
“Climate Change Mitigation and the Role of Technologic Change: Impact on selected headline targets of Europe’s 2020 climate and energy package”

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Abstract

The European Union launched a set of policies as part of its 2020 climate and energy package aimed at meeting its 20/20/20 headline targets for smart, sustainable and inclusive growth. This paper evaluates how successful new-to-the-market climate change mitigation technologies (CCMT) are in helping EU member states (MS) to reach these goals and, furthermore, whether there are differences between sectors subject to EU-wide policies. To do so, we seek to relate CCMT patent counts to two specific headline targets: (1) achieving 20% of gross final energy consumption from renewables, and (2) achieving a 20% increase in energy efficiency. Our results provide the first ex-post evaluation of the effectiveness of these technologies for combating climate change. Moreover, our sectoral impact assessment points to significant differences in the way in which these technologies contribute to policy goals across sectors.

JEL classification: O33, O38, Q55, Q58

Keywords: Environmental Policy; Climate Change; Technological Change; Patent Count Data.

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1. Introduction

The first, legally binding global climate deal, adopted by 195 countries in Paris (COP 21) in December 2015, is soon to come into effect, placing all participants under considerable pressure to honor their pledges. Yet, as highlighted by the 2014 report published by the Intergovernmental Panel on Climate Change (IPCC) on climate change mitigation (Edenhofer et al. 2014), the headline target of the Paris Agreement –limiting global warming to a maximum of two degrees in the long run– will be difficult to achieve unless there are major improvements in energy efficiency. Moreover, the report stresses the key role to be played by policies that can cut the demand for energy by fostering investment in energy efficiency projects. In short, technology change as it impacts energy production and energy end use is critical for maintaining global warming below two degrees.

Prior to the Paris Agreement, the European Union, a pioneer in combating climate change, launched a set of policies as part of its 2020 climate and energy package aimed at meeting its 20/20/20 headline targets for smart, sustainable and inclusive growth. As such, technology change explicitly underpins its policy framework; yet, and to the best of our knowledge, there has been no ex-post assessment of the role technology change might play in achieving these goals. Recent studies in the literature concern themselves, primarily, with evaluating the ways in which public environmental policies stimulate “green” technology change, but they do not intend to determine how effective these technologies are in achieving established policy goals and whether their impact varies across sectors. Here, therefore, we seek to measure, first, how successful new-to-the-market climate change mitigation technologies (CCMT) are in helping EU member states (MS) reach these goals and, second, whether there are differences between sectors subject to EU-wide policies. To do so, we seek to relate CCMT patent counts to two specific headline targets, namely, achieving 20% of gross final energy consumption from renewables and achieving a 20% increase in energy efficiency. Thanks to the richness of our data, we are able to determine the impact of different CCMT classes on overall target achievement and on sector-specific achievement rates. Our results

provide the first ex-post evaluation of the effectiveness of these technologies for combating climate change. Furthermore, our impact assessment conducted by sector points to significant differences in the way in which these technologies contribute to policy goals across sectors. As such, our study both broadens our understanding of the impact CCMTs can have and serves to make policy recommendations aimed at ultimately reaching the ambitious climate goals set by the EU and placing it firmly on the pathway to low carbon.

The rest of the study is organized as follows. In section two, we present a brief overview of the 2020 climate and energy package and its respective policies,¹ and in order to provide a clear picture of where the EU currently stands we report the descriptive statistics in relation to headline targets and CCMT measures. This section is followed by a brief literature review in which we examine the most relevant findings. Next, the data for the empirical exercise are introduced along with their descriptive statistics. Section five introduces the reader to the empirical strategy applied in section six where we present the regression results and discuss the special role played by CCMTs. Finally, in section seven, we conclude the study with a number of policy recommendations and we discuss the limitations and potential lines of future research.

2. The EU “2020 climate and energy package” and its respective policies

In 2010, the European Commission (EC) established five headline targets, better known as the Europe 2020 Strategy, outlining where the EU should stand on key parameters by 2020 (European Commission 2010). In order to meet its energy and climate change goals, the EC put together the “2020 climate and energy package”, comprising a set of binding legislation to ensure the following targets are met: (1) 20% reduction in greenhouse gas (GHG) emissions; (2) 20% of gross final

¹ Other types of action taken by the EU in order to meet the 20/20/20 goals include research and innovation programs such as the NER 300 and the Horizon 2020 programs. Both programs do not just tackle a single goal of the 2020 climate and energy package, but aim to benefit all three of them. While the NER 300 program focuses on the funding and diffusion of new-to-the-market low carbon technologies, such as carbon capture and storage technologies (CCS) and renewable energy technologies (RES), the Horizon 2020 program pursues, among other goals, the financing of research and innovation in the areas of resource efficiency and the sustainable supply of raw materials. Special attention, therefore, is paid to waste/water management and resource efficient economies (European Commission 2015b).

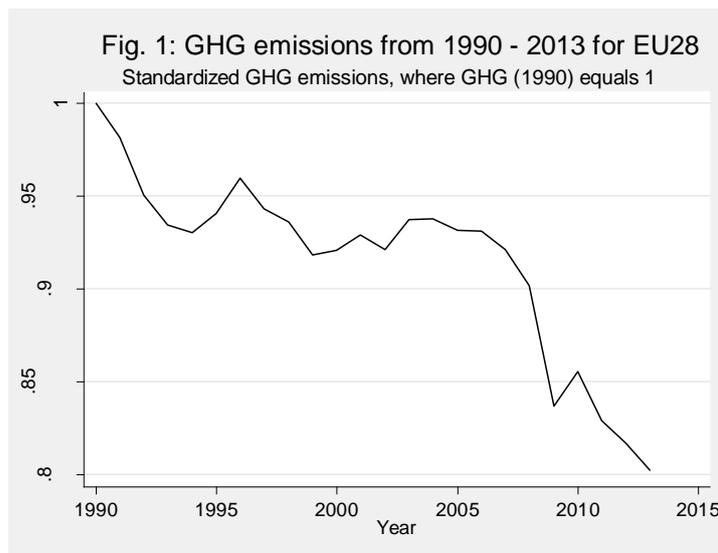
energy consumption from renewables; and (3) 20% improvement in energy efficiency (European Commission 2016).

2.1- 20% reduction in GHG emissions.

The key tool for achieving this target is the EU Emissions Trading System (EU ETS), an EU-wide regulation, covering around 45% of Europe's GHG emissions and applied to energy-intensive industries and, since 2012, to commercial airlines. The ETS is complemented by an additional policy targeting the reduction of emissions – the “Effort Sharing Decision”, which applies to sectors not covered by the EU ETS, including transport, housing, waste, and agriculture. However, in this instance, the policy is not applied homogeneously across MS; thus, because of their differing growth prospects, the richest MS need to reduce their emissions by 20% whereas the least wealthy MS are permitted to increase their emissions in the respective sectors by 20%. As such, and in contrast with the EU ETS, the “Effort Sharing Decision” relies on national emission reduction plans.

The EU seems to have made considerable progress towards this first goal, to the extent that Figure 1 suggests that achieving the target is simply a matter of time. According to Eurostat (2014a), by 2012 the EU had achieved an 18% cut in GHG emissions from 1990 levels. Yet, this progress cannot be attributed solely to the efforts of the EU and its policies; it also reflects the impact of major external factors, in particular the effects of the 2008/09 economic crisis. As stressed by Bel & Joseph (2015), the main driver of emission abatement for sectors under the EU ETS was the economic recession and only a relatively small proportion of the abatement could actually be attributed to policy.

Figure 1: EU-28 GHG emissions, 1990-2013



Note: Total GHG emissions including international aviation and excluding LULUCF
Source: Own calculations

Given that the 2020 climate and energy package’s first goal is within sight, we do not examine in any further depth the effects of CCMTs and GHG abatement here. Moreover, this particular target does not concern our empirical analysis because targets 2 and 3 (see above) very much condition this first goal. Thus, an increase in the share of renewable energy sources in gross inland consumption by fuel type goes hand in hand with a reduction in GHG emissions. Likewise, it is reasonable to assume that a reduction in final energy consumption by means of efficiency enhancements also leads to a reduction in GHG emissions.²

2.2- 20% renewable energy share.

