CECILIA 2050

OPTIMAL EU CLIMATE POLICY

Choosing Efficient Combinations of Policy Instruments for Low-carbon development and Innovation to Achieve Europe's 2050 climate targets

Inducing Greenhouse Gases Abating Innovations through Policy Packages

Ex Post Assessments from EU sectors

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LIST OF ABBREVIATIONS

CER	Certificate Emission reduction
CDM	Clean Development Mechanisms
CIS	Community Innovation Survey
EI	Environmental Innovations
EMS	Environmental Management standards
EU ETS	European Union Emission Trading Scheme
GHG	Green House gases
HPWP	High Performance Work Practices
ISO	International Standard Organisation
NACE	Sector codes of Economic activities http://ec.europa.eu/competition/mergers/cases/index/nace_all.html
NAMEA	(National Accounting Matrix including Environmental Accounts)
WIOD	World Input Output database

1 Executive summary

The report assesses whether and to what extent energy and environmental policy instruments have been relevant forces behind the adoption of environmental innovations in the EU over the past. The focus is thus on the ex post assessments of EI drivers. We take a sectoral perspective, that is theoretically based on neo Schumpeterian evolutionary theory, but also endorsed by recent Eu key reports (EEA, 2013) to investigate through interviews to industry representatives of key EU sectors - Energy, Chemical, paper and card board, ceramics and cement, metals/steel, coke and refinery– the factors that characterise the adoption of techno organisational innovations aimed at enhancing energy efficiency and abating CO_2. In terms of policy, though the EU ETS is an obvious keystone, the attention of the analysis is on 'drivers and brakes' to innovation with some focus on the complementarities and trade off among policy tools as it emerges from interviews. We complement the interview based analysis with econometric evidence on the policy drivers of eco innovation at sector level (Montalvo et al., 2012) by using the last wave of Community Innovation survey that investigates eco innovation adoption. The Industry views are integrated with a 'stakeholder based' analysis drawing upon on union's and policy makers view on the challenges of the green economy. We will specifically analyse the role of industrial relations – a key current issue in EU heavy industrialised countries - in supporting eco innovations and ecological-economic performances. The analysis thus delivers bottom up and ex post based knowledge on the successful and undermining properties of the existent policy mix in EU countries, and consequentially provides hints to ameliorate the (design of) the policy package.

From a methodological point of view, the complementary use of qualitative and quantitative analyses is worthwhile given the pros and cons of both sides. We claim that given the consolidated econometric evidence on the drivers of eco innovations, qualitative investigations originally analyse the concrete developments of eco innovation adoptions in sectors, by providing examples and evidence on specific technologies. This adds original value to the arena of eco innovations studies. Interviews, that are by definition not aimed at giving representative results but 'sector case studies', have the additional positive property that may cover EU as a whole over a dynamic perspective. In fact, the current availability of eco innovation data in the EU (Community Innovation Survey data) limits the analysis to some countries / years. In fact, large cross section and longitudinal datasets are available for patents, namely invention. Our focus is instead on the diffusion and adoption of eco innovations. The most comprehensive dataset on eco innovation is the CIS 2006-2008 by Eurostat. The sector data level covers EU27, while aggregated micro data covers only some countries[1]. The time span is evidently limited. In addition, some key countries did not implement the CIS survey, as Spain and UK. Further, the merge of CIS[2] and taxation/CO2 data at sector level is problematic due to some reclassifications of 'NACE'[3] sectors that occurred over the years.

Nevertheless, it is also useful to exploit quantitative methods applied to CIS data as well: we will originally merge CIS data with sector environmental accounts and energy taxation data to provide new econometric insights on the role of policies as a driver for eco innovation adoption.

Main findings can be summarised as follows. Within the realm of CO_2 related innovation adoption, Environmental and energy policies have had a role in sustaining incremental techno-organizational solutions. Policy pressures appear more effective in energy intensive sectors, where market and policy effects are equally relevant. Sector but also national 'systems of innovation' are highlighted. This calls into question the effectiveness of 'general policies' that do not recognise sector and geographical differences in their design. To some extent, past innovation was driven by different levels of energy taxation by country and sector rather than by specific 'carbon dioxide' policies. This is a key point in the Eu policy agenda: how to achieve effectiveness and efficiency by managing on the one hand the centre-periphery 'federalism' in environmental policy and on the other hand the various (regional) sector economic and innovation 'specializations'. The other general issue is how to balance and design energy and GHG oriented policies that, at least in fiscal terms, are heavily baised towards energy. Though less effcient in principle, general energy taxation (and high market prices for energy) may provide substantial 'innovation and efficiency offsets' when it is high.

A positive note which touches even the 'radicalness' of current innovation in some sectors is the widespread integration between technological and organisational innovations. Their complementarity is key for future achievements and must be recognised in policy design. More negative signals are the lower 'policy effect' in some heavy sectors, as ceramics, which does not present top figures for CO_2 performances. The key innovation wave seems in some sector situations to belong to the past. This

[1] The quantitative analyses in section 6 make use of the most recent and only available data at EU level for EI in the CO2 realm: (i) the Eurostat sector CIS data and the (ii) aggregated meso data (aggregation of similar firms, in clusters) that are provided by Eurostat in the CIS cd-rom. Option (i) is a first best given the wide EU coverage, option (ii) is interesting since it extends the dataset width. From a methodological perspective we rule out analyses on micro data. It would nevertheless impossible to present full EU coverage due to national based availability and copyright issues. The literature on EI at micro level usually develops at National level (Cainelli and Mazzanti, 2013; Horbach et al., 2012).

[2] For all information on CIS see http://epp.eurostat.ec.europa.eu/portal/page/portal/microdata/cis.

[3] http://ec.europa.eu/competition/mergers/cases/index/nace_all.html.

poses question marks on the current Eu policy package, which are reinforced by the relevance of expectations to support the adoption of EI. Another weakness is the low involvement of key agents such as workers and unions in the adoption of EI. The issue is crucial given the importance of jointly adopting techno-organisational-training efforts, that may enhanced by consultations and information within firms, to cope with climate change goals. Environmental policy stringency and policy expectations are thus key drives of EI. Nevertheless, the overall 'policy and institutional' environment is crucial, as EI is also strongly driven by the type and intensity of relationships with other sectors (that supply intermediate goods and 'knowledge'). This is increasingly relevant given the sector integration of the EU economy. Even if the main aim of environmental policy packages is to address market failures in form of negative externalities, integrating considerations on the dynamic efficiency of instruments (namely innovation effects), they should be informed by an designed around a diversified set of issues and considerations which characterise the 'innovation environment'.

We describe in this section the main conceptual background to the analysis of the policy drivers of eco innovation adoption. The sections will discuss general issues regarding EI (environmental innovations, Kemp, 2010; Diaz Lopez; 2011; Costantini and Mazzanti, 2013; Mazzanti and Montini, 2010), then moving to the specific insights offered by the empirical literature (that touches upon invention and innovation). Within this literature, we devote special attention to the part of literature that addresses the role of the EU ETS. We also specifically discuss the conceptual issues and main references that regard the 'sector oriented' view offered by neo Schumpeterian theory.

2. Introduction and Conceptual frameworks

2.1 Environmental Innovations in the EU: general overview of main issues

Environmental innovations (EI) are crucial to create synergies between sustainability and competitiveness towards the green economy (EEA, 2013). This is a fact that goes back to the pillars of growth theory in economics, revitalised by the advent of sustainability policy oriented thinking in the final part of the last century. Innovation per se is a keys stone in the EU Lisbon agenda that should create the pre-conditions for achieving and integrating social, economic, environmental goals by 2020 and in the longer run (Gilli et al., 2013). The literature that addresses the dynamics of EI has developed on a theoretical ground along the classical research on the static and dynamic efficiency of regulatory instruments (economic vs. command and control, fiscal tools and emission trading), including the effects of innovation spurred by the regulatory stimulus (Hahn and Stavins, 1992; Goulder and Parry, 2008). More recently, an evolutionary economics setting has also been adopted (Mulder and Van den Bergh, 2001), focused on the co-evolution of innovation, policy and economic dynamics in socio-bio-economic systems (Kemp, 1997; Kemp, 2010).

The advancement towards a greener and more competitive economy is possible only if all components of social welfare are taken into account by firms, stakeholders, policy makers. Environmental innovations (Rennings, 2000, 1998) are a key factor, as it is well known that sustainable economic growth depends upon a constant investment in technological and organizational/labour related new ways of managing production. The EI potential must be enriched and embedded within a very broad set of related factors and economic, social environmental effects. One of the most recent definitions of eco-innovation defines it as the production, application or use of a product, service, production process or management system new to the firm adopting or developing it, and which implies a reduction in environmental impact and resource use (including energy) throughout its life-cycle (Kemp, 2010). This definition includes innovations whose environmental effects are not intentional. A relevant distinction can be made between end-of-pipe technologies and clean technologies integrated in the production process. EI in technological and organizational flavours is an important part of the transition to a more sustainable society but is not the only element that needs to change. The move towards and the progress forward the green economy requires a complete understanding and analysis of the nexus between institutional, technological, political, economic and societal factors to envisage a new paradigm. This learning by doing exercise that must involve all communities together: academia, research, and policy makers, business, and workers representatives, NGO, civil society.

Those are agents who possess stakes and may provide skills and knowledge to integrate sustainability with economic competitiveness, including the consideration of social-economic values that go beyond profits and GDP. This requires a sharp and deep knowledge ‘from inside’ of how EI develops and is adopted by social organizations and how it spreads throughout the economy. From inside means to consider how economic and social institutions perceive and react to the challenge of establishing a green economy. From inside perspectives (the firm behaviour, the role of workers inside the firm, the interactions between firms and policy makers, firms and unions, etc.) should then meet the exogenous forces that trigger EI at a macro level.

The drivers of EI are multifaceted and touch upon various spheres of society and policy making (Horbach et al., 2012). Well-designed policies can spur EI if firms believe that innovation offsets are greater than regulatory costs (Costantini and Mazzanti, 2012). The Porter way of thinking on EI (Porter, 2010) requires a full redefinition of the innovation diamond and strategy of the firm, taking into account the important role of complementarities and trade-offs among innovation practices (Antonioli et al., 2013). This sort of strategic thinking is even more relevant when dealing with relatively more radical innovations such as CO2 abatement, that requires an integrated rethinking of technological and energy processes, compared to the application of end of pipe technologies to abate pollutants. This is part of the motivation behind the absence of absolute decoupling for CO2 in most OECD countries. Similar relevance of complementarity attains to the design and introduction of policies that should be coherently integrated within the environmental-energy realm and considering this against innovation and industrial policies.

A substantial amount of literature has treated, both from an empirical and a theoretical point of view, the impact of environmental policies and the relative merits of several instruments and instrument mixes. An idea of the extent of the related contributions can be derived by looking at some influential papers on the impact of environmental policy instruments on invention, innovation and adoption of environment friendly technologies (Johnstone et al., 2010; Jaffe et al., 2003; Requate, 2005; Vollebergh, 2007), or on the substantial literature on the design of environmental policy (see the seminal book by Baumol and Oates, 1988). Several aspects of the impact of environmental policy instruments are, however, yet to be investigated. The impact of policy choices on innovative activities, efficiency and distribution is indeed the consequence of a complex mixture of the features of environmental policy design, such as credibility and complementarity with other policies, as for instance public support to innovation activities (see for example Costantini and Crespi, 2012; Costantini and Mazzanti, 2012).

Firms might well introduce EI even without policies in place if they recognise – along corporate social responsibility strategies - the long run productivity gain that can derive from being early movers in some technological domains. In addition to that, the inclusion of a firm in dense agglomerated areas (e.g. districts, that are on average a small component of the EU industry, but very relevant in some countries where SME prevail. Anyhow, SME performances are at the core of European competitive advantages and overall performances) might give concrete visibility to intra sector and between sectors knowledge spillovers (Cainelli et al. 2012; Costantini et al., 2013). Some innovation and environmental market failures might be mitigated in those contexts where geographical and technological proximities enhance the adoption of EI. This surely may occur in integration with external factors – FDI, foreign ownership – and policies.

The civic 'society' is definitely a source of 'inspiration' for the adoption of EI. NGOs, Unions among other agents might contribute to support and stimulate adoptions to reconcile environmental and economic payoffs in the territory and within the firm. The firm itself emerges as an open entity. If its boundaries are formally those defined by contractual agreements with other economic agents, its environmental and economic effects spill over. The firm is embedded in the territory and could maximize a value that goes beyond mere profits: worker's conditions, environmental effects are among the pillars of the new objective function of the firm. In this context, the issue of industrial relations has been overlooked in addressing the way EI might be supported.

In fact, we remark here that the definition of EI is not only about specific technologies; it includes also new organizational methods, products, services and knowledge oriented innovations. Organisational methods are also closely linked to education and training, and then human capital formation within firms. It is worth spending some words on the definition of organisational changes, at least as we intend them here. The literature often adopts the term High Performance Workplace Practices (HPWP), to define a set of organisational changes which can be thought as drivers of superior innovative or economic performances for the firm, or beyond that we can state. Coupled with this set of practices that are related to changes in production organisation and labour organisation, Human Resource Management (HRM) practices are also relevant, which are associated with the training activities sphere. The human capital embodied in employees becomes a fundamental resource which is able to sustain and to direct absorptive capacity. It becomes clear the importance of training activities that help generating and accumulating skills and competencies: this is overlooked with reference to EI adoption and development. Indeed, when a firm passes through organisational changes, such as the introduction of HPWP, then the employees could be asked to learn how to manage and how to behave in a new organisational environment. Reconfiguring the organisational system in a way that increases the workforce involvement and skill base, through the implementation of complementary HPWP/HRM practices, may be functional to the creation of an environment that smoothly absorbs and exploits also radical innovations. In this work we focus on the (policy) drivers of EI. It is not easy to fully integrate the environment and the economy at least in the medium short run. Nevertheless, a long run view that revolves around the issues of well-designed policies and redesign of innovation strategy may achieve that aim.

2.2 Innovation by sectors

Sectoral differences have achieved a considerable consideration since the Pavitt (1984) taxonomy was introduced into the economics of innovation: science-based, specialized suppliers, supplier dominated and scale intensive firms. The categorization was based on sources and patterns of technological change.

From a conceptual point of view, we mainly refer to the integrated concepts of sectoral and national systems of innovation which have consolidated in the innovation oriented evolutionary theory (Malerba, 2004) and have been exploited in the environmental economics literature looking at EI and policy (Crespi, 2013; Costantini and Mazzanti, 2012). Malerba promotes a sectoral system view of innovation: he stresses that sectors differ greatly with respect to their knowledge basis, technologies, production processes, policy and institutional environments, complementarity between innovations, market demand. Regarding policies, both on the strict innovation/industrial side and on the environmental side, these arguments matter since a 'one size fits all' approach may be not effective to support innovation diffusion and consequently economic and environmental performances. This is a hot debate in the EU: 'mainstream economics' have probably influenced the implementation of policies that were constructed on this one size fits all paradigm. The alternative is to shape policies according to sector and also regional features along more bottom up and diversified approaches.

Along such conceptual lines, Peneder (2010) analyses the differences between firm level studies and sector analyses: firm's heterogeneity is crucial, but also differences between sectors and regularities are important. Sectors represent a crucial and idiosyncratic 'place' where innovation is developed and diffused: "Industry characteristics matter and cannot be ignored [] to design policy programs and tailor them more effectively to the needs of targeted firms" (Peneder, 2010). We may also refer to the consolidated paradigm of technological regimes early developed by Malerba and Orsenigo (1997). They observe that technological regimes may be a fruitful concept for studying how innovative activities are organised differently and industries evolve over time. More relevant for us, their main finding is that innovative activities are sector specific, insofar as the features of technological environments are common to groups of industries. They therefore find differences across sectors in the patterns of innovation and dynamic economic performance and similarities across countries. This is a key conceptual justification for studying sectors at various degrees of aggregation in a realm in which innovation plays a major role in linking economic and environmental performance (Ambec and Lanoie, 2008; Jaffe and Palmer, 1997; Porter and van der Linde, 1995). According to Breschi *et al*. (2000), this reasoning is not aimed at excluding the relevance of national systems of innovation but affirms that an analysis based on sectors maximises the possibility of investigating the behaviour of agents in a dynamic innovative world (Costantini and Mazzanti, 2012; 2013).

As example of a general and descriptive EU sector perspective on innovation , Table 1 exhibits the ranking of the five main countries (Germany, France, Italy, Sweden, Netherlands, the selection of which depends upon relevancy, heterogeneity, data availability) by percentage of adoption of environmental innovation. To provide various insights, we sketch some general economic categories and more specific ones such as some key services, utility sectors that are important insofar they manage natural resources, and heavy industrial sectors that for that reason are under the EU ETS policy aimed at cutting CO_2 (potentially inducing innovation).

If we look at the three main eco-innovation indicators we mentioned, it is clear that leaders are Germany and France. Italy achieves the worst performance in most sectors, except some ETS sector (manufacture of metal products, manufacture of paper, air transport) and a few services sector (financial services, services for the business economy).

Table 1. Adoption of environmental innovation over 2006-2008. Ranking of five countries.

		leader CO_2 Innov	leader emission innov	leader waste reduc inn
General	Manufacturing	Germany	Germany	Germany
General	All Core NACE activities related to innovation activities	Germany	Germany	Germany
General	Industry (except construction)	Germany	Germany	Germany
Services	Financial and insurance activities	Netherlands	France	France
Services	Financial service activities, except insurance and pension funding	France	France	France
Services	Services of the business economy	Sweden	France	France
Services	Innovation core services activities	Germany	Germany	France
Services	Insurance, reinsurance and pension funding, except compulsory social security	Sweden	Netherlands	France
ETS	Manufacture of basic metals	Germany	Germany	Germany
ETS	Manufacture of basic metals and fabricated metal products, except machinery and equipment	Germany	Germany	Germany
ETS	Manufacture of chemicals and chemical products	Germany	Germany	Germany
ETS	Manufacture of coke and refined petroleum products	Germany	Germany	Germany
ETS	Manufacture of fabricated metal products, except machinery and equipment	Germany	Germany	Germany
ETS	Manufacture of other non-metallic mineral products	Germany	Germany	France
ETS	Manufacture of paper and paper products	Germany	Germany	Germany
ETS	Air transport	Germany	Germany	France
Utility	Sewerage	France	Germany	Germany
Utility	Sewerage, waste management, remediation activities	Sweden	Germany	France
Utility	Waste collection, treatment and disposal activities; materials recovery	Germany	Germany	France
Utility	Water collection, treatment and supply	Germany	France	France
Utility	Water supply; sewerage, waste management and remediation activities	Sweden	Germany	France

Source: CIS Data extracted from Eurostat on line database (May 2013).

Table 1 shows the expected dominance of Germany in EI adoption, which reflects the German leadership on invention (Glachant et al., 2011). Germany leadership is driven by the superiority of its industrial core sectors.

The evidence for services is more mixed. Germany does not lead. France is on average the country which presents the best performance, with Sweden and Netherlands also appearing leaders in some cases. In services that are more integrated with industry Germany nevertheless appear to lead in some cases, thus showing the relevance of vertical integration. Though Italy presents a consistent gap concerning CO_2 innovation, its role is not negligible in waste technological adoption, which indirectly relates to CO2 abatement. The role of packaging waste systems that have been effectively implemented by firms through covenants and schemes that fund recycling and recovery might be investigated in the future.

A final look at 'utility' related sectors shows that while the Germany strength is plausibly confirmed in (highly regulated) areas such as waste management and collection, France plays a major force as well. The gap between France and Italy in this field, where big utilities and public-private company are important players in the production of mixed public services, is worth being further investigated. The role of the (typology of) 'decentralization' of public services (higher in Italy in general terms) and related policies is a possible key issue. Its relationships with environmental innovations have been an overlooked fact.

2.3 Inducing EI through policies: the state of the art

The link between environmental regulation and competitiveness has been the focus of economic debate for decades. Until twenty years ago, the economic discipline was dominated by the idea that being the firms profit maximising, any attempt conducted by environmental regulation in abating pollution, would necessarily traduce in an increase of internal costs for the compliant firm. In this framework of analysis in fact, if there were profitable opportunities of reducing pollution, an optimizing firm would certainly already have adopted it. Moreover, many theoretical studies during the 1970s give support to the idea that a country comparative advantage could have been affected in a negative manner by a stringent environmental regulation. For instance, the works of Pethig (1975), Siebert (1977) and McGuire (1982), stress that environmental policies increasing firms' internal costs affect countries competitiveness, decreasing exports, increasing imports, and lowering the general country's capacity to compete in an international market. Moreover, in the long-run, if the production factors are free to move across countries, a more stringent environmental regulation can produce movements of the manufacturing capacity from more regulated countries to less regulated ones (which are often called "Pollution Havens" in modern environmental and trade studies). In this view, command and control regulation for example, restricting the choice of technologies or inputs in the production process, would increase the constraints a firm has to face, while taxes and tradable permits, charging productions by-products (wastes or emissions) generate costs that did not exist before the regulation. Nevertheless, in the last two decades, many scholars challenged this main idea. In particular Porter and Van der Linde in different contributions (1991, 1995), strongly criticised this approach, underlining that the consolidated paradigm was not considering all the aspects of the environmental regulation/competitiveness relationship. Moving from the static approach in which technology was held constant to a dynamic context, the authors showed how in practice some of the loss of competitiveness related to the environmental regulation was compensated by an increase in innovation driven by the policy itself. In the view of Porter and Van der Linde in fact, a properly designed policy framework may pose a pressure on firms, pushing them to develop new innovations and promoting technological change. In this view, this additional policy driven innovation may offset the loss of competitiveness due to the additional costs of regulation. In particular, Porter and Van der Linde show how regulation can act through 5 different channels (1995). First, regulation signals companies about likely resource inefficiencies and potential technological improvements; second, regulation focused on information gathering can achieve major benefits by raising corporate awareness; third, regulation reduces the uncertainty in environmental pollution activities, fourth, regulation, posing pressure on firm cost function motivates costs saving innovations, fifth regulation makes free riding behaviour in the transition phase through an innovation based equilibrium more difficult. Based on this seminal work Jaffe and Palmer (1997), discerned the three different implications of the Porter Hypothesis, proposing a taxonomy, that is helpful in discerning the different lines of research that have further developed. The first idea, also called Narrow Porter Hypothesis, shows that certain types of environmental regulations are able to stimulate innovation, following the idea that the policy design matters and command and control policies are generally (with exceptions) less efficient than economic instruments in promoting innovation and technical change. A second version of the Porter hypothesis, called weak, in a nutshell states that a well design environmental regulatory system, may stimulate certain kind of innovation. Finally, the stronger version of the Porter hypothesis says that not only regulation is able to spur innovation, but also that this gain in efficiency is able to completely offset the loss on competitiveness due to compliance costs. In other terms this last approach suggests that a more stringent and well-designed regulation promotes competitiveness.

The original idea of Porter has been strongly criticised, especially by Oates et al. (1995) which suggests that the entire Porter reasoning was based on wrong assumptions, and in particular not compatible with the concept of profit maximizing firms. Nevertheless, this is the exact point stressed by Porter himself. In his view firms operate in a dynamic and uncertain framework, where the agent behaves following

Simon’s idea of bounded rationality. In such a context, the rationality of firms is moved by the managers who might have different objectives with respect to the firm, or that do not have the competence to innovate at an adequate level. Following this line of reasoning, some theoretical works explained the Porter hypothesis as due to risk-adverse manager (Kennedy, 1994), or resistant to costly changes in their routines (Ambec and Barla, 2007), or rationally bounded (Gabel and Sinclair-Desgagé, 1998). Ambec and Barla (2002), on the other side, argue that whenever managers have private information on the outcome of R&D investments and the Government don’t, a problem of asymmetric information may rise, from which managers may derive a rent. On the contrary, if a Government enacts a stringent environmental regulation, it can deprive managers of their advantage, overcoming this problem. Obviously, the eventual presence of this inefficiency supports the presence of the Porter Hypothesis.

Besides the discussed theoretical contributions, the core debate around the Porter Hypothesis has been developed through many different empirical studies. Following the survey conducted by Ambec et. Al. (2010) these works can be divided in three different macro sections, representing respectively the three different connotation of the PH: weak, strong and narrow.

