for firms to better evaluate their resource allocation. He claims that we are "*in a transitional phase of industrial history in which companies are still inexperienced in handling environmental issues creatively*" (Porter & van der Linde, 1995/b), but that properly designed regulation, even when first imposing costs on firms, may spur innovation which can *offset* the spending on pollution abatement (Wagner, 2003).

Porter's intuition builds on the theory of asymmetric information, and develops from the acknowledgement that managers are affected by two main issues: (1) incomplete information and (2) limited time attention. The idea is that regulation can inform markets and correct this information asymmetry, eventually adjusting the inefficiency, in a way that can be profitable for firms as well[3]. A fundamental condition which is necessary for the innovation process to be set in motion is that regulation be framed correctly. Bad regulation can hurt competitiveness, but innovation-friendly regulation does not necessarily increase costs and can promote innovation, resource productivity and competitiveness (Porter & van der Linde, 1995/a).

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[3] According to Porter and van der Linde (1995/a), regulation is needed for six main reasons: (1) to create pressure that motivates companies to innovate; (2) to improve environmental quality when innovation and improvements in resource productivity do not completely offset compliance costs; (3) to raise awareness about resource inefficiencies; (4) to increase the likelihood that innovations will be environmental friendly; (5) to create demand for environmental improvement until companies and customers are able to better evaluate resource inefficiencies and the true cost of pollution; (6) to have a "level playing field" during the transitional phase towards innovation-based environmental solutions, ensuring that companies do not gain positions by avoiding environmental investments.

In Porter's perspective, optimal regulation should be focused on outcomes, rather than technologies[4], it should make use of phase-in periods and market incentives and should be implemented as close to the end user as practical, to allow for the greatest possible flexibility in the end product and in the production and distribution stages. Additionally, the regulatory process should be stable and predictable, it should be developed with an understanding of the industry's economics, by involving industry actors from the beginning and should be as little time and resource consuming as possible. Finally, regulators should enact strict rather than lax regulation, harmonize or converge regulations in associated fields and develop regulations in synchronization with other countries, or slightly ahead of them, to be able to reap the benefits of increases in net exports of technology (Porter & van der Linde, 1995/a).[5]

At the time they were formulated, Porter's strong claims generated mixed reactions, especially because they were supported by relatively isolated case studies and anecdotal evidence. Opponents criticized in particular the underlying assumption according to which firms would systematically overlook opportunities for improving their environmental performance which would also increase their competitiveness, metaphorically suggesting that it is impossible to find a ten dollar bill on the ground, since someone else would have already picked it up[6] (Wagner, 2003).

This work will try to provide an empirical test of the Porter hypothesis, by analyzing the relationship between stringency of environmental regulation and innovation in a cross-country setting. To address this question, patent applications in selected OECD countries will be used as a measure of innovation, and a recent reclassification scheme developed by the European Patent Office will be exploited to identify environmental

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[4] Regulation focused on technologies, such as "Best Available Technology" (BAT) or "Best Available Control Technology" hinder innovation (Porter & van der Linde, 1995/a).
[5] For a more thorough discussion, refer to Porter & van der Linde, 1995/a.
[6] Another highly criticized aspect of the Porter hypothesis is that assumption that regulatory regimes are able to design stringent and at the same time efficient environmental regulation (Wagner, 2003)

innovation only. More specifically, the analysis will consider inventions within the newly established subclass “Y02E”, which corresponds to “Greenhouse gases (GHG), reduction of emissions related to energy generation, transmission or distribution”. As a measure of environmental stringency instead, a new indicator, the yearly percentage change in greenhouse case emissions, will be used, along with some additional measures related to arguably the most significant international agreement in the field of environmental protection - the Kyoto protocol – with the purpose of testing whether or not more stringent regulation leads to higher innovative activity.

As shown in further detail in the following sections, results appear to be in line with Porter’s hypothesis and seem to confirm that the more stringent regulation, the higher the degree of innovative activity, as measured by the number of successful patent applications. Additionally, results provide some support to the claim that in order to have positive effects on competitiveness, regulation needs to be shaped efficiently and that market based instruments are more effective in spurring innovation.

The remaining of this work will be structured as follows: section 2 will focus on the existing theoretical and empirical studies which have attempted to test or explain the Porter hypothesis; section 3 will be focused on the definition of the research question, and on the description of the data and techniques that are used; section 4 will provide an interpretation of the results, section 5 will focus on a model check and finally section 6 will conclude by providing some policy implications and suggestions for further research.

2. Literature review

The analysis of the relationship between stringency of environmental regulation and innovation is not uncommon in the literature. One can distinguish among two main streams: one is mostly concerned with theoretical aspects, while the other is focused on empirical tests of the relationship.

2.1. Theoretical literature

The first body of literature is interested in particular in determining which environmental policy instrument can provide firms with the greatest incentive to innovate from a theoretical standpoint. It should be noted that a significant amount of research came long before Porter's articles were published. For example, Magat (1979) considers four types of environmental regulation: (1) technology-based effluent standards (such as "Best Available Technology" or BAT standards); (2) non-technology-based effluent standards (i.e. emission limits or quotas); (3) effluent charges (fees or taxes) and (4) marketable pollution permits or certificates. He concludes that "*technology-based standards provide the weakest incentives for both abatement technology and output technology innovation*", but he notes that they provide strong incentives for diffusion. As for the remaining three instruments – non-technology-based standards, charges and marketable permits - he shows that their effects on abatement technology and output technology innovation will be the same, conditional that these instruments be set at dynamically equivalent levels (that is if they are not forced to be constant over time). In particular, he shows that such kinds of regulation will induce firms to bias their R&D efforts towards abatement technology innovation, and concludes that the previously mentioned regulatory approaches will most likely increase the level of abatement technology innovation while most likely decreasing a firm's rate of output technology innovation. In line with these findings, Downing and White (1986), and Milliman and Prince (1989) show that "market-based instruments" provide stronger incentives to innovate than "command and control" regulation.

Wagner (2003), following Endres (1994), reports four criteria to assess policy instruments from an economic point of view: (1) efficiency, that is the extent to which an instrument is able to lead to a Pareto-optimal attainment of predefined emission levels; (2) dynamic incentive effects, that is the degree to which an instrument is able to encourage innovation over time; (3) impacts on competition, which refer to the degree to which instruments may or may not distort competition (for instance related to the entry of new players into the market); and (4) environmental effectiveness, or the ability to lead to a predefined environmental target. Wagner (2003) evaluates the performance of standards, taxes and certificates, and concludes that marketable permits or certificates will function the best relative to the four performance criteria.

Following the formulation of the Porter hypothesis, another set of papers started questioning the mechanisms behind it, wondering in particular why firms would need government regulation before engaging in innovation which would anyways be in their interest (Palmer & Simpson, 1993). Palmer, Oates and Portney (1995) oppose Porter's claims, maintaining that environmental regulation cannot, as a general rule, lead to higher profits; as previously mentioned, they note that his arguments (unreasonably) rely on the assumption that firms are systematically unable to recognize profitable new opportunities from technology unless regulation "opens their eyes".

Porter's co-author, van der Linde (1993) addressed these critiques, insisting that regulation is justified by three reasons. A first reason relates to firms' inertia towards change: while firms are generally reluctant to explore new technology fields, regulation will provide them with the necessary incentive to start investigating such different areas. Secondly, regulation communicates to firms that governments have serious intentions about bringing environmental issues into their agenda, thus functioning as a *signal* to industry. Lastly, given that firms will receive benefits completely offsetting compliance costs only in a limited number of cases, government regulation will force them to innovate. Additionally, government intervention guarantees that firms will engage in R&D at socially optimal levels, which may not happen absent regulation, if firms consider exclusively their private benefits.

Sinclair-Desgagné (1999) provides some support to the mechanisms described by Porter and van der Linde, by pointing to organizational failures as an explanation to the reason why firms would systematically overlook opportunities. In particular, he brings forth the case of low-hanging fruits, i.e. "*cheap incremental innovation that firms just see after facing some pressure*", as evidence of incentive and coordination problems happening within firms. His most interesting contribution stems from the acknowledgement that failures can happen also at organizational level as well as at market level.[7]

Overall, the theoretical literature agrees on the fact that innovation is more likely to occur when market-based rather than command-and-control instruments are used. However, while there is some agreement that certain firms may profit from stricter regulation, not everyone agrees with the claim that industry-wide profits should in general increase or decrease.

2.2. Empirical literature

A first body of empirical evidence related to the Porter hypothesis was provided by Porter himself: Porter and van der Linde (1995/a) report several case studies of industrial sectors and companies that have gained a competitive advantage through innovation following more stringent

[7] The reference to organizational failures interestingly links Porter's mechanisms to the literature on organizational learning and cognitive myopia. For a more thorough discussion, please refer to March & Levinthal (1993)

regulation. For instance, Porter and van der Linde (1995/b) describe the case of the Dutch flower industry, which after facing increasingly strict regulation on the release of chemicals revolutionized its processes in a way that resulted in lower environmental impact, lower costs, improved product quality and higher global competitiveness. Other examples include the cell battery, printing ink, electronics manufacturing, pulp and paper and refrigerator industries (Porter & van der Linde, 1995/b). As previously mentioned, this approach largely relies on isolated, anecdotal evidence, and cannot be generalized.

A second body of empirical literature instead focuses more properly on a broader assessment of the relationship between strictness of environmental policy and competitiveness. These studies interpret Porter's claims in different ways, and adopt distinct definitions of the concepts of "competitiveness" and "stringency of regulation", thus resulting in alternative approaches. Additionally, these studies focus on different units of analysis: some of them are developed at firm level, some of them at industry level and finally some other studies are developed at country and cross-country level.

In one of the first papers trying to establish the relationship between competitiveness and stringency of regulation, Jaffe and Palmer (1997) distinguished three versions of the Porter hypothesis.

First, the so called "weak" version holds that environmental regulation will stimulate *certain kinds* of environmental innovations: because the introduction of regulation essentially modifies the shape of firms' maximization problem by imposing more constraints, firms will choose to adjust their resource allocation and divert funds towards more environmentally friendly innovations. Given that regulation poses additional constraints onto the maximization equation, this version does not predict productivity gains, but simply a change in the nature of the output.

Second, the "narrow" version originates from the claim that in order to stimulate innovation, environmental regulation should be focused on outcomes, and not technologies or processes. This version implies that efficient, flexible, market-based policy instruments will provide greater incentive to innovate than rigid regulations, such as those prescribing the use of "Best Available Technology".

Last, the "strong" version of the Porter hypothesis is the one which more clearly describes a "win-win" situation. In particular, it assumes that properly designed regulation will induce innovation that will more than offset costs of compliance, thus increasing profits. An implication which follows from this version is that regulation would be socially desirable, regardless of the environmental benefits it could produce.

Because Porter suggests that higher competitiveness will come through innovation, many empirical tests of the hypothesis employ measures that are derived from innovation studies: some focus on "input" measures (i.e. R&D expenditures, as in Jaffe & Palmer, 1997), while others choose "output" measures (i.e. successful patent applications, as in Lanjouw & Mody, 1996, de Vries & Withagen, 2005 or Lanoie & alia 2007).

As for the definition of regulatory stringency, some studies employ an "internal" measure, such as pollution abatement costs at firm level, assuming that the higher the costs sustained by the firm, the more stringent the environmental policy (Jaffe & Palmer, 1997; Bhatnagar & Cohen, 1997); other studies instead opt for "external" measures, such as environmental monitoring by government (Bhatnagar & Cohen, 1997), environmental stringency indexes (de Vries & Withagen, 2005) or membership to international treaties in the field of environmental protection (de Vries & Withagen, 2005).

Lanjouw and Mody (1996) analyze the impacts of increases in environmental compliance costs of patenting of environmental technologies using international data on expenditures for compliance with environmental regulation and environmental patents. They find that increasing compliance costs have a positive effect on patenting of new environmental technologies. Jaffe and Palmer (1997) instead, using data from U.S. manufacturing industries in the period 1977-1989 find no statistically significant relationships between regulatory compliance expenditures and patenting activity, but do find a significant positive relationship between regulatory compliance expenditures and R&D expenditures by the regulated industry after controlling for industry-specific effects. Bhatnagar and Cohen (1997), following the approach suggested by Jaffe and Palmer (1997), find that more stringent environmental regulations, measured by pollution abatement cost expenditures and government monitoring, spur environmental innovation, as measured by green patent applications, but find no evidence of increasing industry profits.

De Vries and Withagen (2005), in one of the few cross-country studies, analyze the relationship between environmental policy regarding SO_2 and patent applications in relevant patent classes. They develop three alternative models which measure environmental regulation differently, first by the use of dummy variables relating to international agreements, second by the use of an environmental sensitivity performance index, third using SO_2 emissions. The authors find some evidence that strict environmental policies lead to higher levels of innovation, but do raise some concerns relating to the identification of the correct patent classes and to the measurement of regulatory stringency. [8]

One last piece of information should be considered: while the literature has not been able to find robust evidence to support the Porter hypothesis, Porter and van der Linde themselves (1995/a) point out that there is no strong counterevidence either: the vast majority of the studies was not able to highlight major adverse effects of environmental regulation on competitiveness, and the authors claim that the ones which did register adverse effects on competitiveness were based on data that was generated under frameworks characterized by inefficient regulation.

[8] The issues will be discussed in further detail in section 3.

3. Data, empirical model and econometric strategy

The main purpose of this work is to provide a contribution to the existing literature by trying to empirically test whether stringency of regulation has any effect on innovation activity, as measured by patents. While building on the literature, the analysis will introduce novelties both in the measurement of regulatory stringency and in the assessment of innovativeness. It will develop from the acknowledgement that many of the existing methods which attempt to evaluate stringency of regulation are inadequate for a number of reasons that will be further detailed, and which justify the introduction of a new, more objective evaluation of regulatory stringency. This new approach will be coupled with the use of a recently established classification scheme for environmentally-related innovations, which will allow better identification of relevant patents.

The following sections will present the problems encountered in the literature so far and illustrate the approach chosen to answer to these issues. Next, the discussion will focus on a description of the data used in the analyses, which can be broadly divided in two categories: data referring to stringency of environmental policy and data that refer to environmentally-related patents.

3.1. Problems in the literature

The following sections will give a detailed account of the issues identified in the literature so far. The discussion will focus on two main areas: first problems related to the measurement of regulatory stringency, and then problems related to the assessment of innovativeness.