This target is included in the “Renewable Energy Directive” and, in common with GHG reduction policies, national renewable targets vary across MS, depending on their initial position and overall potential (European Commission 2009). For example, Sweden is required to achieve a target of 49%, while Malta has been set a goal of just 10% (National Renewable Energy Action Plan Sweden 2010; National Renewable Energy Action Plan Malta 2010). The directive aims to foster

² We are aware of critical views of this hypothesis, e.g., Herring (2006). However, the kind of energy savings/efficiency increases as outlined in the Energy Efficiency Directive 2012/27/EC do not favor a reduction in the implicit energy price; hence, “rebound” and “takeback” effects are not expected.

cooperation among MS by promoting three mechanisms: statistical transfers of renewable energy, joint renewable energy projects, and joint renewable energy support schemes. Additionally, the directive promotes the use of sustainable biofuels in order to meet a 10% renewable energy target in the transport sector (European Commission (a) 2015).

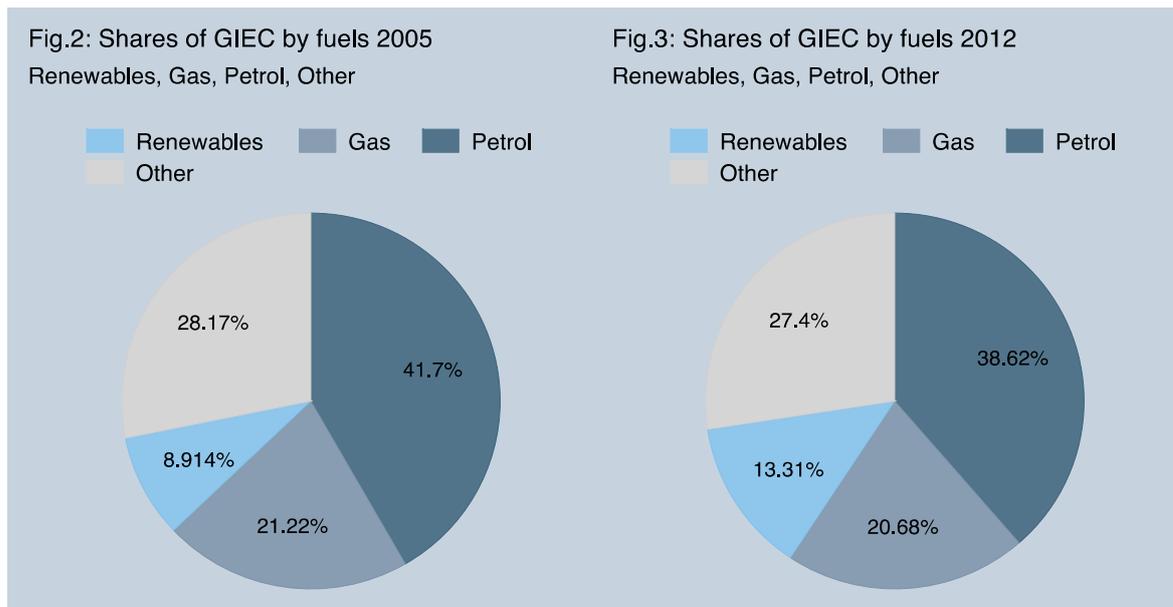
Considerable progress has also been made with respect to the sources of renewable energy. Gross inland energy consumption³ by fuel increased from 8.9 to 13.3% over the period 2005 through to 2012 (Figures 2 and 3), representing a growth of 49% over the whole period. At the same time, all the shares of gross inland energy consumption (GIEC) by fuel type dropped, the largest fall being recorded by petroleum products (~ 3% reduction). These substitution effects are worth stressing since the burning of fossil fuels, for such activities as the production of electricity and transport, is one of the main drivers of climate change (EPA 2016; NASA 2016)⁴.

However, the positive overall trend conceals huge differences between countries: Sweden, Bulgaria, and Estonia have already met their 2020 renewable energy targets, while many, including Malta, Netherlands, the UK, and Luxembourg are some distance from reaching their respective goals (Eurostat 2014). Hence, much has to be achieved to ensure that all MS hit the 2020 target of a 20% share of renewables in gross final energy consumption.

Figures 2 & 3: Shares of gross inland energy consumption by fuel type (GIEC), 2005 & 2012

³ Here, we use gross inland energy consumption as opposed to gross final energy consumption. While we are aware that the goals set out in the “2020 climate & energy package” employ the latter indicator, gross inland energy consumption (see definition in Appendix) provides good approximation.

⁴ The category “other” in the figures includes solid fuels, nuclear heat, and waste.



Source: Eurostat & own calculations

2.3- 20% improvement in energy efficiency.

To achieve the 2020 climate & energy package's third goal, the EC issued Directive 2012/27/EU, that is, the Energy Efficiency Directive (European Commission 2012). The directive is built on three pillars that seek to ensure the 20% increase in efficiency is met. The first comprises the National Energy Efficiency Action Plans (NEEAP) and annual reports. The NEEAPs include the estimated energy consumption, planned energy efficiency measures, and the individual goals of each MS and have to be revised and resubmitted on a three-year basis. The annual progress reports serve to verify whether targets have been reached.

The second pillar comprises the so-called national building renovation strategies, whereby each MS indicates how they intend to stimulate investments through the targeting of renovation in the commercial and residential building sectors. Additionally, the EU states are obliged to renovate at least 3% of their government building stock.⁵ The third pillar comprises the energy efficiency obligation schemes. These schemes target energy distributors or retail energy sales companies with

⁵ EU countries, as an alternative to renovating 3% of government-owned or -used buildings, have the option of implementing behavioral changes or undertaking major renovation work (i.e., increasing energy performance above minimum requirements). To be considered valid, the work must achieve the same degree of energy savings.

the aim of achieving a 1.5% energy saving in annual sales to final consumers by means of the implementation of energy efficiency measures.⁶

In assessing the achievement of this energy efficiency target, two points need to be borne in mind: first, the indicators used to measure the energy efficiency of the MS and, second, the base year selected. As regards the former, several indicators can be used to describe energy efficiency⁷; however, the EC ruled that national targets should be expressed as either primary energy consumption or final energy consumption⁸ (European Commission 2013). In the case of the second point, the EC established 2007 as the baseline projection for energy consumption. Accordingly, the EC estimated that 1,853 Mtoe (million tons of oil equivalent) of primary energy will be consumed in 2020 (European Commission 2012). A 20% reduction would correspond, therefore, to a primary energy consumption of 1,482 Mtoe or a final energy consumption of 1,086 Mtoe, respectively (The Coalition for Energy Savings 2013).

In our data sample one single sector is responsible for nearly one third of final energy consumption in the EU, namely, the transport (31.8%)⁹. The trends recorded in sector-specific final energy consumption are shown in Fig. 5, highlighting a number of interesting observations. First, the evolution in final energy consumption differs in the transport sector compared to the remaining sectors. While there appears to be a downward trend in consumption in the transport sector (following a minor increase between 2005 and 2007), consumption fluctuates in the remaining sector. Hence, consumption in the transport sector does not seem to be as volatile against economic performance as are the other sectors since “other’s”¹⁰ final energy consumption

⁶ MS can also opt for alternative policy measures that boost increase energy efficiency, including energy/carbon taxes, training and education and financial incentives for the deployment of energy efficiency technologies.

⁷ They include Primary Energy Consumption, Final Energy Consumption, Final Energy Savings and, Energy Intensity.