For what concerns the first group of works, referring conceptually (and often not explicitly) to the so called “weak” version, one of the first contributions is Jaffe and Palmer (1997), which tested for the presence of a Porter hypothesis using as a proxy for environmental regulation the pollution abatement expenditure, and as a proxy for innovation the total firm R&D expenditure and the total number of patent applications in a panel of U.S manufacturing industries in the period 1973-1991. Their findings support the idea that compliance expenditure has a positive and significant effect on innovation measured as R&D, while they did not find significant results in the patent related specifications. This last unexpected result may be due to the nature of the dependent variable: the authors used in fact the total patent counts, instead of using the environmental related ones. In another work along this line, Brunnermeier and Cohen (2003) used US manufacturing industry data and empirically analysed the determinants of environmental technological innovation, using as innovation proxy the number of environmental patent applications, and as proxies for regulation both pollution abatement expenditures and number of air and water pollution control inspections. They found a significant impact of the first variable, and a not significant impact of the second one. Among other covariates, they found that international competition stimulates environmental innovation. A larger effect is found by Carrion-Flores and Innes (2010) using US sectoral data, even though the effect on long run emission reduction which is induced by innovation is small. Another work on patent data at firm level is Popp (2003), which by analysing 186 plants in U.S. from 1972-97 found that the tradable permit scheme for the reduction of SO_2 has been able to promote technical change, increasing SO2 removal efficiency and decreasing operating and removal costs. Moving to cross country studies, De Vries and Withagen (2005) studied the effect of SO2 environmental regulation on national patent counts in relative technological classes, founding some evidence of a link between policy stringency and environmental innovation. More recently, a second example of cross country study is Johnstone et. al. (2010), who address the effect of many different policy instruments on the innovative performance of the main renewable technologies (Solar, Wind, Geothermal, Ocean, Biomass and Waste), for 15 OECD countries, over the period 1978-2003. They find a general strong evidence of a Porter hypothesis. In most of their specifications different policy instruments are positively and significantly related to technological change, and more interestingly they discerned the effect of different policy designs on different technologies. Subsidies and feed-in tariffs are for example more suitable to induce innovation on more costly technologies like solar power, while tradable certificates show a stronger effect on technologies that are close competitive to fossil fuel, like wind power. More recently, Kneller and Manderson (2012), analyzing the case of 25 UK manufacturing industries over the period 2000-2006, consider the role played by expenditure in pollution control in affecting innovation measured with environmental R&D. It is found that the effect is positive as environmental R&D may crowd out other types of R&D investments.

Johnstone et al. (2012) carry out an analysis using both an unbalanced panel of 77 countries over the years 2001 and 2007 using data from the European Patent Office (EPO) World Patent Statistical (PATSTAT) database and the World Economic Forum's (WEF) 'Executive Opinion Survey'. They use a cross-country dataset finding that higher environmental stringency positively affects environmental innovation. Finally, Nicolli and Mazzanti (2011) studied the effect of environmental policies on innovation in the specific waste streams of paper and plastic packaging waste, end-of-life vehicles, composting, and on aggregate waste for OECD countries from 1970 to 2007. They found two important results: first, in the case of specific waste streams regulation does seem to play an important role in the promotion and diffusion of innovation, second, they outlined how the waste sector seems to have reached a degree of technological maturity, and it is now experiencing a decreasing trend in patenting activities. These results seem to suggest that there have been two different policy eras in the case of waste in OECD countries, a first and older wave of policies (end of the 1980s beginning of the 1990s) that produced a technological shock in the system and a second and more recent wave of policy, which seems to have less impact on environmental innovation.

The second strand of literature refers to the "Strong" version of the Porter Hypothesis, i.e. it is devoted to test if there is a link between environmental regulation and competitiveness of the firms. A review of this literature can be found in Jaffe et al.

(1995), where most of the papers reported there found a negative impact of environmental regulation on productivity. Nevertheless, more recent works by Berman and Bui (2001) and by Alpay et al. (2002) found that respectively refineries in the Los Angeles area and Mexican food processing industries experience an increase in competitiveness associated with increased regulation stringency. Moreover, Lanoie et al. (2008), in a study on 17 Quebec manufacturing sectors have found a modest but significant effect of regulation on competitiveness once the dynamics of the process is taken into account. The original critique moved by Porter and Van der Linde, was in fact motivated by the lack of dynamics that affected these studies at that time. Hamamoto (2006) finds that environmental regulations have had a positive effect on productivity in Japanese manufacturing sectors, through positive effects on R&D. Lanoie et al. (2008) show that this lack of dynamic is still present in empirical studies, especially when competitiveness at time 0 is regressed against environmental regulation at the same point in time. This may have produced biased results, because the effect predicted by Porter, if present, might have taken time to develop. For this reason in their study they introduce a lag of three or four years between regulation and productivity, showing that regulation reduces productivity after one year, but this effect is reversed already after two years, and becomes always more evident increasing the lag. Costantini and Mazzanti (2012), test the effect of environmental regulation on export competitiveness of the manufacturing sector, using a gravity model for the EU15 group over the period 1996-2007. They find that generally policies do not seem harmful for export competitiveness, and specifically, some energy tax policies influence positively trade patterns. Finally, the effect of environmental regulations has not been examined only with respect to productivity but also considering whether they affect investment decisions. Gray and Shadbegian (1998) and Gray and Shadbegian (2003) find that U.S. paper mills investment decisions in cleaner production have been caused by more stringent air and water regulations. However, they also detect a negative effect due to the process of diverting those investments from production activ-ities, causing an overall reduction in productivity.

Finally, a third approach is based on the narrow version of the Porter hypothesis, i.e. flexible regulatory policies are more likely to promote innovation than more prescriptive forms of regulation. This approach follows Porter's idea that the design of the policy actually matters, and discerns the effect of Command and control regulation (CAC) and economic instruments. In particular Porter and Van der Linde (1995) argue that CAC in particular has to respect three principles, in order to be able to spur innovation:

1) They must leave the approach to innovation to firms and not to the regulating agency

2) The stringency of CAC instruments must improve continuously, and avoid to lock-in any particular technology
3) The regulatory process must be certain and time consistent. Potential uncertainty of the policy lever would increase the risk that investors face in the market, slowing down innovation.

On the other side market based and flexible instruments, such as emission taxes and tradable certificates, are more favourable, since they leave firm more free to find the best technological solution to minimize compliance costs. A summary of this strand of literature would be beyond the scope of this work, and a good review can by the way be found in Driessen (2005), who concludes that environmental taxes provide a stronger incentive for innovation than other policy types.

2.4 Environmental Innovations adoption: the role of the EU ETS

The EU-ETS and its ability to promote innovation have been analyzed extensively at the theoretical level (among others, Requate, 2005; Carraro *et al.*, 2010; Convery, 2009; Ellerman *et al.*, 2010; Clò, 2008; Borghesi, 2011; Zetterberg *et al.*, 2012). However, there are not extensive empirical investigations of the innovation effects of the EU-ETS, including its pilot phase in 2005-2007. Kemp (2010) and Kemp and Pontoglio (2011) comment on the innovation effects of ETS in an related study, pointing to the lack of large scale empirical analyses.

Several authors use case studies; although the existing studies provide some interesting insights, they are based mainly on sector specific evidence. Pontoglio (2010) highlights innovations deficiencies in the Italian paper and cardboard sector; Tomas *et al.* (2010) analyze the Portuguese chemical sector, and Rogge *et al.* (2011) study the energy sectors in Germany. Overall, they show that the impact on innovation of the EU-ETS has been limited so far because of the scheme's initial lack of stringency and predictability and the relatively greater importance of contextual factors. Additionally, the impact varies significantly across technologies, firms, and innovation dimensions and is most pronounced for Research and Development (R&D) on carbon capture technologies and organizational changes. For example, in a study involving 42 interviews with German power sector companies, Rogge and Hoffmann (2010) find that the EU-ETS mainly affects the rate and direction of technological change in power generation technologies, in large-sized coal-based power generating companies where carbon capture technologies are added as a new technological trajectory. In another important survey of the innovation effects of ETS in the EU power sector, Schmidt *et al.* (2010, p.1) conclude that `the EU-ETS has limited effect on the innovation activities (adoption and R&D) of both users and producers of power generation technologies. However, the perception of long-term GHG reduction targets has a significant influence on all innovation dimensions'.

Other analyses provide evidence of the integration of EI with other strategies. Muuls and Martin’s (2011) study is based on interviews with firm managers in six European countries. The authors find that sector differences outweigh cross-country differences. Moreover, using dummy variables to capture whether the firm is part or not of the ETS mechanisms, the authors find mixed evidence on the process and product innovations related to the ETS. On the one hand, there seem to be few differences between ETS and non-ETS firms in terms of `process and product' innovations; on the other hand, the expected stringency of the cap has a significant EI effect. Uncertainty about future scenarios and price volatility might be hampering EI (Gronwald and Ketterer (2011).

A rare extended EU level study is by Dechezlepretre and Calel (2012) who use EI patents finds mixed evidence to support the induced technological change hypothesis. There are some signs of greater EI innovation for ETS firms, but more refined estimates that combine matching methods with difference-in-differences show that the EU-ETS has not affected the direction of technological change. Part of the reasoning revolves around the fact that in the first phase the allocation procedure made national states responsible for quota allocations (Clò, 2008; Woerdman *et al.* 2008). This resulted in different levels of stringency depending on the quotas allocated and the historical emissions levels in each sector and country. The effects are thus expected as being highly idiosyncratic, in coherence with the theoretical framework based on national and sector systems of innovation.

The survey of the relevant literature has provided a rationale for the original investigation of policy induced innovation effects at sector level, where both qualitative and quantitative evidence is relatively scarcer, though being the only way to reconstruct a EU wide perspective in empirical terms.

3 The policy impact on environmental innovations: the survey and data

The analysis we present in this work aims at filling some gaps in the empirical literature on eco innovations. The main research hypothesis we test in section 4 is whether EI that were adopted over 1998-2012 — had some policy support behind. In doing so, we take a full sectoral perspective. Though some quantitative exercises partially look at sectoral specificity in the recognition that sectors possess idiosyncratic technological features and specific policy responses (Cainelli and Mazzanti, 2013; Marin and

Mazzanti, 2013), it is only through more qualitative investigations that we can touch the concrete innovations that were introduced. One gap we want to fill is thus to offer a sector based view of the policy induced hypothesis, entering the realm of what technological and organisational innovations took place because of the policy effort (see Questionnaire in the annex).

Specificity is thus sought with respect to (i) innovations adopted, (ii) policies that supported innovations. In addition, in cases where policies were not the main force behind adoption, we comment on the other factors that were eventually behind innovations (market factors) and main hampering factors. Sector by sector features thus emerge through this exercise that complements existing econometric based evidence[4]. We also add one specific section to address the role of unions and industrial relations in the process of supporting the adoption of EI in firms as key strategy to reconcile environmental, social and economic goals.

Interviews were administered to specific industry representatives over June-July 2013 by a specialised Italian company (SWG Trieste). We initially selected 48 'cases', namely potential interviewees, defined by 6 sectors (Ceramics and cement, steel, paper and cardboard, transport, energy, coke & refinery) and 8 countries (CZ, PL, IT, DE; UK, ES, FR, NL). In total, 124 industry association representatives were provided. We knew that not all cases where fully relevant, as example, the ceramics sector is relevant in 3 countries in the EU (DE; IT, ES). 29 associations were successfully contacted. Response rates are thus 52% if compared to the 48 cases and 24% if the overall list of 124 representatives is taken as benchmark.

In addition to the initial set of interviewees, depending upon availability, new representatives were contacted. Researchers themselves administered some questionnaires following personal contacts and contacts provide by the industry associations. The analysis is thus finally built upon around 45 telephone or direct (vis à vis) interviews, including those pertaining to unions (§2.7). We again stress that this analysis is not aimed at providing a full representative analysis. The aim is to draw out 'sector case studies' with a EU coverage (instead of focusing deeply on only one sector). It is obvious that as in all surveys, the ex post results is affected by the rate of response. Usual rates for surveys range between 5 and 20%. The issue of subjective bias is common to most applied analysis based on surveys, for discussions we refer to Collantes (2007). We here apply an approach, based on semi structured interviews, as in Mazzanti and Zoboli (2006), who analysed the effect of waste policies on techno organisational trajectories, and Anadon et al. (2013) who rely on expert's opinions to analyse technology idiosyncratic sector features

[4] The annex shows figures related to economic and environmental performances by sector in the EU.

As it was already said, section 6 then complements the 'case study' based evidence by econometrically analysing the most recent EU sources on innovation adoption, namely the CIS, integrated with other economic and environmental data to assess the role of policy and knowledge related drivers of EI. The data used for econometrics are described in section 6[5].

4 Empirical evidence: sector case studies[6]

We here summarise the main evidence we derive from the series of qualitative interviews administered to various experts at sector level, mainly *industry representatives*. We recall that the rationale behind interviewing industry associations is to take a sector perspective and capture evidence that represent the industry (not specific firms[7]).

We stress again that qualitative interviews originally provide evidence on techno-organisational innovation adoption that complements more quantitative analysis which by definition and data constraints is not able to deliver sector-based evidence. Though results are not fully general in kind, the views of industry and not firm's representatives enlarge the innovation perspective scope[8].

In each of the case study, we provide information on the interviewees when it is possible. At the end of each section, a general overview of the sector innovation-economic-environmental performances is presented.

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[5] The quantitative analysis was included as a suggestion we received in the Brussels September workshop. Though it does not deliver - given data constraints - sector by sector evidence (longer time series would be needed, as in Marin and Mazzanti, 2013, to implement econometric techniques – such as seemingly unrelated regressions - which deliver sector specific evidence on innovation drivers), it is the only way to quantitatively provide EU wide evidence on innovation drivers. Firm based analyses cannot aim at such goal.

[6] Though we try to maintain homogeneity in the narrative development and structure of sections in §4, sector representatives responses and involvement (usually) differ by sector and country. The ex post survey analysis thus greatly depends upon commitment to being interviewed and involved in the research.

[7] Alternative research paths might be 'corporate case studies' or large surveys on firms. Studies based on samples of interviews appear in the innovation and management disciplines (among others we refer to Dubois and Gadde, 2002; Colyvas et al., 2002; Vohora et al., 2004). A recent paper in the energy field is by Anadon et al. (2013) based on 67 interviews. They aim at launching research questions and presenting the qualitative perspective on techno-organisational dynamics, which is not captured by quantitative large scale studies. There are cases where even small samples are used to carry out quantitative analysis, as in the seminal paper by Ichniowski et al. (1997) on steel finishing lines.

[8] In some cases where industry representatives were not available, large corporate firms were interviewed. In those cases, the firm and also sector innovation perspective are under scrutiny.

4.1 Energy

Environmental and Energy policies as innovation drivers

Interviews overall highlight the great importance of environmental and energy policies in shaping the rate and direction of innovation activities. This result appears to be in line with recent literature which showed that the policy inducement effect on technological change is relevant in this sector (Costantini and Crespi, 2007; Johnstone et al., 2010). Energy is the most studied sector in the empirical literature, for its economy size and environmental impact. Compared to other sectors, references to the scientific evidence is frequently possible.

Regarding the support of polices, it is possible to distinguish between two main sets of policies: 1) legislation aiming at reducing the CO2 emissions; 2) legislation aiming at promoting renewable energy.

According to the opinions expressed by the interviewed experts, within the first set, the major policy instrument is represented by the Emission Trading Scheme (ETS), which actually represents a key pillar in the EU policy framework (Borghesi, 2011). The discussion with experts also highlighted that the legislation aiming at reducing the CO_2 emissions has not much contributed to technological innovation per se in large combustion plants, but mainly promoted a fuel switch option. On the other hand, policies aiming at reducing CO2 emissions has spurred the generation and diffusion of *process innovations* related to carbon capture and storage.

With respect to the legislation, aiming at promoting the production and consumption of renewable energy, the experts stressed that it has led to significant technological innovations in the field of renewable energy. In this context, the policies producing most relevant impacts in terms of technological innovation emerged to be feed-in tariffs and tradable green certificates. Regulation and financial support for sustaining renewable energy led to significant *product innovations*, concerning in particular technologies for the production of photovoltaic and wind energies. Moreover, the policy framework has induced relevant innovation efforts in the field of technologies for the production of energy using biomasses[9]. However, in this field, new generation technologies are still not fully developed and further research is needed in this sector

[9] Policy makers of Emilia Romagna region (Environment directorate) interestingly noted that 'environmental trade offs' between GHG and local pollutants policies/aims are emerging. Biomasses are needed to comply with EU renewable targets. Nevertheless, if compared to other renewable, their PM potential is higher: GHG vs PM trade off emerges instead of complementarity (e.g. ancillary benefits).

in order to achieve large scale production of energy from biofuels obtained from new generation technologies (Costantini et al., 2013a,b).

An additional element is that despite the importance of technological innovations induced in the field of renewable energy, these are mainly *incremental innovations* to make renewables energy production more efficient.

Another important policy area leading to substantial innovative activities concerns regulations for energy saving in the residential sector (Noailly and Batrakova, 2010). In particular the experts highlighted that Ecolabelling schemes and incentives for energy efficiency in buildings favoured the generation and diffusion of innovations in new materials, fluorescent lighting, condensing boilers and cold generation.

Finally, it should be stressed that many innovations introduced in the energy sector have been patented with increasing trends in energy patenting activities in recent years (OECD, 2013).

The role of policies in non-technological innovation

According to the information we collected, public policies emerged as an important factor also for the development of *organizational innovations*. This is an important result as it confirms the importance of complementarity between technological and organizational innovation (Antonioli et al., 2013; Wagner, 2007; Ziegler and Nogareda, 2009). Renewable energy policies spurred organizational innovations in many companies. The same is true for ETS which led to substantial organizational changes for implementing and managing monitoring emissions activities. With regard to this latter aspect, the importance of firms' functions devoted to environmental monitoring has substantially increased, with the creation of dedicated units for managing environmental monitoring and coordinating all relationships with environmental authorities for the implementation of ETS and environmental standards. This is to some extent an unintended and possibly relatively overlooked impact of policies along the efficiency rationale. The whole set of organizational change measures matter, not only EMS and ISO.

Interviewed experts have highlighted that the major organizational innovation at the system level has been the market liberalization of the energy sector. The joint effect of this market reform with the implementation of renewable energy policies favoured the introduction of major organizational innovations also at the firm level.

The liberalized market gave the possibility to nontraditional parties to produce electricity themselves. Incentives have been created in order to compensate the excess cost of renewable energy compared to fossil based energy. Policy instruments, such as feed-in tariffs or green certificates have been created to this scope. Similarly, tradable guarantees of origin have been created as well in order to differentiate renewable power from fossil based power. In some countries, similar guarantees of origin have been created to differentiate bio-methane from natural gas. Tradable green certificates and guarantees of origin, clearly represent innovative concepts in the energy sector[10].

This policy framework promoted renewable energy production at consumer level, in particular photovoltaic at household level, but also spurred the development of renewable energy projects both in traditional and non-traditional energy companies. This phenomenon led to substantial organizational innovations within firms due to the creation of new and differentiated energy production plants and increasing needs of coordination activities between them. New professional competences and dedicated personnel have been increasingly used by firms for energy trading activities and for the management of energy production from different sources.

Policy Interactions

The contemporaneous presence of many different policy instruments is perceived by the interviewed experts as a critical point for the design of the policy framework and the effective achievement of environmental goals. This view is in line with the fast growing literature on this specific issue (Abrell and Weigt, 2008; Böhringer et al., 2008; Del Rio Gonzalez, 2007; Braathen, 2011). In particular the co-existence of different policy tools may represent an obstacle for innovation and for the achievement of environmental goals, even though the importance of preserving diversity in the portfolio of policy tools has been also highlighted in the interviews.

At the general level, policies that target renewables are perceived as not helping the achievement of objectives in terms of increasing energy efficiency. More specifically, a quite common view among the interviewed experts is that instruments other than ETS negatively interact with ETS as they are not aligned to it[11]. According to this view, the use of policy tools different from ETS has increased the cost of climate change policies and left a very low carbon price (Borghesi, 2011). In particular, policies for renewable energies substantially contributed to the declining trend of emission permits prices

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[10] At a more general level, it is worth noting that 'market rules' and environmental policy may conflict. As example, policy makers of Emilia Romagna region (Environment directorate) stressed the trade off between the need of obeying to strict free market rules (e.g. buying inputs such as secondary materials by auctions in markets) and 'industrial policy', namely the possibility to support the creation of clusters of firms in a defined region aimed at specific environmental and employment goals. Policy makers are prevented to set a framework where some firms / sectors contract the provision of secondary materials from local players, a key input in the overall process. To some extent, this is also again the trade off between policy certainty (price certainty, provision certainty) and free market instruments functioning.

[11] This is coherent with the discussion in WP1 (Italy report).

and to reduce incentives for investments aimed at decreasing emissions for unit of produced energy from traditional plants.

Even though different policy tools are seen as negatively interfering, the interviews stressed the idea that the implementation of an articulated array of policy incentives and regulations has the potential to favour the development of different technologies, which may lead to the emergence of relevant technological complementarities. A policy mix may help to correct for multiple reinforcing failures of private governance structures, such as pollution externalities and technological spillovers (Lehman, 2010). In this respect, it seems that the problem in the current policy framework is not represented by the presence of diversified tools but mainly by the lack of a proper policy coordination between different instruments[12] which does not allow to valorize potential positive interactions between them and, conversely, increases the cost of reaching the fixed policy objectives (OECD, 2007)[13].

Main insights

The interviewed experts share the opinion on the important role of environmental and energy policies in shaping the rate and direction of innovative activities in the energy sector. Interestingly, this effect emerged to be important for both technological (product and process) and non-technological (organizational) innovations. With respect to the former, innovative efforts in the energy sector mainly led to incremental innovations rather than radical ones, with increasing trends in patenting activity in this sector.

Referring to tables A.1-A.2, we note that the most significant period for the sector is between 2002-2008, when CO2 stopped increasing as in the past and 'economic efficiency' (CO2 on value added) started a substantial decrease. The qualitative analysis highlight a significant role for environmental and energy policies, which is also

[12] Policy makers of Emilia Romagna region (Environment directorate) nevertheless posed the question mark on whether we should aim at reaching full coherence. A pragmatic alternative form their experience is to set sector policy guidelines within a multi sector platform.

[13] Interviews with Policy makers in the Environment area (Emilia Romagna Region, Italy) highlighted that having diversified and experienced many tools generated inconsistency but also knowledge. The key point now is to use and select tools (case by case; namely sector by sector, area by area) on the basis of the aims one defines (that depend upon their properties). As example, environmental and economic/employment aims may be synergic, but even in that case they can be achieved with different weights. Our knowledge should now drive the selection (out of the potential pool of existent and latent instruments) of tools depending upon specific aims. In addition, both policy makers and firms reciprocally recognise the value of 'policy certainty' even more than that of reducing 'negative interactions'. It is true that the two issues might be also correlated. A massive uncertainty depends upon the insufficient coordination between EU, national, and regional levels, along static and dynamic perspectives.

found by works in the relevant literature. Nevertheless, it is always difficult to disentangle energy policies and market factors, such as oil price trends. We observe that over 2002-2008, the time span of EU ETS and other EU policies, oil prices increased. We refer to Johnstone et al. (2010) for further discussions around this issue.

Though the sector as the EU economy does not present structural breaks over the past 2 decades (EEA, 2013), the performance has smoothly improved in efficiency terms. This is coherent with the emphasis on the incremental nature of most innovations. Those are surely insufficient to reach the 2030-2050 targets

While the negative interfering effects of implementing different policy tools have been highlighted, the interviews have also pointed out the potential of adopting a differentiated portfolio of policy tools if proper policy coordination is implemented.

Finally, the analysis suggests that the joint effect of market liberalization in the energy sector and of the implementation of renewable policies produced strong organizational innovations both at the system and company levels. In this respect, a crucial element to sustain this process appears to be represented by research activities for the development of smart grids. The generation of innovations in electrical infrastructures, the implementation of new grid management processes and the development and diffusion of new technologies for stocking energy from renewable emerged as crucial element for the research agenda in the energy sector.

Auditions in the energy sector

Name	Country	Role	Organization
Erwin Cornelis	BE	Expert Energy Policy	VITO NV
Maria Rosa Virdis	ITA	Expert Energy Sector	ENEA
Giulio Cicoletti	ITA	Head of sustainable development direction	ASSOELETTRICA

Auditions by SWG[14]

5	IT_001	Italy
6	UK_001	United Kingdom
10	UK_005	United Kingdom
22	DE_001	Germany
23	DE_001	Germany

Table 2 - Main figures on economic, innovation and environmental performances[15]

Energy										
CO_2/VA			EI (CO_2 abatement)			Labour productivity (VA/unit of labour)				
Average EU	Top Countries		Average EU	Top Countries		Average EU	Top Countries			
11.95	France	1.080	41%	Latvia	71%	775.77	Hungary	9353.20		
	Sweden	1.142		Belgium	65%		Czech Rep.	2438.16		
	Austria	1.256		Austria	59%		Sweden	2226.34		

Source: CIS EUROSTAT data and WIOD dataset (September 2013 elaborations). VA is sector value added[16].

[14] Excel files and audio files of interviews are delivered by SWG as output. SWG does not provide names, only codes, by contractual issues.

[15] Tables at the end of sector assessments present the EU 27 figures. Appendix B also delivers EU15 figures.