3.1.1. Regulatory stringency

While theoretically strong and widely used in the literature, some of the measures of regulatory stringency described in the literature review in the previous section appear to be weak in practice.

Pollution abatement costs for instance are generally self reported by firms through surveys. They can be very imprecise and may be affected by respondents' bias (Bhatnagar & Cohen, 1997). Moreover, higher reported pollution abatement cost might not necessarily signal tougher regulation as they may very well be an indication of inefficiency at firm level. Another issue highlighted by Xing and Kolstad (2002) in the use of pollution abatement and control costs relates to the lack of a reliable definition of control cost, which raises concerns over the validity of such figures, especially for the purposes of data comparability in cross country settings.

Similarly, increasing levels of government monitoring - an alternative measure used in the literature - might not necessarily be a sign of higher enforcement, but simply of higher coverage in reporting and data gathering (Bhatnagar & Cohen, 1997).

Environmental stringency indexes such as the one developed in Cagatay and Mihci (2003) appear to be a promising approach, but due to large data requirements they are not particularly suited for use in studies which attempt to capture cross sectional effects in long time series[9]. In practical terms, it may happen that countries be wrongfully classified as environmentally "stringent" by the simple fact that they have joined an international treaty, which may not necessarily be the case. Additionally, whenever based on data that is not collected according to a consistent standard, empirical studies will suffer from the same lack of comparability mentioned before.

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[9] In fact, de Vries & Withagen (2005) use the "Index of Environmental Sensitivity Performance" developed by Cagatay and Mihci (2003) only to define levels of environmental stringency. The index is used to generate dummy variables relating to different stringency levels, assuming that stringency is constant across years.

As for membership to international treaties, these are usually modeled through the use of dummy variables (as in de Vries & Withagen, 2005), which are generally not able to effectively capture policy variability alone. Moreover, previous literature has identified two more fundamental issues in the use of international agreements as a proxy for stringency of regulation. First, international agreements are often void of effective enforcement mechanisms. This means that being part of an international agreement does not imply *per se* that the country will comply with the obligations agreed upon. Additionally, it has been recently argued that because of the voluntary nature of such international treaties, membership will be strongly affected by a self selection bias, meaning that only those countries that can reasonably expect to be able to satisfy the requirements established in the agreement will actually opt in (Aichele & Felbermayr, 2011).

It should be noted that this does not mean that dummy variables describing membership to international agreements should not be used when modeling stringency of regulation. Rather, such indicators can be very useful, but they are best used in combination with other variables, as they cannot be expected to capture policy variability alone.

3.1.2. Innovativeness

When considering how to measure innovativeness, two main approaches have been followed in the literature: the use of patent applications or R&D expenditures. While neither approach is perfect, patent applications are generally preferred, since there exist two major impediments in the use of R&D expenditures, as detailed by Griliches (1990). First of all, R&D expenditures are inputs in the innovation process, and will not necessarily translate into successful outputs. Secondly, R&D expenditure data is often inaccurate and can hardly be broken down by industry and technology group. Conversely, patents present a number of advantages: first, they offer wide and detailed data availability; second, they are by definition related to inventiveness; third, they are based on an objective and fairly stable standard, subject to little variability in its definition over time.

Even though patent applications are generally considered to be better than R&D expenditures, the literature has identified two main issues with their use: intrinsic variability and classification (Griliches, 1990). Intrinsic variability refers to the fact only some patents have considerable economic value, while many will be irrelevant. Classification instead refers to how patent data should be allocated to appropriate industry or product groupings. While economic relevance is not particularly interesting for the purposes of this study, whose goal is to simply assess the degree of innovation generated by environmental policy (and not its actual market value), classification is a more significant issue.

One of the main challenges faced by previous studies (such as Jaffe & Palmers, 1997 and Bhatnagar & Cohen, 1997) in the literature is in fact directly related to classification, and consists in finding a way to correctly identify and isolate patents within sectors of interest. The difficulties arise from the fact that patent documents relating to particular applications may be found under many different technology areas and not under one single classification scheme. The issue, described first in Lanjouw and Mody (1996), Taylor, Rubin and Hounshell (2003) and Popp (2005), was dealt with by using keywords and analyzing patent abstracts in subsequent screening phases, as detailed by de Vries & Withagen (2005), until only appropriate patents were included in the final database. Nevertheless, Johnstone et al. (2010), point out that despite the procedure, identification of all relevant patent classes still remains a concern.

3.2. A new approach

This section will describe the new approach that is put forth, first by focusing on the proposed measure of environmental stringency, and then considering the measure of innovativeness. Finally it will describe the data used in the econometric model that will be presented in further detail in the subsequent section.

The main sources used in this work are the United Nations Framework Convention on Climate Change, for data on emission levels, and the KITeS database, compiled by Bocconi University, Milan, to gather information about environmentally related patents.

Because of data availability and potential consistency issues in data sources, the analysis is restricted to a sample of OECD countries: Austria, Australia, Belgium, Canada, Switzerland, Czech Republic, Germany, Denmark, Spain, Finland, France, United Kingdom, Greece, Hungary, Ireland, Island, Italy, Japan, Luxembourg, Netherlands, Norway, New Zealand, Poland, Portugal, Sweden, Slovak Republic, Turkey and the United States of America. The time series dimension of the data extends over the period 1990 - 2007[10].

3.2.1. Regulatory stringency

Unlike some of the previous literature, this analysis originates from the assumption that stringency of environmental regulation cannot be observed directly. Chimeli, Braden and Han (1999) claim that measuring the "*forcefulness of environmental regulation is exceedingly difficult*", due to

[10] Even though data availability extends to more recent years, it was chosen to limit the analysis to the year 2007 because of the potential strong bias in patent data caused by the long publication process, which can take up to 3 years.

the unreliability and non-comparability of most of the available data on regulation cost.

An interesting approach (proposed by Chimeli, Braden & Han, 1999 and Xing & Kolstad, 2002) relies on the idea that environmental stringency is unobserved, but that it can be evaluated starting from actual emission levels of pollutants over a period of time. The intuition is that – after controlling for size – relatively larger emission levels will be associated with laxity of environmental stringency, whereas relatively smaller emission levels will signal deeper engagement in environmental policy.

While embracing this approach, it is here argued that policy variability can hardly be captured by the simple *stock* of emission levels and its evolution over time. Stock levels may be relatively constant over time, and might poorly capture shifts in policy and legislative approaches.

This work maintains instead that what actually matters when evaluating the effects of different trends in environmental stringency is the *change* in emission levels over time, not their absolute values. This approach appears to be promising considering that significant environmental policy changes may be reflected in moderate but nevertheless meaningful fluctuations in emission levels. In other words, the claim is that *increasing* levels of emissions will be associated with *lower* environmental stringency; conversely, *decreasing* levels of emissions will be linked to *higher* stringency.

Building on this intuition, the yearly change in greenhouse gas emissions since 1990 was adopted as a new measure of environmental stringency. The use of the percentage change has the advantage of achieving cross country comparison, irrespective of initial size, and of increasing policy variability. The choice of the year is also not arbitrary: while some sources report emission levels going back to the 80s and earlier periods, starting from 1990 levels of greenhouse gases have been recorded systematically within the United Nations Framework Convention on Climate Change, and have been used to evaluate the improvements of countries that have ratified the Kyoto protocol. The Kyoto protocol is arguably one of the most significant international agreements in the field of environmental protection. As of Article 3 of the Kyoto Protocol, in fact, "*the Parties shall ensure that their aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases […] do not exceed their assigned amounts, with a view to reducing their overall emissions of such gases by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012.*"

In practice, most of the signatory countries have committed to emission reductions in a range between 6 and 8 percent of 1990 emission levels. Signatory countries are required to submit annual greenhouse gas inventories including additional information to demonstrate compliance with the Protocol. Moreover, individual country submissions are subject to review of the inventories by expert review teams (Framework Convention on Climate Change, 2011).

Overall, the objectiveness of the indicator, the common purpose in the collection of the data and the compliance to a unique standard ensure altogether full comparability both across countries and over time, thus increasing reliability with respect to some other data sources used in the past in the literature.

3.2.2. GHG emissions – data description

Emission data comes from official submissions of greenhouse gas releases by countries that are parties to the Climate Change Convention, and contains estimates for direct greenhouse gases, such as CO_2 (carbon dioxide), CH_4 (methane), N_2O (nitrus oxide), PFCs (perfluorocarbons), HFCs (hydrofluorocarbons), SF_6 (sulfur hexafluoride) as well as for indirect greenhouse gases such as SO_2 (sulfur dioxide), NO_x (nitrogen oxides), CO (carbon oxide) and NMVOC (non-methane volatile organic compounds).

Data reports clarify whether balances take so called "Land use, Land-Use Change and Forestry (LULUCF)" activities into consideration or not. LULUCF refers to initiatives such as planting trees, managing forests and limiting deforestation. While such programs "can provide a relatively cost-effective way of offsetting emissions" (Framework Convention on Climate Change, 2010/b), it may often be difficult to estimate greenhouse gas removals and emissions resulting from such activities. This is why for the purposes of this study, and to increase accuracy of the data, it was established that selecting reported emission levels excluding LULUCF, as available on the United Nations Framework Convention on Climate Change website, would be a more appropriate choice.

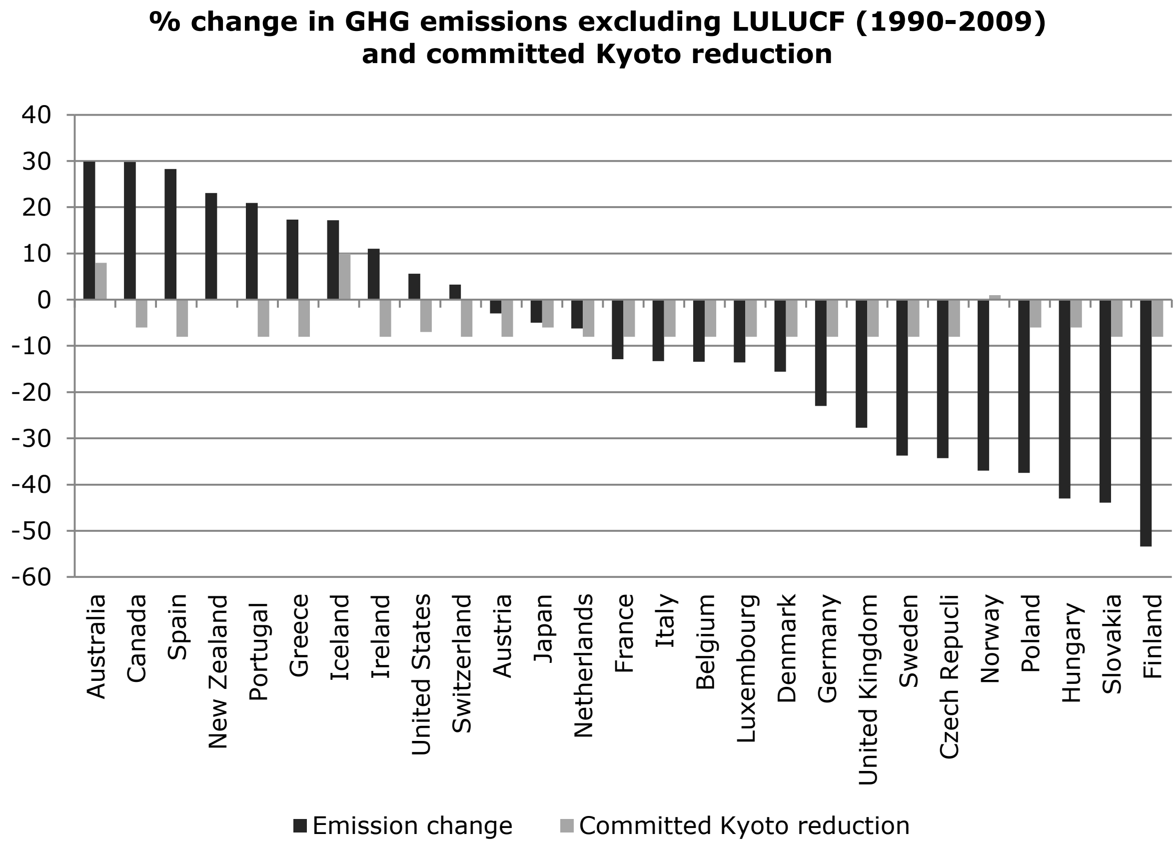

Figure 1

Author's elaboration United Nations Framework Convention on Climate Change data

Emission change: actual variation in emission levels, as recorded by the UNFCCC. Committed Kyoto reduction: reduction pledged by member states upon signature of the Kyoto protocol.

Source : http://unfccc.int/files/inc/graphics/image/jpeg/changes_excluding_2010.jpg

As evidenced by Figure 1, while many large economies have registered significant contractions, for some countries emission levels have increased over the last 20 years. This fact guarantees a certain level of variability and suggests that the data can be used to observe diverse policy approaches in the different countries.

3.2.3. Innovativeness

Previous sections described the "keyword search" procedure used in the literature to identify environmentally related patents. Such procedure is not necessary in this study, as a reclassification operated by the European Patent Office (EPO) provides an easier and more reliable way to identify relevant patents. As stated in a information brief published by the EPO,

> *" […] up to now, it has not always been easy to find sector-related information on patented technologies, and in particular on new, emerging technologies, using the existing patent classification schemes. For this reason, the European Patent Office (EPO) has established a new classification scheme for technical attributes or technologies that can be loosely referred to as clean energy technologies – a specific sub-sector of climate change mitigation technologies, whose 200 or so new categories make it much easier to retrieve information."*
>
> Clean energy and patents
> European Patent Office, 2010

Patent offices operating under the World Intellectual Property Organization (WIPO) use the IPC (International Patent Classification) system to organize patents into relevant classes; the ECLA (European Classification System) system is an extension of the IPC, used by the EPO, which has introduced the new "Y" class explicitly identifying "clean energy technologies". While the reclassification into class Y is still ongoing, the EPO has already made part of it available to the public. Subclass Y02, which includes "Technologies or Applications for Mitigation or Adaptation against Climate Change" relates to specific clean energy technologies and is further split into subclass Y02C and Y02E, respectively defining: (1) "greenhouse gases – capture and storage/sequestration or disposal", and (2) "greenhouse gases – emissions reduction technologies related to energy generation, transmission or distribution". Detailed listing of relevant technologies classified under subclass Y02C and Y02E is available in the appendix.