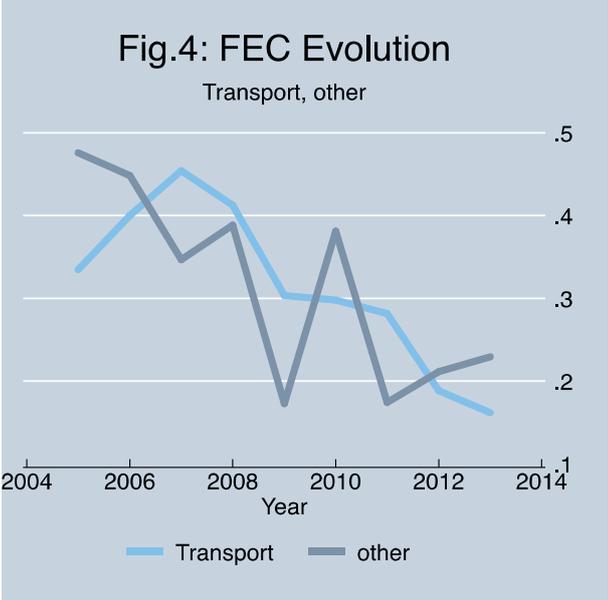
⁸ A definition of both can be found in the Appendix.

⁹ We focus on overall and transport specific FEC, as we are particularly interested in the way in which CCMTs impact energy efficiency overall and sector specific. However, data for sector-specific CCMTs were only available for the transport sectors, which limited our analysis accordingly.

¹⁰ The sectors included in this category are Industry, Agriculture/Forestry, Services, Residential, and other (non-specified), with Industry accounting for the largest share.

experienced a sharp increase in the recovering of the economic crisis 2008/2009 while the transport sector steadily reduced its consumption.

Figure 5: Final Energy Consumption (FEC) by Sector



Note: Fig. 5 uses standardized FEC consumption for the sector “other” and the transport sector for comparability reasons. Source: Eurostat & Own Calculations.

Finally, during the observation period energy efficiency increased overall; thus, final total energy consumption fell by 7.1% between 2005 and 2012. However, the reduction in final energy use is not spread evenly across sectors; in the case at hand, final energy consumption in the transport sector reduced by “only” 4.75% suggesting that other sectors were responsible for the major decrease in consumption.

3. Related literature

In recent years, much has been written about the relationship between the impact of environmental policies and technology change. However, when it comes to meeting the goals of these policies, much less has been written about the specific impact of new-to-the-market technologies.

Many studies draw on the “induced innovation” hypothesis that was first formulated by Hicks (1932) and which was later reformulated in terms of environmental policies by Porter & van der Linde (1995) and renamed the Porter Hypothesis, which states that well-designed environmental policies can foster the deployment of environmental-friendly technology change. One study that examines this relationship in depth is Popp (2003). Popp exploits a policy regime change from a classical command-and-control regime to a market-based approach to study the effects on patenting activity, and the effectiveness of new patents, following the introduction of the Clean Air Act (CAA) in 1990. Thus, while patenting activity – measured in patent counts – fell after the introduction of the CAA, the focus taken by R&D activity also shifted. Before the transition to market-based regulation, companies affected by the policy concentrated their R&D efforts on reducing the costs of compliance with the regulation; after 1990, their R&D was more concerned with improving the efficiency of technology aimed at reducing emissions. Although the absolute number of patents fell in 1990, the market-based approach increased the efficiency of new patents aimed at guaranteeing a more environment-friendly production.

Using patent data to determine the role environmental policies play in relation to the development of technological innovations in renewable energy sources (RES), Johnstone et al. (2009) show that different kinds of policy instrument favor the innovation of different RES. Overall, the paper finds that public policy plays a key role in fostering new-to-the-market technologies. In the case of the more costly RES (e.g. solar energy), targeted policy instruments, such as feed-in-tariffs, have a significant effect on such technologies; whereas, broad-based policies, such as emission trading, foster technology change that is competitive with conventional energy sources.

Further evidence that environmental policies are an important factor when it comes to “green” technology change can be found in Haščič et al. (2010). This paper identifies a link between policies combating climate change and the generation and diffusion of CCMTs. However, evidence is presented that innovation not only depends on public policy but also on a country’s innovative capacity. Thus, there is a classic mismatch between the needs of developing countries with respect

to specific CCMTs and the development of these technologies given their lack of innovative capacity. In contrast, developed countries lack the incentives to develop these technologies. As the authors suggest, cooperation between these two parties would overcome this mismatch.

Focusing on the European flagship policy for climate change mitigation, the EU ETS, Cael and Dechezleprêtre (2016) match EU ETS firms with firms not affected by the policy and apply a difference-in-differences estimation in an attempt at separating the impact of the policy on the development of low-carbon technologies from other external factors. The authors measure technological change in terms of the number of patent applications registered at the European Patent Office (EPO). In this way, they are able to untangle the surge in CCMT patenting that coincided with the launch of the EU ETS in 2005. According to their estimates, the policy was responsible for almost a 1% increase in CCMTs, when compared to the counterfactual scenario. Furthermore, their firm-level estimates highlight that the EU ETS has, on the one hand, a limited impact on overall low-carbon patenting, while, on the other, the policy has a strong and targeted effect on a small set of firms under the regime.

Probably the most related work to ours stems from Soltmann et al. (2014). Using industry-level panel data, the paper aims to explain the link between green innovation and performance, measured as value added. In that way, the authors showed that the relation between green innovations and performance is U-shaped meaning that for most industries the associated effect is negative up to a certain turning point. Nevertheless, this study does not answer our research questions: to what extent green technologies can contribute to reach climate policy goals.

Several more studies have sought to explain the link between environmental regulation and technology change (Jaffe & Palmer (1997), Jaffe et al. (2002), Popp (2006), Anderson et al. (2011), Fontini and Pavan (2014)); however, they all take a different focus on the ways in which environmental policies impact on technology change. Yet, to the best of our knowledge, no study to date has analyzed the effectiveness of these technologies with respect to the different goals established by environmental policy. With this objective in mind, we seek to provide an initial

measure of how CCMTs, in general, contribute to achieving climate and energy targets and, more specifically, how the different branches of these technologies impact on sectoral policy measures. Thus, we focus on the European 20/20/20 goals and their respective measures, as outlined above, and the impact of selected CCMTs. In this respect, our study is, we believe, the first to undertake the impact assessment of different CCMTs and policy headline targets. However, before undertaking the empirical analysis, the data used in this study are presented along with their summary statistics.

4. Data

Because the European 20/20/20 goals and their respective policies are of a cross-country character, we constructed a longitudinal data set covering all 28 MS of the EU from 2005 until 2012 in order to capture this.¹¹ Our final sample comprises a total of 224 observations. The data for this study have been taken from three sources: PATSTAT, Eurostat, and the World Bank Database. All data for the different CCMT patent classes have been extracted from PATSTAT, the official patent register of the EPO, and then aggregated to country-levels in order to match the aggregation levels of the other covariates. From this latter database, commodity prices for oil, coal, and natural gas have been taken. All other data, including the final energy consumption and the share of renewable energy in gross inland energy consumption, were taken from Eurostat.

4.1. The evolution of CCMTs between 2005 and 2012 and their link to Europe's 20/20/20 goals

As we are particularly interested in the impact of CCMTs on two of the “2020 climate and energy package” goals (20% increase in renewable energy sources and a 20% reduction in FEC), we begin by examining the evolution of these specific technologies. As a proxy for green technologies, we use patent applications for CCMTs filed at the EPO. Much attention has been dedicated to

¹¹ Note that we not only evaluate the 20/20/20 goals but we also consider the way in which the CCMTs can play a role in achieving these goals. That is why we focus both on the timeframes for the different policies making up the climate and energy package as well as on the longer time horizon.

examining the advantages and drawbacks associated with this proxy (Griliches 1990). The main drawback of patent data is that they only capture part of the outcome of an innovative activity, since not all technological improvements are patented, voluntarily or otherwise, while innovations might also be of an organizational nature.