[16] Value added is in national € millions. Labour is accounted in thousands of labor units. For emissions we refer to WIOD description, as it follows. Energy accounts are compiled using extended energy balances from the International Energy Agency (IEA) as a starting point. Additional information was used to bridge between territory and residence principles (adjusting for bunkering and international transport, tourism, defence, embassies) and to allocate IEA accounts to the target classification and accounting concepts consistent with WIOT (e.g. distribution of transport activities and auto-produced electricity among industries). The very first step in deriving energy accounts from international energy balances, as provided by IEA, is to establish a correspondence-key linking energy balance items and NACE entries plus households. Some of the energy balance items can be directly linked to the production of certain NACE entities, but in some cases the energy balance item is related to more than one industry. For instance, the energy balance item "road transport" needs to be distributed over all industries plus households. Likewise, the energy balance item "commerce and public services" needs to be distributed over a number of services. Losses are also a relevant part of the energy accounts and an important element in the assessment of energy efficiency. All losses are recorded and allocated to the supplying industry. **Air emissions are estimated from energy accounts.** The general approach implies the use of activity data and emission factors, following the general formula: E = AR× EF. The emission (E) is obtained by multiplying a certain triggering activity (AR: activity rate), e.g. production of the metal industry as measured by output value, by a certain emission factor (EF). Such factors embed the concept of a linear relationship between the activity data and the actual emissions. Several technical guidance documents provide such emission factors, in particular those prepared for the compilation of national emission inventories under international conventions such as United Nations Framework

4.2 Chemical

The industry associations we interviewed, that represent different EU areas (ES, UK, CZ), overall state that the policy packages[17] were relevant to support innovations to abate CO_2. Specific and idiosyncratic elements nevertheless emerge.

The UK representative specifically stated that policy effects had been somewhat negligible presumably referring to specific climate change policies, given that the chemical sector entered the EU ETS system in a second phase. A large part of EI innovation in some sectors developed well before the EU climate change policies took place. The statement on the other hand also rules out the role of climate change expected policies as an activator o early mover type of behaviour. Outside specific environmental policies[18], fuel taxation is recognised as a key driver for fuel efficiency. Again, this opens the debate over the efficiency and effectiveness of mere energy taxation, not strictly targeting GHG contents[19].

The sector seems to have adopted EI (e.g. fuel efficiency) mainly due to increasing costs and, interestingly, to react to the economic crisis. In this case one can infer that energy cost efficiency was sought as a strategy to cope with cost competitiveness within the economic downturn.

It is interesting to note that the Spanish representative suggests that EI adoptions were practically abandoned during the recent crisis[20]. This may re-proposes a north-south divide in the way the environment and the green economy challenge is tackled through eco-investments.

It is that the Czech representative is the one that flags the role of energy and environmental policies most, namely the Energy efficiency directive, The Renewable Energy directive and the EU ETS as well. He/she claims that emissions decreases over 2000-2012 was largely obtained with the support of policies.

Convention on Climate Change (UNFCCC) and the Convention on Long-Range Transboundary Air Pollution (CLRTAP). Additionally, two very important secondary sources of information for emission factors are used: the results of the FP6 project EXIOPOL (http://www.feem-project.net/exiopol/) and the Emission Database for Global Atmospheric Research (EDGAR) information system (http://www.pbl.nl/en/themasites/edgar/ index.html). Activity data will concern the use of energy, broken down into energy commodities and sectors as reported in IEA statistics.

[17] We recall that we mainly referred to the country policy packages outlined in the WP1 of CECILIA project. Interviewees may well reason beyond that packages in any case.

[18] Another key issue that is discussed within WP1.

[19] Throughout the interviews, the vision by which energy taxation could be a better option, even if does not specifically target GHG, because it is implemented ‘upstream’, has emerged. This perspective is supported by scientists in the ecological economics / material flow analysis arena.

[20] See section 5 on this issue.

Overall, the main techno-organisational innovations on which the sector centred its action were energy efficiency measures in petrochemical sector, and ISO / corporate social responsibility strategies regarding organizational change. ISO14001 is a key element for the Spanish chemical sector; they note the importance of hitting the most polluting part of the process by implementing life cycle assessments[21]. All in all, techno-organisational actions appear to be somewhat policy driven in the Czech Republic. It might be noted the apparent major role of EU policies for sectors belonging to new member states.

For the Spanish case, instead the actions appear to follow from voluntary /CSR strategies, in absence of a structured national policy to abate CO2. The Spanish chemical sector tend to privilege subsidies instead of taxation, given financial constraints most small and medium firms face in front of CO2 obligations. Besides the obvious preference of firms and sectors for subsidies, this opens a window on the future design and use of ETS revenues to support (more) specific innovation actions in the various branches through consultations processes.

It is worth emphasising that Chemical representatives as well highlight some distortionary elements are claimed for the potential clash between the EU ETS architecture and energy/renewable policies.

Main insights

Policy packages have had some effects on both technological and organisational innovations. In this case, country idiosyncrasies emerge more visibly. The policy effect seems to be more heavily perceived in situations (e.g. Eastern EU Industry) wherein firms have to close economic, environmental gaps with the EU15, while lower in others (e.g. the UK case). More specific CO2 oriented actions, partly due to the new entrance of the sector into the EU ETS, appear to be driven by voluntary actions to cope with market conditions and demand pressures. In some cases where economic conditions have become more difficult over time (Spain), the market driver appears not to be sufficient.

Looking at the performances over the past (tables A.1), the chemical sector performs well both in terms of overall emission trends and efficiency trends, actually very well for CO2 trends as such. The trend over 20 years presents even somewhat radical changes. Observing the timing and the shape of those trends, voluntary actions and/or policy anticipation appear more relevant than reactions to policy events.

[21] ISO14001 appears a crucial element. The correlation between technological and organizational elements of innovation is highlighted by the reported patented innovations due to the ISO procedure (Spanish case).

Further quantitative analysis is nevertheless needed to assess the nature and significance of breaks.

The role of energy efficiency emerges crucial from a technological point of view, as well as the key role of ISO certifications as a complement to technological dynamics. Technological and organisational innovations are both relevant, with the latter potentially acting as complement or also main umbrella for innovation adoption. Policies interactions are perceived as potentially detrimental, specifically in the clashing between energy and climate change policies.

A pretty high heterogeneity by countries seem to prevail, in other words 'national' systems of policy induced innovations mechanisms, rather than sector based mechanisms sharing similarity across the EU. This may partly depend upon the 'clusterisation' and specialisation' of chemical activities within the EU (cluster of feedstock-production-R&D).

Auditions by SWG[22]

9	UK_022	United Kingdom
16	CZ_014	Czech republic
21	ES_015	Spain

Table 3 - Main figures on economic, innovation and environmental performances

Chemical									
CO2/VA			EI (CO2 abatement)			Labour productivity (VA/unit of labour)			
Average EU	Top Countries		Average EU	Top Countries		Average EU	Top Countries		
1.73	Malta	0.008	24%	Belgium	53%	624.06	Hungary	9977.27	
	Ireland	0.029		Germany	49%		Sweden	1607.23	
	Luxembourg	0.050		Romania	46%		Czech Rep.	983.26	

Source: CIS EUROSTAT data and WIOD dataset (September 2013 elaborations).

[22] Excel files and audio files of interviews are delivered by SWG as output.

4.3 Ceramics

The Ceramics case study is based on a series of telephone and vis à vis interviews. It draws upon many interviews with Italian experts within sectors, given the high relevance of Italy in this sector from a EU perspective[23].

Historic waves of environmental driven innovations

One key funding among others is that in past decades environmental policies has been the main stimulus for innovation in Italian ceramic industry. They were National and Regional policies, set far before 2000. We can flag three main policies in the past, driving three innovation waves.

The 1970ies. Bovine fluorosis and emissions control. Even if pollutants concentration in emissions and refuses is lower than in heavy industries, the localization of so many firms in a restricted territory of about 50 squared km implied environmental problems. The most striking was bovine fluorosis, a cattle disease particularly shocking in the production area of Parmesan cheese. In 1970, when Regional Administrations are invested with the problem of regulating environmental impact of industries, in Emilia-Romagna the Ceramic sector is involved in defining threshold and limits to be observed. 100% of district's firms were equipped with filters within 10 years [TiP].

The 1980ies. Water pollution. The good performance of joint regulation (institutions and firms) on emissions suggested to do the same with water. This is the decade of water filters, depurators and hydro-cycle closure in the industry.

The 1990ies, Waste treatment. After the first two waves, commanded standards lacked of stringency until mid 1990ies, when total production of tiles reached 450 millions squared meters (they were 200 millions in 1970). It was the chance to upgrade the production system to more efficient technologies mainly in the field of waste treatment, with refuse recovery and raw materials recycling; at the same time this effort begins to be valorised with consumer-oriented campaigns aimed at capturing higher shares of market [TiP].

In those years, in the industry begin to circulate new voluntary tools such as process certification standards (EMAS, ISO 14001), and labelling systems (Ecolabel, Leed, that is in a blur area between process standard and product labelling), nowadays followed by LCA (EPD) and energy (ISO 50001) standards [SaW].

The 2000s, Energy. Finally, in last 10-15 years the soaring energy costs leaded to the introduction of efficiency devices, both in processes, with new kilns, furnaces, ovens

[23] We interviewed both on the telephone and vis-à-vis three contacts from institutions/associations, and three from firms of the Ceramics District in Sassuolo (Modena province, Emilia-Romagna Region).

and new methods to recover energy, and in products' composition, with row materials more performing from an energy point of view [SaW, FR_005, UK_009][24].

Patented inventions and innovations

Though the main focus of the work bends on the innovation adoption and diffusion side, in following pages we address both "invention" and innovation issues: the first one describes a drastic change in product or process, in most cases followed by a patent application by the holder; the second one depicts an incremental process of adoption and diffusion of the invention, where the amelioration does not entails any "leap-frogging" and does not consent any patent registration.

Even though not unfamiliar with patents, ceramic/cement industry is much more characterized by innovation processes, rather than by inventions. It's more prone to incremental rather than to drastic innovation [TiP]. This trend is confirmed here: questionnaires evidence is remarking there're no patented innovations in their sector [UK_009, ES_003, PL_003, FR_005]. Similar evidence was found in Mazzanti and Zoboli (2009).

In the Italian Industry, the reasons for the low number of patents are on one hand the costs of patenting, that joint with the narrowness of the protection's breadth and with the unstoppable circulation of news, products, and technical solutions in a so restricted area, are perceived as too high [TiP]; on the other hand, because in many cases inventions escape the rationale of patenting, since you would have to patent the "curve" of use of a trivial recycled row material in mixtures, and it's almost impossible to maintain it as an "original" process [ToE].

The most important product patents refers to two categories: slim tiles [MaM, SaW] and new tiles' functionalities, meaning in this last case Self Cleaning, Anti-Bacterial, and Photo-Catalytic ceramic tiles [BoG, SaW]. Both families of innovations have tangible environmental benefits: reduction in production process' CO2 emissions, lower needing of gas [ToE], lower weight to be carried, lower material to be dismissed and landfilled [MaM], but even a more healthy environment, energy saving [SaW], and

[24] This almost thirty years-long effort led Italian ceramic industry on the top with respect to environmental performance, so that since 2000 the European Union environmental Best Available Techniques (BAT) in this sector have been based upon Italian technology [CoA, ES_003]. Moreover, because of its concentration, Italian ceramic industry is still heavily regulated, and subject to Integrated Environmental Authorization (the same of the most pollutant industries) [MaM]. For this reason, international members of sectorial forums use to label the solutions to green the sector prospected by Italian representative as too difficult to be implemented [ToE].

pollution remedies (in tiles production, pollution is directly related to the weight of products) [TiP].

Within the Italian ceramics sector, the Sassuolo District is one of the most important ceramic production areas in Europe: in 2011 Italian industry was the main player in Europe, covering up to 26% of European production value (with Germany covering 18% and Spain 13%)[25], up to 79% of export value for unglazed and up to 47% for glazed ceramic tiles in Europe (dropping respectively to 32% and 23% in the World)[26]. The Sassuolo District hosts 586 firms and more than 20.000 employees, equal to 95% of Italian ceramic producers.

The Sassuolo district (the most relevant in North-east of Italy) lost a lot in terms of innovation force, due to the fact that today the machinery sector industry (furnaces, atomizers, packagers) – that is the real core of innovation in ceramics - is completely external, while not too long ago it was internal or, at least, very close to have a real interchange in requests, ideas, and solutions [MaM]. Nowadays, research and innovation in production systems follow their own patterns, and ceramic industry just purchases the available techniques with no interaction. The same happens with innovation in enamels, produced by paint industry [Toe, TiP].

It's worth noticing that, even though replying that many inventions and innovations have been fostered by environmental and energy policies, even foreign respondents admitted that they're not aware of any patented innovation in their national industries [FR_005, UK_009, PL_003, ES_003].

Drivers of innovation

All respondents agree that in the considered interval inventions and innovations in ceramic industry are not the reaction to environmental policies, but mostly the response to market demand, and to international market factors (the two features being perceived as the same, in an industry that exports 70-80% of the production). The channels to transform environmental performance in higher market demand are the product labels such as EU Ecolabel and, LEED standard certification. Ecolabel is appreciated in Northern Europe, but - albeit launched almost 20 years ago (10 years ago in ceramics) - it's not well-known by general public [ToE]; granted firms consider it unsatisfactory, even because of bureaucracy and slowness by National authority in answering to requests [MaM].

[25] CeramUnie (The European ceramic Industry Association), 2012, *Paving the way to 2050: The Ceramic Industry Roadmap*. Data taken from Prodcom, Eurostat.
[26] Data from UN Comtrade, Commodity Codes 6907 (Unglazed ceramic flags. paving. hearth or wall tiles), and 6908 (Glazed ceramic flags and paving. hearth. wall tiles).

On the opposite, the more recent LEED certification is gradually meeting a growing reputation, mostly in richest markets throughout the world: Northern America and Persian Gulf, Korea and Japan [MaM, BoG], now widening to richest niches in UK and Northern Europe [ToE]. In addiction, Real Estate Funds in US and Canada are interested in sustainability, so that the ecological rating of the building is quite important. The LEED standard assigns higher rating for building materials with good environmental performance with respect to production, disposal, and recovering [SaW].

Another main driver for (process) innovation is cost saving, that involves energy efficiency [BoG]. The innovation for this item stems from more efficient machineries (kilns furnaces and atomizers), heat and energy co-generation turbines, PV modules. Many of them imply subsiding forms as white/green certificates or feed in tariffs, but they're collateral advantage of the energy efficiency policy, not at all the driving force [MaM]. The energy saving issue is stressed even by non-Italian experts, both in ceramic and cement industries: according to them, most of the process innovation implemented in those sectors are due to the need to reduce the impact of fuel price increases, both recovering energy still present in heat and steams refuses and, in a more modest way, addressing to biomass and renewable sources [UK_009, PL_003, FR_005]. In some cases, the need to intervene in the energy process leaves companies without enough resources to be invested in other kinds of process amelioration, becoming in this way a deterrent rather than a driver for technological change [UK_009].

Being a sector dominated by SME, ceramic industry relies even on different kinds of services from outside the firm to support the development and adoption of CO2 abatement: with respect to energy saving, there is a continuous communication and information flow coming from machinery industry (furnace and atomizer producers) [MaM]. Other communication services are provided directly from the entrepreneurial association, and independent R&D centres; this is, for instance, the case of the introduction of LCA in many companies' process, conveyed by Centro Ceramico [ToE].

Interaction between different policy instruments and the EU ETS

There's no complete agreement among respondents with respect to the issue of policies interaction. Some of them remark that on a technical point of view there is a reciprocal positive influence between CO2 abatement policies and energy saving policies, so that the latter could be a driver for the former. At the same time, other interviewees remark that on one side there is an evident overlapping between EU's and domestic regulations, and between different instruments, generating confusion, complexion, and higher costs for EU companies [ES_003, FR_005, UK_009]. In this sense, the interaction between policies ends up overall in a deterrent for development, and detrimental for global competition.

As far as the EU ETS is concerned, the cap was set with reference to 2005-2008[27], while the efficiency process has been implemented in the last 1990s-early 2000s, when the standard furnaces were replaced with roll-furnaces that reduces the burning time from 2 hours and half to 45 minutes. This means that at the moment it's very difficult for firms to abate under the cap, and they mainly have to buy quotas on the market [MaM]. Being a sector subjected to Carbon Leakage, an amount of quotas were allocated free, but now the European Commission proposed to drop ceramics out from Carbon Leakage category, so that the problem with emissions will become even harder [CoA][28].

The main critical comments on ETS by Italian Employers Association refers on one hand to the lack of transparency and of political commitments on future scenarios, affecting the capability to plan for investments[29]; on the other hand, it regards additional costs in terms of bureaucracy and human resources required by the ETS system. The last one is a burden, in an industry dominated by Small-Medium Enterprises as Ceramics [Coa].

A different position is somewhat expressed by non italian respondents, all of them agreeing that ETS was the main EU environmental-energy policy, capable to re-address the industry to higher efficiency performances. This is true in particular with respect to energy consumption [UK_009, PL_003, ES_003, ES_004, FR_005].

R&D, cooperation and industry upgrading

As mentioned, the Italian ceramic industry is concentrated in the Sassuolo District, Emilia-Romagna Region. It is an area deeply studied in the past by Sociologists (Piore,

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[27] Italian ceramic firms had to choose their ETS consumption benchmark between two possibilities: an average of 2005-06-07-08 consumption, and a second average of 2009-10. All firms have chosen the first interval, because the second one was in crisis time, with production and energy consumption drastically cut with respect to previous years.

[28] Another question mark on the future of the industry is related to the European Road Map 2050 targets (an emission abatement of 80%): it would mean a switch to electric or biogas fed furnaces, cogeneration, and other techniques that, according to simulations run by Italian Entrepreneurial Association (Confindustria Ceramica), it would imply a 90 billions euro investment, equal to 2.5% of the total industry revenue.

[29] To quote Confindustria Ceramica's representative, it is difficult to plan for investments when the actual average price of Green certificates in 2013 is 4.34 euro per ton, while all official previsions were 30 euro per ton [CoA]. A similar position is expressed by the European Ceramic Industry Association (Cerame-Unie), claiming that "For investment security, the ceramic industry needs a consistent and predictable legal framework across the EU's climate and energy policies" (Cerame-Unie, 2012, *cit.)*.

Sabel, Helliwell, Putnam), and Industrial Economists (Brusco, Arrighetti e Seravalli, Russo), who identified in "social capital" (i. e. the collective preferential treatment and cooperation between individuals and groups within local community) the main driver for local economic development[30].

In spite of this, nowadays the degree of cooperation in R&D and industry upgrading among the firms of the district seems to be weaker with respect to the past. Any firm is quite jealous of its own ideas and productions, while being all so close, and using the same providers, means a high level of potential reciprocal copying [ToE].

Recently regional government promoted two R&D common projects (CerPosa and InProCer), but the involvement of firms was unsatisfactory: in both experiences, a deep mistrust still emerges among operators, perceiving each other as competitors [TiP].

According to local stakeholders, an undeniable role in promoting the upgrading of the industry in an environmental direction has been played by the national employers' association (Confindustria Ceramica). In last 15 years they made aware members on the importance of an eco-friendly approach in the industry, promoted best practices and kept informed operators on novelties. Another institution operating as a scaffolding structure[31] for Italian industry is the Ceramics Center (Centro Ceramico), than runs research projects for the benefit of the whole sector [SaW].

Main insights

Due to a three-decades experience in enforcing thresholds to emissions and pollution, the Ceramic Industry has a long tradition in upgrading and innovation in an environmental direction.

From mid-1990s, the main drivers for innovation in the industry were not predominantly environmental policies, but market competition and costs saving, even

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[30] Helliwell J., Putnam R., 1995, *Economic Growth and Social Capital in Italy*, Eastern Economic Journal, Vol. 21;
Piore M. J., Sabel C. F., 1984. *The Second Industrial Divide*. New York: Basic books;

[31] In innovation theory a scaffolding structure (or simply a scaffold) is Institutions supporting network relations among agents in the complex and uncertain environment generated by innovation and technological change. They can be R&D centres, local university departments, public bodies, scientific journals, sectoral conventions, online discussion spaces, aimed at searching new solutions, disseminating information, interpreting the environment, addressing the change in a specific industry or territory. For a deeper insight in complexity theory notions see: Lane D., Maxfield R., 1997, *Complexity, foresight and strategy*, in Arthur W., Durlauf S., Lane, D. (eds.), The Economy as a Complex Evolving System II, Redwood City, CA, Addison-Wesley;
Lane D., 2011, Complexity and Innovation Dynamics, in Antonelli C. (Editor), Handbook on the Economic Complexity of Technological Change, Northampton, MA, Edwar Elgar

if with a non negligible positive impact on environment: in an industry with a low emphasis to patenting, the most important innovations in last years have been the introduction of heat and energy co-generation with respect to processes (adaptive innovation), and the research of new functionality for tiles with respect to products (photo-catalytic, anti-bacteria, self-cleaning, slimness).

Certification policy, both product and process, is viewed as a market signalling tool, even if it is even a support to be more efficient, in a sector where regulation is very demanding. Today, the whole Italian ceramic industry is committed to design a unique sustainability label for products. An ISO standard based upon a rating system that is bound to be the first ISO standard for products. According to insiders, a righteous pattern to be pursued by European Commission would be to enforce directives and reward most virtuous producers; This is not the mechanism entailed by ETS, perceived by operators as a system that penalizes without enforcing any amelioration. The criticism to ETS seems not to be shared by the majority of international respondents: as a matter of fact, they depict ETS as an important policy to foster process innovation addressed to energy efficiency, even through the increase in costs imposed by the recourse to green certificates or to renewable energy.

In the interval 1998-2012 policies seem to have been a weak driver for innovation[32]. Nowadays, they're are rather an instrument to dialogue with the public sector; designing policies is a strategic activity carried out by the Italian entrepreneurial association (Confindustria Ceramica) in connection with law and policy maker at the different levels (Regional, National and Communitarian). This is food for thought for policy makers: while it is true that Ceramics is not such an heavy emitter as energy, and its CO2/VA trends have improved over the past (see appendix), the overall performance in terms of CO2 emissions have somewhat worsened. The sector on the aggregate has not been capable of reducing its impact as steel has, for example. The weak reaction to more recent policies and/or the lack of proper sector specific design of such policy packages might be the issues at stake.

[32] This evidence is coherent with the econometric analysis on CIS data (focus 2006-2008) presented by Borghesi et al., (2012), who discusses some strong potential weaknesses of ceramics in relation to its innovative response to the EU ETS stringency.

Table 4 - Main figures on economic, innovation and environmental performances

Ceramic and Cement						
CO2/VA		EI (CO2 abatement)		Labour productivity (VA/unit of labour)		
Average EU	Top Countries	Average EU	Top Countries	Average EU	Top Countries	
3.70	Malta 0.046	28%	Luxembourg 62%	464.14	Hungary 8332.52	
	Netherlands 0.790		Austria 52%		Czech Rep. 759.71	
	Finland 1.351		Ireland 48%		Sweden 673.23	

Source: CIS EUROSTAT data and WIOD dataset (September 2013 elaborations)

Code	Name	Role[33]	Organization
CoA	Contri Andrea	Environmental Expert, Contact for ETS	Confindustria Ceramica, www.confindustriaceramica.it
SaW	Sancassiani Walter	Head	Focus Lab Ltd,, www.fabbricaideedistretto.it/
TiP	Timellini Pier Giorgio	Head	Centro Ceramico Bologna, www.cencerbo.it
BoG	Borghi Gabriele	Responsible for product certification	Casalgrande Padana Inc. www.casalgrandepadana.it
MaM	Maffei Marco	Quality and Env. Manager	Florim Ceramiche Inc. www.florim.it
ToE	Tonelli Elisa	Quality and Env. Manager	COEM Ceramiche Inc. www.coem.it

Auditions by SWG[34]

Code	Country
IT_003	Italy
UK_009	United Kingdom
FR_005	France
ES_003	Spain
ES_004	Spain
PL_003	Poland

[33] The three stakeholders from institutions were a University Professor, Head of the Centre for Research and Experimentation in Ceramic Industry and Chairman of two international working groups on environmental Ceramic tiles standards; a consultant in sustainability, participation processes and Corporate Social Responsibility involved in Emilia-Romagna Ceramic district, organizer and scientific head of the Green Economy Ceramic District Festival; finally, the Environmental and ETS Expert of Confindustria Ceramica. The three contacts from firms were Quality and Environment or Product certification Managers.

[34] Excel files and audio files of interviews are delivered by SWG as output.

4.4 Coke and refinery

The set of interviews offer interesting insights on the perceived impact that a few key policies have had on innovation in this specific sector. Respondents come from countries with largely different total emissions (see Table A.1 in the appendix) and emissions intensity (see Table A.2), thus covering a broad spectrum of diverse contexts ranging from the virtuous UK coke&refinery sector with a very low emission intensity (much below the EU average) to the extremely polluting Czech and Polish coke&refinery sectors that are about 70 times more intensively polluting than the UK (cf. Table A.1).