The use of this new, fully retrospective, classification scheme answers to one of the main concerns raised by previous literature, that is the identification of the right patents to assess innovation in certain sectors (as in Jaffe & Palmer, 1997). Moreover, since the classification is carried out by professional experts collaborating with the Intergovernmental Panel on Climate Change (IPCC), the selection process turns out being highly reliable and - for the purposes of academic research pertaining to this study - significantly less subject to personal discretion of the researcher carrying out the investigation.

3.2.4. Patents – data description

Patent data comes from the KITeS database, which is built on the European Patent Office database, and contains detailed information, including patent publication number, priority year, applicant and inventor information, IPC and ECLA classifications. From the KITeS database, patents belonging to class Y02 were isolated, and matched to their corresponding application year and applicant(s)[11]. Fractional counts were then calculated for the years 1990-2007, and patents were assigned to countries based on the applicant's nationality. Fractional counts were here used to avoid double counting of patents, which may happen if patent applications are filed by applicants of different nationalities. Whenever this is the case, by convention it is assumed that all applicants contributed equally to the development of the patent, and each of the involved countries is assigned a share of the patent reflecting the contribution of their citizens. Such system avoids inflating the number of final patents while at the same time accounting for national contributions. Subsequently, only the OECD countries named in the previous section were selected, while the remaining countries were removed from the dataset. The procedure left 32504.25 patents in class Y02, split between subclass Y02C (1259.02) and subclass Y02E (31245.23). The obtained counts were rounded to the nearest integer[12]. Detailed patent counts are available in the appendix.

An initial analysis of the development of patenting intensity highlights a significant increase in the activity after 1997, as shown in Figure 2. While we observe an overall increase in patenting which involves all patent classes over the last 20 years, aggregate patents in class Y02 from countries listed in this work have more than tripled, particularly so after the adoption of the Kyoto protocol (in 1997) and its ratification.

This trend suggests a rising interest in clean energy technologies, apparently fed by international policy changes. This fact increases the relevance of the present study in that it questions the causes behind the growth in patenting activity in the subclass of interest.

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[11] An alternative solution could have been to match patents to countries based on their inventor's nationality, rather than the applicant's. While in practice this difference is negligible for the purposes of this study (producing patent counts), as a matter of principle assigning patents to applicants is more appropriate since it is applicants that under European law are "deemed to be entitled to exercise the right to a European patent" (European Patent Convention , Art. 60(4)).

[12] Rounding is necessary for modeling purposes, and has very little effect on patent counts. Y02E class contains 31245.23 patents, before rounding vs. 31289, after rounding, a negligible difference of 0.1%.

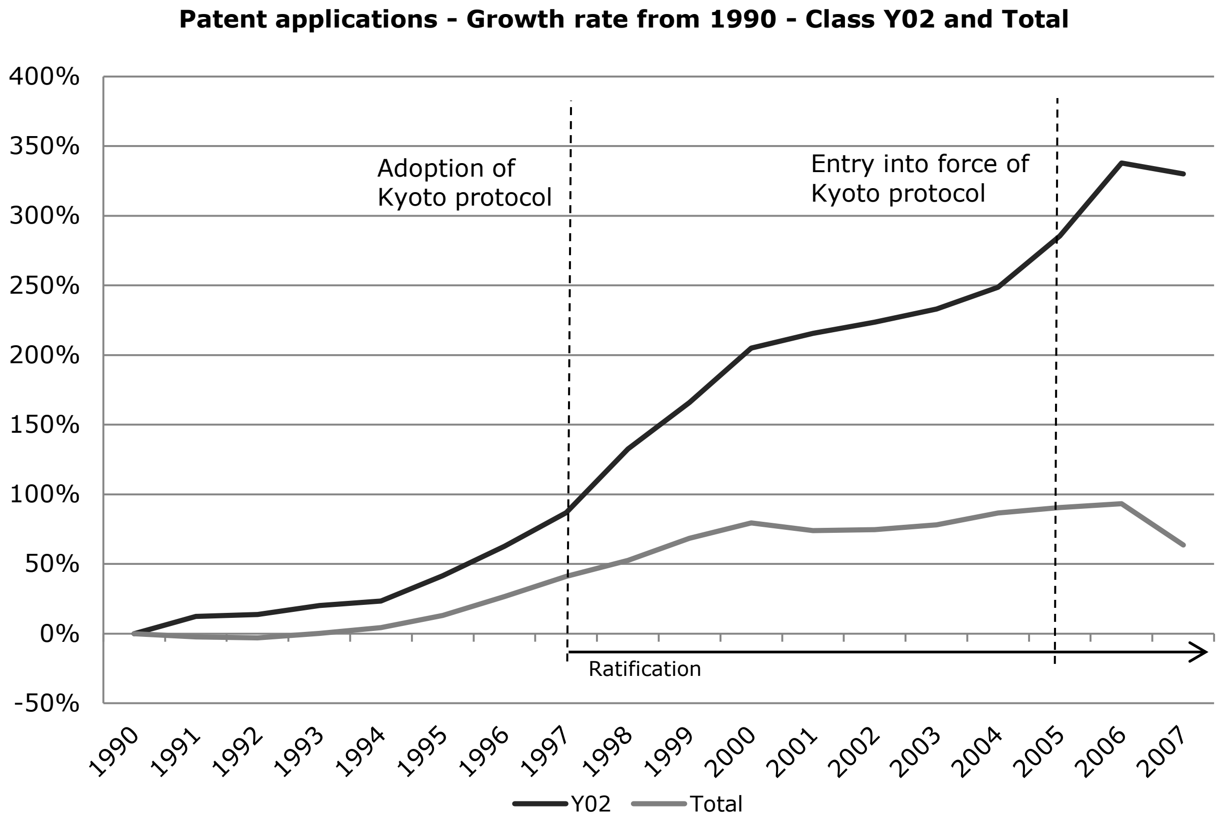

Figure 2

Author's elaboration on KITeS data

3.3. Data description and econometric model

Following Johnstone et al. (2010), the model that was specified reads the following equation:

$$(PATENTS_{i,t}) = \beta_1 (STRINGENCY_{i,t}) + \beta_2(X_{i,t}) + \alpha_i + \varepsilon_{i,t} \qquad (1)$$

where i=1,…,30 is an index for the cross-sectional dimension (country), and t = 1990,…,2007 is an index for time. The dependent variable, PATENTS, is measured by the number of successful patent applications in subclass Y02, while the explanatory variables include stringency of regulation (STRINGENCY), and X, a vector of control variables.

Fixed effects (α_i) are also introduced to account for country-specific heterogeneity. All residual variation is modeled in the error term ($\varepsilon_{i,t}$).

When estimating the number of occurrences of an event (non negative integers), or event counts, such as patent applications, count models have been suggested. To estimate Eq. (1) it is therefore possible to use either a Poisson or a negative binomial model.

Count data models are estimated by maximum likelihood methods; the estimated coefficients model the log of expected counts as a function of predictor variables.

The Poisson model imposes rather strict constraints on the distribution of event counts; in particular it requires that the mean (μ) and the variance (σ^2) be the same. Whenever this is not the case – that is in case of under-dispersion (if $\sigma^2 < \mu$), or over-dispersion (if $\sigma^2 > \mu$) – a negative binomial distribution (which does not require the variance to be equal to the mean) may be preferred, since consistency of Poisson estimations is conditional on the distribution of event counts.

As an alternative to the negative binomial distribution, the Poisson quasi-maximum likelihood estimator can be used. It has been shown that such estimator is fully robust to distributional misspecifications, and maintains also certain efficiency properties even when the distribution is not Poisson (Wooldridge, 2002). The fixed effects procedure used in this work employs a quasi-maximum likelihood estimator, therefore the dependent variable describing patent counts ($PATENTS_{i,t}$) was assumed to follow a Poisson distribution. Notice that even if the very strict distributional assumptions required by the Poisson model are not met, the estimator will still be consistent and efficient.

The general econometric strategy when modeling environmental stringency is inspired by Xing and Kolstad (2002), who use emission levels to test a version of the "pollution heaven hypothesis", that is to assess the impact of stringency of regulation as a determinant of foreign direct investment.

Environmental stringency is then derived from the following:

PATENTS = f (STRINGECY, X) (2)

GHG = e (Z, STRINGENCY) (3)

Where in equation (3), GHG is a measure of pollution emissions (greenhouse gases), Z is a vector of exogenous determinants of emissions and STRINGENCY is the unobserved measure of environmental stringency.

Assuming that e is invertible in STRINGENCY, (3) can be solved for STRINGENCY, to obtain:

STRINGENCY = h (Z, GHG) (4)

which is substituted into equation (2) to get:

PATENTS = g (X, Z, GHG) (5)

While obtaining equation (5) is quite straightforward from a theoretical point of view, the econometric estimation of the model poses some issues: the focus of this work lays in the relationship between environmental innovation and stringency of regulation, modeled through the change in emission levels. When estimating their relationship, however, a methodological issue related to a potential problem of endogeneity arises.

Such term describes a situation in which an explanatory variable is correlated with the error term. This causes the estimates to be biased and inconsistent, and may be produced by three main reasons: (1) omitted variables (that is when we would like to control for more variables but we are not able to include them in the regression); (2) measurement errors (that is when we use an imperfect measure of an independent variable to evaluate its effect on the dependent variable, and the imperfection turns out to produce a correlation with the error term), and (3) simultaneity (that is when at least one of the explanatory variables is simultaneously determined with the dependent variable) (Wooldridge, 2002).

In this work, the dependent variable is a count of patents listed as "clean energy technologies", and given the nature of one of the independent variables, the change in emission levels, it may be claimed that an observed decrease in emissions is actually due to a larger availability of technologies that do not produce emissions or at least produce them in lesser amounts. In other words, an issue of simultaneous estimation of the left and right hand side of the equation in (1) may occur and it may be argued that the stream of causality be inverse, from the dependent variable (patent counts) to the independent variable (emissions) instead of the opposite.

Some observations can be put forth: successful patenting does not necessarily bring *per se* effective commercialization of the patented technology. "Clean energy technology" patents would significantly contribute to the decrease of emissions only if the patented technology reached the market and replaced traditional energy sources. One initial consideration is that clean energy technology patents represent a rather limited sector in the economy (1-2% of the total number of patents, in the considered timeframe), and are unlikely to have such a dramatic impact on overall emission levels as to justify a reduction in emission levels which reaches 20-30% since 1990 in many countries.

Another consideration comes from the analysis of the energy mix composition in the countries included to the research. One way to test whether "clean energy technology" patents play a role in determining the fall in emissions is to look at the development of the share of energy produced from renewable sources, considering that renewable energy technologies constitute a major contribution to "clean energy technology" patents. If we observe at the same time: (1) an increase in the share of energy produced from renewable sources and (2) a decrease in emission levels, then this could be an initial indication that technologies patented in subclass Y02 have been successfully marketed and have had a considerable effect on emission levels.

However, as shown in Figure 3, there is no compelling evidence supporting this hypothesis, since the energy mix has not really changed over the last 15 years on average in the considered countries. What appears more clearly instead is a general stability in the share of energy produced from renewable sources, apart from few significant exceptions (Denmark and Sweden), and a modest general increase of renewable sources in several EU countries. More detailed data is included in the appendix.

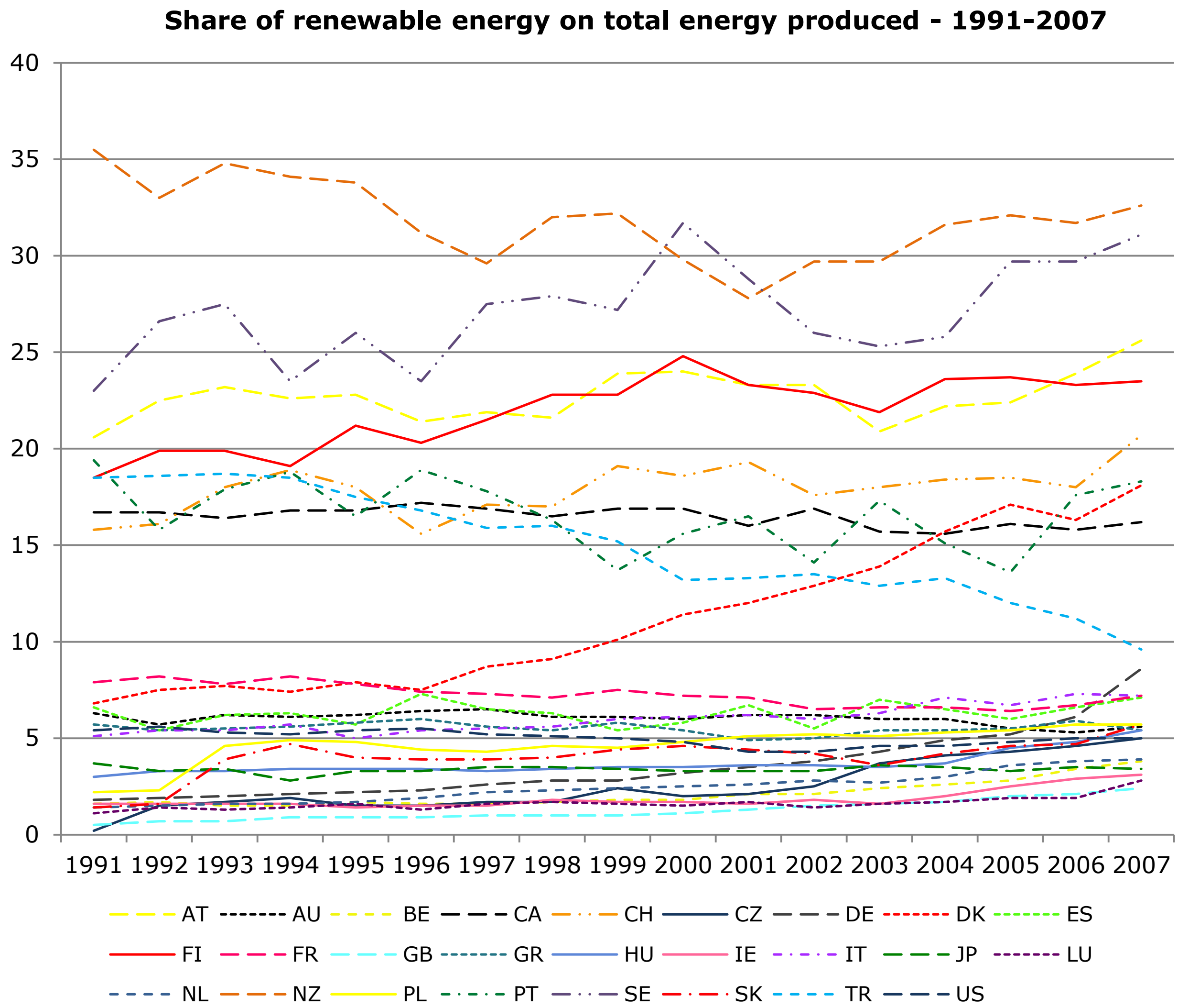

Figure 3

Author's elaboration on OECD data[13]

[13] Island is not reported because of strongly outlying behavior (mean value for share of renewable energy on total energy produced = 72.6%)

While "clean energy technologies" may also impact on emissions by decreasing those released by traditional energy sources, the mildly negative correlation between the number of patents and the share of renewable energy produced in the countries included in the analysis (Spearman correlation coefficient = -0.057) provides an initial indication.