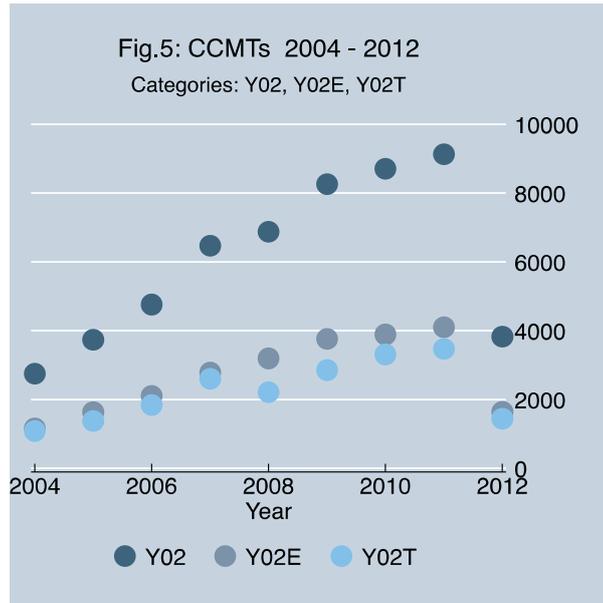
Bearing these shortcomings in mind, patent data are nevertheless a valid and frequently used measure for the innovative activity of firms, sectors, or countries. These patents are grouped under the patent class Y02 and its respective sub-classes Y02B, -C, -E, and -T¹², which were recently created to keep track of green technologies (Veefkind et al. 2012). Given the focus of this paper, only patents belonging to the super-class Y02 and to the sub-classes Y02E, and -T are used further in this study. Thus, we associate the goal of a 20% increase in renewable energy sources to patents in the Y02E category, that is, patents associated with achieving a reduction in GHG emissions during energy generation, transmission and distribution (EPO 2015a). The goal of a 20% increase in energy efficiency is linked to the Y02 super-class for total FEC, and to the Y02T sub-class (CCMTs related to transportation (EPO 2015b)) for the FEC of the transport sector.

If we examine the evolution of the different CCMTs in our database, we see (Fig. 6) that every single category has experienced considerable growth over the observation period,¹³ with Y02-E and -T category patents being responsible for the greatest increases in absolute numbers. With this in mind, and comparing these findings with those related to an increase in the share of renewables and with both overall and sector-specific energy efficiency/drop in FEC, there would appear to be a causal relationship between them.

Fig. 5: CCMTs over the period 2004 to 2012 (EU Aggregates)

¹² A detailed description of the different patent classes can be found in Table A1 in the Appendix together with example technologies for each category.

¹³ Note that the fall in number of CCMTs in the years 2012 is not due to a reduction in innovative activity among the MS; rather, it reflects the time lag between patent applications and patent approvals. We discuss this when considering CCMTs as a regressor in the estimations.



Source: PATSTAT & Own Calculations

Since companies can not only access new technologies of a given year but as well technologies from previous years, we use a patent stocks instead of patent flows. Additionally, and following Munari and Oriani (2011) this patent stock depreciates on a yearly basis in order to address the fact, that knowledge becomes outdated over time. Formally, the patent stock for year t and country i was created using the following equation:

$$Patent\ Stock_{i,t} = (1 - \delta)Patent\ Stock_{i,t-1} + Patents_{i,t} \quad (I)$$

, where Patent Stock equals the accumulated patent counts for the Y02, Y02E, and Y02T patents, respectively and Patents are the newly developed technologies of a given year. δ is the depreciation rate. We decided to employ a depreciation rate of 15% per year guided by the studies of Jaffe (1986), Cockburn and Griliches (1988), Hall and Oriani (2006)¹⁴. In order to identify correctly the impact of CCMTs on the different policy measures a broad set of control variables was employed. Thus, we clearly distinguish between the goals of a 20% increase in the share of renewables and a 20% increase in energy efficiency.

¹⁴ Nevertheless, we additionally performed all regressions using depreciation rates between 10% and 30%, whereby the outcomes are relatively stable over the whole range which is in line with Jaffe (1986)

4.2. *Variables concerning the 20% increase in the share of renewable*

As discussed, we use GIEC by fuel type as our dependent variable in the case of this specific target. Given that we are especially interested in the role of CCMTs related to energy production/consumption, our key variable is patent counts in the Y02E category (that is, patents related to energy generation, transmission and distribution). We opted to use this patent class only as these technologies are closely related to our dependent variables in this section.

Additionally, and so as not to falsely attribute any effects to these technologies, we exploit several more covariates. We employ GDP growth rates in our model to determine whether a country's economic performance in a given year influences GIEC. A second set of covariates includes commodity prices, given that a change in the relative price of a specific commodity due to a price change in another might possibly increase/decrease its use for energy production. Therefore, the prices of oil and coal are included as regressors in our model¹⁵. To account properly for the demand side of energy consumption, we embed the number of manufacturing enterprises in our model.

Finally, we use the number of electricity¹⁶ firms in our regressions. If a country has a high number of such firms, it is more likely to have a higher share of renewables in its production mix than countries with just a few but dominant companies. This rationale is motivated by the fact that renewable energy facilities, compared to conventional power plants, are more dependent on location and country endowments and, in general, produce less energy than, for example, coal-fired plants. Thus, in order to meet demand, more of these plants/companies are needed. Therefore, we would expect a negative impact of fossil fuels on GIEC and a positive impact of renewables on GIEC in our regressions.

4.3. *Variables concerning a 20% increase in energy efficiency*

In the case of a 20% increase in energy efficiency, the dependent variable is final energy consumption (FEC) (see discussion above). First, we wish to determine the overall effect of

¹⁵ Due to multicollinearity issues, we do not include natural gas prices in our regressions.

¹⁶ Enterprises included in the NACE D category (Electricity, gas, steam, and air condition supply).

CCMTs on total FEC. Our first estimate uses total FEC per country in a given year as the endogenous variable. Second, we are interested in how sector-specific CCMTs contribute to an increase in energy efficiency in the transport. Thus, the sector-specific specification uses the FEC of the transport sector. In common with our first goal, our core variable here are the CCMTs related to the different sectors. These comprise patent counts for the Y02 category for total FEC and Y02T counts for the FEC of the transport sector.

Additionally, we control for other factors that might influence FEC. Thus, we employ GDP growth rates in our specifications to capture any impact of economic performance on FEC. Furthermore, employment rates are included because of the close relationship identified with energy consumption (Tivari 2010). Moreover, and as above, the number of manufacturing enterprises is included as there may be a causal relationship with FEC. The energy intensity of an economy and the sectors analyzed also form part of the specification, since we expect a greater intensity to have, in general, a positive effect on overall FEC and on this consumption in the respective sectors. Energy intensity in this study is calculated as the ratio between FEC (total and sectorial) and real GDP for a given year and country.

In the case of the sectorial equation, additional covariates are employed to control sector-specific trends. For the transport sector, we used the different modal splits for passenger and freight transport on both roads and rail, since a shift from one mode to the other may influence the FEC of the transport sector. Finally, we included a measure of the quantity and performance of road transport, namely, tons of goods transported per kilometer during the observation period. A detailed overview of all variables used in the empirical analysis can be found in Table 1.