Drivers of innovation

All respondents agree that the implemented energy and environmental policies had an effect on both technological and organizational innovations, though they tend to disagree on the importance of such an effect. When asked about the two most relevant innovations, the UK respondent (UK_016) specifically mentioned energy management systems and Combined Heat and Power generation (discussed in more details below) as equally important innovations, while the Czech representative mentioned the creation of 'carbon footprint schemes' and of 'CO2 task forces' as the most relevant organizational innovations.

Among the relevant energy/environmental policies being implemented, three out of the five respondents (CZ_011, ES_011, NL_009) claimed that the EU climate change policy was a key factor for either technological or organizational innovations. Interestingly enough, however, the Dutch respondent (NL_009) claimed that the EU ETS (that currently covers 174 firms in the mineral oil refineries sector, see Table A.3) – though being in principle a key policy – was insufficient in practice so far, since the carbon price was simply too low. This viewpoint seems consistent with his/her statement that energy/environmental policies in general had little impact on innovation, which was mainly driven by economic rather than environmental reasons. Although the Dutch respondent showed the most critical position among the five interviewees, also the Polish representative pointed out that energy/environmental policies in general had little/no impact on innovation in this sector.

One possible exception in this sense might have been the Ospar Convention for the protection of the marine environment in the North-East Atlantic, which according to the Dutch respondent (NL_009) successfully reduced CO2 emissions from the coke&refinery sector without incurring any conflict with other existing policy instruments. This is case of unintended effects from another environmental policy arena, if we additionally consider that the Marine strategy deals with pollution more than climate change. This example, together with the critical viewpoint expressed on the EU-ETS, seems implicitly to suggest that in this sector recent market-based policies might have been less effective than the command and control policies adopted in the past. Under this perspective, we remark some similarity with ceramics case study, though the Coke and refinery sector appears overall more dependent upon policy levers.

Perception of harmonisation problems across countries and sectors

Two respondents (ES_011, NL_009) complained about the lack of sufficient policy harmonisation among countries. This may seem *prima facie* rather surprising, given the increasing effort of the EU to centralise its energy/environmental policy (with a unique EU emission permits ceiling in the last phase of the EU ETS rather than different national ceilings) and to harmonize the national standard and certificate systems of its member States through the Directive 2009/28/EC. The harmonisation problem emphasised by the respondents, however, does not concern only the relationship between EU member States, but also (if not especially) the relationship between EU and non-EU countries. This clearly emerges from the answer of ES_011 who pointed out the existence of a risk of carbon leakage deriving from an excessively high number of environmental policy instruments adopted within the EU, especially in comparison with the rest of the World.

A similar harmonisation problem is perceived also across sectors. In particular, both ES_011 and PL_010 claimed that the little/no impact that energy and environmental policies have had on technological and organizational innovation in coke and refinery depends on the innovation activity operated by other sectors. In his/her view, the main innovations should concern cars' and planes' producers to whom the coke&refinery sector provide fuel for transportation. The issue is relevant given that it touches upon the ‘sector integration’ effect that we address more extensively through quantitative analysis in section 6.

PL_009, instead, places emphasis on the hindering innovation effect of the EU support to 1st generation biofuels rather than “advanced” biofuels (2nd generation biofuels and alternative biofuels, such as hydrogenated vegetable oil).

These answers should be taken with much caution as they may denote a partial and conservative viewpoint aimed at defending sectoral interests. A defensive approach that is not surprising since oil mineral refinery is the 3rd most polluting sector accounting for about 7% of the EU total verified emissions (see Table A.4).

These answers, however, may also denote a tendency to reciprocally ascribe other sectors the lack of innovation results in order to avoid the unilateral implementation of new and more stringent sectoral policies. This seems to recall the similar behaviour of mutual accusation that is frequently observed across countries when the environmental and climate goals originally set by the international community turn out to be missed at the end of the observation period.

Interaction between different policy instruments

Basically all respondents – though with different nuances - pointed out that the high overlapping of different policy instruments, may have been detrimental for innovation, generating confusion and adding to the overall complexity of the system. The British respondent (UK_016), for instance, claimed that the introduction of a carbon floor pricing has hindered the continuation of Combined Heat and Power (CHP) projects, some of which were cancelled due to the policy change and the withdraw of the government support to CHP. This is a particularly serious problem since the CHP is reasonably seen by UK_016 as a key innovation in the sector. In fact the CHP, namely, the simultaneous generation of usable heat and power in a single process that use heat otherwise wasted when generating energy or mechanical power, can save about 20% energy costs; a crucial feature in this sector since – as pointed out by the Spanish respondent - “in the refineries, 70% of the operative costs are coming from energy” (ES_011). Moreover, CO2 per unit of energy produced by the CHP is about one half that produced by a conventional coal-fired power station, according to the estimations performed by the Department of Energy and Climate Change of the UK Government (cf. http://chp.decc.gov.uk/cms/).

Other respondents (e.g. ES_011, PL_010) emphasised the existence of possible conflicting goals between the renewable energy policy and the energy efficiency policy. The Polish respondent, in particular, argued that taxing policies have made very profitable for refineries to produce diesel fuel, which ended up increasing rather than decreasing the emissions. In his/her opinion, moreover, the fiscal policy have favoured small refineries more than large refineries. It follows that, at the end of the day, the emissions of smaller refineries are way higher than those of the bigger firms, with a negative effect on the emissions trend of the whole coke&refinery sector.

Main insights

Three main issues seem to emerge. First, the recognition of the role played by the EU policy as a driver for innovation, even if the relevance is not always on ‘current’ or recent policies. More distant policy waves could be responsible of the innovation we observe today, or environmental policies taking place in other areas could also provide unintended effects.

Figure A.1 and A.2 presents for the aggregated sector a somewhat different trend with respect to the others. In effect, the most significant (radical) change in efficiency is related to the late 90's (the Kyoto years), when the emissions generated by one unit of economic value sharply decreased. Since then, the sector has not progressed much more. Its overall emissions and CO2/value have been more or less constant over 2000-2008.

Second, the perception of the harmonization problem, both across countries and across sectors. This issue touches upon the general umbrella of national and sector systems of innovation: from a conceptual point of view, non harmonization is mostly detrimental where significant differences exist. Environmental and other policy settings might take this view into account. While non harmonization can generate cost in terms of unbalanced possibilities of supporting sustainability and competitiveness, it is also true that tailoring policies to specific needs could be efficient and effective in some cases. It is interesting that the ' across sector' harmonization reflects here also key sector 'integration' issues: environmental performances by sectors are directly or indirectly assesses (the latter flows an integrated approach). The innovative and environmental performance of all sectors, coke & refinery in specific terms, should be analyses along both lines. Input output extended to environmental accounts shed light on the theme. Section 6 will address the integration issue, namely integration as a lever of innovation.

Third, the identification of interaction problems among different policy instruments mainly shows a consensus on the detrimental effect on innovation due to policy overlapping, with potential conflicting goals between renewable and energy efficiency policy[35]. In terms of policy design, a specific criticism of taxing policies shows up: they favoured small refineries and made very profitable to produce diesel fuel, so that, at the end of the day, emissions of smaller refineries are way higher than those of the bigger firms. Besides the defined sector case study, this issue reposes the question on the relative efficiency and effectiveness of general energy taxation (high as share of GDP, more consolidated, upstream imposed, as not related to CO2 emissions) and specific environmental taxation (low and declining as share of GDP, less consolidated, 'downstream' imposed, as related to CO2 emissions) around which proper ecological tax reforms should be based.

[35] That links to the aforementioned trade offs between renewable targets and local pollution targets and policy.

Auditions from SWG

Code	Country	Industry
UK_016	United Kingdom	Coke&refinery
CZ_011	Czech Republic	Coke&refinery
ES_011	Spain	Coke&refinery
NL_009	Netherlands	Coke&refinery
PL_010	Poland	Coke&refinery

Table 5 - Main figures on economic, innovation and environmental performances

Coke and Refinery									
CO2/VA			EI (CO2 abatement)			Labour productivity (VA/unit of labour)			VA share
Average EU	Top Countries		Average EU	Top Countries		Average EU	Top Countries		
10.04	Romania	0.023	18%	Czech Rep.	60 %	2473.81	Hungary	53636.79	
	Ireland	0.886		Romania	60 %		Sweden	1819.41	
	Grece	1.237		Germany	54 %		Denmark	1475.63	

Source: CIS EUROSTAT data and WIOD dataset (September 2013 elaborations)

4.5 Paper and cardboard

CO2 emissions from the paper industry are due to the production of electricity and heat power, which are needed for the production process to take place [IT_009].

The 2012 data from the CEPI (Confederation of European Paper Industries)[36] show, with few exceptions, an encouraging trend in terms of environmental impacts; for example, direct CO2 emissions per kt of product decreased by 2.8% between 2010 and 2011 (and by 37.8% in 2011 as compared to 1991). However, the good environmental trends can at least partly be linked to the ongoing economic crisis, as underlined by the French expert [FR_016].

[36] CEPI (2012), Key Statistics, European Pulp and Paper Industry.

The five available interviews cover five different countries (Italy, U.K., France, Netherlands and Poland). In what follows we summarize the main conclusions that could be drawn from such interviews.

At single countries level, a significant role in energy efficiency improvements and innovation has been played by energy costs. This has been the case in Italy where large energy costs have boosted investments in energy efficiency and specific energy production systems, such as combined heat and power, to achieve a higher degree of competitiveness on the EU and international markets [IT_009]. Competitiveness (in terms of energy costs reduction) is also identified in itself as a source of improvements of energy and environmental management, linked but not based exclusively on climate targets [PL_011]. Focusing specifically on organizational innovation, a major example is the development of sustainable forest management practices, where the pulp and paper industry has been the largest investor among industrial sectors, though not being the main user [IT_009]. Organizational innovation in the direction of increasing energy efficiency is suggested to take place due both to the costs of energy and to environmental policies [UK_017]. The development of the Italian system of collection for scrap paper, as well as “green” demand, can be identified as additional significant drivers of innovation in the pulp and paper industry [IT_009]. The Dutch expert further recognizes the importance of industry actors in driving improvements towards energy efficiency, although the large costs of energy are still seen as the main driver [NL_011].

Policies and interactions

The italian expert [IT_009] suggests that regulations related to energy and environmental quality, in particular the EU ETS, do not seem to play a leading role in driving innovation; rather, such regulations contribute to incremental innovation processes which are already in place. Somehow paradoxically, regulations might reduce CO2 abatement activities, when public bureaucracies make regulatory processes slower, harming the implementation of efficient technologies (as it might be the case with respect to the local authorities’ delays in Italy). Also, the NIMBY syndrome might play a negative role, by limiting the use of biomass as a source of energy. On the other hand, when dealing with organizational innovations, an important role is recognized in the waste policy realm (specifically focusing on the institution of the Italian consortium for packaging paper recovery) [IT_009]. The regulatory policies seem to have also contributed to increases in the use of biomass in energy production in France [FR_016], where biomass itself accounts for a significant part of thermal energy production in the sector under scrutiny.

The policy instruments identified as the most relevant to the pulp and paper sector are linked to emissions from electricity and heat production, mostly EU ETS [IT_009] [FR_016] [NL_011], white certificates [IT_009], as well as the Renewable Energy Directive [FR_016] [NL_011] and (at least concerning Italy) combined heat and power incentives [IT_009]. The UK environmental agreement is also suggested as a key instrument [UK_017]. Further, the IPPC Directive [NL_011] as well as the expected evolution of standards related to other important air pollutants (e.g. NOx and water pollution) are accounted for as important, suggesting that a more integrated approach to pollution is advisable [PL_011]. Eco-labeling also plays a role in driving reductions in the environmental impact of production [PL_011]. Interactions, albeit sometimes negative, across instruments might arise: a significant example is found in the subsidies to renewable energies in Italy, which are judged as disproportionate with respect to environmental benefits and take financial resources away from other technologies, such as high efficiency combined heat and power [IT_009]. Policy related uncertainty due to instruments interactions might damage innovation and generate competitiveness issues [UK_017]. A typical example of (potentially) negative interaction is identified by the French expert [FR_016] in the overlapping between the EU ETS and the (currently debated) Carbon Tax. Also the interaction across renewables and energy efficiency targets can be a deterrent to innovation, when the measures are not weighed efficiently. Instruments that set targets in the long run (such as the Renewable Energy Directive) are key in perspective, while other local instruments are more relevant for the sector at the moment [NL_011]. Finally, an example where interaction across instruments is good concerns waste management and biomass related policies. A proper waste policy makes reuse and recycling easier and, at the same time, reduces the amount of waste that is not recovered [NL_011].

Technological and organizational Innovations

In the latest ten years no path breaking innovations have been identified; only incremental improvements in the efficiency of the paper production process have taken place [IT_009].

The existence of process innovations has been suggested by French and Dutch experts. In France the sector witnessed innovation in biomass use and cold generation [FR_016], while in the Netherlands innovative activities include energy efficiency measures related to the use of “new” presses instead of vacuuming, implying a reduction in the amount of energy needed for drying. Also relevant in this respect is the high percentage of used paper and cardboard in packaging which also brings about savings in energy. These are not new techniques but, again, can be viewed as incremental improvements, which are made possible by a significant local networking [NL_011].

In Poland, the optimization of existing vacuum systems and minimization practices in relation to the amount of water needed in production are among the most important innovations. Process innovation also features the substitution of other fossil fuels with a larger use of gas to reduce CO2 (so that new machineries and new boilers have to be installed). Plantation of poplar trees (to produce paper and/or energy) is also part of a pilot innovative project [PL_011].

The development of sustainable forest management practices has been observed; this is relevant although, as already anticipated, the pulp and paper industry is not the largest user [IT_009]. A continuous focus on organizational innovations devoted to energy efficiency improvements (and driven by costs of energy as well as by environmental policies) has been identified [UK_017].

Also relevant, under an organizational point of view, the increase in networking that has taken place in the Netherlands, implying a more integrated approach towards environmental problems along the whole pulp and paper value chain [NL_011].

In general, a significant change in the management practices can be identified, also based on a deeper involvement of staff and personnel through improvements in environment-related motivation. Environmental reporting is expected also to improve the image of pulp and paper industries [PL_011].

Significant hurdles have been recognized by the Italian expert with respect to the patenting activity, mostly due to a missing integration between industrial and/or innovation policies, as well as to a lacking stability and the related uncertainty linked to regulatory design and implementation [IT_009]. In general, little information has been provided concerning the patenting of innovations in this specific sector.

Main Insights

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The main messages stemming from the interviews support the view of the pulp and paper sector as a “mature” industry where the bulk of the innovating activity has taken place through incremental improvements.

Without stretching too much the parallel between empirical trends and qualitative analyses, figures A.1 and A.2 show those significant reductions in emissions and improvements in efficiency occurred in the 90’s. Since then, the emissions trend is positively correlated to the oil price trend, whose increasing evolution seems to boost efficiency in the past decade.

Key environmental policy instruments have been identified by respondents, but a crucial driver is recognized in the substantial energy costs and the need to improve competitiveness by reducing such costs. Important technologies in the sector are related to the use of biomass from scrap paper in producing energy: a specific role for policies is identified in this respect, but some difficulties (for example related to the NIMBY syndrome) are also reported. Examples of negative interactions across policy tools are recognized.

Auditions from SWG

Code	Country	Industry
IT_009	Italy	Paper
UK_017	United Kingdom	Paper
FR_016	France	Paper
NL_011	Netherlands	Paper
PL_011	Poland	Paper

Table 6- Main figures on economic, innovation and environmental performances

Paper and Cardboard									
CO2/VA			EI (CO2 abatement)			Labour productivity (VA/unit of labour)			VA share
Average EU	Top Countries		Average EU	Top Countries		Average EU	Top Countries		
0.47	Malta	0.006	22%	Belgium	59%	329.64	Hungary	5187.19	
	Ireland	0.033		Austria	48%		Sweden	708.65	
	Lithuania	0.046		Portugal	40%		Czech Rep.	659.90	

Source: CIS EUROSTAT data and WIOD dataset (September 2013 elaborations)

4.6 Steel[37]

The set of past policies implemented at EU level appears to had an impact on technological and organisational EI adoptions. The effect due, to the energy intensive structure of the sector, might mainly be attributed to high (and different) energy taxation across EU countries rather than to specific CO2 policies, Energy related policies matter more than CO2 targeted instruments. In more specific terms, the EU ETS allocation of quotas has been so far abundant in relation to sector needs. Even the phase where the tonne of CO2 was around 25€ was not of extreme relevance as a driver to EI. Among economic instruments, the set of certificate based tools, such as green CERs and 'white certificates' that provided market incentives to increase energy efficiency and use of renewables, had a stronger relevance in steel firms in comparison to the EU ETS schemes, that are somewhat criticised for their 'excessive' national differentiation across EU members. Over the past decade, but more in the first part of the century, when CO2 prices were higher, CDM markets had an influence and were exploited, given the strong international flavour of steel markets.

Two main innovations are possibly emerging out of the past technological development. They mainly refer to the energy mix natural gas[38] – electricity, which is crucial for steel production. The first is the co-generation of electric and gas based power, which has been stimulated by CER markets and also local community benefits (given that heating is possibly provided for residential houses nearby a steel factory). One main dynamics of technological change occurred along the energy axis. There existed significant space to improve energy efficiency some years ago in steel production; energy discontinuity, the control of power in relation to effective use, more refined control and monitoring of specific production process parts were all elements that were characterised by 'low hanging fruits'. Establishing widespread and specific energy monitoring has required investments in training and technological tools; nevertheless the energy costs fully justified the cost. Again, even if each addition in the specific downstream control of parts of the production process is subject to cost benefit analysis, the production process is now usually monitored in the energy efficiency at a very 'decentralised' level.

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[37] We currently base our case study evidence on two interviews. One administered by SWG and the other by UNIFE at Tenaris Dalmine factory in Bergamo vis à vis 6 experts in different fields of environmental strategies. TENARIS is one of the main steel multinational worldwide: 26000 employees, 10 Billions of turnover, 16 Millions tonnes of steel produced. We asked Tenaris R&D managers to answer by taking also a 'sectoral view' on technological developments. The Italian and EU industry representatives interviews are eventually included by November. Definitions of contacts are still on, after some past refusals.

[38] In most factories the balance is 50-50% between electricity and natural gas sources. A reasonable aim to further reduce energy costs is to abate natural gas by 15-20%.

The role of organisational change, or better high performance work practices (HPWP) is interestingly highlighted as third key innovation way. Within such practices, training programmes dominate. The chain seems to start at technological level, then training complements the EI adoption. Training is key to make concrete the technological options: energy efficiency improvements highly depends upon the behaviour of blue collars at the production level, and also on their feedbacks on further marginal efficiency improvements to machinery functioning / timing[39]. Some leader firms in the sector have current training goals that should cover 95% of the workforce and 2% of working hours of formal training. The role of training has recently been noted by Horbach et al (2012) and Cainelli et al. (2012) in EI econometric studies on Italy and Germany. Training and ISO14001 can be more relevant than EMS for most steel firms.

The representatives of the steel industry in the Netherlands states that the sector has developed a key process innovation to abate CO2. it is worth noting two facts: the role of organisational innovations and the importance of looking at sector-sector relationships (integration). All interviews emphasise the role of policies for sustainable building as a driver of innovation (in some branches of the sector), namely interaction with the building sector to build on a sustainable and forward looking way (Use of sustainable material for buildings to improve energy efficiency and energy saving). As example for organisational innovations they cite the 'National Environmental Database with environmental data of each product and giving a number of environmental and energy indices for each product. The database is managed by a non profit organization lead by the government, in charge of making this database coherent and working.

Regarding the 'patent' issue, this seems negligible in terms of GHG reduction potential. Patents might relate to very specific interventions that are not so diffused (diffusible), thus mainly forward looking (e.g. main examples: recover energy from emissions in addition to processes; achieving 80-85% internal recycling of 'tubes' production residual . The large bulk of the EI strategy is the adoption of somewhat idiosyncratic techno-organisational strategic elements, whose diffusion is to be evaluated case by case due to technological differences between firms in the sector.

[39] We note that the 'discontinuity' of the steel production is one of the most problematic issues for energy efficiency and economic efficiency as well. The management of 'start and go' procedures (and heating/cooling) is crucial for energy efficiency, and is related often to the creation of 'energy management teams'.

The role of other sectors and specifically suppliers is mixed. Overall, the adoption of EI is not driven by external sources. One main reason is that firms are on average big and belonging to multinationals. They obey to national/international market development and the role of 'districts' is less prominent (if compared to ceramics).

Finance has on average a moderate role. Low level of debt/turnover and high steel prices in the period 2004-2008 largely explain the unnecessary role of banking and finance in terms of support to investments.

Instead, industrial suppliers and clients matter. On the supplier side, 'pump' producers had to be involved[40] to deliver long run oriented efficient pumps and more efficient high tonnage elevators. On the clients side, as example, steel factories producing elements for pipelines should satisfy higher environmental standards in Northern EU countries (e.g. Norway, Sweden), even in terms of low level of pollutants that affect land.

It could be noted that the lack of agglomeration economies' as district and the strong competitiveness oriented behaviour between big steel firms prevents the creation of cooperative actions to tackle GHG. In fact, even the scale of steel firms might be insufficient to efficiently deal with complex and global environmental issues. Cooperative behaviour might in principle lead to the creation of large scale pollution treatment establishments.

Main Insights

Overall, the sector underlines that policies were effective and pushed innovation in both technological and organisational realms. The 'policy definition' is in this sector relevant, given the high importance of energy costs that could amount up to 30-33% of total costs (for the product transformation). Energy costs matter to support techno-organisational innovations that abate costs, more than emissions. The better Italian steel performance in the CO_2/VA indicator (graphs available upon request on Eurostat data) indicates that higher costs of energy drives environmental efficiency. If on the one hand this is a dynamic side effect of the well known 'environmental positiveness' of monopolies (that increase prices), on the other hand reposes the issue of the relative effectiveness and efficiency of energy and environmental taxes (broadly economic instruments). Future policies (e.g. the future implementation of the EU energy Directive) might exploit the 'pros' of both tools. In some cases, it might be true that the indirect effects of high energy taxation are more effective than CO_2 tailored

[40] Interestingly enough, in big firms conflict may be initially present between the technology area and the area that manages the relationships with clients and suppliers, which should incorporate non mere cost motivations (but also environmental energy motivations, of longer content in terms of costs).

economic instruments. All in all, in the case of Steel, only higher CO2 prices – even higher than 25-30€ per tonne, would significantly change the technological behaviour with specific respect to the carbon content (not only energy content) of options.

What emerges is also that policies have so far marginally increased the value of already existing 'low hanging fruits'. More costly and problematic actions, such as cutting CO2 through a full closure of the material loops and enhanced recyclability of material along the process, are (unacted) ways for the future. A clear distinction is thus made between energy and CO2 (a public good) and – correlated – between past achievements and 2030-2050 targets[41].

The past performance of the sector are somewhat coherent with what emerges here: CO2 trends have slightly declined but seems unaffected by the ETS policy period, while the CO2/VA trends is one of the best across sectors: cost reduction energy strategies and product market dynamics are the most relevant drivers.

Table 7 - Main figures on economic, innovation and environmental performances

Basic Metals						
CO2/VA		EI (CO2 abatement)		Labour productivity (VA/unit of labour)		VA share
Average EU	Top Countries	Average EU	Top Countries	Average EU	Top Countries	
2.84	Denmark 0.156	32%	Luxembourg 75%	289.83	Hungary 4336.23	
	Lithuania 0.164		Austria 67%		Sweden 747.34	
	Slovenia 0.426		Romania 64%		Czech Rep. 600.66	

Source: CIS EUROSTAT data and WIOD dataset (September 2013 elaborations)

[41] One envisaged market constraint is the presence of medium long run contracts for natural gas (15-20 years).

5 Industrial Relations and the Green economy

Industrial relations in EU: setting the scene

The challenges faced by the trade unions in the last years, mainly brought by the economic crisis that is still shacking the EU labour markets (there are more than 23.5 million unemployed), has probably diverted part of the 'energy' of the unions from green issues toward issues concerning the adverse effects of the crisis on the labour markets and workers: e.g. Work programme of the European social partners 2012-2014 and Framework of Action on Youth Employment (http://www.etuc.org/r/20).

The disruptive power of the crisis could have also undermined the well-established and structured social dialogue matured in the last decades among EU social partners. However, it has been recognised that social partners are of extreme importance in dealing with the implementation of reforms and measures to cope with the crisis's challenges (Eurofound, 2009). Social partners may bargain over measures that preserve employment, they know the skill gaps in the labour market, so they can possibly address the training programmes towards those kinds of skills and they can act as moderators when the adoption ofunpopular measures is necessary. Moreover, the crisis has shifted the primary focus of the bargaining process toward wages, after the acknowledgment of their slower increase in EU with respect productivity from the mid-90s (ETUC, 2010) and the need to boost the demand in EU.