Nevertheless, given the potential issue, a slightly different version of the above model was considered, to solve the problem. An alternative estimation strategy will be also considered as a further consistency check.

3.4. Estimation technique

As mentioned in previous sections, patents belonging to category Y02 are split into two sub-categories. The vast majority of them (96.13%) belongs to category Y02E, which specifically identifies "emission reduction technologies related to energy generation, transmission or distribution". As suggested by the name, these patents belong to the energy sector only, and after isolating them, fractional counts, as previously described, were produced once again.

CO_2 emission levels can also be split by category. As available on the United Nations Framework Convention on Climate Change, reported greenhouse gas emissions belong to 7 distinct categories: (1) Energy, (2) Industrial Processes, (3) Solvent and Other Product Use, (4) Agriculture, (5) Land Use, Land-Use Change and Forestry, (6) Waste, and (7) Other (Framework Convention on Climate Change, 2011). From total emissions, those listed under "Energy" were subtracted. Thanks to this procedure, a measure of yearly CO_2 equivalent emissions, net of those generated from energy sources, was obtained. The yearly percentage change in the period 1990-2007 was then calculated and used in further analyses.

The equation that was specified reads like the following:

$$(PAT\_Y02E_{i,t}) = \beta_1 (GHG_{i,t}\text{-}E_{i,t}) + \beta_2(ENV_{i,t}) + \beta_3(X_{i,t}) + \alpha_i + \varepsilon_{i,t} \quad (6)$$

where $PAT\_Y02E_{i,t}$ is the number of successful patent applications in subclass Y02E and exclusively identifies technologies related to clean energy generation and transmission, and $(GHG_{i,t}\text{-}E_{i,t})$ is the yearly change in greenhouse gas emission levels, measured in CO_2 equivalents, excluding emissions listed under "Energy". $ENV_{i,t}$ is a set of additional environmentally related variables. In the specific case, three dummy variables are introduced: one for the adoption of the Kyoto protocol ($Kyoto\_adoption_{i,t}$), one for its ratification ($Kyoto\_ratification_{i,t}$) and one for the use of an emission trading platform where to exchange pollution permits. Because as of today the only active platform is in Europe, the dummy variable describes the introduction of European Emission Trading System ($EU\_ETS_{i,t}$). $X_{i,t}$, as before, is a vector of control variables, including the size of population ($population_{i,t}$), the share of renewable energy produced in the country over total energy production ($share\_renewable_{i,t}$), and a variable describing the share of Y02E patents on total patents ($percent\_Y\_patents_{i,t}$)[14]. Fixed effects (α_i) are also introduced to account for country-specific heterogeneity while all residual variation is modeled in the error term ($\varepsilon_{i,t}$).

This strategy leaves the structure of the initial model intact, but it removes the source of potential reverse causality as from a theoretical standpoint variations of "non-energy" emission levels cannot be determined by "clean-energy" patents. In other words, the stream of causality is cleared, and if a decrease in emission levels is observed together with an increase in patents, then it can be claimed that the higher innovative activity is due to the more stringent legislative regime identified by lower emission intensity.

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[14] Alternative control variables were tested, but were not reported in the final specification because of non statistical significance. These included GDP (but as stock and in log form), research and development expenditure on GDP, and population (in log form).

Before proceeding to estimation, the meaning of the three environmentally related dummy variables will be described in some further detail.

Kyoto_adoption: this variable describes the formal signing of the Kyoto protocol. It takes on value 1 starting from 1997 (the year in which the Kyoto protocol was agreed upon) for all those countries that initially manifested the intention of underwriting the protocol, and 0 otherwise. Adoption basically coincides with a declaration of intent involving emission reduction over a certain period of time, a voluntary statement of commitment by signatory countries (United Nations, 2012). It should be noted that adoption does not automatically translate into a legally binding statement, as it first requires national ratification.

Kyoto_ratification: this variable describes the conversion into national legislation of Kyoto commitments. It takes on value 1 after ratification, and 0 otherwise. Ratification implies approval at domestic level and gives domestic effect to the treaty (United Nations, 2012).

EU_ETS: this variable takes on value 1 from 2005 for all those countries that participate to the European Emission Trading System, the first emission trading platform ever implemented, and 0 otherwise. As mentioned above, within the timeframe covered in this study, it also represents the only active emission trading platform. Emission trading is one of so called "flexible mechanisms" under the Kyoto protocol, and falls within "market based" emission control systems, in that it gives an actual market price to the "right to pollute" (Framework Convention on Climate Change, 2010).

The table below provides some basic descriptive statistics. More detailed country specific information is available in the appendix.

Table 1 - Descriptive statistics					
	min	**max**	**mean**	**median**	**std dev**
Patent applications - class Y02E - Total	0.00	850.03	64.17	10.00	150.44
GHG-E change (CO_2 equivalent)	-22.70	28.26	-0.48	-0.33	4.18
Population (thousands)	258	301280	34881.34	10331	55600.95
Share_renewable[15]	0.20	80.80	13.09	6.00	15.78
Percent_Y_patents	0.00	0.25	0.022	0.015	0.027
Kyoto_adoption	0.00	1.00	0.59	1.00	0.49
Kyoto_ratification	0.00	1.00	0.31	0.00	0.46
EU_ETS	0.00	1.00	0.12	0.00	0.32

To conclude, the table below summarizes the data sources.

Table 2 - Data sources	
Variable	**Source**
Patent applications - class Y02E	Own elaboration on KITeS data
GHG-E change (CO_2 equivalent)	Own elaboration on UNFCC data
Population (thousands)	OECD database
Share_renewable	OECD database
Percent_Y_patents	Own elaboration on KITeS data
Kyoto_adoption	Own elaboration on UNFCC data
Kyoto_ratification	Own elaboration on UNFCC data
EU_ETS	Own elaboration on EU data

[15] Share_renewable is characterized by a strongly outlying behavior in Island, with values ranging from 67.40 to 80.80 percent.

4. Estimation and interpretation of results

In the following section the results of the estimation will be introduced. First some regression outputs will be presented, and then an interpretation of the results will follow.

Table 3
Poisson fixed effects estimation of equation (6)

	Model 1	Model 2	Model 3	Model 4
year	**0.06831** *(0.000)*	**0.08407** *(0.000)*	**0.04188** *(0.000)*	**0.04805** *(0.000)*
population	0.00000 *(0.255)*	**0.00000** *(0.006)*	0.00000 *(0.238)*	0.00000 *(0.075)*
share_renewables	-0.01585 *(0.164)*	-0.01800 *(0.128)*	-0.007760 *(0.526)*	**-0.02040** *(0.015)*
percent_Y_patents	**0.24950** *(0.000)*	**0.24502** *(0.000)*	**0.25774** *(0.000)*	**0.24908** *(0.000)*
GHG-E_change	**-0.01548** *(0.000)*	**-0.01265** *(0.000)*	**-0.00636** *(0.000)*	**-0.00427** *(0.017)*
Kyoto_adoption			**0.32128** *(0.000)*	**0.32619** *(0.000)*
Kyoto_ratification		**-0.15739** *(0.000)*		**-0.08590** *(0.020)*
EU_ETS				**0.11196** *(0.032)*
N	475	475	475	475
Log pseudolikelihood	*-1230.87*	*-1211.96*	*-1149.38*	*-1136.16*

Conditional fixed effects Poisson regression. Group variable: country
Significance level in parenthesis
Coefficients marked in bold are significant at 0.05 level
All models are estimated using robust standard errors

Table 3 summarizes the results of the estimation of eq. (6). All models are estimated by Poisson fixed effects procedure, using robust standard errors.

Several models were fitted, including different combinations of the explanatory variables[16]. The central finding relates to the main variable of interest, the yearly change in emission levels (GHG-E_change). In all of the fitted models the coefficient is negative and highly significant. Recalling that positive values for GHG-E_change represent an increase in emissions, the negative sign on the regression coefficient confirms the initial hypothesis of the study. More specifically, results point to the fact that environmental patenting is positively affected by decreasing emission levels.

As noted earlier, Poisson regression models the log of the expected counts as a function of predictor variables. This means that a one unit change in the predictor variable will produce a change in the difference of the logs of expected counts equal to the respective regression coefficient, holding all other regressors in the model constant.

Looking at model 1 in Table 3 above, for instance, if GHG-E_change were to increase by one unit (corresponding to a one percent increase in emission levels), the difference in the logs of expected patent counts would decrease on average by 0.01547 units, while holding all other variables in the model constant.

Going back to the initial claim that increasing levels of emissions would be associated with lower environmental stringency and vice versa, the negative sign associated to GHG-E_change indicates that stringent regulatory regimes are beneficial to innovation.

An alternative and more straightforward interpretation of Poisson regression results come from the transformation of coefficients into so

[16] Apart from the model reported in Table 3, estimated with a time trend (year), an alternative estimation including a set of year dummies was also tested. Results, not reported, confirmed the findings discussed in this work. In particular the direction and significance of the main variable of interest (GHG-E_change) was largely unaffected by the alternative model specification.

called “incidence rate ratios”. We define “rate” as the number of events per unit of time; in the context of this study, we will consider the number of successful patent applications within a one year time period.

Recalling that estimated coefficients represent the difference between the log of expected counts, or more formally,

$$\beta = \log(\mu_{x+1}) - \log(\mu_x) \qquad (7)$$

where β is the regression coefficient, μ is the expected count and the subscripts represent the predictor variable X evaluated at x and x+1 (implying a one unit change), and recalling that the difference of two logs is equal to the log of their quotient, that is

$$\log(\mu_{x+1}) - \log(\mu_x) = \log(\mu_{x+1} / \mu_x) \qquad (8)$$

we can estimate the incidence rate ratios by exponentiation of the original Poisson regression coefficients. Table 4 reports the incidence rate ratios.

Looking again at model 1, this time in Table 4, we can conclude that if GHG-E_change were to increase by unit (or in other words, if emission levels rose by one percent), the rate ratio for PAT_Y02E would be expected to decrease on average by a factor of 0.985, while holding all other variables in the model constant. Alternatively, it can be claimed that a one percent decrease in emission levels would lead to an average change in expected patent counts by a factor of 1.015 (corresponding to a 1.5 percent increase).

Further analysis of the regression outputs highlights an interesting pattern described by the three dummy variables included in some model specifications. Overall, initial findings are fully confirmed.

After model 1, all subsequent models, which present more control variables, witness a decrease in the magnitude of the coefficients associated with GHG-E_change. At the same time, Kyoto_adoption and EU_ETS exhibit highly significant and positive coefficients, while Kyoto_ratification displays a negative sign.

Table 4 – IRR from Poisson fixed effects estimation of equation (6)

	Model 1	Model 2	Model 3	Model 4
year	**1.071** *(0.000)*	**1.088** *(0.000)*	**1.042** *(0.000)*	**1.049** *(0.000)*
population	0.999 *(0.255)*	**0.999** *(0.006)*	0.999 *(0.238)*	0.999 *(0.075)*
share_renewables	0.984 *(0.164)*	0.982 *(0.128)*	0.992 *(0.526)*	**0.980** *(0.015)*
percent_Y_patents	**1.283** *(0.000)*	**1.278** *(0.000)*	**1.294** *(0.000)*	**1.283** *(0.000)*
GHG-E_change	**0.985** *(0.000)*	**0.987** *(0.000)*	**0.994** *(0.000)*	**0.996** *(0.017)*
Kyoto_adoption			**1.379** *(0.000)*	**1.386** *(0.000)*
Kyoto_ratification		**0.854** *(0.000)*		**0.918** *(0.020)*
EU_ETS				**1.118** *(0.032)*

Incidence rate ratio calculated as exp(β)
Marginal effect equal to IRR-1

In light of the definitions reported in section 3.4, the pattern observed in particular in model 4 uncovers several effects, in some cases partially offsetting:

- Kyoto_adoption suggests a strong role for market expectations, which translates into a focus on the clean energy sector and a relative increase in patenting activity. More specifically, because

Kyoto adoption as previously described coincides with the simple *commitment* to reduce emission, and does not require any formal or strictly binding statement before ratification, the strongly positive coefficient associated to the variable has very interesting implications. In this case in fact, market expectations must correspond with the anticipation that national governments will engage in tougher regulation as a means to meet Kyoto obligation, thus further confirming the initial hypothesis of the study.

The magnitude of the coefficient is also impressive, as it suggests that countries that have adopted the Kyoto protocol are expected to have on average a rate 1.386 times greater for PAT_Y02E than non adopting countries (as of model 4).[17]

- Kyoto_ratification suggests a mildly negative effect of translation of adoption into actual legislation, possibly implying an adverse reaction of market players to formal enforcement mechanisms. These may in fact be translated into extra implementation costs for private firms, which may therefore negatively impact on innovation as measured by patents.

  With respect to the magnitude of the effect, the coefficient from model 4 suggests that countries that have ratified the Kyoto protocol are expected to have on average a rate for PAT_Y02E smaller by a factor of 0.918, relative to countries that have not ratified the Kyoto protocol, corresponding to a 8.2 percent difference in patent counts.

- EU_ETS suggests a positive effect of market based mechanisms of emission control. This appears to be in line with one of the main claims raised by Porter and demonstrates how efficient regulation is conducive of efficient resource allocation, innovation and growth.