Table 1: Summary Statistics and Description

VARIABLES	Description	N	mean	sd	min	max
GIEC_renew	GIEC by renewable energy sources; 1000 tons of oil equivalents (TOE)	224	5,321	6,537	0.500	32,252
GIEC_petrol	GIEC by total petroleum products; 1000 tons of oil equivalents (TOE)	224	22,555	30,275	869.5	121,893
GIEC_gas	GIEC by Gas; 1000 tons of oil equivalents (TOE)	224	15,292	22,807	0	85,473

GIEC_total	GIEC total; 1000 tons of oil equivalents (TOE)	224	62,954	84,462	870.4	351,704
FEC_total	Final energy consumption total; 1000 tons of oil equivalent (TOE)	224	41,006	53,913	381.5	223,424
FEC_trans	Final energy consumption Transport; 1000 tons of oil equivalent (TOE)	224	13,183	17,743	197.5	63,406
gdp_growth	Real GDP growth rate; Percentage change on previous year	224	1.604	4.331	-14.80	11.90
oil_brent	Crude oil, Brent, \$/bbl, real 2010	224	81.95	15.41	62.07	104.1
coal	Coal, Australia, \$/mt, real 2010	224	84.48	24.15	54.30	123.6
emp_rates	Employment rate (15 to 64 years); annual averages	224	64.25	6.000	50.80	77.90
num_manu	Number of Manufacturing enterprises	224	80,573	97,042	816	481,813
num_ele	Number of enterprises belonging to the NACE D category	224	1,526	2,852	3	18,554
modal_pass_road	Modal split of passenger transport; Passenger cars; percentage	224	81.42	5.317	64.20	92.30
modal_pass_train	Modal split of passenger transport; Trains; percentage	224	5.648	3.177	0	12.60
modal_freight_rail	Modal split of freight rail transport; percentage	224	19.19	15.99	0	70.20
tonnePerKilo	Transported Tons of Freight per Kilometer; Thousand Tons	216	66,435	81,963	896	343,447
enrInt_total	Energy Intensity total economy, FEC/real GDP (in millions)	224	0.134	0.0625	0.0586	0.438
enrInt_trans	Energy Intensity Transport Sector, FEC/real GDP (in millions)	224	0.0426	0.0171	0.0198	0.125
Y02_dep15	Patent stock for the Y02 category (Depreciation Rate 15%); priority date	224	419.2	1,074	0	7,334
Y02E_dep15	Patent stock for the Y02E category (Depreciation Rate 15%); priority date	224	186.2	442.8	0	3,083
Y02T_dep15	Patent stock for the Y02T category (Depreciation Rate 15%); priority date	224	156.0	472.8	0	3,162
Number of groups		28	28	28	28	28

Note: In the case of “*tonnePerKilo*” no data could be obtained for Malta. Possible disturbances due to this missing data is discussed in the result section.

5. The econometric specification

As we wish to analyze the specific impact of CCMTs on two key targets of Europe’s climate and energy package, two sets of estimations are performed for each goal. The first set of estimations concerns the goal of achieving a 20% increase in energy from renewable sources. We not only show how the CCMTs of the Y02E category impact the GIEC of renewable sources, but also how these

technologies affect the shares of sources other than renewables and overall consumption. The following equation is estimated for the GIEC for each fuel type:

$$GIEC_{by\ fuel_{i,t}} = \alpha_i + \beta_1 Y02E_dep15_{i,t} + \beta_2 gdp_growth_{i,t} + \beta_3 coal_{i,t} + \beta_4 oil_brent_{i,t} + \beta_5 num_manu_{i,t} + \beta_6 num_elec_{i,t} + u_{i,t} \quad (II-V),$$

where *GIEC by fuel* is a placeholder for GIEC by renewables, gas, petrol, and overall consumption (in order to avoid repeating the same equation). α is the model's constant. Y02E_dep 15 is the patent stock for the Y02E category applying a 15% depreciation rate. Thereby, the stock for the first year, 2005, are the depreciated patent counts of year 2004 plus the patent counts of year 2005. In this manner, we do not only make use of a stock but as well incorporate the fact that there might be a delay between the patenting of a technology and its actual use in the production process. *gdp_growth* is the real GDP growth rate, measuring a country's overall economic performance. The variables *coal* and *oil_brent* represent coal and oil prices in our regressions, respectively. The number of manufacturing and electricity enterprises is represented by the variables *num_manu* and *num_elec*. Finally, *u* is the error term of the econometric specification, capturing all non-observable characteristics of GIEC. The subscripts *i* and *t* determine the cross-section and the time dimension of the variables, respectively.

Our second set of estimations seeks to capture the overall and sector-specific impacts on FEC of CCMTs, that is, how increased energy efficiency can be achieved by employing “green” technologies. Thus, we are first interested in the effects of CCMTs on total FEC and, second, in specific CCMT effects on FEC in the transport. The two resulting estimation equations can be stated as follows:

$$FEC_total_{i,t} = \alpha_i + \beta_1 Y02_dep15_{i,t} + \beta_2 gdp_growth_{i,t} + \beta_3 emp_rates_{i,t} + \beta_4 num_manu_{i,t} + \beta_5 enrInt_total_{i,t} + u_{i,t} \quad (VI)$$

$$\begin{aligned}
FEC_{trans_{i,t}} = & \alpha_i + \beta_1 Y02T_dep15_{i,t} + \beta_2 gdp_growth_{i,t} + \beta_3 emp_rates_{i,t} + \\
& \beta_4 num_manu_{i,t} + \beta_5 enrInt_trans_{i,t} + \beta_6 modal_freight_rail_{i,t} + \\
& \beta_7 modal_pass_road_{i,t} + \beta_8 modal_pass_train_{i,t} + \beta_9 tonnePerKilo_{i,t} + u_{i,t} \quad (VII)
\end{aligned}$$

where FEC_{total} and $-trans$ are the corresponding energy consumptions for total FEC and the transport sector. α is the constant of the specification in all three equations. The variables $Y02_dep15$ and $Y02T_dep15$, are the patent stocks for the respective sector and in total following the same considerations as in equations II - V. As above, gdp_growth is the annual real GDP growth rate. emp_rates represents the annual mean employment rates in our sample. num_manu stands for the number of manufacturing enterprises per country and year. $enrInt_total$, and $-trans$ are the respective energy intensities of the studied sectors. With respect to the sectorial specification, additional covariates are included to capture sector-specific dependencies.

The FEC equation for the transport sector (Eq. VII) includes these additional variables: $modal_freight_rail$, $modal_pass_road$, $modal_pass_train$, and $tonnePerKilo$. The first three represent the modal shifts in freight and passenger transport¹⁷ and the last represents tonnes of goods transported per kilometer by freight transport.

We decided to employ a fixed effect estimator in order to capture non-observable, time-invariant country heterogeneity. This approach can be considered appropriate since country differences are pronounced in our sample given differences in population, demographics, and political systems, to identify just a few. By using a fixed effect estimation, we automatically take these factors into consideration. The results of the Hausman test, conducted to determine whether to use fixed or random effects, however, are not trustworthy in the case of our regressions. Nevertheless, in line with the above reasoning, we favor the use of the fixed effect specification.¹⁸ Due to the presence of

¹⁷ We did not include the modal share of road transport with respect to freight transport because of strong multicollinearity issues.

¹⁸ Our main results do not vary greatly when random effects are used. These results are available from the authors upon request.

heteroscedasticity and cross-section dependency in our sample, we employ Driscoll-Kraay standard errors in order to obtain robust estimates of our standard errors.

6. Results

In this section, we present the results of the regressions described above. We first describe the results concerning a 20% increase in the share of renewables (Table 2) and, second, the results related to energy efficiency and CCMTs (Table 3).

6.1 A 20% increase in the share of renewables and the effect of CCMTs in the energy sector

As can be observed in Table 2, all estimations show overall statistical significance, since the F-statistic in each case (Eq. II-V) leads to the rejection of the H_0 that all coefficients are jointly equal to zero. Furthermore, the goodness-of-fit for equations I-IV, measured as the within R^2 , shows high values for equations II-IV and a moderate level for equation V. Finally, the full set of EU countries is used in this empirical exercise resulting in 224 observations.