Despite the actual scenario of social dialogue and industrial relations is strongly oriented toward the solution of labour markets problems triggered by the economic crisis, the position of European Trade Unions Confederation (ETUC henceforth) on environmental issues is strong and resolute. The main challenge is how to in integrate green issues in the actual recession scenario. The plans and actions delivered by ETUC are synthesised in several publications (e.g. ETUC, 2009; 2011). ETUC is firmly committed to the creation of a global agreement that makes it possible to reach ambitious goals in terms of CO2 reduction in order to avoid an increase of more than 2°C by the end of the century (ETUC, 2012a). Contextually, ETUC is extremely sensible to the social dimension of the transition toward a green economy and provides guidance to set up a roadmap that necessarily needs to start from the workplaces and from the actions that the ETUC affiliates may implement at local level, possibly exploiting the experience accumulated through best practices (ETUC, 2012b).

The need and strong willingness of ETUC to include the environmental issues in the agenda as an opportunity to exit from the slowdown with a greener and sustainable economy represents the starting point from which we can enucleate the highlights and the considerations from interviews to union representative and union policy advisers[42].

European unions confederations: Environment is a primary issue, but the social dimension must be preserved

The ETUC position on environmental bargaining is a progressive one. At EU level ETUC adopts a strong and positive position on climate policy negotiation, because the issue is on the agenda and it will remain on the agenda.

As an example, Benjamin Denis[43]directly stated that “ETUC has supported the backloading procedure on ETS”. The ETUC is strongly aware of the problems linked to the ETS[44]: low CO2 price, over-allocation of allowances, carbon leakage. For such a reason, ETUC has recently supported the backloading procedure, which is a measure to contrast the low CO2 prices, due to an excess of emission allowances, postponing the auction for further emission allowances. However, ETUC considers the backloading a simple emergency measure and it put forward a Just Transition (JT) approach. The JT roadmap is for sure steep and it necessitates of ambitious policies and interventions, as well as it calls for a stable and serious investment plan. The ETUC proposes to tackle the climate change through a set of policies and actions that can be included in the Lisbon Strategy. The objective of ETUC is that workers share the gains of a transition toward a greener economy (Scott, 2009). The structural changes in employment needed to develop a ‘green continent’ must be foreseen in order to set up and deploy the necessary complementary policies in education and training.

In favouring a transition towards a sustainable economy ETUC is also active in promoting an international dialogue dimension with WTO and ILO, as well as with other international partners, because of its awareness that climate change is a global challenge.

A final point stressed by the ETUC advisor is that labour and environment must not be regarded as alternative choices. A transition towards a greener economy can and must be developed with a strong social dimension. If green policies are coupled with labour policies, such as policies addressed to sustain workers re-training, then there is no risk for workers given by a low-carbon economy: green and labour policies must proceed concurrently becoming two main pillars for the EU growth .

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[42] We do not intend to draw any general conclusion, but simply reporting the opinions of the unions interviewed.

[43]ETUC Policy Advisor

[44]See http://www.etuc.org/a/11107to get furtherinformation on ETUC position and http://www.friendsofets.eu/etuc-supports-ets-backloading-and-longer-term-fixes/ for extended views on the backloading procedure onETS

As far as the industryAll position is concerned we can affirm that it shares the ETUC considerations. More specifically, the policy adviser, said that especially for energy intensive sectors a long term strategy aiming at sustain innovation and reorganization for a general reduction of material and energy utilization is supported. The competitive advantages in these sectors, but also in the other ones, must be achieved through innovation strategies rather than simple cost saving strategies. The transition strategy toward a greener economy and toward a reduction in energy use for energy intensive sectors through innovation and reorganization has more general implications in terms of education and training of the workforce. On this point it might be the case that green policies, inducing environmental innovations, may displace the labour force in the short run, especially in a recession period. Indeed, pricing environmental externalities may hinder the competitiveness of energy intensive sectors; short run and long run objectives must be conjugated in order to secure both sustainability and employment protection.

National (Italy) considerations: lack of debate on environmental issues and lack of maturity

If the situation at EU level is a progressive one with the trade unions directly active in proposing green policies, at the Italian national level the unions position seems to be underdeveloped on environmental issues. Unions confederations are certainly engaged on green issues[45]. They clearly recognize the need for a long term and integrated policy approach on the energy issue and on the sustainable development process. At the same time the UIL confederation argues that pricing environmental externalities through the back-loading procedure might be detrimental for the EU manufacturing sectors competitiveness, especially in a period of economic crisis.

The general state of the industrial relations that emerges from the respondents' words is negative. The respondents affirm that not much is left to the unions on issues such as work organization and innovation, the leadership is in the management's hands. The trade unions presence is only marginal and residual in defining innovation strategies. Unions usually react in an adaptive and defensive way to the management actions, especially in the last years of crisis.

The respondents perception is that the Italian industrial relations have suffered from a sort of cultural regression in the relations between firms and unions in the last

[45] See the following web sites in order to get information on the activity of the three major Italian trade union confederations, CGIL, CISL and UIL respectively: http://www.cgil.it/Aree/Sviluppo.aspx?T=AMBTER; http://www.cisl.it/ambiente-e-energia/; http://www.uil.it/ambiente/default.htm.

decades. The responsibility is both of the firms and of the unions, which did not realized to be in the middle of a restructuring process of the Italian capitalism.

The weakening of the social dialogue has been also reflected on the debate on environmental issues, which is substantially absent.

The interviewed union representatives agree in considering the debate on green issues out of the agenda. Neither at firm level, nor at national level the Italian unions put forward strong propositions in terms of environmental policy. As far as the application of compulsory and not compulsory green behaviours and strategies the union representatives perceive a wide gap between small and large firms, in favour of the latter (also for what concerns health and security issues).An example comes from Dalmine, a leading metallurgy firms, with establishments abroad. Dalmine is strongly committed to reduce the environmental impact of its production as well as to make the work environment more secure and healthier. However, the environmental innovations introduced, only partially due to a binding policy, had for sure a positive effect on efficiency. Without this positive effect on the cost/benefit balance for the firm it might be the case that the environmental innovation had not been introduced. By the same token, another respondent confirms that according to his experience many firms introduce environmental innovations and green processes to get eco labels they can spend as a marketing tool.

As stated by the ETUC respondent, also for the Italian firm level trade unions representatives there is no trade-off between labour and environment. However, the lack of sensitivity from firms and trade unions on green issues hampers the possibility to open a proper debate that leads to policy actions. In particular, according to a respondent, trade unions do not consider the green economy as an opportunity for new jobs and in this contingent moment they simply try to manage the adverse effects of the crisis on workers with a defensive strategy.

In synthesis, the faint attempt to introduce eco-bargaining in the last years have been hampered by the crisis. However, at national level the attempt to introduce environmental issues in the debate is still alive, as it emerges from the national confederations position. With this aim, training programmes have been activated in order to find a political path sustained by trade unions and addressed to introduce green elements in the bargaining activity (e.g. environmentally friendly process and product). If processes and products change in order to become greener, it emerges the necessity to rethink the quantity and quality of workers, implementing coordinated green and labour policies.

Uncertainty of policies and investments: the two main (perceived) obstacles towards a green economy

The last set of information collected through un-structured interviews can be put under the general heading of ‘obstacles to green economy’, as perceived by the trade unions.

Starting from the EU level, the main obstacle is constituted by the lack of adequate monetary investment to sustain the policies endorsed in order to reach the 2050 environmental goals. The road-map for building a low-carbon economy cannot be followed without serious investments. If EU leaders want to combine transition by keeping industry in Europe and considerably reducing green-house gases emissions they have to settle a proper amount of financial investment and it has to be certain. On this point an example is the EU behavior in financing Carbon Capture and Storage (CCS) projects: the funding designed to be awarded to these kind of projects this year and amounting to around 1.2 billion euros was diverted toward renewable energy projects, also because of the lack of guarantee from member states to co-finance such projects both because of austerity measures and because of the very low price of CO2.

At the Italian level, beside the lack of investments, the green policy uncertainty (and lack of green policies) plays a major role in undermining a path toward a green economy: even in this case the policy makers behaviours in front of a CCS project in Porto Tolle is an example of the damage and of the delay that uncertainty may induce in the transition towards a greener economy. The feeling expressed by the respondents is that it would be better, also for small firms, having a more stringent but certain policy rather than making adjustment as necessary because of an uncertain environmental policy.

Main insights

First, Environmental issues and sustainable development of primary importance, but with a strong social dimension. Regarding industrial relations, Uncertainty on environmental policies (local level) and uncertainty on financial investment (EU level) are two of the main obstacles toward the achievement of shared environmental objectives within firms. A managerial top down approach has more and more prevailed over time. Size and economic performances help structuring collaborative industrial relations, though consultation is usually the most unions might be offered, while negotiations on innovation and environmental goals are rare even in Corporate Social Responsibility oriented firms.

6 Quantitative evidence: sector based econometric analysis of the policy drivers of CO_2 related innovations[46]

This section takes a complementary steps further. It is devoted to analysing the relationship between policies and eco innovations through econometric methods. As already mentioned, though the analysis at EU level is currently intrinsically limited by data issues (absence of panel data on eco innovation adoption at EU level, lack of full information on potential policy proxies at sector level), this evidence provides complementary insights to those we discussed above. In addition, the merge of sector innovation data and policy data from very recent available sources at EU level (EUROSTAT and WIOD primarily) is an original way to challenge the involved research questions.

Summing up, the main aim is to investigate the extent to which climate change and energy policies (exemplified by various indicators of environmental regulatory stringency) affect the propensity of European sectors to adopt eco-innovations aimed at reducing CO2 emissions. In this section, we again use a full sectoral level perspective by exploiting the detailed information of the CIS2008. the only source on eco innovation adoption with EU coverage currently available. This analysis is in section 6.1.

In addition to the assessment of the policy-induced hypothesis, we enrich the econometric analysis by other two ways that touch upon the role of external sources of innovation. On the one side we address the role of services, namely the role of industry-services integration as a driver (or hindering effect) of eco innovations (Cainelli and Mazzanti, 2013, EEA, 2013; Gilli et al., 2013). We exploit EU input-output tables – integrated with coherent CIS sector data - to analyse the role of (vertical) integration as a source of eco innovation adoption. The increasing inter sectoral integration is to be taken into account and might play a role in explaining the current adoption of EI.

Second, we also assess the role of external (to the firm) sources of innovation by using CIS data[47] and focusing on the *breadth and depth* hypothesis, which calls into question the role of the relationships with other agents as a driver of innovation (clients, suppliers) (Montresor et al., 2013, JRC EC policy brief on eco innovations[48]). The issue

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[46] Data used for estimates are available for replication. Do Stata files are also available on request.

[47] CIS 'aggregated' firm data, as the EUROSTAT cd rom on CIS delivers. Firms are clustered in groups. This creates a meso level of analysis.

[48] Quoting Montresor et al. (2013, p.4): "The array of sources (e.g. business partners and/or public research organisations) from which firms draw in accessing external knowledge – the BREADTH of their knowledge sourcing – can enable them to tap into a variety of information signals and competencies. If

is that of 'open environmental innovations' and the role of external sources of knowledge from which to absorb (Cainelli et al., 2012). We use the same Eurostat CIS dataset, but focusing on the specific CO2 related innovation question that CIS 2006-2008 presents to replicate the analysis on a specific type of EI.

Summing up, we exploit the two available datasets on eco innovation adoption at EU level that touch sector levels: the CIS sector dataset and the 'micro aggregated' CIS datasets. The latter present a more limietd focus but allows an extension of the dataset. CIS is merged with WIOD and EUROSTAT data sources at sectro level.

6.1. The Policy drivers of sector EI: econometric evidence

We present evidence on the basis of the two main relevant datasets at EU level that currently cover EI adoption: (i) the primary source of sector CIS data that offers full EU coverage (freely downloadable); (ii) the 'aggregated' (meso) firm CIS data provided by Eurostat[49].

6.1.1 Sector CIS data

Regarding data issues, we use CIS2008 at the country and sectoral level (Eurostat) and we further merge these data with CO2 air emissions and value added by sectors for the year 2005 from the Eurostat NAMEA (National Accounting Matrix including Environmental Accounts[50]) and with the EU27 input-output table for year 2008 (Eurostat). We end up with 448 observations for 16 EU countries[51] and 43 sectors (23 industrial sectors and 20 service sectors)[52].

The CIS2008 is a unique source of information on the eco-innovative behaviours of European firms, covering the period 2006-2008. For the purposes of our analysis, we use information on the adoption of eco-innovations aimed at reducing CO2 emissions and on self-reported motivations for eco-innovation (of any kind). Moreover, we use

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properly controlled, their combination could increase the firm's innovativeness. Similarly, the intensity (i.e. number of interactions) with which firms draw on external knowledge providers – the DEPTH of their knowledge sourcing – can make them more innovative too. Through sustained interaction with each of the different possible sources of knowledge, firms are able to share feedback with them, mutually adapt their understanding and reach actual assimilation of external knowledge"

[49] Under formal contract between Eurostat and UNIFE.

[50] On NAMEA innovation and economic related issues, we refer to Costantini et al., (2012). We use 2005 to define a lag with respect to 2006-2008 (mitigating simultaneity and endogeneity) and due to data availability concerns.

[51] Belgium (BE), Czech Republic (CZ), Germany (DE), Estonia (EE), Finland (FI), France (FR), Hungary (HU), Ireland (IE), Italy (IT), Lithuania (LT), Netherlands (NL), Poland (PL), Portugal (PT), Romania (RO), Sweden (SE), Slovakia (SK).

[52] Because of missing information for either emission data or CIS data, our potential sample of 688 observations is reduced to 448 observations.

some standard control variables related to R&D, cooperation and adoption of other innovations (product or process) that are common to the literature on eco innovation drivers (Horbach et al., 2012; Cainelli et al., 2012; Kemp and Pontoglio, 2012, Ghisetti and Quatraro, 2013). A detailed description of the variables is reported in tables 8-11.

CO2 emission intensities of sectors are employed as proxies of environmental regulatory stringency. CO2 emissions and value added, in current euros, are retrieved from the NAMEA (National Accounting Matrix including Environmental Accounts) collected by Eurostat for the year 2005. While the CIS2008 use the Nace rev. 2 as sectoral classification, no information on emissions was available with a Nace rev. 2 classification prior to 2008. For that reason, we reclassified CO2 emissions by Nace rev 1.1 sectors for 2005 to the Nace rev 2 classification.

To investigate the extent to which environmental regulation drives eco-innovation aimed at reducing CO2 emissions, we use a cross-sectional regression analysis in which the dependent variable, the share of firms in the sector and country adopted eco-innovation (EI_CO2), is explained by a series of covariates. We apply a linear econometric model (STATA is the software) in which we include, in addition to our 'policy' variables, a series of controls and sector and country dummies, to account for unobserved differences in the propensity to eco-innovate by country and sector.

The cross-sectional nature of the data limits the possibility to interpret the estimates in a causal way, due to the possible presence of unobserved heterogeneity and reverse causality. Moreover, we could not find any reasonable and available instrumental variable for our policy variables. Due to these caveats, results should be interpreted in terms of conditional correlations.

Before commenting on the result of our econometric analysis, it is worth discussing some descriptive evidence. Table 9 reports the correlation matrix among our variables of interest while

First, we observe some strong (unconditional) correlations among our variables of interest. The correlation among the variables regarding the motivation for eco-innovation (existing and expected regulations, market demand and voluntary codes) is positive and in most cases above 50 percent. The same high correlation, above 50 percent, is found for the three variables regarding emission intensity and among traditional variables measuring innovation (cooperation, R&D and product-process innovations). Aggregate figures by country and sector show a great heterogeneity for most of our variables of interest.

The results for various specifications of the relationship between environmental regulation and eco-innovation are reported in Table 12. We report results for a sub-sample of industrial sectors only (from letter B to letter F of the Nace rev. 2 classification) as well as for the full sample of sectors. First, we observe little influence of our control variables, besides a strong positive effect of average firm size, as drivers of eco-innovation. Engagement in R&D is never significant while cooperation is sometimes positive and weakly significant for industry and process-or-product innovation is negative and weakly significant, again for industry only.

In columns 1 and 4 of Table 12 we observe a strong positive effect of expected regulation and market demand as drivers of the adoption of eco-innovation to reduce CO2 emissions while no effect is found for existing regulation and voluntary codes. The absence of effect for existing regulation is not so surprising, given the absence of ambitious limits in place for the period 2006-2008. However, European firms seem more concerned by future policies, such as the first and second phase of the EU ETS and other possible policies to achieve the ambitious targets set by the EU in terms of CO2 emission reduction[53]. Finally, due to the public good nature of the benefit deriving from the adoption of eco-innovation reducing CO2 emissions, the presence of a market demand for low carbon goods and services is a strong incentive for firms to adopt eco-innovations in this field. These results appear to be very similar for the two considered samples.

In column 2 and 5 of tab. 12 we just include past CO2 emission intensity as an indicator of policy stringency. Emission intensive sectors and countries are more likely to attract the attention of policy makers as well as being required to pay relatively more environmental taxes (if any) per unit of monetary output than other less emission-intensive sectors. This assumption is somewhat confirmed by the strong correlation between emission intensity and 'existing' and 'expected' regulation as reported by firms (correlation of about 44 percent in both cases). In our regression framework, we observe that more emission intensive sectors and countries are more likely to adopt CO2-related eco-innovations[54].

Finally, when we include both self-reported perceptions on regulation and past emission intensity in the same specification (columns 3 and 6 of table 12), we observe that the effect of emission intensity turns out to be insignificant while no change is observed for other drivers.

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[53] The EU 2020 package sets the target of cutting GHG emissions of 20 percent by 2020 from 1990 level while the 'Roadmap for moving to a competitive low-carbon economy' aims at abating 80 percent of GHG emissions by 2050.

[54] Current availability of energy and environmental taxation data at sector level prevents analyses that use specific policy proxies. CO2/VA is a generally widespread proxy of stringency.

Table 8 - Description of the variables

Variable	Description
% EI_CO2	Share of firms which introduced at least one eco-innovation with the environmental benefit “reduced CO2 footprint (total CO2 production) by your enterprise”
Existing regulations	Share of firms which introduced environmental innovations (any kind) in response to “existing environmental regulations or taxes on pollution”
Expected regulations	Share of firms which introduced environmental innovations (any kind) in response to “environmental regulations or taxes that you expected to be introduced in the future”
Market demand	Share of firms which introduced environmental innovations (any kind) in response to “current or expected market demand from your customers for environmental innovations”
Voluntary codes	Share of firms which introduced environmental innovations (any kind) in response to ”voluntary codes or agreements for environmental good practice within your sector”
log(CO2/VA)	Logarithm of sectoral CO2 emissions per value addedd (year 2005)
log(upstr_emiss)	Logarithm of CO2 emission intensity per value added by upstream sectors (weights from EU27 input-output table for 2008)
log(downstr_emiss)	Logarithm of CO2 emission intensity per value added by downstream sectors (weights from EU27 input-output table for 2008)
% has R&D	Share of firms which performed R&D expenditure
% cooperate	Share of firms which cooperate on innovation activities with other enterprises or institutions
% prod or proc	Share of firms which introduced product or process innovations
log average size	Logarithm of average firm size of the sector (in terms of employees)

Table 9 – Correlation matrix

Correlation		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
% EI_CO2	(1)	1	0.2502	0.3268	0.3525	0.3819	0.3405	0.0840	0.1644	0.0191	0.0725	0.1810	0.2481
Existing regulations	(2)		1	0.8570	0.4760	0.5760	0.4484	0.3152	0.4270	-0.1441	0.0583	-0.1554	0.1945
Expected regulations	(3)			1	0.5578	0.6036	0.4447	0.3367	0.4244	-0.0500	0.1156	-0.1134	0.1877
Market demand	(4)				1	0.6097	0.1424	0.0529	0.1470	0.1691	0.2228	0.0300	0.1557
Voluntary codes	(5)					1	0.2162	0.0751	0.1877	0.0625	0.2316	0.0846	0.1672
log(CO2/VA)	(6)						1	0.5151	0.6175	-0.1448	0.0261	-0.0638	0.2306
log(upstr_emiss)	(7)							1	0.8007	-0.2371	-0.0719	-0.2402	0.0072
log(downstr_emiss)	(8)								1	-0.2607	-0.0076	-0.2078	0.0304

% has R&D	(9)	1	0.5943	0.5274	0.2676
% cooperate	(10)		1	0.6692	0.4267
% prod or proc	(11)			1	0.3005
log average size	(12)				1

Table 10 - Descriptive statistics (‘environmental’ variables; averages weighted by the number of firms)

Country	% EI_CO2	Existing regul	Expected regul	Market demand	Voluntary codes	CO2/VA	Upstr emiss	Downstr emiss
BE	28%	21%	17%	14%	27%	0.61	1.31	0.37
CZ	17%	43%	28%	16%	25%	0.59	1.9	0.56
DE	37%	19%	18%	17%	18%	0.35	0.97	0.31
EE	13%	27%	21%	18%	28%	1.49	3.39	1.38
FI	25%	17%	20%	32%	30%	0.48	1.05	0.35
FR	21%	23%	14%	19%	27%	0.22	0.66	0.18
HU	19%	44%	38%	35%	37%	0.61	1.31	0.39
IE	33%	29%	21%	26%	31%	0.51	1	0.41
IT	15%	25%	18%	14%	16%	0.4	0.73	0.26
LT	18%	41%	34%	27%	26%	0.57	3.61	0.96
NL	14%	9%	8%	12%	11%	0.21	1.23	0.27
PL	20%	28%	19%	14%	14%	1.9	3.03	1.18
PT	32%	32%	18%	21%	41%	0.74	1.33	0.43
RO	20%	37%	20%	17%	17%	1.22	2.33	0.88
SE	28%	8%	14%	15%	15%	0.34	0.69	0.27
SK	11%	41%	31%	14%	20%	0.87	2.7	0.68
Sector	% EI_CO2	Existing regul	Expected regul	Market demand	Voluntary codes	CO2/VA	Upstr emiss	Downstr emiss
B	31%	35%	28%	14%	31%	5.38	3.01	3.39
C10-C12	28%	26%	20%	13%	21%	0.46	0.55	0.16
C13-C15	13%	19%	12%	10%	15%	0.33	0.27	0.17
C16-C18	24%	26%	20%	20%	21%	0.4	0.34	0.4
C19-C23	25%	31%	25%	22%	22%	1.79	1.06	0.65
C24-C25	25%	25%	18%	16%	19%	0.63	1.17	0.52
C26-C30	23%	30%	22%	21%	23%	0.17	0.4	0.19
C31-C33	18%	22%	16%	14%	17%	0.37	1.19	0.45
D	47%	43%	39%	23%	28%	12.97	8.84	3.87
E	35%	48%	37%	26%	37%	3.05	1.27	1.15

F	20%	31%	22%	27%	26%	0.08	0.81	0.1
G	21%	25%	15%	16%	21%	0.08	2	0.33
H	42%	29%	26%	15%	22%	0.89	2.11	0.67
I	17%	15%	13%	12%	26%	0.1	0.21	0.05
J	10%	8%	5%	9%	10%	0.07	1.3	0.23
K	14%	11%	8%	11%	14%	0.02	0.44	0.14
L	19%	23%	16%	18%	26%	0	0.57	0.07
M	16%	11%	9%	13%	15%	0.04	0.71	0.32
N	13%	11%	7%	12%	16%	0.08	3.09	0.49
Total	**23%**	**24%**	**18%**	**17%**	**21%**	**0.49**	**1.17**	**0.38**

Table 11 - Descriptive statistics (control variables; averages weighted by the number of firms)

Country	N	% has R&D	% coop	% prod or proc	average size
BE	31	55%	24%	58%	65.79
CZ	30	44%	10%	50%	62.05
DE	36	41%	13%	79%	87.71
EE	24	38%	22%	55%	47.14
FI	16	73%	17%	54%	69.4
FR	39	47%	11%	43%	63.29
HU	31	41%	7%	26%	62.07
IE	21	32%	9%	54%	57.2
IT	35	34%	6%	50%	42.38
LT	24	44%	9%	29%	54.4
NL	42	44%	9%	35%	81.55
PL	24	29%	8%	28%	82.66
PT	28	41%	14%	57%	49.04
RO	21	25%	3%	34%	75.36
SE	21	61%	18%	54%	71.69
SK	25	42%	6%	33%	67.87
Sector	N	% has R&D	% coop	% prod or proc	average size
B	12	34%	8%	41%	145.37
C10-C12	14	40%	9%	55%	64.56
C13-C15	14	42%	6%	41%	49.43
C16-C18	44	37%	7%	52%	48.47
C19-C23	61	58%	17%	64%	89.42
C24-C25	31	46%	10%	57%	53.33
C26-C30	71	70%	21%	70%	132.7
C31-C33	16	50%	9%	55%	52.12
D	13	33%	16%	56%	276.32
E	28	38%	11%	54%	79.58
F	8	25%	4%	32%	31.24
G	22	29%	7%	46%	51.51
H	37	22%	5%	43%	74.05
I	3	31%	6%	35%	46.65
J	13	66%	20%	68%	76.67
K	19	38%	18%	62%	213.37
L	3	35%	8%	42%	42.32
M	35	47%	14%	61%	47.4
N	4	37%	5%	35%	82.27
Total	**448**	**41%**	**10%**	**51%**	**66.31**

Table 12 - Econometric results – direct emission intensity only

Dep: % EI_CO2	Industry			All sectors		
	(1)	(2)	(3)	(4)	(5)	(6)
% cooperate in	0.0416	0.158*	0.0490	-0.0293	0.0677	-0.0279
innovation activities	(0.0924)	(0.0808)	(0.0932)	(0.0709)	(0.0627)	(0.0711)
% has R&D	0.00383	-0.00450	-0.00302	0.0347	0.0517	0.0349
	(0.0482)	(0.0543)	(0.0477)	(0.0336)	(0.0388)	(0.0335)
% has product or	-0.0737	-0.149**	-0.0836	-0.0181	-0.0831	-0.0244
process innovation	(0.0715)	(0.0730)	(0.0717)	(0.0555)	(0.0589)	(0.0562)
log average size	0.0183*	0.0229**	0.0173*	0.00695	0.0158*	0.00648
(employees)	(0.0101)	(0.0109)	(0.0102)	(0.00851)	(0.00933)	(0.00842)
Existing regulations	-0.0782		-0.0788	-0.0184		-0.0159
or taxes	(0.0836)		(0.0824)	(0.0727)		(0.0720)
Expected regulations	0.281***		0.262***	0.268***		0.251***
or taxes	(0.0861)		(0.0855)	(0.0770)		(0.0772)
Market demand	0.169**		0.168**	0.178***		0.179***
	(0.0697)		(0.0699)	(0.0607)		(0.0611)
Voluntary codes	0.111		0.114	0.135**		0.139**
	(0.0749)		(0.0739)	(0.0619)		(0.0617)
log(CO2/VA)		0.0133***	0.00668		0.0113***	0.00509
		(0.00507)	(0.00477)		(0.00438)	(0.00411)
Constant	0.210***	0.317***	0.228***	0.189***	0.289***	0.198***
	(0.0544)	(0.0573)	(0.0571)	(0.0466)	(0.0478)	(0.0475)
N	312	312	312	448	448	448
R2	0.618	0.545	0.621	0.648	0.561	0.649
F	15.15	12.55	15.02	21.41	18.29	21.00
Test country dummies	15.18***	14.36***	15.51***	14.89***	15.19***	15.03***
Test sector dummies	2.792***	4.365***	1.996**	4.186***	8.322***	2.517***

OLS estimates. Robust standard errors in parenthesis. * p<.1, ** p<.05, ***p<.01

6.1.2 Aggregated meso firm level data evidence

Differently from the full sector analysis we just commented on, the aim of the present section is to investigate the extent to which various indicators of environmental regulatory stringency affect the propensity of European firms, located in several countries (11 countries[55]), to adopt eco-innovations aimed at reducing CO2 emissions. The Meso aggregated firm level data are extracted from the CIS2008, merged with national economic and environmental accounts.