[17] While self selection, as described in Aichele & Felbermayr, 2011, may be at least partially responsible for the magnitude of the coefficient, it does not seem likely to have a strong role in this case thanks to the vast use of control variables (country fixed effects, share_renewables,and percent_Y_patents in particular)

> Turning once again to the magnitude of the coefficients, model 4 implies that countries in which the Emission Trading System has been implemented present an expected count which is on average 11.8 percent higher than for countries having no Emission Trading System in place.

Overall, the joint effect of GHG-E_change, Kyoto_adoption, Kyoto_ratification and EU_ETS seem to confirm Porter's claim that a more stringent regulatory regime is able to foster innovation. Results are also consistent with the idea that market incentives will be beneficial to innovation.

It may be claimed that the effect measured by GHG-E_change is rather modest, especially when compared to Kyoto_adoption, Kyoto_ratification and EU_ETS. Looking at model 4, in fact, we notice how a one percent increase in emission levels will produce a decrease in patent counts by a factor of 0.996, corresponding to a 0.4% increase in PAT_Y02E following a one percent fall in GHG emissions.

What should be noticed however is that this coefficient measures the *yearly* impact on patent counts. While the short run the impact over a 12 month period might indeed be moderate, the medium to long run impact can turn out being significant in practical terms.

Figure 4 shows the growth rate in greenhouse gas emissions (net of those originating from energy sources) over the period 1990-2007. What appears clearly is a strong trend, either towards an increase in emission levels (positive values) or towards a decrease in them (negative values). This picture suggests that countries tend to be rather consistent in their GHG control policies over time.

More interestingly, the picture highlights how the variation in emission levels is, for most countries, in the order of a two digit range (more than a ±10 percent change) on 1990 levels. This suggests that the long run effect of falling emission levels, representing tough regulation, can have a significant impact on patent counts.

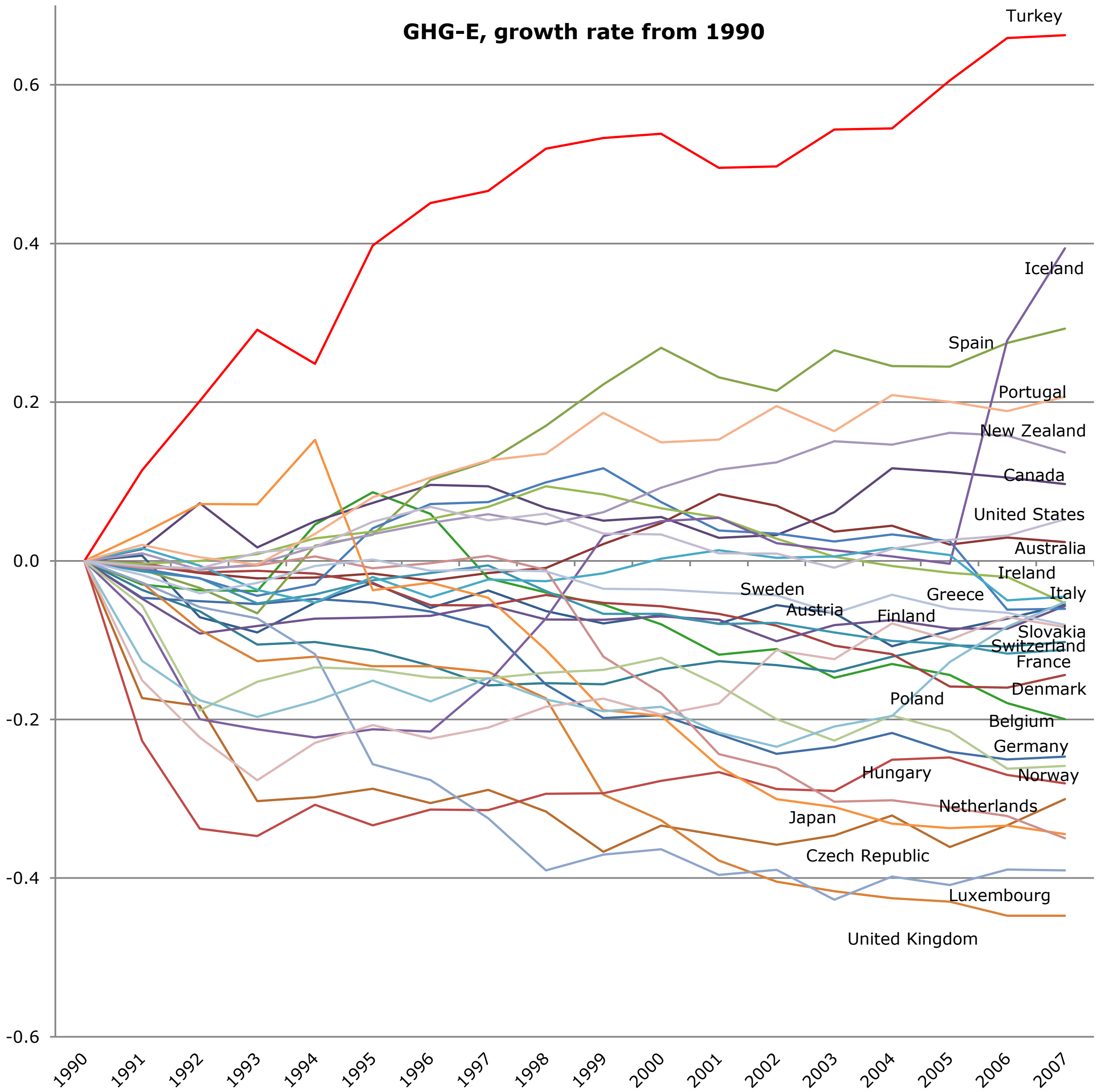

Figure 4

Author's elaboration on UNFCC data

5. Model check

Previous sections have raised a potential issue related to the simultaneous estimation of the left and right hand side of the main equation of interest, and proposed the model described by equation (6), presented in the preceding section, as an answer to the problem.

A more "traditional" solution to the topic of endogeneity, however, rests in the use of instrumental variables. The general idea behind instrumental variables is to go around the source of potential reverse causality by replacing the endogenous variable with one or more variables, called instruments, that are correlated with the "problematic" variable, but which at the same time are not correlated with the error term in the explanatory equation. In this case, finding a suitable instrument means identifying a variable which can satisfactorily predict emission levels, and that at the same time will impact on class Y02 patents, but only indirectly, through emission levels, and not via other routes (i.e. it cannot predict patent counts directly by itself or through an omitted variable).

The issue of endogeneity has already been dealt with in the literature, and some instruments have been proposed. A few approaches employed in the past will now be reviewed. Next it will be discussed whether the methods described in the literature are applicable in this study.

Xing and Kolstad (2002), while assessing the relationship between foreign direct investment and regulatory laxity in the environmental context, use a set of variables as instruments: the real GDP of a country, an index describing the structure of the energy mix produced in a country, the share of industry output in GDP, the rate of infant mortality and population density.

De Vries and Withagen (2003), while estimating the impact of regulatory policy on innovative activity as measured by patents, use GDP, value added in selected industries and per capita R&D expenditure to instrument for stringency of regulation.

The above instruments do not appear to be suitable to this work, either because they do not fulfill the requirements needed by instrumental variables, or because they represent weak instruments. The challenge is to identify a variable able to influence innovation intensity only through its effects on emission levels and it is the author's opinion that none of the approaches put forth in the literature would be adequate for this case.

An alternative, more appropriate indicator, has been identified for this work in the stock of registered vehicles (cars). The theoretical appropriateness of an instrument may be evaluated against against two "restrictions", which may be summarized through the following two questions:

Inclusion restriction: Does the stock of cars impact on the level of GHG emissions?

Exclusion restriction: Does the stock of cars impact on the number of Y02 patents other than through emission levels?

The stock of registered vehicles seems to pass both tests: it is highly correlated with the stock of GHG emissions of a country (Spearman correlation coefficient = 0.9851), therefore it does indeed impact on the level of GHG emissions. At the same time, it appears to be exogenous to the number of "green" patents filed in a country given their limited size in the national economy, therefore it is reasonable to assume that it impacts on the number of Y02 patents only through its effect on emissions. For these reasons, the stock of registered vehicles appears to be a suitable instrument for analysis.

The data source for this variable is once again the OECD database. Due to data availability, the time series dimension of this section of the analysis is limited to the years 1991-2005.

The model that will be estimated looks very much like equation (6) above, but the variables included in the analyses will be slightly different as some of the original modifications that were introduced in the main analyses are no longer necessary under the new setup with instrumental variables.

The equation that is specified reads like the following:

$$(PAT\_Y02_{i,t}) = \beta_1 (GHG_{i,t}) + \beta_2(ENV_{i,t}) + \beta_3(X_{i,t}) + \varepsilon_{i,t} \qquad (9)$$

where $PAT\_Y02_{i,t}$ is the number of successful patent applications in both subclass Y02E and Y02C, and $(GHG_{,t})$ is the full stock in greenhouse gas emission levels, measured in thousands of tons of CO2 equivalents. $ENV_{i,t}$ is the usual set of additional environmentally related variables ($Kyoto\_adoption_{i,t}$, $Kyoto\_ratification_{i,t}$ and $EU\_ETS_{i,t}$). $X_{i,t}$, as before, is a vector of control variables, including the size of population ($population_{i,t}$), the share of renewable energy produced in the country over total energy production ($share\_renewable_{i,t}$), and a variable describing the share of Y02 patents on total patents ($percent\_Y\_patents_{i,t}$). All residual variation is modeled in the error term ($\varepsilon_{i,t}$).

In the instrumental variable procedure, $GHG_{i,t}$ will be instrumented for by the stock of registered vehicles. Table 6 reports the results of the instrumental variable estimation.

The main results described in the previous section find a substantial confirmation in the IV estimation. Most notably, the coefficient associated to the level of greenhouse gas emissions is negative and highly significant, thus suggesting once again that stringency of regulation, identified by lower emission levels, is beneficial to innovation.

As for the remaining variables included in the various model formulations, their significance levels do not allow us to draw definitive conclusions. What can be noted, however, is that at least in model 2 and 3, the sign of Kyoto_ratification and Kyoto_adoption remain consistent with previous models.

Table 6 – IV estimation
stock GHG emissions = stock registered vehicles

	Model 1	Model 2	Model 3	Model 4
year	**0.092** *(0.000)*	**0.094** *(0.000)*	**0.070** *(0.005)*	**0.069** *(0.040)*
population	**0.0374** *(0.000)*	**0.0375** *(0.000)*	**0.0375** *(0.000)*	**0.0374** *(0.000)*
share_renewables	-0.0007 *(0.937)*	-0.0007 *(0.940)*	-0.0005 *(0.958)*	-0.0005 *(0.950)*
percent_Y_patents	0 .0248 *(0.710)*	0.0255 *(0.704)*	0.0246 *(0.708)*	0.0248 *(0.709)*
GHG	**-0.0774** *(0.012)*	**-0.0778** *(0.013)*	**-0.0775** *(0.012)*	**-0.0773** *(0.013)*
Kyoto_adoption			0.2192 *(0.312)*	0.2162 *(0.355)*
Kyoto_ratification		-0.0395 *(0.834)*		0.0264 *(0.894)*
EU_ETS				-0.0705 *(0.793)*

Instrumental variable Poisson regression
Stock of greenhouse gases instrumented for with stock registered vehicles
Significance level in parenthesis
Coefficients marked in bold are significant at 0.05 level

6. Conclusions

This work, inspired by the discussion that originated from the publication of an article written in 1991 by Michael E. Porter, has tried to empirically test the hypothesis that stringency of environmental regulation can have a positive impact on innovation and competitiveness.

To address this question, patenting activity in selected environmentally-related patent classes in a sample of OECD countries over a period of nearly 20 years, has been investigated. The analyses have in particular exploited a recent reclassification scheme implemented by the European Patent Office. A rather innovative approach in the definition of regulation was adopted, using, among others, the yearly change in greenhouse gas emission levels as an indirect indicator of legislative stringency. This choice is built on the intuition that increasing emission levels will be associated with environmental laxity, while falling emission levels will signal environmental severity.

Results of the econometric estimation substantially confirmed the hypothesis stated above, suggesting that regulatory stringency fosters innovation as measured by the number of successful patent applications.

This finding has relevant policy implications, as it encourages increasingly strict legislative regimes and provides supporting evidence against the more traditional idea that rigidity in environmentally related lawmaking is detrimental to innovation, hinders growth and deters competitiveness by increasing costs for firms.

Most notably, these results encourage international convergence towards more rigorous environmental legislation and the foundation of a stronger global regime along the line drawn by and in pursuance of Kyoto commitments.

Another significant result, though mostly based on rather qualitative indicators, relates to the positive effects on innovation of market-based policy instruments such as the European Emission Trading System. Such findings confirm what was suggested by the theoretical literature, and promote further application of price-based means against more traditional "command and control" legislative tools.

This work has introduced some novelties especially in the measurement of environmental stringency; as a suggestion for further research, it would be interesting to try and validate the indicator in other studies, possibly widening its application to additional areas.

Finally, it is crucial to stress the importance of the initiative of the European Patent Office and its efforts in establishing a new classification scheme explicitly addressing environmentally related innovations. This is probably the most important stimulus to extend research in the area which should be exploited by scholars in the future.