All the variables used in our regressions show the expected behavior. Starting with the control variables employed to capture all effects other than those caused by CCMTs, we can see that total GIEC and GIEC by fuel type are sensitive to the overall economic performance of countries, measured as real GDP growth rates (*gdp_growth*). Their coefficients present high (Eq. II, IV) to moderate (Eq. III,V) statistical significance throughout all the estimations. However, the impact of GDP growth rates is not the same for all four estimations. While positive growth rates have a positive impact on total GIEC and on GIEC from petrol or gas sources, the impact on the share of renewables in GIEC falls with increasing GDP growth rates. This suggests that in order to meet the energy needs of a growing economy, energy producers rely more on conventional fuel sources than they do on renewable sources; thus, there is no sign of any decoupling of energy from different sources and economic growth measured in GDP growth rates. In the case of the impact of coal prices in our regressions for GIEC by fuel type, the resulting sign might initially be surprising, as it seems to point to a substitution effect among energy consumption by fuel type. Indeed, rising coal

prices lead to a greater consumption of the other sources (namely, petrol and gas). The same impact is observed for total GIEC. This is hardly surprising if we consider that nearly 60% of total GIEC is made up from GIEC from petrol and gas sources.

Table 2: Fixed Effects Estimation Results for GIEC by fuel:

VARIABLES	(II) GIEC_total	(III) GIEC_renew	(IV) GIEC_petrol	(V) GIEC_gas
Y02E_dep15	-13.84*** (1.632)	4.768*** (0.715)	-5.904*** (0.922)	-3.308*** (0.667)
gdp_growth	194.9*** (17.06)	-19.62** (6.654)	66.17*** (8.778)	62.98** (24.36)
Coal	39.46*** (6.760)	-8.991 (5.465)	21.31*** (2.796)	28.96*** (3.460)
oil_brent	-58.59*** (14.60)	29.37** (8.593)	-42.38*** (2.875)	-51.83*** (5.486)
num_manu	0.207*** (0.0276)	-0.0738*** (0.0103)	0.189*** (0.0204)	0.0661*** (0.00474)
num_ele	-0.443** (0.133)	0.182*** (0.0507)	-0.499*** (0.107)	0.0628 (0.0947)
Constant	50,717*** (3,087)	8,487*** (590.5)	10,765*** (1,526)	12,183*** (631.9)
Observations	224	224	224	224
Number of groups	28	28	28	28
F-statistic	700.6	110.8	173.5	438.0
R ² (within)	0.546	0.638	0.717	0.239

Driscoll-Kraay standard errors in parentheses

*** p<0.01, ** p<0.05

However, the same does not hold for GIEC from renewable sources. Following our estimation result for this category (Eq. II), no statistically significant relationship between GIEC and renewable and coal prices can be found. As for crude oil prices (*oil_brent*), the sign and significance levels obtained are as expected. Thus, higher oil prices reduce the share of petrol and gas sources, as well as total GIEC, while GIEC from renewables is affected positively. If we recall, however, that the lion's share of GIEC is made up from petrol and gas sources, this result is expected. However, the close relationship between crude oil, on the one hand, and natural gas, on the other, should be borne in mind when seeking to understand the negative impact of rising oil prices on

GIEC from gas sources (Asche et al. 2006).¹⁹ Given that the manufacturing sector is one of the largest consumers of energy, the resulting positive sign and high significance of the coefficient representing the number of manufacturing enterprises (*num_manu*) in equations II, IV, and V are expected.

However, here again, this estimation result is not valid for the GIEC of renewables sources (Eq. III) as it appears that a larger manufacturing sector negatively influences the share of renewables in GIEC. In order to meet the energy needs of this sector, energy producers seem to rely more heavily on fossil fuels, in a similar relationship to that observed for the impact of GDP growth rates. As predicted in section four, a higher number of energy firms in a country positively impacts GIEC from renewable sources (Eq. III) and negatively impacts total GIEC and GIEC from petroleum sources (Eq. II & IV). However, no statistically significant result could be obtained for GIEC from gas sources, even though the obtained sign presents a negative impact of *num_elec* in equation V.

In the case of our variable of interest, the patent stock for the Y02E patent category (*Y02E_dep15*), all coefficients present high levels of statistical significance and their impact follows the underlying theory. For total and for sources other than renewables, the impact of the CCMTs of the energy sector is negative with respect to GIEC (Eq. I, IV, and V) while the impact on GIEC from renewables is positively influenced by these technologies (Eq. III).

Given that we are particularly interested in the impact of these technologies, Figures 6-9 describe their impacts on the different GIEC analyzed in this study for different levels of the Y02E patent stock. The range, which indicates the impact of Y02E-categorized technologies, extends from 0 to the mean Y02E patent stock plus two times its standard deviation (~1100). Bearing in mind that the average patent count stands at around 186, we are able to draw some conclusions with respect to the share of renewables in GIEC and the other fuel sources. As expected, and in line with the

¹⁹ Given the close relationship between crude oil and natural gas prices and the resulting multicollinearity problem, we decided to employ crude oil prices only in our regressions.

regression results presented in Table 2, GIEC is reduced by an increasing number of Y02E patents for total, petroleum, and gas sources (Figs. 6, 8, and 9) and increases for GIEC from renewable sources (Fig. 7).

Focusing specifically on the goal of achieving a 20% share of energy from renewables, we are interested in determining what would happen to GIEC from renewables if there were an X% increase in Y02E patents in our data sample. This relationship can be obtained in a straightforward manner as we employ a linear prediction. For example, a 10% increase of the Y02E patent stock from its mean would result, on average, in an increase of around 1.61% in GIEC from renewables. A rise in the number of patents from 186 to 205 would result in an increase in GIEC from renewables in our sample of between 5,320 TOE and 5,406 TOE, on average. Indeed, a scenario in which CCMTs are increased by 10% is not unusual. For example, and given our data sample, the average Y02E patent stock increased by 10% between 2009 (227 Y02 patents) and 2010 (249 Y02 patents).²⁰ This result underlines the important role that CCMTs can play to meet the goal of a 20% share of renewables in gross final energy consumption. Hence, policies fostering the innovation and deployment of these technologies can be of core relevance to reach this goal.

Fig. 6: Predicted Margins of Y02E stock on GIEC total

Fig. 7: Predicted Margins of Y02E stock on GIEC from renewables

²⁰ As discussed above, patent counts for the Y02 class and its subclasses experienced a fall after 2011. If we restrict our analysis to the 2005-2011 time horizon, the impact of CCMTs increases slightly; however, our overall sample size decreases. Given this trade-off, we opted to use the full as opposed to the reduced sample. As such, our estimates are a conservative estimate of the impact of CCMTs, given that future increases in these technologies could have an even stronger impact on policy measures.