As anticipated above, the 'micro aggregated' level data at our disposal stems from the CIS2008 (cd-rom version, not available at Eurostat website), in which it is possible to find specific questions on environmental innovations. Among the latter we focus the attention on the innovation aimed at reducing CO2 emission. In order to empirically test the hypothesized positive relation between CO2-reducing innovation and policy actions/stringency we merged the firm level CIS data with CO2 air emission and value added by sectors for year 2005 from the Eurostat NAMEA (National Accounting Matrix including Environmental Accounts) and with the EU27 input-output table for year 2008 (Eurostat). The number of observations suitable for the analysis is of around 24000 units, located in 11 EU27 countries and belonging to 19 different sectors, which are classified according to the NACE Rev2[56] classification by Eurostat.

Since the types of variables used in the analysis are as those used in the section above that treated the full sector perspective between environmental innovation and policy stringency, we do not duplicate the description of such, but we provide the rationale at the basis of variable inclusion in the models.

On the one hand, several standard controls are included as factors potentially influencing firms innovation activity: size; sector; group belonging; public funding received for innovation activities; activities usually defined as innovation inputs (R&D and cooperation with partners to develop innovations) and other innovation types introduced (organizational innovations) that may thought to be complementary to environmental innovations. On the other hand, we use a set of more specific variables related to the environmental innovation adoption that encompass both self-reported motivations for eco-innovation (of any kind) adoption and CO2 emission intensity for each sector, which can be considered as a proxy of environmental regulation stringency. CO2 emissions and value added, in current euros, are retrieved from the NAMEA (National Accounting Matrix including Environmental Accounts) collected by Eurostat for the year 2005.

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[55] Czech Republic (CZ), Germany (DE), Estonia (EE), Hungary (HU), Italy (IT), Lithuania (LT), Latvia (LV), Portugal (PT), Romania (RO), Slovakia (SK). Belgium (BE) is included in the CIS2008 dataset at our disposal, but it is excluded from the analysis because of outliers values in the emission variable (CO2/ValueAdded).

[56] While the CIS2008 use the Nace rev. 2 as sectoral classification, no information on emissions was available with a Nace rev. 2 classification prior to 2008. For that reason, we reclassified CO2 emissions by Nace rev 1.1 sectors for 2005 to the Nace rev 2 classification

To investigate the extent to which environmental regulation drives eco-innovation aimed at reducing CO2 emissions, we use a cross-sectional regression analysis in which the dependent variable, a binary variable that assumes value 1 if CO2-related eco-innovation (EI_CO2) is adopted and 0 otherwise, is explained by a series of covariates. We apply a simple probit model because of the cross-sectional nature of the data. The problems related to endogeneity and reverse causality in a cross-section environment prevent us to interpret the estimates in a causal way. Due to these caveats, results should be interpreted in terms of conditional correlations.

Before commenting on the result of our econometric analysis, it is worth discussing some descriptive evidence. Table 13 reports the correlation matrix among our variables of interest while Table 14 report some descriptive statistics by country and sector for the environmental variables: EI-CO2, environmental innovation motivations and CO2 emission intensity. A first look to the correlation matrix shows strong bivariate correlations only for the motivations at the basis of environmental innovations, while for the other covariate the correlation coefficients are largely lower. As far as the environmental variables are concerned we see that German and Portuguese firms seems to be the major adopters of EI_CO2 innovations. At macro-sector level, we notice that industry firms are the main adopters of EI_CO2 and they also have a high level of policy stringency, proxied by the CO2/VA variable.

The results for various specifications of the relationship between environmental regulation and eco-innovation are reported in Table 15. The results are presented both for the full working sample of firms and for those belonging to the industry macro sector, which enclose the sectors from letter B to letter F of the Nace rev. 2 classification.

Among the controls, size seems to matter in the propensity to adopt EI_CO2 (medium and large firms perform better than small firms), innovation inputs seem to be important as well, as the financial support of innovation activities coming from local authorities, while the same kind of support from central government or EU are not robust to the inclusion of self-reported motivation behind the environmental innovations adoption. Organisational innovations do not seem to be complementary to EI_CO2 innovation.

As shown in all the model specifications in which they are included, the EI policy/market motivations are always strongly significant (Table 15 columns 1 and 4). This holds true for the full working sample and for the industry sample. Looking more closely to the coefficient it is possible to notice that the marginal effect is stronger for voluntary codes in the full sample, while for industry it turns out that expected regulations or taxes has the stronger marginal effect on the propensity to introduce EI_CO2. In terms of marginal effects, market demand motivations rank always at the bottom, pointing to a scarce incentive stemming from the public good nature of the benefit deriving from the adoption of eco-innovation reducing CO2 emissions. These results holds true also when we include past CO2 emission intensity as an indicator of policy stringency (Table 15 columns 3 and 6) in the specification.

The inclusion of an usual indicator of policy stringency shows the importance of policy driven behavior in the adoption decision of CO2-related eco-innovations. The relation is positive and strongly significant: firms located in institutional context in which regulations are more stringent tend to have a higher propensity to adopt EI_CO2[57].

[57] We might also look at whether eco-innovation is influenced by the average emission intensity of downstream and upstream sectors. Results are available upon request. Nevertheless, due to data coverage and contents, the analysis of downstream and upstream effects is mainly related to sector based econometric analysis.

Table 13 – Correlation matrix

Correlation		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
EI_CO2	1	1														
Existing regulations	2	0.33	1													
Expected regulations	3	0.33	0.60	1												
Market demand	4	0.31	0.39	0.41	1											
Voluntary codes	5	0.32	0.40	0.39	0.45	1										
log(CO2/VA)	6	0.06	0.08	0.07	0.00	0.03	1									
log(upstr_emiss)	7	0.02	0.10	0.08	0.04	0.06	0.42	1								
log(downstr_emiss)	8	0.02	0.08	0.06	0.00	0.06	0.66	0.73	1							
R&D	9	0.13	0.14	0.14	0.16	0.16	-0.09	0.04	0.00	1						
Cooperate	10	0.11	0.15	0.14	0.16	0.17	-0.04	0.11	0.08	0.32	1					
Group	11	0.07	0.09	0.10	0.09	0.11	-0.09	0.09	0.02	0.18	0.24	1				
FunLoc	12	0.06	0.04	0.05	0.07	0.03	-0.04	-0.10	-0.11	0.10	0.08	-0.03	1			
FuncCentral	13	0.08	0.10	0.09	0.11	0.09	-0.01	0.01	0.00	0.27	0.25	0.07	0.15	1		
FunEU	14	0.06	0.09	0.09	0.07	0.07	0.01	0.02	0.04	0.13	0.18	0.03	0.12	0.24	1	
Org	15	0.01	0.02	0.01	0.01	0.00	-0.01	-0.02	-0.03	0.02	0.00	0.00	0.02	0.01	0.00	1

Table 14 - Descriptive statistics by country and macro-sector ('environmental' variables)

	EI_CO2	Existing regul	Expected regul	Market demand	Voluntary codes	CO2/VA	Upstr emiss	Downstr emiss
	Relative freq. Distribution					mean		
COUNTRY								
CY	0.12	0.10	0.08	0.06	0.18	1.11	1.72	0.81
CZ	0.23	0.47	0.33	0.19	0.32	1.29	1.84	0.69
DE	0.33	0.21	0.19	0.19	0.19	0.69	0.86	0.32
EE	0.11	0.31	0.25	0.21	0.32	2.23	2.13	0.85
HU	0.21	0.45	0.41	0.36	0.37	0.93	1.18	0.44
IT	0.20	0.31	0.23	0.21	0.22	0.50	0.64	0.25
LT	0.10	0.21	0.15	0.13	0.11	1.23	1.27	0.69
LV	0.18	0.26	0.15	0.10	0.32	0.97	1.33	0.54
PT	0.32	0.35	0.21	0.25	0.46	0.94	1.11	0.50
RO	0.29	0.47	0.27	0.24	0.24	1.70	2.21	0.92
SK	0.20	0.51	0.38	0.19	0.25	1.70	1.98	0.82
SECTOR								
1. Manufacturing	0.26	0.38	0.28	0.24	0.29	1.06	1.32	0.52
2. Industry (excl. manufacturing)	0.28	0.44	0.34	0.25	0.33	3.68	0.89	0.79
3. Services	0.17	0.22	0.16	0.16	0.22	0.24	1.31	0.44
Total	0.23	0.33	0.24	0.21	0.27	1.06	1.27	0.52

Table 15 - Econometric results – direct emission intensity only

	All sectors			Industry		
Dep: EI_CO2	(1)	(2)	(3)	(4)	(5)	(6)
Existing regulations	0.413***		0.413***	0.395***		0.395***
or taxes	(0.0251)		(0.0251)	(0.0290)		(0.0290)
Expected regulations	0.414***		0.414***	0.411***		0.410***
or taxes	(0.0265)		(0.0265)	(0.0303)		(0.0303)
Market demand	0.392***		0.392***	0.362***		0.362***
	(0.0249)		(0.0249)	(0.0289)		(0.0289)
Voluntary codes	0.448***		0.448***	0.382***		0.383***
	(0.0238)		(0.0238)	(0.0282)		(0.0282)
Cooperate	0.0943***	0.199***	0.0949***	0.0901***	0.183***	0.0909***
	(0.0233)	(0.0218)	(0.0233)	(0.0280)	(0.0263)	(0.0280)
R&D	0.0963***	0.196***	0.0960***	0.0911***	0.190***	0.0903***
	(0.0221)	(0.0208)	(0.0221)	(0.0265)	(0.0250)	(0.0265)
Group	-0.0117	0.0433**	-0.0104	-0.00603	0.0544**	-0.00649
	(0.0227)	(0.0213)	(0.0227)	(0.0278)	(0.0262)	(0.0278)
FunLoc	0.114***	0.168***	0.114***	0.131***	0.179***	0.131***
	(0.0366)	(0.0342)	(0.0366)	(0.0426)	(0.0399)	(0.0426)
FunCentral	0.0412	0.0785***	0.0413	0.0206	0.0571*	0.0214
	(0.0302)	(0.0283)	(0.0302)	(0.0346)	(0.0327)	(0.0346)
FunEU	0.0443	0.133***	0.0453	0.0399	0.141***	0.0424
	(0.0392)	(0.0363)	(0.0392)	(0.0460)	(0.0430)	(0.0460)
Org	0.00488	0.00889	0.00529	-0.00393	0.00622	-0.00368
	(0.0242)	(0.0228)	(0.0242)	(0.0289)	(0.0274)	(0.0289)
Size 50-249	0.0714***	0.102***	0.0702***	0.0971***	0.118***	0.0963***
	(0.0229)	(0.0215)	(0.0229)	(0.0278)	(0.0264)	(0.0278)
Size +250	0.325***	0.442***	0.322***	0.357***	0.469***	0.356***
	(0.0303)	(0.0284)	(0.0303)	(0.0370)	(0.0351)	(0.0371)
log(CO2/VA)		0.0396***	0.0381***		0.0350**	0.0329**
		(0.0132)	(0.0141)		(0.0158)	(0.0167)
Constant	-1.355***	-1.147***	-1.365***	-1.209***	-1.000***	-1.230***
	(0.113)	(0.109)	(0.113)	(0.124)	(0.120)	(0.124)
N	26407	26407	26407	16758	16758	16758
r2_p	0.216	0.101	0.217	0.181	0.0761	0.181
chi2	5450.5***	2643.2***	5441.6***	3170.8***	1417.8***	3169.0***

Marginal effects; Robust standard errors in parentheses; (d) for discrete change of dummy variable from 0 to 1

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

6.2. External sources of eco Innovation: econometric evidence

We here analyze the external sources of innovation, primarily represented by suppliers of intermediate inputs, through sector data and CIS aggregated data, in coherence with the above commented results-

6.2.1 Sector based analysis

In table 16 we want to investigate the extent to which eco-innovation behavior is influenced by the average emission intensity of upstream sectors (i.e. suppliers of intermediate inputs).

CO2 emission intensities of upstream and downstream sectors are employed as proxies of environmental regulatory stringency. CO2 emissions and value added, in current euros, are retrieved from the NAMEA (National Accounting Matrix including Environmental Accounts) collected by Eurostat for the year 2005. While the CIS2008 use the Nace rev. 2 as sectoral classification, no information on emissions was available with a Nace rev. 2 classification prior to 2008. For that reason, we reclassified CO2 emissions by Nace rev 1.1 sectors for 2005 to the Nace rev 2 classification. Upstream and downstream emission intensity measures have been estimated by weighting emission intensity of other sectors with the EU27 input-output table for 2008. Due to the limited availability of country-level input-output tables based on the Nace rev. 2 classification, we decided to use the European table for all countries. Moreover, the first table available is the one for 2008. Upstream emission intensity reflects the emission intensity of suppliers of a sector weighted by the share of intermediate input for each supplying sector. Downstream emission intensity uses as weights the share of output sold to downstream sectors as intermediate inputs.

Upstream and downstream emission intensity measures have been estimated by weighting emission intensity of other sectors with the EU27 input-output table for 2008. Upstream emission intensity reflect the emission intensity of suppliers of a sector weighted by the share of intermediate input for each supplying sector. Downstream emission intensity uses as weights the share of output sold to downstream sectors as intermediate inputs.

In Table 16, it is interesting that the way the question about CO2-related eco-innovations is formulated into the CIS2008 suggests to firms to consider emissions along the whole supply chain (footprint). Sectors with more emission intensive upstream partners are thus required to eco-innovate more than other sectors in order to reduce their CO2 footprint. This is the case according to our estimates. The positive and significant effect of upstream emission intensity (columns 1 and 4) is actually stronger in statistical significance and magnitude that the effect of 'direct' CO2 emission intensity (columns 2 and 5). However, when including also self-reported drivers of eco-innovation, the effect of both direct and upstream emission intensity is no longer significant.

Finally, in table 17 we look at downstream emission intensity as driver of eco-innovation. Considering 'CO2 footprint' in the broadest way would requires downstream emission intensity to be taken into account by firms ('from cradle to grave' approach). There is some evidence of downstream CO2 intensity to stimulate eco-innovation aimed at abating CO2 (columns 1 and 4), even though the effect is not robust to the inclusion of direct CO2 emission intensity and self-reported policy drivers.

Table 16 - Econometric results – direct and upstream emission intensity

Dep: % EI_CO2	Industry			All sectors		
	(1)	(2)	(3)	(4)	(5)	(6)
% cooperate in	0.149**	0.152**	0.0489	0.0737	0.0721	-0.0271
innovation activities	(0.0754)	(0.0772)	(0.0935)	(0.0600)	(0.0609)	(0.0713)
% has R&D	-0.00629	-0.00920	-0.00295	0.0455	0.0465	0.0345
	(0.0542)	(0.0537)	(0.0478)	(0.0384)	(0.0386)	(0.0335)
% has product or	-0.119*	-0.126*	-0.0839	-0.0686	-0.0763	-0.0238
process innovation	(0.0718)	(0.0729)	(0.0722)	(0.0576)	(0.0586)	(0.0563)
log average size	0.0255**	0.0245**	0.0172*	0.0177*	0.0168*	0.00661
(employees)	(0.0103)	(0.0106)	(0.0101)	(0.00911)	(0.00912)	(0.00833)
log(upstr emiss)	0.0311***	0.0259**	-0.000455	0.0211***	0.0158**	0.00165
	(0.00942)	(0.0103)	(0.00942)	(0.00767)	(0.00788)	(0.00677)
log(CO2/VA)		0.00492	0.00681		0.00710	0.00468
		(0.00551)	(0.00509)		(0.00450)	(0.00412)
Existing regulations			-0.0792			-0.0148
or taxes			(0.0840)			(0.0725)
Expected regulations			0.262***			0.249***
or taxes			(0.0870)			(0.0780)
Market demand			0.169**			0.178***
			(0.0710)			(0.0616)
Voluntary codes			0.114			0.139**
			(0.0740)			(0.0619)
Constant	0.269***	0.283***	0.229***	0.258***	0.272***	0.196***
	(0.0531)	(0.0558)	(0.0577)	(0.0452)	(0.0465)	(0.0476)
N	312	312	312	448	448	448
R2	0.555	0.556	0.621	0.563	0.566	0.649
F	13.82	13.76	14.55	19.08	18.33	20.61
Test country dummies	15.85***	15.32***	15.19***	15.66***	15.7***	15.04***
Test sector dummies	3.423***	3.39***	1.814*	14.64***	8.582***	2.505***

OLS estimates. Robust standard errors in parenthesis. * p<.1, ** p<.05, ***p<.01

Table 17 - Econometric results – direct and downstream emission intensity

Dep: % EI_CO2	Industry	All sectors

	(1)	(2)	(3)	(4)	(5)	(6)
% cooperate in	0.148*	0.154*	0.0490	0.0677	0.0675	-0.0277
innovation activities	(0.0756)	(0.0789)	(0.0932)	(0.0605)	(0.0615)	(0.0711)
% has R&D	0.00203	-0.00573	-0.00312	0.0471	0.0481	0.0346
	(0.0548)	(0.0539)	(0.0478)	(0.0386)	(0.0388)	(0.0336)
% has product or	-0.121*	-0.136*	-0.0829	-0.0713	-0.0798	-0.0240
process innovation	(0.0731)	(0.0741)	(0.0726)	(0.0577)	(0.0587)	(0.0563)
log average size	0.0254**	0.0236**	0.0173*	0.0177*	0.0166*	0.00658
(employees)	(0.0106)	(0.0108)	(0.0102)	(0.00938)	(0.00932)	(0.00840)
log(downstr emiss)	0.0294**	0.0186	0.00112	0.0255**	0.0168	0.00174
	(0.0122)	(0.0130)	(0.0113)	(0.0109)	(0.0112)	(0.00955)
log(CO2/VA)		0.00940*	0.00646		0.00855*	0.00481
		(0.00540)	(0.00508)		(0.00453)	(0.00423)
Existing regulations			-0.0784			-0.0154
or taxes			(0.0831)			(0.0724)
Expected regulations			0.261***			0.250***
or taxes			(0.0858)			(0.0775)
Market demand			0.167**			0.178***
			(0.0700)			(0.0615)
Voluntary codes			0.113			0.138**
			(0.0741)			(0.0619)
Constant	0.263***	0.293***	0.227***	0.253***	0.272***	0.196***
	(0.0544)	(0.0586)	(0.0594)	(0.0469)	(0.0487)	(0.0491)
N	312	312	312	448	448	448
r2	0.544	0.549	0.621	0.560	0.564	0.649
F	13.66	13.54	14.64	19.08	18.38	20.49
Test country dummies	15.73***	15.39***	15.17***	15.81***	15.90***	15.06***
Test sector dummies	3.675***	3.542***	1.929**	12.39***	8.226***	2.501***

OLS estimates. Robust standard errors in parenthesis. * p<.1, ** p<.05, ***p<.01

6.2.1 Aggregated firm based analysis

Tables 18 and 19 present descriptive statistics and main findings. The most striking result is the relevance of both Breadth and depth effects, namely scope and intensity of relationships with external providers of knowledge. The main difference is the way the effects enter. The first is significant through a linear effect, the second shows a more non linear effect.

Among relational sources of knowledge provision, we notice the only effect of 'suppliers', that testimony the role of intermediate goods provision and integration for the support and diffusion of EI. SIM is also a significant factor.

Overall, taking also into account the irrelevance for this sample of countries of policy related factors both on the innovation and environmental side, the analysis shows that external and internal sources of information are relevant on a diversified basis: the variety of knowledge providers, the intensity of interactions, the specific role played by suppliers (among which services arise as a possible key player).

This evidence calls into question the fact that taking a broad approach to 'firm's boundaries', the 'knowledge environment' is a compelling driver of EI, as much as relevant as policies, and in some cases more relevant. When policies fail to impact, EI is driven by the environment where firms and sectors are embedded. This 'environment' is potentially affected by the overall set of regulations, well beyond environmental economic policies. Remaining Environmental policy and economic instruments the main theoretically founded driver of EI to address the various market failures we face (innovation and environmentally related), the integrated set of regulatory actions is capable of influencing EI by positively affect other realms, such as the networking and knowledge environment where firms operate.