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8. Appendix

8.1. Appendix A – Detailed data information

Descriptive statistics										
	Patent applications – Class Y02E					GHG-Energy (tonnes of CO2 equivalents)				
Country	**min**	**max**	**mean**	**median**	**std dev**	**min**	**max**	**mean**	**median**	**std dev**
AT	4.5	36.83	16.17	14.5	10.15	20314	22918	21416.17	21299.5	671.77
AU	4	29	15.65	15.5	7.78	126070	140132	131063.9	130610	4287.91
BE	3	25.5	11.72	10	7.74	25143	34120	29417.06	29916	2568.23
CA	11.5	81.33	43.04	41.83	21.79	122904	137253	130698.3	130762	4347.75
CH	18	76.17	41.94	38.5	18.23	9256	10981	9764.944	9696	453.5
CZ	0	6	1.06	1	1.61	24699	39008	27693.56	26883	3503.61
DE	143	645.5	328.84	367.33	156.49	171554	228860	195789.7	188747	20791.86
DK	5	91.83	32.68	30	25.75	13589	16175	15117.72	15267.5	847.85
ES	0	70	17.41	10	22.21	68164	94367	83539.17	87045.5	9031.66
FI	3	28	11.67	10	5.77	14274	15882	14762.06	14704	345.9
FR	42.08	200.42	99.27	80.33	47.79	162424	183966	173409.9	172881	7124.68
GB	24.83	126.33	60.31	56.33	29.73	94198	170504	127760.1	130581	27198.14
GR	0	10.5	2.44	2	2.62	25321	30136	27591.56	27769.5	1432.97
HU	0	3	1.38	1	1.27	17592	26932	19542.33	19148	2035.01
IE	0	17	3.38	1	4.8	22542	26047	24376.39	24247.5	949.27
IS	0	1	0.12	0	0.33	1268	2275	1585.111	1628.5	275.6
IT	10.5	98	39.09	26.5	25.53	95323	102238	99173.17	99515	2412.1
JP	169	765	522.84	665.5	238.55	122972	216112	161557.1	159377	31728.86
LU	0	7	2.65	2	1.94	1422	2482	1785.222	1571.5	377.04
NL	6.5	66	28.28	29	17.98	37639	58248	50105.5	54051.5	8325.96
NO	1	20	9.49	7	6.36	14894	20186	16957.17	17153	1308.68
NZ	0	7	2.06	2	1.88	35343	41527	38419.06	37900	2193.22
PL	0	4.5	1.05	0	1.41	64211	83869	70735.06	69084.5	5050.98
PT	0	6	1.75	1	2.02	18977	23055	21350.94	21781.5	1486.76
SE	14	44.5	26.97	27	7.54	17751	19341	18665.83	18620	468.56
SK	0	3	0.62	0	0.86	13620	18834	15879.78	15505	1344.94
TR	0	2	0.82	1	0.81	54901	91285	78596.28	82139	10267.84
US	240.6	850.03	473.94	469.33	196.63	870379	938683	900565.2	898190	21402.95

AT=Austria, AU=Australia, BE=Belgium, CA=Canada, CH=Switzerland, CZ=Czech Republic, DE=Germany, DK=Denmark, ES=Spain, FI=Finland, FR=France, GB=Great Britain, GR=Greece, HU=Hungary, IE=Ireland, IS=Island, IT=Italy, JP=Japan, KR=South Korea, LU=Luxembourg, MX=Mexico, NL=Netherlands, NZ=New Zealand, PL=Poland, PT=Portugal, SE=Sweden, SK=Slovak Republic, TR=Turkey, US=United States of America

Fractional patent counts – subclass Y02E																												
	AT	**AU**	**BE**	**CA**	**CH**	**CZ**	**DE**	**DK**	**ES**	**FI**	**FR**	**GB**	**GR**	**HU**	**IE**	**IS**	**IT**	**JP**	**LU**	**NL**	**NO**	**NZ**	**PL**	**PT**	**SE**	**SK**	**TR**	**US**
1990	4.00	1.00	4.00	18.50	23.00	.	122.33	2.00	.	6.00	59.00	35.00	2.00	1.00	.	.	16.00	153.50	4.00	18.17	6.00	.	.	.	6.00	.	.	222.50
1991	13.50	4.00	4.00	16.00	20.00	.	154.50	13.00	2.00	3.00	61.50	35.50	2.00	2.00	.	.	18.50	169.00	.	11.00	3.00	.	.	.	18.00	.	.	240.60
1992	4.50	9.00	3.00	22.00	27.50	1.00	143.00	6.00	.	9.00	56.00	29.00	2.00	1.50	.	.	10.50	205.33	1.50	7.50	1.00	1.00	.	.	14.00	.	.	246.67
1993	8.00	6.00	3.00	17.00	18.00	.	164.83	7.00	6.00	10.00	60.33	24.83	2.00	3.00	.	.	24.50	203.00	1.00	11.50	3.00	2.00	.	.	21.00	.	.	250.00
1994	10.00	10.00	5.25	22.50	27.00	.	151.33	21.00	5.00	6.50	42.08	29.33	.	.	1.00	.	25.00	214.00	.	6.50	3.00	1.00	1.00	1.00	17.90	.	.	268.10
1995	6.50	8.00	5.00	11.50	25.00	.	164.33	11.00	3.00	12.00	50.33	34.33	.	.	4.00	1.00	26.50	283.00	3.00	7.00	6.00	2.00	.	2.00	19.00	.	.	312.00
1996	9.00	6.00	6.00	25.80	24.00	1.50	200.67	12.33	4.00	5.50	71.50	39.50	.	2.00	1.00	.	17.17	369.00	2.00	22.50	11.00	.	.	.	44.50	1.00	.	269.50
1997	14.50	11.50	8.50	35.67	33.50	.	228.50	5.00	2.00	8.00	79.83	36.67	2.00	.	2.00	.	17.00	397.00	5.00	24.00	6.00	3.00	.	3.00	27.00	.	1.00	364.83
1998	8.50	15.00	4.00	41.83	38.50	.50	276.33	30.00	7.00	8.00	79.67	60.33	1.00	1.00	.	.	20.00	494.50	2.00	29.00	14.00	2.00	.	1.00	33.00	.	1.00	469.33
1999	4.50	21.00	10.00	44.17	40.50	1.00	374.50	34.50	13.00	14.00	91.17	51.33	1.00	1.00	.	.	24.50	665.50	5.00	31.00	2.00	2.50	.	1.00	29.00	.50	.	409.50
2000	15.50	15.50	17.00	55.17	47.00	1.00	413.33	33.33	13.00	10.00	80.33	71.17	2.00	.	7.00	.	31.00	727.50	3.00	46.33	13.00	1.00	.	.	29.50	1.00	1.00	511.83
2001	26.50	18.50	12.50	60.50	50.50	1.00	454.60	20.50	11.00	14.00	90.40	56.33	4.00	3.00	.50	.	42.50	720.33	2.00	34.90	7.00	1.00	3.00	2.00	27.00	.	2.00	554.93
2002	16.00	18.00	19.61	69.00	51.00	.	418.37	34.00	11.00	10.00	110.83	72.11	.	.	1.50	.	50.33	685.50	3.00	36.11	6.50	1.00	1.00	.	32.00	.	2.00	628.80
2003	21.50	29.00	25.50	65.67	37.00	.	367.33	46.00	10.00	12.00	125.00	77.00	4.00	.	1.00	.	48.50	765.00	.50	19.00	15.50	2.50	2.00	1.00	27.00	3.00	1.00	638.00
2004	18.50	25.50	18.50	81.33	62.00	1.00	409.83	47.03	26.00	14.33	147.17	80.50	2.00	3.00	6.00	.	69.00	723.83	3.00	32.33	17.50	4.00	4.50	1.00	36.30	2.00	1.00	617.50
2005	24.33	21.50	14.50	57.00	63.50	1.00	467.33	69.50	45.00	15.00	200.42	96.50	3.50	1.00	4.50	.	56.50	745.33	2.00	33.33	20.00	.	2.33	6.00	26.00	1.00	2.00	734.83
2006	36.75	21.50	17.50	68.50	71.83	4.00	556.08	73.50	70.00	28.00	154.08	126.33	10.50	3.00	12.00	1.00	85.00	763.97	7.00	62.83	14.00	5.00	1.00	6.00	30.33	1.00	2.00	850.03
2007	36.83	26.00	25.33	38.00	76.17	6.00	645.50	91.83	68.00	19.00	187.00	104.50	5.50	3.00	17.00	.	98.00	756.50	5.00	66.00	18.83	7.00	3.00	4.00	27.00	1.00	1.00	690.50

AT=Austria, AU=Australia, BE=Belgium, CA=Canada, CH=Switzerland, CZ=Czech Republic, DE=Germany, DK=Denmark, ES=Spain, FI=Finland, FR=France, GB=Great Britain, GR=Greece, HU=Hungary, IE=Ireland, IS=Island, IT=Italy, JP=Japan, KR=South Korea, LU=Luxembourg, MX=Mexico, NL=Netherlands, NZ=New Zealand, PL=Poland, PT=Portugal, SE=Sweden, SK=Slovak Republic, TR=Turkey, US=United States of America

Fractional patent counts – all patent classes																												
	AT	**AU**	**BE**	**CA**	**CH**	**CZ**	**DE**	**DK**	**ES**	**FI**	**FR**	**GB**	**GR**	**HU**	**IE**	**IS**	**IT**	**JP**	**LU**	**NL**	**NO**	**NZ**	**PL**	**PT**	**SE**	**SK**	**TR**	**US**
1990	610.36	326.67	425.36	483.37	2098.44	20.50	11227.56	326.92	231.50	408.83	4766.85	3211.67	22.20	60.50	64.50	2.50	2122.33	12892.08	56.00	1895.52	134.75	16.00	10.00	6.00	927.33	2.00	3.00	17825.26
1991	593.18	351.67	467.55	499.83	1939.55	19.00	11101.28	361.67	297.83	391.00	4778.63	3109.86	19.50	46.33	63.00	7.00	2150.67	11693.83	66.50	1834.59	179.67	45.00	6.70	5.50	902.92	1.00	3.00	17730.75
1992	558.10	365.92	493.35	546.62	2063.53	20.00	11193.55	395.58	262.33	507.83	4486.15	2982.80	32.57	37.17	89.50	4.00	1984.44	10889.83	62.00	1823.41	209.83	54.00	6.00	12.50	1056.83	3.00	.00	18211.36
1993	599.82	401.50	605.44	584.75	1968.47	18.00	11455.41	428.05	322.58	600.45	4674.59	2937.59	15.50	44.17	101.50	.50	2076.75	11088.92	121.00	1830.30	188.83	55.83	8.33	18.00	1118.55	3.00	2.00	18995.12
1994	597.83	399.33	532.75	640.67	2098.62	16.00	12108.08	462.15	324.33	697.00	4805.88	3053.42	23.50	34.41	92.67	1.00	2079.10	10868.08	68.17	1691.58	192.75	59.17	12.17	16.00	1367.15	4.00	1.50	20455.79
1995	556.33	434.04	601.63	767.73	2105.23	9.50	12686.88	481.50	334.17	738.00	4999.29	3207.58	23.00	41.83	108.50	5.00	2225.67	12450.50	63.67	1770.25	248.17	60.00	10.00	16.00	1504.92	4.00	1.00	22560.52
1996	633.92	415.33	640.33	917.93	2309.75	24.00	15037.15	600.03	357.81	920.13	5413.54	3460.12	30.00	46.00	140.17	9.50	2539.17	14197.25	94.70	2001.45	273.67	71.50	13.48	18.00	1872.87	4.00	12.00	24043.95
1997	794.33	549.42	793.65	1250.47	2688.73	30.50	16909.96	589.42	480.50	1099.31	6085.10	3679.08	48.39	53.17	154.18	8.00	2776.23	15286.23	131.08	2075.17	282.17	100.25	19.00	23.50	2148.82	10.50	15.00	26768.44
1998	812.00	564.11	829.08	1346.94	2878.28	43.98	18705.99	702.47	488.42	1261.15	6558.01	4134.73	51.83	36.50	191.00	9.50	2865.37	16145.67	137.33	2201.58	323.33	88.25	22.50	27.33	2225.48	7.50	25.83	29137.05
1999	858.33	838.58	874.58	1584.52	3159.17	44.00	20090.18	756.42	595.02	1603.12	7021.57	4471.92	45.00	83.33	231.67	18.50	3235.32	18797.82	147.50	2570.90	352.00	134.00	24.49	40.50	2409.08	11.50	19.33	31342.83
2000	1027.42	875.24	835.76	1565.27	3395.39	47.00	21285.05	849.95	645.07	1616.11	7036.65	4763.90	47.00	60.33	220.45	26.00	3444.55	21770.72	141.33	2882.97	371.42	154.50	24.00	38.50	2507.60	7.17	35.42	32279.27
2001	1025.12	850.80	872.77	1525.64	3494.80	43.90	20864.04	826.12	703.25	1634.55	7029.36	4451.18	60.58	66.00	278.70	22.50	3478.38	20086.48	128.33	3004.67	341.58	127.67	44.25	45.00	2312.92	6.00	42.50	31256.45
2002	1039.27	849.12	1002.11	1492.30	3412.56	59.25	20294.29	864.33	789.60	1508.11	7013.65	4266.87	58.75	83.70	271.17	38.50	3756.85	20393.75	142.17	3030.84	343.00	155.97	67.60	37.87	2184.47	14.33	62.75	31780.11
2003	1153.28	878.27	989.75	1502.70	3537.75	89.00	20204.14	974.28	766.81	1434.35	7485.46	4217.46	65.25	78.50	264.24	31.50	3742.28	21502.00	150.83	2836.08	305.78	172.83	82.93	53.83	2279.20	16.20	68.00	32283.11
2004	1167.28	936.83	1147.64	1807.16	3769.98	89.25	21110.44	967.87	985.67	1566.20	7802.30	4107.02	49.00	98.00	271.44	31.50	4025.50	22538.33	144.11	2818.46	356.00	161.92	93.33	63.25	2438.61	12.00	103.50	33627.47
2005	1189.67	990.22	1180.31	1927.96	4186.50	74.00	21729.40	993.33	1080.70	1480.70	7937.68	4109.72	84.03	78.50	343.03	37.00	4224.33	21323.07	164.50	2945.14	447.67	147.08	85.55	78.08	2748.61	17.50	154.83	34847.86
2006	1352.38	861.13	1803.56	1841.81	4980.25	115.00	22777.15	1027.00	1135.43	1514.86	7885.05	4348.79	81.23	99.50	327.67	38.20	4258.45	20891.70	229.90	4399.48	406.26	149.25	101.50	72.50	2863.97	25.33	177.00	32543.94
2007	1181.33	628.42	1723.81	1549.03	4118.55	113.50	20419.82	1010.03	1039.71	1354.17	7039.60	3660.15	71.03	84.50	323.00	33.67	3761.39	18271.02	202.00	3356.71	326.25	102.75	115.10	80.50	2507.38	17.00	168.00	25224.08