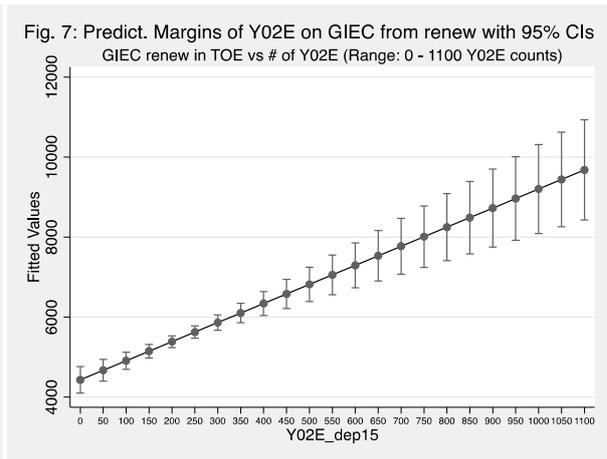
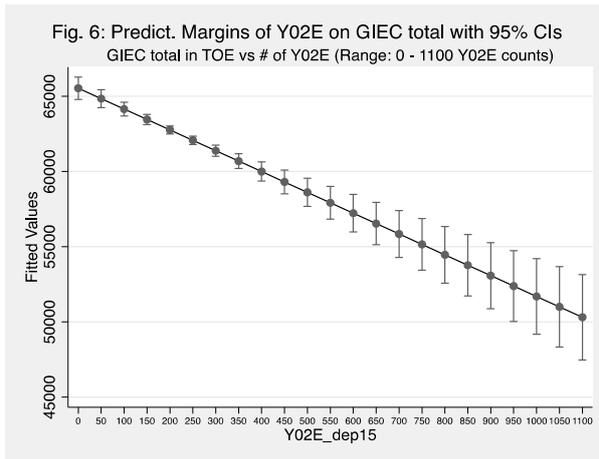
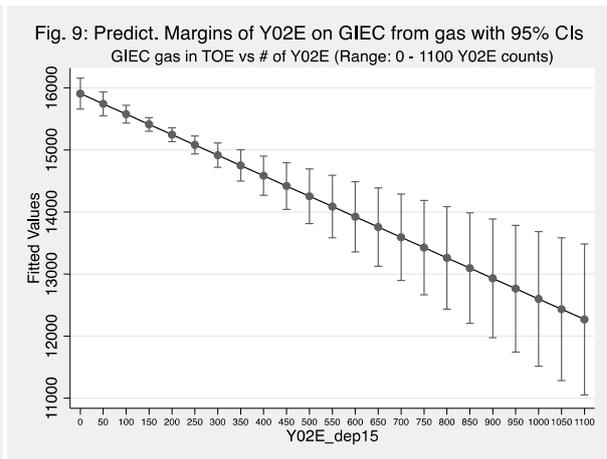
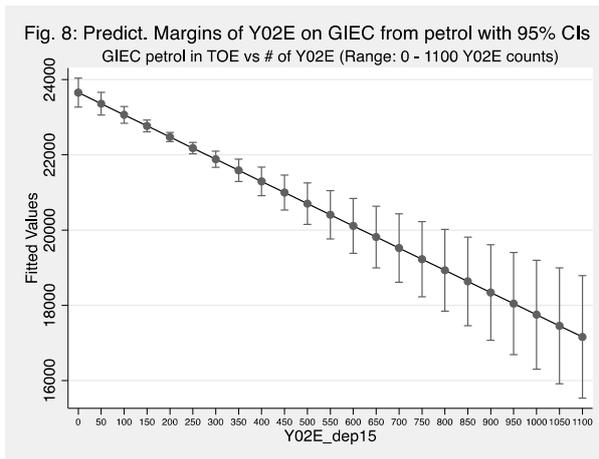


Fig. 8: Predicted Margins of Y02E stock on GIEC by petroleum

Fig. 9: Predicted Margins of Y02E stock on GIEC from gas



Note: Predicted margins are based on estimation results shown in Table 2

Finally, as can be seen in Table 2, it seems that all the covariates that have a positive effect on total GIEC and on GIEC from petroleum and from gas have a negative impact on GIEC from renewables, and vice versa. This peculiar observation may be important in designing future policies targeting GIEC from different fuel sources.

6.2 A 20% increase in energy efficiency

Table 3 presents the impact of CCMTs with respect to the target of a 20% increase in energy efficiency together with various covariates for total FEC and by end-use sector. In line with the previous results, the overall fit of equations (VI) and (VII) is given, as indicated by the corresponding F-statistic values. The proportion of variability of the dependent variables explained, as expressed by the R^2 statistic, extends from around 46% for FEC total to around 74% for FEC in the transport sector. It should be noted that for regression (VII) only 216 observations were available, as a full set of data for all the covariates could not be obtained for Malta. However, given the overall size of Malta, any potential disturbance created by not including these observations is expected to be minimal. As with the previous results, we first discuss the impacts of our control variables and then focus on the effects of CCMTs in our regressions.

The first variable that all three estimations in Table 3 have in common is *gdp_growth*, representing real GDP growth rates and accounting for the overall economic performances of the countries in our sample and the link to FEC. Given that this variable presents a moderately positive statistical significance only in the case of total FEC (Eq. VI) and not for the sectorial equations (VII), it would appear that such shocks as the global economic recession did not influence FEC across the MS in the transport sector. This result is in line with Fig. 6, where total FEC showed a relationship with economic performance and FEC in the transport sector did not fluctuate during the years of economic recession or recovery but instead decreased continually. However, as one of the aims of the Energy Efficiency Directive is to decouple energy use from economic growth, no statistically significant relationship at all would be desirable.

As for employment rates, for total FEC and FEC in the transport sector, the expected positive link is present between these two variables, indicating that total FEC and FEC in the transport sector are sensitive to the overall employment rates of a given country and year. Total FEC and FEC for transport are, furthermore, influenced by the total number of manufacturing enterprises. The reasons for the positive and statistically significant impact on total FEC are the same as those outlined for Eq. II in Table 2, whereas the positive and significant sign in the case of the transport

sector reflects the close link between the manufacturing and transport sectors with the latter supplying the former.

The last of the variables that the two equations (Eq. VI-VII) have in common is the respective levels of energy intensity (*enrInt_total*, and *-_trans*). In each case, the coefficient indicates a positive impact on the respective rates of FEC and is statistically significant at 1%, thus capturing the general trends in overall FEC and in consumption across sectors.

Table 3: Fixed Effects Estimation Results for FEC (total, transport):

VARIABLES	(VI)	(VII)
	FEC_total	FEC_trans
Y02_dep15	-2.739*** (0.743)	
Y02T_dep15		-1.052*** (0.141)
gdp_growth	60.78** (22.13)	-0.744 (7.550)
emp_rates	204.6** (68.66)	118.0*** (13.94)
num_manu	0.165*** (0.0126)	0.0468*** (0.00995)
enrInt_total	10,227*** (2,428)	
enrInt_trans		17,788*** (3,627)
modal_freight_rail		50.31*** (7.005)
modal_pass_road		108.5*** (18.22)
modal_pass_train		-303.2*** (71.78)
tonnePerKilo		0.0356*** (0.00397)
Constant	14,255*** (3,632)	-8,749*** (1,435)
Observations	224	216
Number of groups	28	27
F-Statistic	298.5	889.9
R ² (within)	0.456	0.742

Driscoll-Kraay Standard errors in parentheses

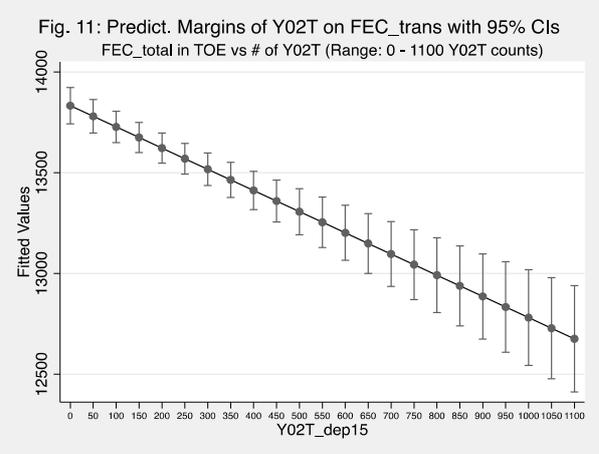
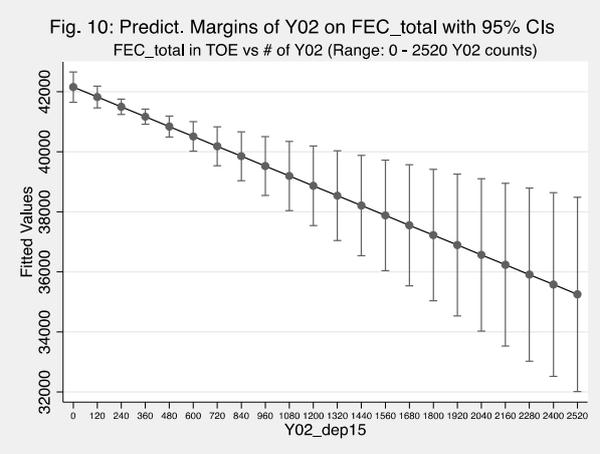
*** p<0.01, ** p<0.05

The variables that capture the specific characteristics of FEC in the transport sector (Eq. VII) all present high levels of significance. As expected, the modal splits for passenger transport (*modal_pass_road, - train*) highlight the fact that shifting from road- to rail-based modes in the case of passengers lowers FEC in the transport sector. However, this does not seem to hold for FEC in the rail freight transport. Here, an increasing share of rail freight transport increases FEC in the transport sector. Finally, we introduced *tonnePerKilo* as a load factor for road freight transport and, as expected, a positive impact is observed as this measure increases.