Table 18 – Descriptive statistics (Eurostat Cd rom CIS data)

Variable name	N	Min	Max	Mean
EI-CO2 (share of firms adopting CO2 abatement innovations)	6424	0	1	0,278954

BREADTH (numbers of knowledge providers)	6424	0	9	5,322229
DEPTH (number of interactions with knowledge providers)	6424	0	9	0,886831
RD (presence of R&D expenditures)	6424	0	1	0,574409
SIM (social integration mechanisms, namely if the information from inside the firm is relevant)	6424	0	1	0,767279
Info_SUP (information sources provided by suppliers)	6424	0	1	0,509963
Info_CUS (information sources provided by customers)	4515	0	1	0,435437
Info_COM (information sources provided by competitors)	6424	0	1	0,38901
Info_OTHERS (information sources provided by other agents)	6424	0	1	0,023039
ECOPOL (country/sector-specific CO2 emission intensity in terms of Value Added in 2006)	6424	-3,00411	1,075207	-1,20102
COOP (presence of innovation oriented cooperation with other agents)	6424	0	1	0,261831
LogTURN06 (turnover in 2006)	6424	-6,90776	24,3889	12,92064
MNC (firm affiliated to a multinational)	6424	0	1	0,164851
EXPORT (export oriented firms)	6424	0	1	0,756849
INNOPOL (if the firm received public funding in support of innovation)	6424	0	1	0,310399

Table 19 – Econometric outcome: EI and external knowledge sources

	(1)	(2)	(3)	(4)	(5)
	EI_CO2	EI_CO2	EI_CO2	EI_CO2	EI_CO2
BREADTH	0.107***	0.106**	0.0887*	0.0903*	
	(0.0139)	(0.0462)	(0.0475)	(0.0475)	
DEPTH	0.0479*	-0.0353	0.0276	0.0192	
	(0.0255)	(0.0532)	(0.0638)	(0.0912)	
DEPTH2		0.0190*	0.0210**	0.0193*	
		(0.0106)	(0.0103)	(0.0106)	
BREADTH2		0.000274	0.00214	0.00501	
		(0.00426)	(0.00483)	(0.00500)	
BREADTH*RD			-0.00942		
			(0.0303)		
DEPTH*RD			-0.0980*		
			(0.0555)		
BREADTH*SIM				-0.0490	
				(0.0350)	
DEPTH*SIM				-0.0622	
				(0.0854)	
Info_SUP					0.263***
					(0.0846)
Info_CUS					0.0832
					(0.0842)
Info_COM					0.0938
					(0.0854)
Info_OTHERS					0.313
					(0.251)
ECOPOL	0.118	0.112	0.108	0.115	0.0882
	(0.105)	(0.105)	(0.105)	(0.104)	(0.125)
COOP	0.00508	0.00645	0.0138	0.0106	0.116
	(0.0737)	(0.0738)	(0.0737)	(0.0737)	(0.0952)
SIM	0.395***	0.407***	0.394***	0.692***	0.512***
	(0.0938)	(0.0986)	(0.0996)	(0.185)	(0.107)
MNC	0.0178	0.0181	0.0162	0.0156	0.0596
	(0.0861)	(0.0861)	(0.0863)	(0.0861)	(0.112)
EXPORT	-0.221***	-0.220***	-0.224***	-0.224***	-0.186*
	(0.0822)	(0.0822)	(0.0824)	(0.0823)	(0.0975)
INNOPOL	-0.0513	-0.0511	-0.0487	-0.0527	0.0106
	(0.0693)	(0.0694)	(0.0693)	(0.0693)	(0.0867)
RD	0.100	0.105	0.255	0.0989	0.242***
	(0.0731)	(0.0738)	(0.187)	(0.0735)	(0.0877)
LogTURN06	0.212***	0.210***	0.210***	0.211***	0.183***
	(0.0255)	(0.0257)	(0.0257)	(0.0257)	(0.0343)
	(0.112)	(0.112)	(0.112)	(0.112)	(0.137)
Constant	-4.021***	-4.015***	-4.044***	-4.101***	-3.719***
	(0.334)	(0.343)	(0.344)	(0.347)	(0.409)
N	6,424	6,424	6,424	6,424	4,516
PseudoR2	0.0858	0.0862	0.0867	0.0867	0.0642
Chi2	514.3450***	518.2043***	522.9264***	518.5559***	257.6639***

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1; sectors and country dummies are included.

7 Conclusions

The analysis based both on interviews to experts - sector representatives, field experts – and on econometric investigations, has dug up interesting insights on the innovative solutions to abate GHG that the key industry sectors adopted in the recent past as responses to policy and market pressures. The results represent the ex post scenario (assessment) which is complemented by further investigations on future techno-organizational trajectories to abate GHG.

The qualitative analysis performed in the first part of the report, as well as the conclusions obtained, are subject to several caveats. A first important limit might be linked to the difficulty by respondents to disentangle the different phases involved in the innovation process. Also, there are sectors where radical changes are simply not possible (e.g. the production process of some chemicals cannot be changed), and the result of innovation efforts and policies might be linked to a multiplicity of impacts that are not easy to be analysed separately (for example in terms of spillovers across sectors). A final remark is related to the impossibility to use the information obtained from the questionnaires to make a full assessment of innovation performances across sectors and countries due, among other things, to the large variability of the strictness of environmental policy in some respects, together with the potential differences arising across sectors and even within the same sector across countries. Some of these limits have been, at least partially, addressed through quantitative analysis.

Overall, as expected, environmental policy packages appear to exert a role in the evolution of CO2/ energy technologies. The number of interviewees that stated polices had not been relevant is negligible. Nevertheless, as also expected from other results in the literature, in depth investigation of the causes behind eco innovations adoption makes the picture more mixed.

First, policies appear to be of high relevance in some sectors, namely Energy, Coke and refinery and, to a more limited extent, paper and cardboard, all heavy CO2 emitters under the EU ETS scheme. Energy and emission intensity emerges as a driver also from quantitative based analysis. It is pretty interesting to note the idiosyncratic evidence that the ceramics and cement sector outlines. At least for the 'ceramics', environmental policy is currently speaking a way to interact with policy managers to develop and design better policies. The bulk of significant CO2 related innovations appeared well before 2000, apparently driven by environmental considerations, but partially detached from policy making. Costs (mostly energy related) and competitiveness might have played a role in this respect (and are also important in the paper and cardboard sector), suggesting the need to compare innovation incentives not only across EU States and sectors, but also worldwide. The role of strict GHG related policies was mild even in the case of the chemical sector: partly because of the late entrance in the EU ETS, partly due to its heavy impact on the environment, energy efficiency solutions and voluntary certifications were at the basis of the sector strategy. The metal/steel case shares some similarity with the chemical sector. Then, as expected from the neo Schumpeterian theory on innovation (sectoral systems), notwithstanding the presence of national idiosyncratic features in the 'drivers' and adoption of EI, sector differences emerge with specific contents.

Second, at a more general and transversal level, it is worth noting that the hypothesis – posed by innovation economics studies and tested in the literature mainly by quantitative analysis - that technological and organizational innovations are both relevant and complement is not rejected: organizational innovations were relevant in most sectors, often operating as leading force for the technological development. This is a key outcome to insist on this 'complementarity' in the future path towards 2030 and 2050 aims, whose achievement is possible only by integrating technological, organizational, and behavioral/education innovations.

Third, referring specifically to policies effects and features, two main considerations emerge. In some sectors – energy, chemical, ceramics, paper and cardboard, detrimental types of interactions were signaled, specifically between climate change and energy policies (coke and refinery is an exception, again signaling potential sector-specific issues). Linking to this point, the innovative solutions are biased towards the 'energy efficiency side', following a policy bias that most countries reveal (this is coherent with the features of policy packages that WP1 investigates). Notwithstanding the fact that reducing CO2 is largely an energy efficiency issue, the investigation confirms that specific and radical solutions to climate change have not been applied so far. Incremental innovations prevailed. The sectors trends and figures (Annex A) support this statement for a larger part.

Fourth, as additional note for policy making, some sectors state the need of financial support within a given policy package. Policy certainty and some financial support are two pre conditions to sustain (initial) innovation adoption and diffusion. While on the one hand this is possibly part of a lobbying effort by industries or a preference for 'non taxation policy tools' (knowing that environmental taxes and subsidies belong to the same 'family', being the latter embedded in the first), sector representatives strongly recognize the role of policies in the field of climate change challenges. Looking forward towards the auction based era of EU ETS and the chances posed by EU energy/carbon taxation, it is worth thinking about the design of 'ecological tax reforms' tailored at specific sector needs. Such fiscal reforms might be structured - with the contribution of sectors knowledge on innovation idiosyncratic features and options for short term and long run goals – according to specific revenue recycling schemes that transfer part of the green taxation revenue to best sectors players. Policy efficiency, knowledge sharing and sectors involvement could be brought together. These considerations also suggest a more general policy design issue, in terms of the relationship between policies in the form of subsidies and the innovation performances; in other words, the request for policy instruments that "pay" for innovation implies the need to be careful in the shaping of such instruments, not to damage their efficiency and cost effectiveness.

Fifth, the incremental nature of the techno-organizational evolution is confirmed by the additional industrial relations perspective. The adoption of innovation in firms through shared participative solutions is not frequent, even in CSR-oriented and more proactive firms. The current situation appears black and white, with a risk of increasing divergence regarding environmental-economic-social performance between large firms (in value added, export oriented sectors) and the rest of the economy, where firm networking is a way to cope with size related criticalities (e.g. ceramics as fruitful example). Divergences that, on the basis of EU country sector specializations might then be reflected at national level. Industrial relations are participated in large firms, where local and global sustainability is integrated with innovation and economic productivity. Cost efficiency and information/consultation nevertheless prevail, while full negotiations of innovative solutions is more and more absent even in large corporations.

Sixth, the sector based quantitative analysis presents various insights on the effects of environmental policy and other drivers of EI that changes view but complements the broader qualitative insights. First, we do observe a strong positive effect of *expected* regulation and market demand as drivers of the adoption of eco-innovation to reduce CO2 emissions, whilst existing regulations do not influence adoption. This might call into question the current stringency and effects of EU policies and enhance the power of expectations and policy credibility for future achievements. By using past CO2 emission intensity (CO2 on value) as an indicator of policy stringency, we additionally do find that emission intensive sectors are more likely to adopt CO2-related eco-innovations. The aforementioned results are valid for the economy as a whole and for industrial sectors only.

Seventh, we also show that not only environmental policies matter to sustain EI adoptions. Other 'external' drivers play a role. Looking at the role of inter sector integration and knowledge sources, we observe that sectors with more emission intensive upstream 'partners' are eco-innovate more to reduce their CO2 footprint. The positive and significant effect of upstream emission intensity (supplier's emission intensity) is actually stronger than the effect of 'direct' CO2 emission intensity (policy effect). Overall, the analysis shows that external and internal sources of information are relevant on a diversified basis: the variety of knowledge providers, the intensity of interactions, and the specific role played by suppliers (among which services arise as a key player).

Within the realm of CO2 related innovation adoption, environmental and energy policies have had a role in sustaining incremental techno-organizational solutions. Policy pressures appear more effective in energy intensive sectors, where market and policy effects are equally relevant. A positive note which touches even the 'radicalness' of innovation is the widespread integration between technological and organisational innovations. Their complementarity is key for future achievements and must be recognised in policy design. More negative signals are the lower 'policy effect' in some heavy sectors, as ceramics, which does not present top figures for CO2 performances. The key innovation wave seems in some sectors situation to belong to the past. This poses question marks on the current EU policy package, which are reinforced by the relevance of expectations to support the adoption of EI. Another weakness is the low involvement of key agents such as workers and unions in the adoption of EI. The issue is crucial given the importance of jointly adopting techno-organisational-training efforts, that may be enhanced by consultations and information within firms, to cope with climate change goals. Environmental policy stringency and policy expectations are thus key drivers of EI. Nevertheless, the overall ‘policy and institutional’ environment is crucial, as EI is also strongly driven by the type and intensity of relationships with other sectors (that supply intermediate goods and ‘knowledge’). This is increasingly relevant given the sector integration of the EU economy. Even if the main aim of environmental policy packages is to address market failures in form of negative externalities, integrating considerations on the dynamic efficiency of instruments (namely innovation effects), they should be informed by, and designed around, a diversified set of issues and considerations which characterise the ‘innovation environment’.

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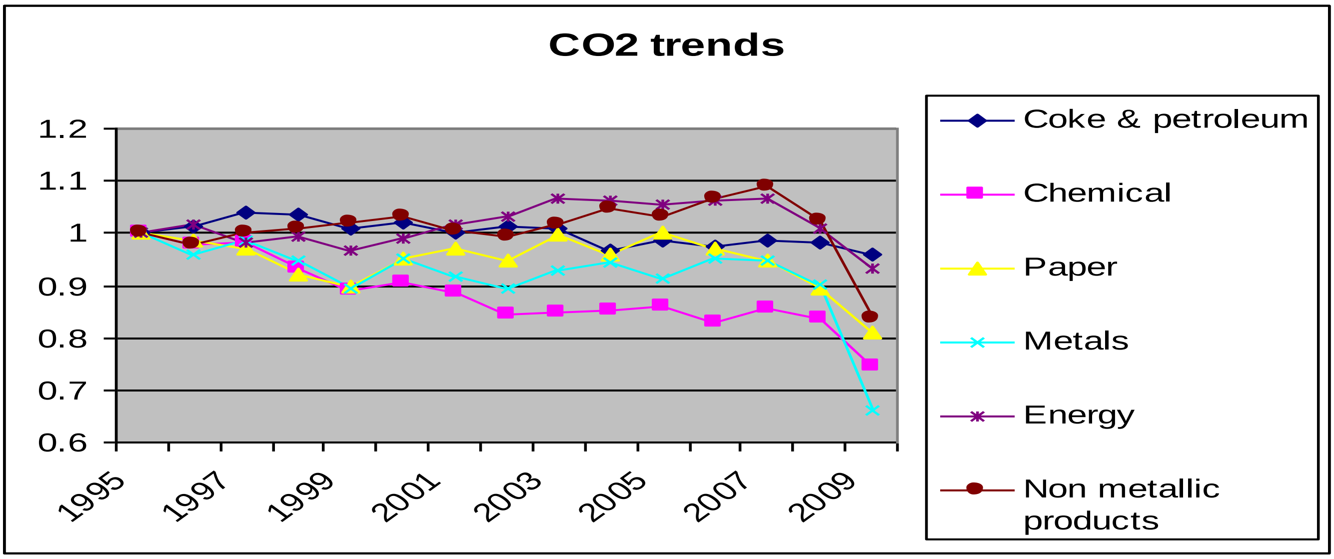
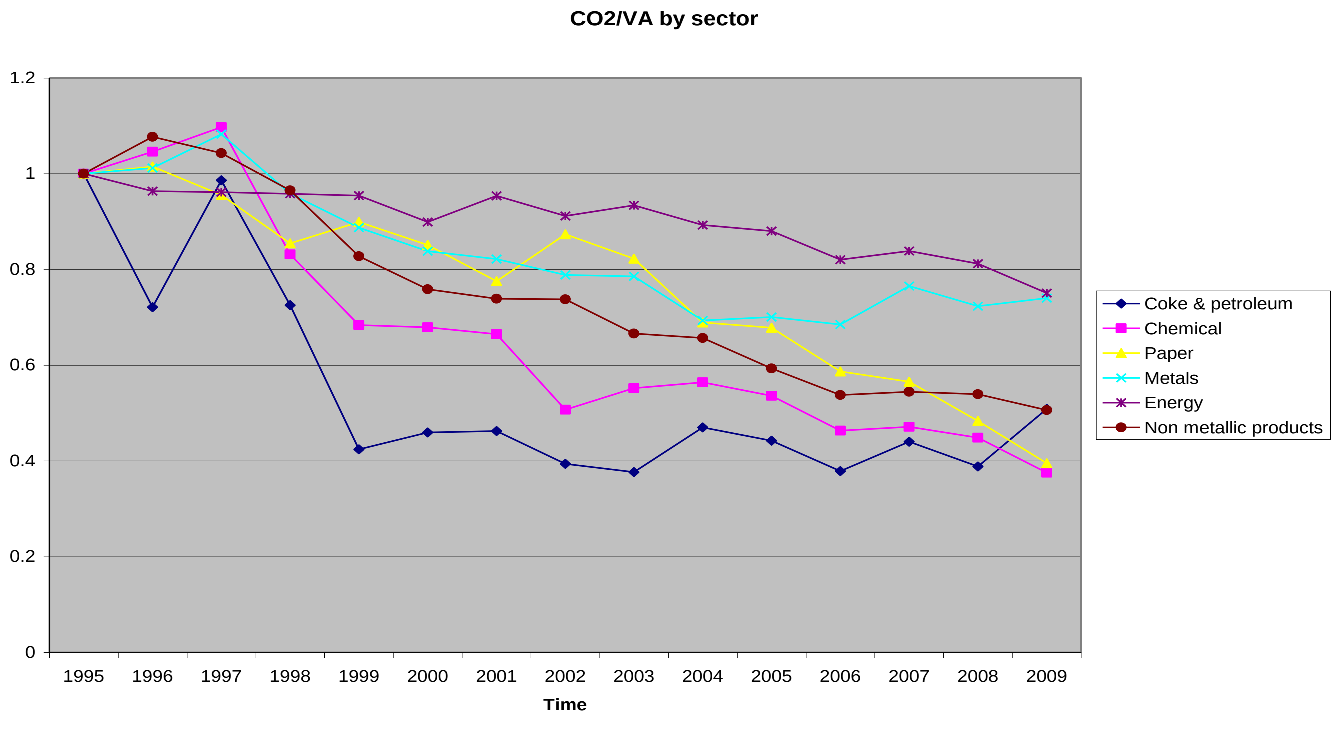
Annex A – Figures and trends on EU sectors[58]

A-1 CO2 trends in the EU (source: WIOD, October 2013)

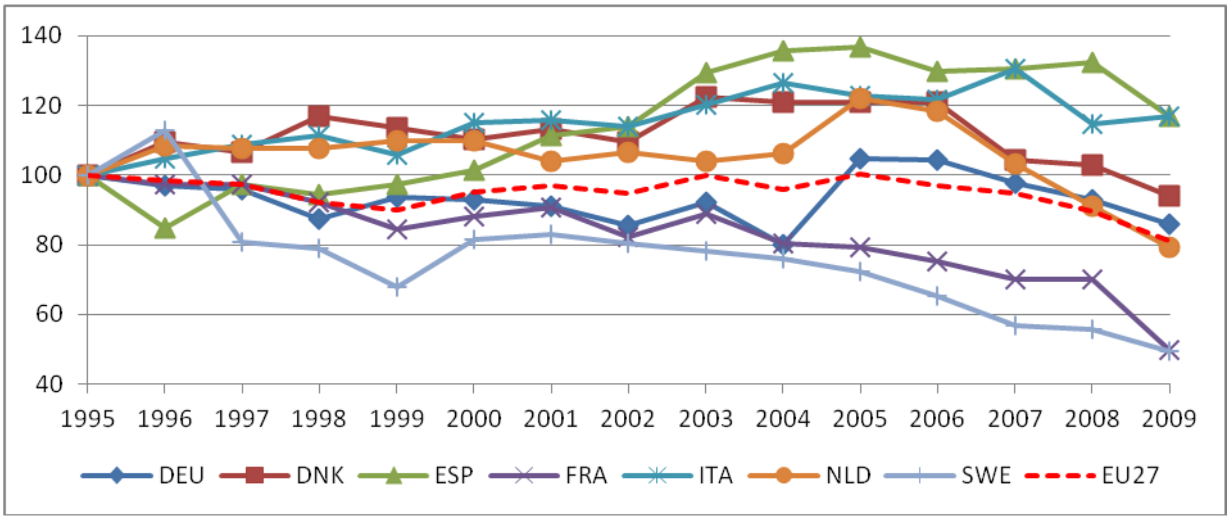




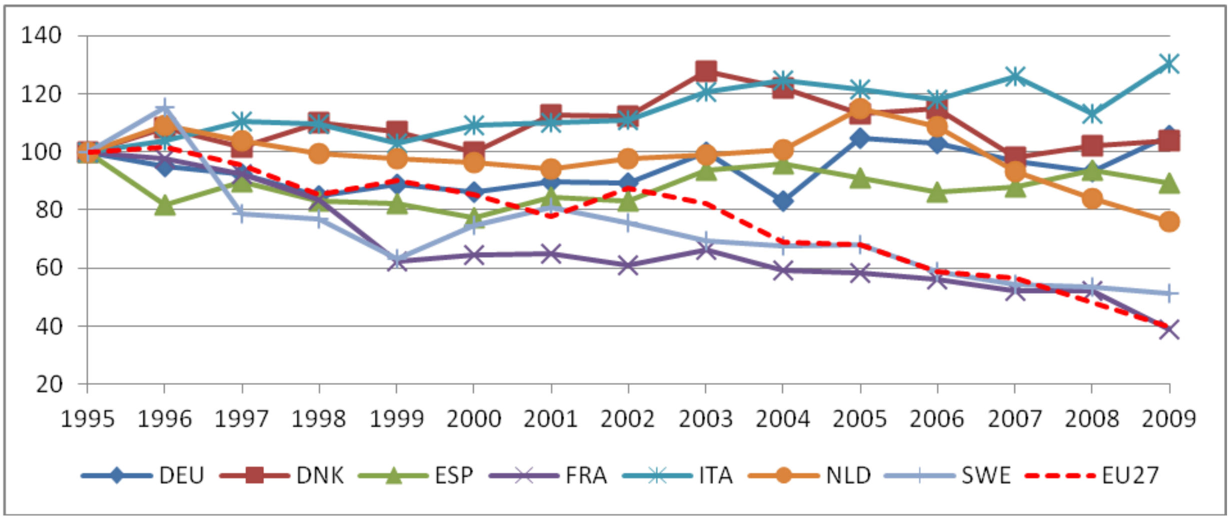
A-2 CO2/Value added trends in the EU (source: WIOD, October 2013)

[58] Figures of CO2 and CO2/VA are also available as tonnes of CO2 and tonnes/€ (excel files).

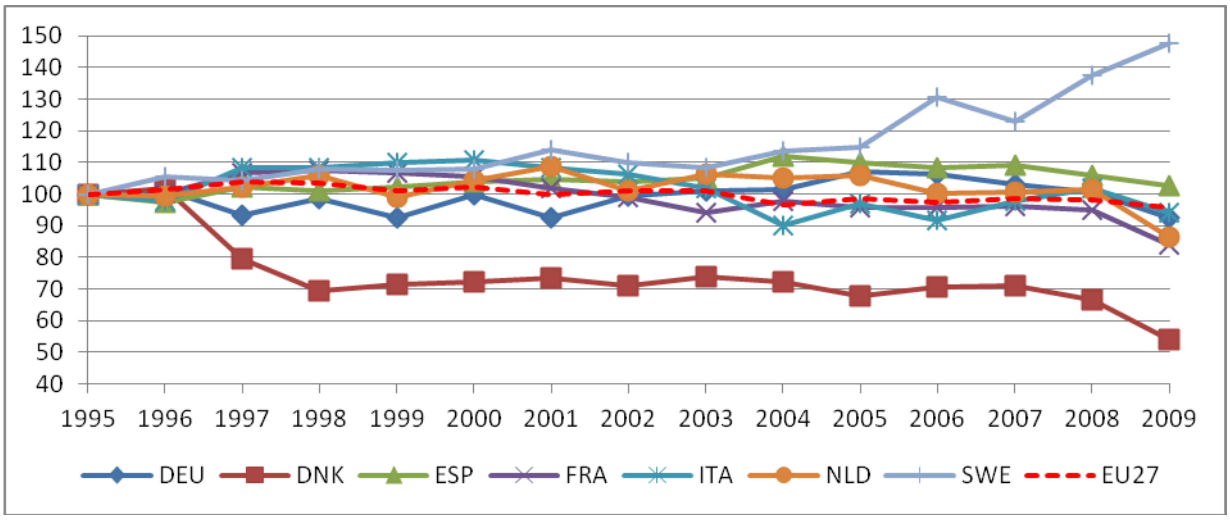
A-3 CO2 trends in the paper sector (source: Eurostat, August 2013)



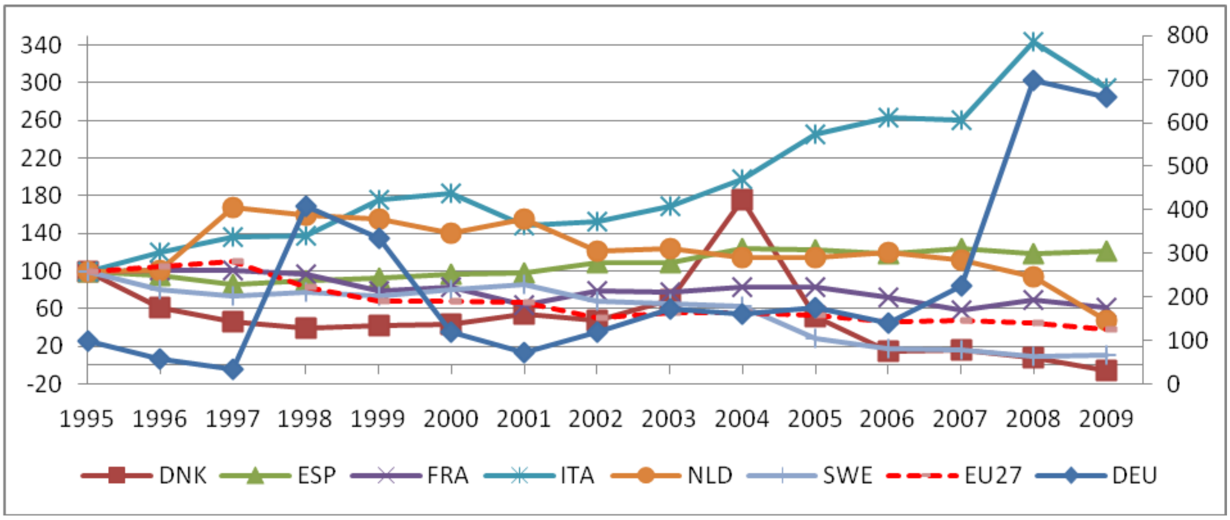
A-4 CO2/Value added trends in the paper sector (source: Eurostat, August 2013)