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Total CO_2 Equivalent Emissions without Land Use, Land-Use Change and Forestry																											
	AT	AU	BE	CA	CH	CZ	DE	DK	ES	FI	FR	GB	GR	HU	IE	IS	IT	JP	LU	NL	NO	NZ	PL	PT	SE	SK	TR	US
1990	78171	418310	143344	590417	53122	195523	1247901	69372	283168	70364	565987	779387	104365	96830	54820	3415	519157	1266553	12827	211852	49767	59112	452935	59417	72490	74155	187029	6166812
1991	82214	419473	145209	582983	54719	181650	1202094	79833	290626	68171	589343	784258	103914	89095	55616	3256	520271	1280828	13367	216436	47711	60002	444396	61515	72860	66358	199128	6127731
1992	75514	424186	143442	607943	54570	165129	1151934	73796	298183	66749	580853	757877	105328	79930	55623	3170	517318	1295167	13151	215086	45928	61081	431580	65544	72556	61592	210229	6227632
1993	75498	426622	142474	601748	51740	158986	1143334	76027	286866	68857	556141	735629	104373	80220	56001	3211	510818	1288630	13264	220065	47893	60785	438380	63956	72439	56217	221662	6353715
1994	76386	428296	148242	622403	50865	148961	1123282	80007	303247	74240	551743	723824	107106	79753	57439	3156	503099	1359841	12431	220038	49841	61739	434466	65274	75005	54432	217151	6443205
1995	79811	440709	150070	639605	51424	153632	1119906	76801	314839	70783	563388	713676	108983	78186	58490	3204	529951	1337417	10104	223249	49661	62330	440282	69499	74313	53350	237507	6533472
1996	82895	446865	153954	658423	52100	160337	1139506	89817	307484	76514	579652	734029	112046	80313	60498	3290	523315	1351342	10165	231296	52769	64285	448806	67368	77924	51854	258621	6735258
1997	82476	458303	145454	671251	51335	153322	1103395	80283	328041	75132	574506	707992	116887	78453	61951	3437	529668	1344717	9458	224664	52733	66878	443467	70435	73250	50737	271882	6793410
1998	81869	472685	151019	677241	52607	145195	1077646	76479	337880	71667	589460	704065	122428	78114	64818	3556	540840	1302181	8574	225524	52852	64950	413143	74934	73784	51176	274046	6834466
1999	80254	483199	144752	690134	52803	140867	1043510	73724	366241	71080	576113	672429	122312	78426	66265	3794	547098	1323275	8992	213520	53849	66992	401307	83296	70407	50455	274778	6885838
2000	80476	496116	145415	716086	51952	147420	1042071	69259	379563	69162	570946	673477	126003	76706	67865	3766	551640	1341800	9766	213161	53387	68433	389427	81225	68900	49235	297006	7076343
2001	84343	507632	144863	709069	52837	149612	1056941	70942	379820	74383	573391	677836	127444	78717	69701	3736	557476	1316957	10275	214995	54596	71025	385999	82337	69521	50621	278112	6972657
2002	86159	509171	143564	715477	51880	145343	1036680	70231	396775	76524	568216	656742	127161	76670	67870	3761	558668	1348983	11044	214317	53361	71416	372786	86897	70378	49783	286204	7004324
2003	91894	517797	145899	738138	52912	144419	1030603	75055	403731	84278	570327	661012	130876	79668	67842	3730	573477	1352792	11486	215370	54154	73893	384621	81703	70914	51010	302753	7039427
2004	90927	525761	146713	742476	53429	145331	1021218	69341	419511	80269	571103	659026	131383	78711	67683	3778	576600	1348700	12900	216762	54767	73007	385557	84078	70369	50776	312261	7155979
2005	92884	527730	142729	731441	54190	144711	999776	65070	433847	68477	573821	654627	134356	79489	69221	3727	574893	1351329	13152	211105	53904	75049	388017	85984	67591	50112	329897	7184959
2006	90103	533054	137737	719157	53734	146036	1002257	73023	426023	79711	557961	648402	130746	77727	68683	4264	563911	1333307	13018	207129	53491	75181	402339	81272	67283	49889	349642	7117145
2007	87373	542105	132908	748262	51757	147055	979873	68409	437130	78144	549635	638194	133395	75385	68035	4509	554569	1364856	12398	205405	55242	73205	400695	79107	65794	47860	379976	7215899

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CO_2 Equivalent Emissions from Energy Industries (Comprises emissions from fuels combusted by the fuel extraction or energy producing industries)

	AT	AU	BE	CA	CH	CZ	DE	DK	ES	FI	FR	GB	GR	HU	IE	IS	IT	JP	LU	NL	NO	NZ	PL	PT	SE	SK	TR	US
1990	55403	289014	111935	467513	42141	156515	1019041	53197	210162	54482	382021	608883	77377	69898	31006	1783	418545	1079002	10345	153972	29581	23359	369066	40346	53181	55321	132128	5287796
1991	59296	290872	114740	458272	44140	149393	983909	63704	218431	53045	407798	618508	77196	68278	31890	1738	418080	1086857	10953	159071	28663	23915	371118	42060	53899	50365	137956	5254607
1992	54369	296887	113193	476115	44287	133251	934694	57861	227678	52324	400894	602250	78935	62091	31817	1864	417328	1094222	10813	157778	29554	25738	362451	46386	54036	46956	144268	5357253
1993	54785	300179	112262	476751	41920	131800	926967	60053	218702	54281	382055	586680	78577	62628	31986	1926	413901	1087744	10962	162533	30784	25183	371014	44979	53671	42597	150776	5465578
1994	54821	301736	115401	493375	41008	121572	905413	64092	228848	59518	375584	573910	80916	61103	32953	1888	407776	1143729	10240	161837	32365	25364	365426	45559	55825	39922	148624	5548988
1995	57677	313486	115950	507726	41685	125827	903117	61096	239443	56039	383989	565864	80891	60239	33800	1919	431380	1156814	8257	165921	32236	25373	369090	48900	54972	38421	160788	5611390
1996	61483	320795	120693	523781	42572	133246	925344	74548	227050	61732	398550	586168	83129	61830	35430	2010	427312	1168964	8368	173600	35556	26832	379809	46298	58858	37241	178960	5796575
1997	60564	331024	114737	536807	42079	125581	893686	65017	245882	60135	391634	561346	87903	59988	36523	2056	431433	1165891	7781	166416	35536	29022	371984	48951	54157	35865	191389	5869661
1998	60542	344545	120868	546150	43318	118520	884476	61000	252440	56962	412529	563149	92771	59096	38771	2042	442823	1135674	7060	168311	35513	27548	343924	53286	54734	35809	190621	5903174
1999	59283	351177	115071	561023	43531	116168	859991	58408	277001	56377	404437	552183	92176	59384	40462	2112	448058	1171028	7428	162630	36438	29048	333344	60667	51779	34892	190614	5976830
2000	59267	360707	116525	586412	42473	121435	857747	54013	286941	54395	399317	558773	97019	57245	42477	2053	450764	1190907	8187	164933	35672	29391	321006	59310	50288	34054	212546	6168025
2001	63385	367500	117175	582599	43246	124092	878128	55848	289929	59681	404076	571734	99423	58960	44591	2016	455540	1178023	8776	171221	37581	31167	320301	60351	50989	35174	196020	6085427
2002	64667	370882	115650	588597	42343	120303	863475	55377	308124	62250	398653	555210	99253	57489	43390	2093	457664	1217798	9528	171565	37203	31229	308575	64106	51908	33071	204018	6117206
2003	70622	383739	119125	607705	43466	118914	855429	60609	311354	69686	402952	561555	103228	60553	43908	2076	472318	1223483	10064	175066	38543	32752	318261	59515	52886	34516	218004	6168167
2004	70613	390773	119391	605223	43776	118840	842054	55069	328572	65574	405717	561027	103499	58534	44026	2137	474362	1223300	11406	176348	38521	32020	318116	61023	51889	33430	227430	6263723
2005	72126	395806	115838	594814	44381	119784	826035	51461	342975	53951	409135	557406	106701	59238	45765	2102	473538	1226961	11684	171239	38057	33522	314862	63090	49440	33156	241754	6282796
2006	68994	399992	111962	583351	43942	120031	830703	59434	332975	65189	395537	554204	105425	58063	45358	2179	468311	1208366	11502	167868	38597	33790	325447	58603	49238	32387	258564	6210164
2007	65859	409749	107765	613471	41899	119773	807504	54563	342763	63167	386330	543950	108039	56014	45493	2234	458519	1241884	10884	167766	40277	32567	321178	56094	48043	30599	288691	6290738

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Share of renewable energy on total energy produced																												
	AT	**AU**	**BE**	**CA**	**CH**	**CZ**	**DE**	**DK**	**ES**	**FI**	**FR**	**GB**	**GR**	**HU**	**IE**	**IS**	**IT**	**JP**	**LU**	**NL**	**NO**	**NZ**	**PL**	**PT**	**SE**	**SK**	**TR**	**US**
1991	20.60	6.30	1.60	16.70	15.80	.20	1.80	6.80	6.60	18.50	7.90	.50	5.70	3.00	1.60	70.20	5.10	3.70	1.10	1.40	48.20	35.50	2.20	19.40	23.00	1.40	18.50	5.40
1992	22.50	5.70	1.70	16.70	16.10	1.50	1.90	7.50	5.40	19.90	8.20	.70	5.40	3.30	1.60	68.50	5.40	3.30	1.40	1.50	49.90	33.00	2.30	15.80	26.60	1.60	18.60	5.60
1993	23.20	6.20	1.50	16.40	18.00	1.70	2.00	7.70	6.20	19.90	7.80	.70	5.50	3.30	1.60	68.30	5.40	3.40	1.30	1.60	48.10	34.80	4.60	17.90	27.50	3.90	18.70	5.30
1994	22.60	6.10	1.50	16.80	18.90	1.90	2.10	7.40	6.30	19.10	8.20	.90	5.60	3.40	1.60	67.90	5.70	2.80	1.40	1.60	46.70	34.10	4.90	18.80	23.50	4.70	18.50	5.20
1995	22.80	6.20	1.70	16.80	18.00	1.50	2.20	7.90	5.70	21.20	7.80	.90	5.80	3.40	1.40	69.30	5.00	3.30	1.60	1.70	49.40	33.80	4.80	16.50	26.00	4.00	17.50	5.40
1996	21.40	6.40	1.60	17.20	15.60	1.50	2.30	7.50	7.30	20.30	7.40	.90	6.00	3.40	1.50	67.40	5.40	3.30	1.30	1.90	44.30	31.20	4.40	18.90	23.50	3.90	16.80	5.50
1997	21.90	6.50	1.60	16.90	17.10	1.70	2.60	8.70	6.50	21.50	7.30	1.00	5.60	3.30	1.50	69.10	5.50	3.50	1.60	2.20	44.30	29.60	4.30	17.80	27.50	3.90	15.90	5.20
1998	21.60	6.10	1.70	16.50	17.00	1.70	2.80	9.10	6.30	22.80	7.10	1.00	5.40	3.40	1.80	70.20	5.60	3.50	1.70	2.30	44.70	32.00	4.60	16.30	27.90	4.00	16.00	5.10
1999	23.90	6.10	1.80	16.90	19.10	2.40	2.80	10.10	5.40	22.80	7.50	1.00	5.80	3.50	1.70	74.00	6.00	3.40	1.60	2.40	45.50	32.20	4.50	13.70	27.20	4.40	15.20	5.00
2000	24.00	6.00	1.80	16.90	18.60	2.00	3.20	11.40	5.80	24.80	7.20	1.10	5.40	3.50	1.70	74.50	6.10	3.30	1.50	2.50	52.50	29.80	4.80	15.60	31.70	4.60	13.20	4.80
2001	23.30	6.20	2.10	16.00	19.30	2.10	3.50	12.00	6.70	23.30	7.10	1.30	4.90	3.60	1.60	75.60	6.20	3.30	1.70	2.60	45.00	27.80	5.10	16.50	28.80	4.40	13.30	4.30
2002	23.30	6.20	2.10	16.90	17.60	2.50	3.80	12.90	5.50	22.90	6.50	1.50	5.00	3.60	1.80	75.00	6.00	3.30	1.40	2.80	50.90	29.70	5.20	14.10	26.00	4.20	13.50	4.30
2003	20.90	6.00	2.40	15.70	18.00	3.70	4.30	13.90	7.00	21.90	6.60	1.60	5.40	3.50	1.60	75.20	6.30	3.60	1.60	2.70	38.80	29.70	5.10	17.30	25.30	3.60	12.90	4.60
2004	22.20	6.00	2.60	15.60	18.40	4.10	4.90	15.70	6.50	23.60	6.60	1.70	5.40	3.70	2.00	74.50	7.10	3.50	1.70	3.00	38.20	31.60	5.30	15.10	25.80	4.20	13.30	4.60
2005	22.40	5.50	2.80	16.10	18.50	4.30	5.20	17.10	6.00	23.70	6.40	2.00	5.50	4.50	2.50	75.60	6.70	3.30	1.90	3.60	46.10	32.10	5.40	13.60	29.70	4.60	12.00	4.80
2006	23.90	5.30	3.40	15.80	18.00	4.60	6.10	16.30	6.60	23.30	6.70	2.10	5.90	4.80	2.90	78.40	7.30	3.50	1.90	3.80	40.10	31.70	5.70	17.60	29.70	4.70	11.20	5.00
2007	25.60	5.60	3.80	16.20	20.70	5.00	8.60	18.10	7.10	23.50	7.20	2.40	5.40	5.40	3.10	80.80	7.20	3.40	2.80	3.90	48.30	32.60	5.70	18.30	31.10	5.70	9.60	5.00

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8.2. Appendix B – Patent information

Y02 - TECHNOLOGIES OR APPLICATIONS FOR MITIGATION OR ADAPTATION AGAINST CLIMATE CHANGE

Y02C - CAPTURE, STORAGE, SEQUESTRATION OR DISPOSAL OF GREENHOUSE GASES [GHG]

Y02C10/00 CO2 capture or storage (0)
Y02C10/02 . Capture by biological separation (155)
Y02C10/04 . Capture by chemical separation (3121)
Y02C10/06 . Capture by absorption (3560)
Y02C10/08 . Capture by adsorption (2990)
Y02C10/10 . Capture by membranes or diffusion (1182)
Y02C10/12 . Capture by rectification and condensation (1447)
Y02C10/14 . Subterranean or submarine CO2 storage (1051)

Y02C20/00 Capture or disposal of greenhouse gases [GHG] other than CO2 (0)
Y02C20/10 . of nitrous oxide (N2O) (3258)
Y02C20/20 . of methane (1478)
Y02C20/30 . of perfluorocarbons [PFC], hydrofluorocarbons [HFC] or sulfur hexafluoride [SF6] (2456)