As our main objective is to quantify the impact of CCMTs on total FEC and on FEC in the transport sector, Figures 10 and 11 show these impacts graphically and comprehensively show how FEC is reduced by an increase in CCMTs.

Fig. 10: Predicted Margins of Y02 stock on total FEC

Fig. 11: Predicted Margins of Y02T stock on FEC in the transport sector



Note: Predicted margins are based on estimation results shown in Table 3

For the two different rates of FEC identified, we established different boundaries for the respective CCMT classes, since the average number of patents in each category varies from class to class. Thereby, the boundaries following the same criteria as the one used in Fig. 7-10. Thus, the boundaries extend from 0 to 2520 Y02 counts for total FEC and from 0 to 1100 Y02T counts for

FEC in the transport sector. In line with the regression results, total FEC and FEC in the transport sector are reduced by an increasing number of CCMTs. However, this effect is not equal across the specifications. Once again, to illustrate this we increase the average number of CCMTs in our sample for each specification by 10% to determine the resulting percentage change. The results of this exercise are summarized in Table 4.

Table 4: Effect of a 10% increase of the respective CCMT stocks on FEC

Pred. aver. FEC total given a Y02 patent stock of 419	Pred. aver. FEC total given Y02 patent stock of 461	Percentage Change (%)
41006 TOE	40891 TOE	≈ 0.28%
Pred. aver. FEC_trans given 156 Y02T patent stock	Pred. aver. FEC_trans given 172 Y02T patent stock	
13668 TOE	13651 TOE	≈ 0.123%

Source: Own calculations

As can be seen in Table 4, the impact of CCMTs varies greatly between the transport sector and overall. Thereby, the effect on total FEC of CCMTs is more than twice as strong than that for the transport sector. One should bear in mind when interpreting the resulting impact of on FEC, that average yearly gross growth rates for the Y02 and Y02T group exceed 10% in most cases, hence, CCMTs help reach the goal of a 20% increase in energy efficiency. Nevertheless, and comparing the outcomes to the results obtained for GIEC for renewables, the impact of CCMTs on energy efficiency (measured here as final energy consumption) is to date limited; however, this could be the result of the non-appliance of these new-to-the-market technologies. Hence, extending the use of these technologies could be critical in determining whether the target of a 20% increase in energy efficiency is achieved or not.

7. Conclusion

We undertook this analysis with the aim of assessing the role that CCMTs play in meeting two of the three headline targets of the “energy and climate package”. In so doing, we related the goal of obtaining 20% of gross final energy consumption from renewables with energy sector technologies

(Y02E-patents) and the goal of achieving a 20% increase in energy efficiency with overall technological change (Y02-patents) and sector specific changes for the transport (Y02T-patents) sector. Our results show that CCMTs not only play an essential part in overall target achievement but that there exist significant differences in the impact of these technologies between sectors. We demonstrated that an increasing number of CCMTs related to energy production, transformation and distribution has a particularly marked impact on the share of energy obtained from renewable sources. Our example shows that a 10% increase of CCMTs in the Y02E category increases the GIEC from renewables by around 1.61%. Given that this increase of patents is actually present in our data sample the transition from year 2009 to 2010, for example, fostering the development of these technologies is crucial for achieving the target of a 20% share from renewables.

Furthermore, the results from the empirical exercise point to a strong, negative and statistically significant impact on fuels other than renewables from the development of Y02E patents. This finding suggests that by promoting these technologies the policy target is more likely to be reached and a considerable decrease in GIEC from fossil fuels, and the dependency on these sources, can be achieved.

In the case of the second target, achieving a 20% increase in energy efficiency, our results suggest that, first, the impact of CCMTs has been limited to date (especially compared to the impact of CCMTs on the first target), and second, the impact of CCMTs varies greatly across overall FEC and FEC in the transport sector. When we tested a scenario in which total CCMTs and sector-specific CCMTs were increased by 10%, the resulting decrease in total FEC was around 0.28%, compared to 0.123% for FEC in the transport. These results indicate that technology change is not affecting FEC evenly across sectors.

These results have several policy implications. First, technology change can play a key role in achieving the ambitious climate goals set by the EU, and hence policies such as the NER 300 program can make the difference as to whether these goals are met or not. Thus, expanding these

policies and creating additional incentives for firms to innovate should place the EU firmly on the pathway to low carbon.

Furthermore, policies like the EU ETS seem to actively encourage the use of new technologies. This is very apparent if we compare the effects of CCMTs on the energy sector that is subject directly to the policy and the effects of CCMTs on firms that lie outside the policy, such as those in the transport and residential sectors. This leads us to our second policy recommendation, which is that policies need to foster the development of these technologies and ensure that these technologies are employed by end users across a range of sectors. In short, it is necessary to promote the application of new CCMTs. In the case at hand, this might result in an increased impact of these technologies in the transport sector, among others, where the impact to date has been limited.

As with most empirical studies, the factors that have placed some limitations on our evaluation are data issues. Although we have been able to separate the impact of CCMTs on FEC into overall and the transport sector, a more detailed breakdown would be desirable so that we might extend our analysis to include, for example, such sectors as manufacturing and waste. Finally, and in order to verify our results, follow-up studies would benefit from a higher data resolution, which would allow the effects to be detected more precisely.

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Appendix:

Definition of the different types of energy consumptions discussed in this study:

Primary Energy Consumption:

Primary energy consumption measures a country's total energy demand. It includes the consumption of the energy sector itself, losses during the transformation (for example, from oil or gas into electricity) and distribution of energy, and the final consumption by end users. It excludes energy carriers used for non-energy purposes (such as petroleum not used for combustion but for producing plastics) (Eurostat 2014 (b)).

Final Energy Consumption

Final energy consumption includes all the energy supplied to the final consumer for all energy uses. It is usually disaggregated into the final end-use sectors: industry, transport, households, services and agriculture (European Environmental Agency 2009).

Gross Final Energy Consumption

Energy commodities delivered for energy purposes to final consumers (industry, transport, households, services, agriculture, forestry and fisheries), including the consumption of electricity and heat by the energy branch for electricity and heat production and including losses of electricity and heat in distribution and transmission (European Environmental Agency 2015).

Gross Inland Energy Consumption

Gross Inland Energy Consumption (GIEC) is the quantity of energy, expressed in oil equivalents, consumed within the national territory of a country. It is calculated as follows: primary production + recovered products + total imports + variations of stocks - total exports - bunkers. It corresponds to the addition of final consumption, distribution losses, transformation losses and statistical differences (Eurostat 2016).

Table A1: The Y02 patent class and exemplary sub-class Y02T (CPC classification)

Patent Class	Definition	Examples
Y02	Climate Change Mitigation Technologies	
Subclass Y02E		
Y02E	Reduction of GHG emissions related to energy generation, transmission or distribution	
Y02E10/00	Energy generation through renewable energy sources	Geothermal Energy / Hydro Energy / Energy from Sea / Photovoltaic (PV)Energy / Thermal-PV hybrids / Wind Energy
Y02E20/00	Combustion technologies with mitigation potential	Combined combustion / Technologies for a more efficient combustion or heat usage
Y02E40/00	Technologies for an efficient electrical power generation, transmission or distribution	Flexible AC transmission systems / Active power filtering / Reactive power compensation
Subclass Y02T		
Y02T	Climate Change Mitigation Technologies related to Transportation	
Y02T 10/00	Road transport of goods or passengers	Internal combustion engine [ICE] based vehicles / Exhaust after-treatment / Use of alternative fuels
Y02T 30/00	Transportation of goods or passengers via railways	Energy recovery technologies concerning the propulsion system in locomotives or motor railcars / Reducing air resistance by modifying contour
Y02T 50/00	Aeronautics or air transport	Drag reduction / Weight reduction / On board measures aiming to increase energy efficiency



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