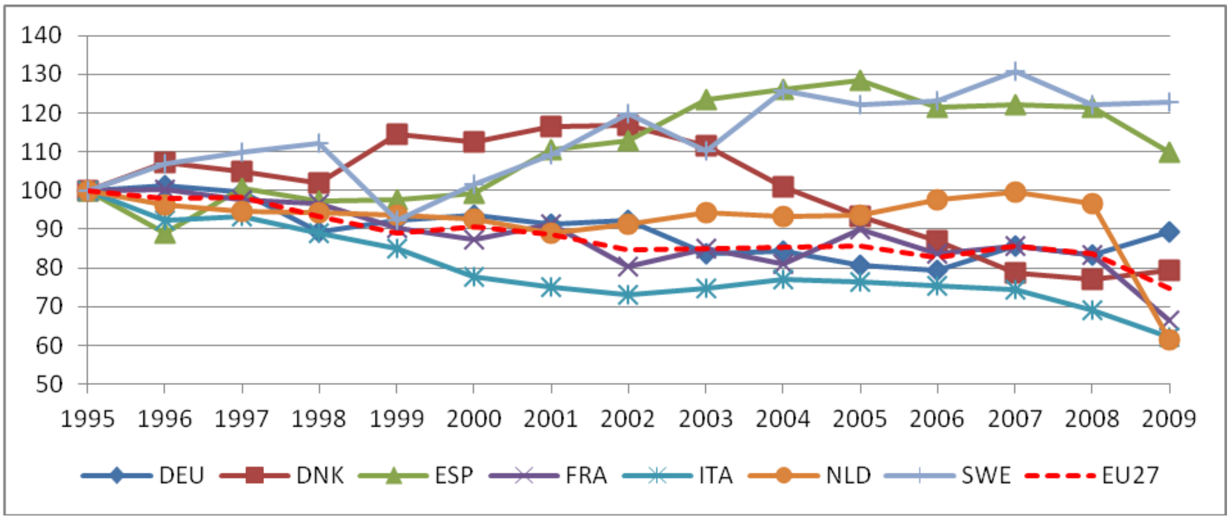
A-5 CO2 trends in the coke and refinery/petroleum sector (source: Eurostat, August 2013)



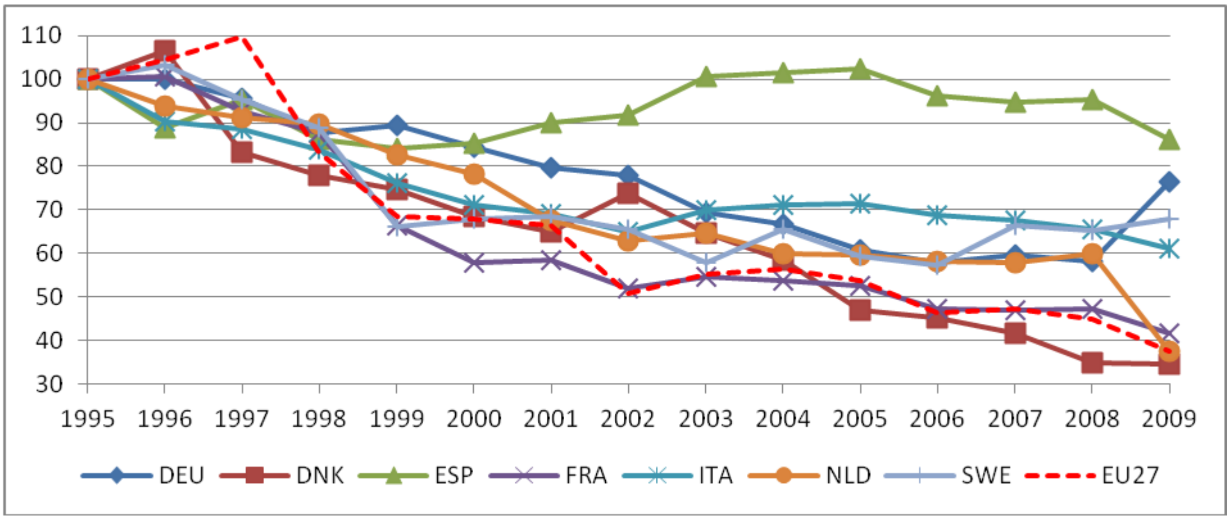
A-6 CO2/Value added trends in the refinery/petroleum sector (source: Eurostat, August 2013)



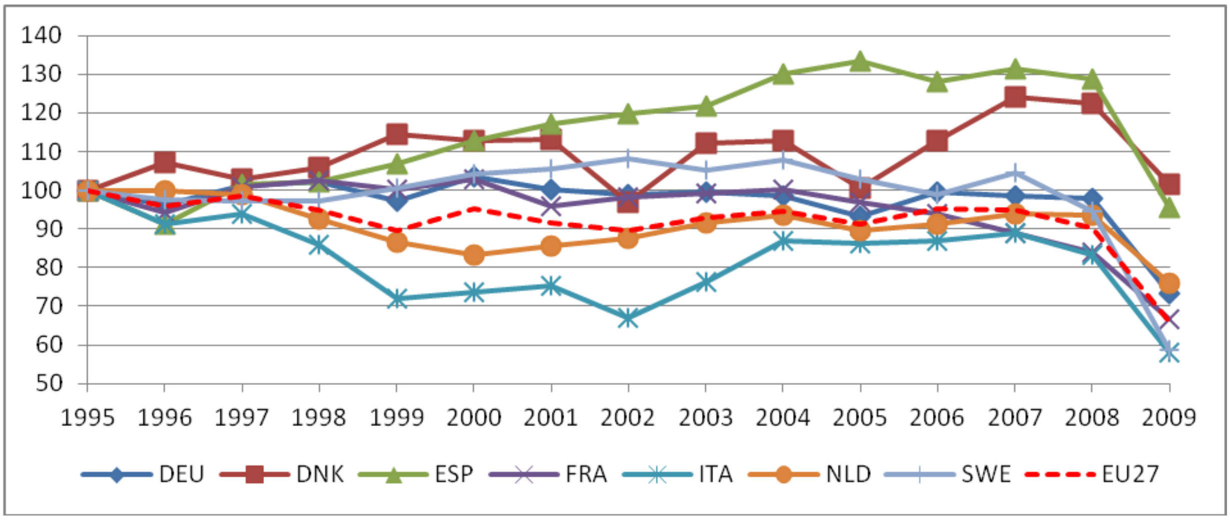
A-7 CO2 trends in the chemical sector (source: Eurostat, August 2013)



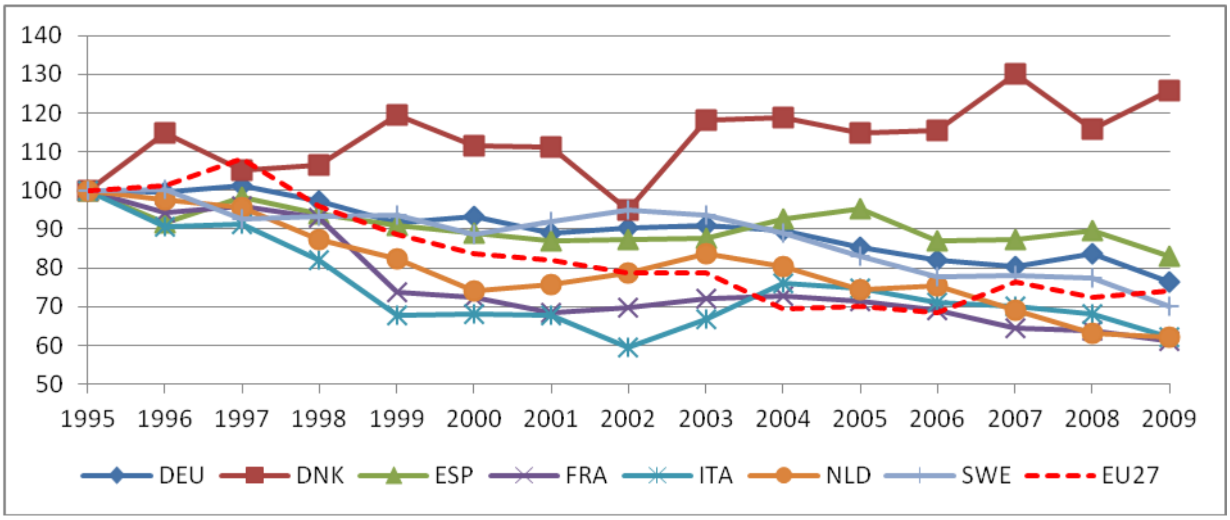
A-8 CO2/Value added trends in the chemical sector (source: Eurostat, August 2013)



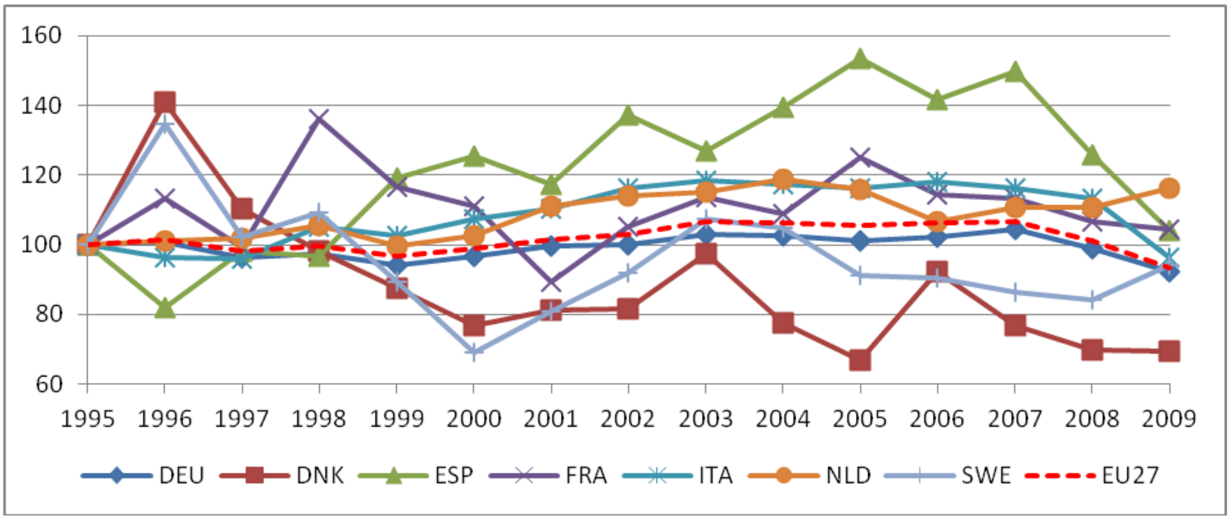
A-9 CO2 trends in the metal sector (source: Eurostat, August 2013)



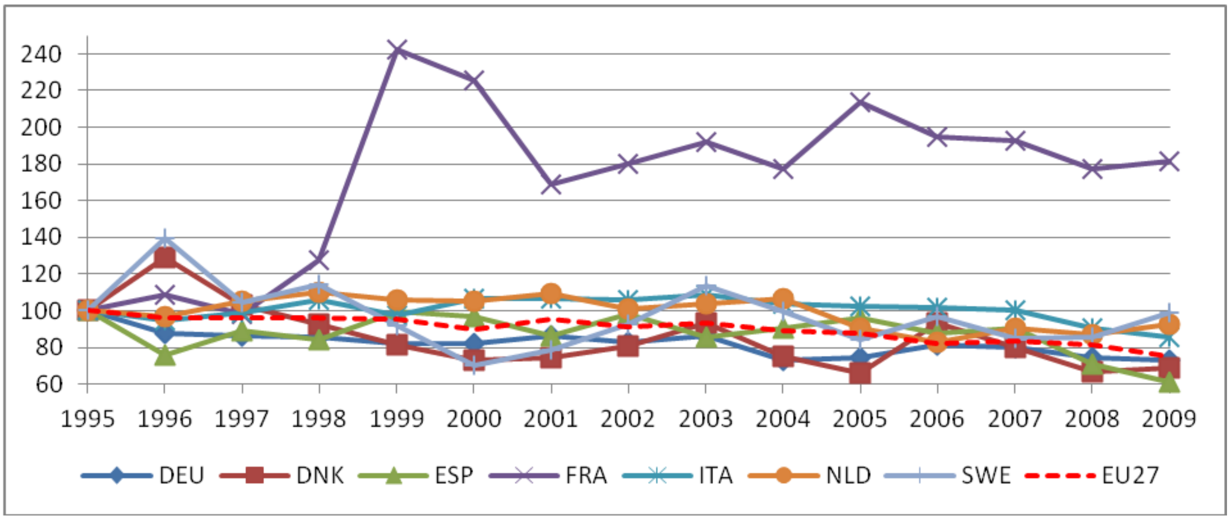
A-10 CO2/Value added trends in the metal sector (source: Eurostat, August 2013)



A-11 CO2 trends in the energy sector (source: Eurostat, August 2013)



A-12 CO2/Value added trends in the energy sector (source: Eurostat, August 2013)



Tables related to section 4.

Table A.1: Mineral oil refineries CO2-e total annual emissions: cross section and cross country analysis (1000 emission unit kt CO2-e)

GEO/TIME	2007	2008	2009	2010	2011	2012
Austria	2867,63	2806,07	2809,23	2724,48	2768,08	2836,13
Belgium	5679,82	6305,84	6234,96	6361,61	5785,15	5935,33
Bulgaria	16,67	13,68	4,69	6,06	11,12	12,95
Czech Republic	1094,93	1086,77	979,90	1053,80	988,08	951,35
Denmark	960,85	916,11	927,49	875,21	855,28	948,99
Finland	3167,15	3398,49	3468,97	3310,40	3359,07	3133,84
France	18501,75	19585,49	18463,52	16758,50	15989,48	13371,54
Germany	28652,60	27209,81	26432,14	25531,17	24860,27	23963,75
Greece	4368,27	4154,60	3979,50	4017,63	3655,98	3875,57
Hungary	1430,05	1423,11	1339,21	1371,51	1452,22	1399,87
Ireland	360,33	366,96	314,98	310,21	285,23	313,37
Italy	25969,20	24736,05	23149,58	24864,21	23691,80	22155,85
Lithuania	1201,67	2090,74	2102,76	1967,11	1903,48	1731,63
Netherlands	11428,29	11872,41	10837,88	10697,70	10884,44	10604,96
Norway	0,00	1794,12	1898,19	1832,40	2030,44	1986,71
Poland	2837,28	2996,07	2920,00	2764,33	3647,74	3835,97
Portugal	2938,37	2949,95	2616,08	2832,14	2612,18	2722,03
Romania	4859,52	4479,83	3355,10	2766,16	2400,58	2263,93
Slovakia	2255,27	2609,54	1751,69	1380,12	1475,76	1279,84
Spain	14958,54	14419,90	13558,44	13098,46	13943,53	14906,96
Sweden	2739,08	3018,12	2939,16	2957,67	2847,04	3023,27
United Kingdom	18063,37	17504,38	16720,40	16482,33	16818,03	15172,39
EU	**154350,63**	**155738,03**	**146803,86**	**143963,19**	**142264,95**	**136426,23**

Source: authors' elaboration on European Environment Agency (2013)

GEO/TIME	2007	2008	2009	2010	2011	2012
Austria	95,56	100,76	98,33	104,67	108,1	108,25
Belgium	59,12	54,93	54,65	55,97	63,95	63,39
Bulgaria	1846,31	2589,76	7443,6	5954,15	3462,36	3063,85
Czech Republic	120,47	141,95	145,11	142,28	157,36	160,1
Denmark	236,81	256,66	241,05	270,19	281,14	258,21
Finland	56,78	54,63	49,67	53,99	56,17	61,44
France	101,98	98,71	102,13	115,57	125,17	151,99
Germany	84,76	90,92	89,83	97,77	104,29	110,34
Greece	51,09	56,13	58,07	55,29	57,04	49,99
Hungary	69,52	74,16	68,26	70,42	68,74	69,77
Ireland	526,33	491,2	515,22	509,64	570,07	523,15
Italy	59,85	63,68	65,65	62,41	66,63	70,68
Lithuania	23,92	15,5	12,68	14,03	16,18	18,98
Netherlands	3,28	3,15	3,32	3,73	3,92	4,19
Norway	0	3,32	3,14	3,45	3,24	3,42
Poland	201,52	198,42	196,31	212,27	164,22	156,24
Portugal	97,92	105,52	104,34	112,23	135,08	142,86
Romania	64	81,07	92,6	128,2	154,48	168,39
Slovakia	75,08	65,91	96,21	125,25	115,91	129,12
Spain	8,34	9,69	8,72	9,49	9,42	8,84
Sweden	20,01	21,34	21,36	22,27	24,27	23,64
United Kingdom	1,92	2,13	2,13	2,16	2,15	2,34
EU	6,82	6,98	7,14	7,29	7,47	7,69

Table A.2: emission intensity (CO_2/GDP) of the mineral oil refinery sector across EU member States

Source: authors' elaboration on European Environment Agency (2013) and Eurostat (2013)

Table A.3: Number of entities (and their size) operating in EU mineral oil refinery sector under EU ETS during the 2007-2012 period

Source: authors' elaboration on European Environment Agency (2013)

	2007	2008	2009	2010	2011	2012
Large (emissions > 500 kt CO2-eq)	95	94	93	93	93	96
Medium (50 < emissions < 500 kt CO2-eq)	32	32	31	31	30	39
Mini (0 < emissions < 25 kt CO2-eq)	14	17	17	16	15	24
Small (25 < emissions < 50 kt CO2-eq)	13	12	12	12	12	13
Zero (emissions = 0 kt CO2-eq)	1	1	1	1	1	2
TOTAL	**155**	**156**	**154**	**153**	**151**	**174**

Table A.4: EU Verified emissions (1000 emission unit kt CO2-e) per sector and per year

Source: authors' elaboration on European Environment Agency (2013)

EU	2005	2006	2007	2008	2009	2010	2011	2012
Combustion installations	1458941,89	1470297,48	1543321,05	1509692,12	1380276,58	1413515,13	1378963,64	1370421,4
Mineral oil refineries	**151103,82**	**149587,18**	**154350,63**	**155738,03**	**146803,86**	**143963,19**	**142264,95**	**136426,23**
Coke ovens	19193,12	21301,04	22077,82	21042,92	15787,54	19985,09	19528,66	16811,33
Metal ore roasting or sintering	12643,64	14115,1	25005,58	17832,44	11038,96	13235,72	13148,88	12322,54
Pig iron or steel	129287,58	132833,31	132174,83	133170,45	95482,69	113729,37	113435,95	112133,59
Cement clinker or lime	177456,73	181974,24	200869,47	190858,09	153122,7	153936,54	152310,59	141810,91
Glass including glass fibre	20162,9	20077,75	21408,37	22793,88	19483,08	20349,42	20908,35	19886,16
Ceramic products by firing	14883,99	15048,7	15038,61	13617,32	9223,97	9119,41	9106,07	8077,6
Pulp, paper and board	30243,95	30316,23	29672,59	31939,32	28294,8	30442,06	29174,08	28294,55
Other activity opted-in	158,77	144,65	20847,03	22987,67	20093,45	20740,78	25433,8	20724,44
Aircraft operator activities	0	0	0	0	0	0	0	83780,29
TOTAL	**2014076,38**	**2035695,67**	**2164765,98**	**2119672,24**	**1879607,63**	**1939016,7**	**1904274,97**	**1950689,03**
Incidence of Mineral oil refineries on total EU CO2-e emissions	**7,50%**	**7,35%**	**7,13%**	**7,35%**	**7,81%**	**7,42%**	**7,47%**	**6,99%**

Data European Environment Agency: http://www.eea.europa.eu/data-and-maps/data/data-viewers/emissions-trading-viewer;

EUROSTAT: http://epp.eurostat.ec.europa.eu/tgm/table.do?tab=table&init=1&language=en&pcode=teina010&plugin=1

Annex B – Figures by sector and country (EU15). Sources: WIOD, Eurostat, CIS.

Energy - EU15										
CO_2/VA			EI (CO_2 abatement)			Labour productivity			Va share	
Average EU	Top Countries		Average EU	Top Countries		Average EU	Top Countries		Top Countries	
4.40	France	1.080	37%	Belgium	65%	386.75	Sweden	2226.34	Austria	3%
	Sweden	1.142		Austria	59%		Netherlands	324.12	Greece	3%
	Austria	1.256		Germany	52%		Luxembourg	273.12	Spain	3%

Chemical - EU15										
CO_2/VA			EI (CO_2 abatement)			Labour productivity			Va share	
Average EU	Top Countries		Average EU	Top Countries		Average EU	Top Countries		Top Countries	
0.45	Ireland	0.029	28%	Belgium	53%	263.17	Sweden	1607.23	Ireland	11%
	Luxembourg	0.050		Germany	49%		Ireland	416.37	Belgium	4%
	Sweden	0.187		France	39%		Netherland	174.29	Netherland	4%

Ceramic and Cement - EU15										
CO_2/VA			EI (CO_2 abatement)			Labour productivity			Va share	
Average EU	Top Countries		Average EU	Top Countries		Average EU	Top Countries		Top Countries	
2.39	Netherlands	0.790	37%	Luxembourg	62%	121.55	Sweden	673.23	Spain	1.4%
	Finland	1.351		Austria	52%		Luxembourg	103.85	Italy	1.2%
	Germany	1.678		Ireland	48%		Netherland	82.64	Austria	1.1%

Paper and Cardboard - EU15										
CO_2/VA			EI (CO_2 abatement)			Labour productivity			Va share	
Average EU	Top Countries		Average EU	Top Countries		Average EU	Top Countries		Top Countries	
0.24	Ireland	0.033	31%	Belgium	59%	127.90	Sweden	708.65	Finland	5%
	Greece	0.152		Austria	48%		Ireland	191.14	Ireland	4%
	Netherlands	0.170		Portugal	40%		Finland	95.05	Sweden	3%

Basic Metals - EU15						
CO_2/VA		EI (CO_2 abatement)		Labour productivity		Va share
Average EU	Top Countries	Average EU	Top Countries	Average EU	Top Countries	Top Countries

0.77	Greece	0.428	41%	Luxembourg	75%	125.49	Sweden	747.34	Finland	4%
	Italy	0.510		Austria	67%		Luxembourg	118.92	Italy	4%
	France	0.578		Germany	57%		Finland	80.40	Luxembourg	3%

Annex C– The questionnaire[59]

The short questionnaire is aimed at assessing *whether and to what extent environmental and energy policies implemented by your country and the EU have influenced the adoption and diffusion of environmental innovations (aimed at reducing CO2) in your specific sector*. The time span of reference is 2000-2012. Innovations are of technological and organisational nature, patented or not. As general reference we provide a table with the main policies that have characterized your country. You may refer to other policies as well.

The analysis is an input for the EU project CECILIA 2050, Combining policy instruments to achieve Europe's 2050 Climate targets (www. Cecilia2050.eu), in order to elaborate a report on the environmental innovations induced by policies in the past.

The report will be publicly available.

[59] This was strictly followed by SWG with the help of a glossary and presenting the policy package as emerging from WP1. In other cases, it operated as a 'fil rouge' to discuss the relevant issues.

1. Think about the effect that environmental and energy policies may have had on **Technological innovations aimed at reducing CO2** in your sector over 2000-2012. Innovation that would not have occurred without the presence of such policies.
    a. Have environmental and energy policies had any effects?
       If the answer is yes, please state
        - Which were the key policies?
            - From the list (or beyond)
        - Was the interaction between different policy instruments a deterrent or a driver?
            - Please define which interaction if possible
        - Can you describe the 2 most relevant innovations, characterizing them as
            - Process/product
        - Were the technological innovations patented? (which)

        If the answer is no, please tell us the most relevant braking factor
        - Lack of stringency
        - Lack of policy commitment
        - Lack of transparency
        - High administrative /transaction costs
        - Low involvement of industrial actors in the process
        - Lack of integration with innovation/industrial policies
        - Uncertainty related to the stability over time of policy/regulation
        - Other………..

2. Think about the effect that environmental and energy policies may have had on **organisational innovation adoption aimed at reducing CO2** over 2000-2012. Innovation that would not have occurred without policies.
    a. Have environmental and energy policies had any effects?
       If the answer is yes, please state
        - Which were the key policies?
            - From the list (or beyond)
        - Was the interaction between different policy instruments a deterrent or a driver?
            - Please define which interaction if possible
        - Can you describe the 2 most relevant organisational innovations?

        If the answer is no, please tell us the most relevant braking factor
        - Lack of stringency
        - Lack of policy commitment
        - Lack of transparency
        - High administrative /transaction costs
        - Low involvement of industrial actors in the process
        - Lack of integration with innovation/industrial policies

- Uncertainty related to the stability over time of policy/regulation

3. In case you have stated that environmental and energy policies **did not** influence inventions and innovations, could you select which factors were behind environmental innovations in your sectors
   a. Internally financed R&D
   b. Cooperation among firms (including R&D)
   c. International market factors
   d. Corporate social responsibility
   e. Market Demand (‘green’ demand)
   f. Civil society pressures (NGO)
   g. Other……………..

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