Y02E - REDUCTION OF GREENHOUSE GASES [GHG] EMISSION RELATED TO ENERGY GENERATION, TRANSMISSION OR DISTRIBUTION

Y02E10/00 Energy generation through renewable energy sources (0)
Y02E10/10 . Geothermal energy (2093)
Y02E10/12 .. Earth coil heat exchangers (600)
Y02E10/12B ... Compact tube assemblies, e.g. geothermal probes (713)
Y02E10/14 .. Systems injecting medium directly into ground, e.g. hot dry rock system, underground water (378)
Y02E10/16 .. Systems injecting medium into a closed well (290)
Y02E10/18 .. Systems exchanging heat with fluids in pipes, e.g. fresh water or waste water (28)
Y02E10/20 . Hydro energy (3232)
Y02E10/22 .. Conventional, e.g. with dams, turbines and waterwheels (4700)
Y02E10/22B ... Turbines or waterwheels, e.g. details of the rotor (8515)
Y02E10/22D ... Other parts or details (5860)
Y02E10/28 .. Tidal stream or damless hydropower, e.g. sea flood and ebb, river, stream (4640)
Y02E10/30 . Energy from sea (tidal stream Y02E10/28) (0)
Y02E10/32 .. Oscillating water column [OWC] (552)
Y02E10/34 .. Ocean thermal energy conversion [OTEC] (560)
Y02E10/36 .. Salinity gradient (31)
Y02E10/38 .. Wave energy or tidal swell, e.g. Pelamis-type (5828)
Y02E10/40 . Solar thermal energy (6553)
Y02E10/41 .. Tower concentrators (1856)

Y02E10/42 .. Dish collectors (1191)
Y02E10/43 .. Fresnel lenses (963)
Y02E10/44 .. Heat exchange systems (23592)
Y02E10/45 .. Trough concentrators (2043)
Y02E10/46 .. Solar thermal plants for electricity generation, e.g. Rankine, Stirling solar thermal generators (2512)
Y02E10/47 .. Mountings or tracking (7662)
Y02E10/48 .. Mechanical power, e.g. thermal updraft (688)
Y02E10/50 . Photovoltaic [PV] energy (38900)
Y02E10/52 .. PV systems with concentrators (not used; see subgroups) (6017)
Y02E10/54 .. Material technologies (0)
Y02E10/54B ... CuInSe2 material PV cells (1347)
Y02E10/54D ... Dye sensitized solar cells (3213)
Y02E10/54F ... Solar cells from Group II-VI materials (923)
Y02E10/54H ... Solar cells from Group III-V materials (2298)
Y02E10/54J ... Microcrystalline silicon PV cells (242)
Y02E10/54L ... Polycrystalline silicon PV cells (598)
Y02E10/54N ... Amorphous silicon PV cells (2615)
Y02E10/56 .. Power conversion electric or electronic aspects (223)
Y02E10/56B ... for grid-connected applications (266)
Y02E10/56D ... concerning power management inside the plant , e.g. battery charging/discharging, economical operation, hybridisation with other energy sources (401)
Y02E10/58 ... Maximum power point tracking [MPPT] systems (300)
Y02E10/60 . Thermal-PV hybrids (1819)
Y02E10/70 . Wind energy (1230)
Y02E10/72 .. Wind turbines with rotation axis in wind direction (4227)
Y02E10/72B ... Blades or rotors (5152)
Y02E10/72D ... Components or gearbox (6191)
Y02E10/72F ... Control of turbines (6857)
Y02E10/72H ... Generator or configuration (4344)
Y02E10/72J ... Nacelles (1034)
Y02E10/72L ... Offshore towers (984)
Y02E10/72N ... Onshore towers (6360)
Y02E10/74 .. Wind turbines with rotation axis perpendicular to the wind direction (6943)
Y02E10/76 .. Power conversion electric or electronic aspects (60)
Y02E10/76B ... for grid-connected applications (699)
Y02E10/76D ... concerning power management inside the plant, e.g. battery charging/discharging, economical operation, hybridisation with other energy sources (168)

Y02E20/00 Combustion technologies with mitigation potential (0)
Y02E20/10 . Combined combustion (0)
Y02E20/12 .. Heat utilisation in combustion or incineration of waste (3075)
Y02E20/14 .. Combined heat and power generation [CHP] (4499)
Y02E20/16 .. Combined cycle power plant [CCPP], or combined cycle gas turbine [CCGT] (3938)
Y02E20/18 ... Integrated gasification combined cycle [IGCC] (2698)
Y02E20/18B .... combined with carbon capture and storage [CCS] (71)
Y02E20/30 . Technologies for a more efficient combustion or heat usage (0)
Y02E20/32 .. Direct CO2 mitigation (0)
Y02E20/32B ... Use of synair, i.e. a mixture of recycled CO2 and pure O2 (853)
Y02E20/32D ... Use of reactants before or during combustion (86)

Y02E20/32F ... Segregation from fumes, including use of reactants downstream from combustion or deep cooling (44)
Y02E20/32H ... Controls of combustion specifically inferring on CO2 emissions (280)
Y02E20/34 .. Indirect CO2 mitigation, i.e. by acting on non CO2 directly related matters of the process, e.g. more efficient use of fuels (0)
Y02E20/34B ... Cold flame (320)
Y02E20/34D ... Oxyfuel combustion (4521)
Y02E20/34F ... Unmixed combustion (1422)
Y02E20/34H ... Air pre-heating (56)
Y02E20/36 .. Heat recovery other than air pre-heating (0)
Y02E20/36B ... at fumes level (1422)
Y02E20/36D ... at burner level (47)

Y02E30/00 Energy generation of nuclear origin (0)
Y02E30/10 . Fusion reactors (329)
Y02E30/12 .. Magnetic plasma confinement [MPC] (173)
Y02E30/12B ... Tokamaks (196)
Y02E30/12D ... Stellarators (52)
Y02E30/12F ... Other reactors with MPC (580)
Y02E30/12H ... First wall, divertor, blanket (266)
Y02E30/14 .. Inertial plasma confinement (181)
Y02E30/16 ... Injection systems and targets (153)
Y02E30/18 .. Low temperature fusion, e.g. "cold fusion" (811)
Y02E30/30 . Nuclear fission reactors (321)
Y02E30/31 .. Boiling water reactors (1146)
Y02E30/32 .. Pressurized water reactors (610)
Y02E30/33 .. Gas cooled reactors (739)
Y02E30/34 .. Fast breeder reactors (413)
Y02E30/35 .. Liquid metal reactors (1753)
Y02E30/36 .. Pebble bed reactors (771)
Y02E30/37 .. Accelerator driven reactors (48)
Y02E30/38 .. Fuel (8102)
Y02E30/39 .. Control of nuclear reactions (8543)
Y02E30/40 .. Other aspects relating to nuclear fission (41692)

Y02E40/00 Technologies for an efficient electrical power generation, transmission or distribution (0)
Y02E40/10 . Flexible AC transmission systems [FACTS] (101)
Y02E40/12 .. Static VAR compensators [SVC], static VAR generators [SVG] or static VAR systems [SVS], including thyristor-controlled reactors [TCR], thyristor-switched reactors [TSR] or thyristor-switched capacitors [TSC] (608)
Y02E40/14 .. Thyristor-controlled series capacitors [TCSC] (43)
Y02E40/16 .. Static synchronous compensators [STATCOM] (18)
Y02E40/18 .. Unified power flow controllers [UPF] or controlled series voltage compensators (391)
Y02E40/20 . Active power filtering [APF] (0)
Y02E40/22 .. Non-specified or voltage-fed active power filters (388)
Y02E40/24 .. Current-fed active power filters (121)
Y02E40/26 .. using a multilevel or multicell converter (83)
Y02E40/30 .. Reactive power compensation (Y02E40/10, Y02E40/20 take precedence) (1717)
Y02E40/32 .. using synchronous generators (262)

Y02E40/34 .. for voltage regulation (296)
Y02E40/40 . Arrangements for reducing harmonics (Y02E40/10, Y02E40/20 and Y02E40/30 take precedence) (700)
Y02E40/50 . Arrangements for eliminating or reducing asymmetry in polyphase networks (472)
Y02E40/60 . Superconducting electric elements and equipment (0)
Y02E40/62 .. Superconducting generators (323)
Y02E40/62B ... Superconducting synchronous generators (158)
Y02E40/62B2 .... with rotating field windings (1782)
Y02E40/62D ... Superconducting homopolar generators (69)
Y02E40/64 .. Superconducting or hyperconductive transmission lines or power lines or cables or installations thereof (192)
Y02E40/64B ... characterised by their form (734)
Y02E40/64B2 .... Films or wires on bases or cores (314)
Y02E40/64B4 .... Multifilaments embedded in normal conductors (226)
Y02E40/64D ... characterised by the disposition of thermal insulation (266)
Y02E40/64F ... characterised by cooling (453)
Y02E40/64H ... Installation of superconducting cables or lines (359)
Y02E40/66 .. Superconducting transformers or inductors (305)
Y02E40/67 .. Superconducting energy storage for power networks, e.g. SME, superconducting magnetic storage (160)
Y02E40/68 .. Protective or switching arrangements for superconducting elements or equipment (509)
Y02E40/69 .. Current limitation using superconducting elements (503)
Y02E40/70 . Methods and systems for the efficient management or operation of electric power systems, e.g. dispatch aiming to losses minimisation or emissions reduction, coordination of generating units or of distributed resources, interaction with loads (517)
Y02E40/72 .. characterised by remote operation, interaction, monitoring or reporting system, e.g. smart grids (364)

Y02E50/00 Technologies for the production of fuel of non-fossil origin (0)
Y02E50/10 . Biofuels (3703)
Y02E50/11 .. CHP turbines for biofeed (185)
Y02E50/12 .. Gas turbines for biofeed (335)
Y02E50/13 .. Bio-diesel (2685)
Y02E50/14 .. Bio-pyrolysis (3150)
Y02E50/15 .. Torrefaction of biomass (183)
Y02E50/16 .. Cellulosic bio-ethanol (2229)
Y02E50/17 .. Grain bio-ethanol (5800)
Y02E50/18 .. Bio-alcohols produced by other means than fermentation (256)
Y02E50/30 . Fuel from waste (5019)
Y02E50/32 .. Synthesis of alcohols or diesel from waste including a pyrolysis and/or gasification step (706)
Y02E50/34 .. Methane (0)
Y02E50/34B ... production by fermentation of organic by-products, e.g. sludge (4958)
Y02E50/34D ... from landfill gas (311)

Y02E60/00 Technologies with potential or indirect contribution to GHG emissions mitigation (0)
Y02E60/10 . Energy storage (0)
Y02E60/12 .. Battery technology (112717)
Y02E60/12B ... Lithium-ion batteries (37390)

Y02E60/12D ... Alkaline secondary batteries, e.g. NiCd or NiMH (16313)
Y02E60/12F ... Lead-acid batteries (1359)
Y02E60/12H ... Hybrid cells (8217)
Y02E60/13 .. Ultracapacitors, supercapacitors, double-layer capacitors (6489)
Y02E60/14 .. Thermal storage (0)
Y02E60/14B ... Sensible heat storage (6303)
Y02E60/14D ... Latent heat storage (4633)
Y02E60/14F ... Cold storage (1203)
Y02E60/15 .. Pressurised fluid storage (970)
Y02E60/16 .. Mechanical energy storage, e.g. flywheels (2725)
Y02E60/17 .. Pumped storage (547)
Y02E60/30 . Hydrogen technology (0)
Y02E60/32 .. Hydrogen storage (0)
Y02E60/32B ... Storage of liquefied, solidified, or compressed hydrogen in containers (4022)
Y02E60/32D ... Storage in caverns (13)
Y02E60/32F ... Reversible uptake of hydrogen by an appropriate medium (2796)
Y02E60/32F2 .... the medium being carbon (440)
Y02E60/32F4 .... the medium being a metal or rare earth metal, an intermetallic compound or a metal alloy (2794)
Y02E60/32F6 .... the medium being an organic compound or a solution thereof (374)
Y02E60/34 .. Hydrogen distribution (215)
Y02E60/36 .. Hydrogen production from non-carbon containing sources (2651)
Y02E60/36B ... by chemical reaction with metal hydrides, e.g. hydrolysis of metal borohydrides (363)
Y02E60/36D ... by decomposition of inorganic compounds, e.g. splitting of water other than electrolysis, ammonia borane, ammonia (2095)
Y02E60/36F ... by electrolysis of water (2828)
Y02E60/36F2 .... by photo-electrolysis (246)
Y02E60/50 . Fuel cells (49964)
Y02E60/52 .. characterised by type or design (0)
Y02E60/52B ... Proton Exchange Membrane Fuel Cells [PEMFC] (31263)
Y02E60/52B2 .... Direct Alcohol Fuel Cells [DAFC] (2718)
Y02E60/52B2B..... Direct Methanol Fuel Cells [DMFC] (8804)
Y02E60/52D ... Solid Oxide Fuel Cells [SOFC] (10678)
Y02E60/52F ... Molten Carbobate Fuel Cells [MCFC] (2919)
Y02E60/52H ... Bio Fuel Cells (837)
Y02E60/52J ... Regenerative or indirect fuel cells, e.g. redox flow type batteries (4444)
Y02E60/54 .. specially adapted for a certain application (109)
Y02E60/54B ... Stationary systems, e.g. emergency power sources (339)
Y02E60/54D ... Transport applications, e.g. automobile, bus, ship (4494)
Y02E60/54F ... Portable applications, e.g. mobile phone, laptop (1372)
Y02E60/56 .. integrally combined with other energy production systems (54)
Y02E60/56B ... Cogeneration of electricity with other electric generators (3633)
Y02E60/56D ... Cogeneration of heat, e.g. hot water, steam (471)
Y02E60/56F ... Cogeneration of mechanical energy, e.g. integral combination of fuel cells and electric motors (234)
Y02E60/56H ... Production of chemical products inside the fuel cell; incomplete combustion (65)

Y02E70/00 Other energy conversion or management systems reducing GHG emissions (0)
Y02E70/10 . Hydrogen from electrolysis with energy of non-fossil origin, e.g. PV, wind power, nuclear (507)
Y02E70/20 . Systems combining fuel cells with production of fuel of non-fossil origin (120)
Y02E70/30 . Systems combining energy storage with energy generation of non-fossil origin (1287)
Y02E70/40 . Batteries, ultracapacitors, supercapacitors or double-layer capacitors, charging or discharging systems or methods for reducing GHG emissions, e.g. auxiliary power consumption reduction, resonant chargers or dischargers, resistive losses minimisation (5)
Y02E70/42 .. specially adapted for vehicles (304)
Y02E70/44 .. specially adapted for portable applications (478)