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Moving diversely towards the green economy. CO2 abating techno-organisational trajectories and environmental policy in EU sectors.

by

Massimiliano Mazzanti and Ugo Rizzo

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MOVING DIVERSELY TOWARDS THE GREEN ECONOMY. CO_2 ABATING TECHNO-ORGANISATIONAL TRAJECTORIES AND ENVIRONMENTAL POLICY IN EU SECTORS

Massimiliano Mazzanti[*] Ugo Rizzo[†]

Abstract

This paper investigates, from ex ante perspectives, potential techno-organisational dynamics aimed at reducing GHG emissions in the EU by 2030 and 2050. We take a qualitative view by exploiting interviews with representatives from principal manufacturing sectors in the EU. The novel value of this analysis is in its focus on 'sectors', which, following neo-Schumpeterian theory, are key 'players' in the technological domain. From a conceptual point of view, we mainly refer to the integrated concepts of sector and national systems of innovation which have consolidated into innovation-oriented evolutionary theory: The EU is characterized by national sector specialisations that emerge from historical developments and markets effects, but also from industrial, innovation and environmental policy effects. In this way this work complements more consolidated quantitative econometric and modelling based analyses, as it presents sector-specific techno-organisational options to help reach the decarbonisation targets. We assess the feasibility of those targets from technological and economic perspectives: specific emphasis is put on the smooth or 'radical' change-driven transition towards a greener economy. Both market and policy factors are considered. The assessment of experts' qualitative responses, together with main outcomes from the literature, shows that heavy industrial sectors share some similarities but also key distinctions in relation to their past and future responses to market and policy dynamics. Their specificities should be taken into consideration when defining the specific design of the future EU policy package for energy efficiency and CO_2 abatement at EU and national levels.

Keywords: techno-organisational change, climate change, EU 2030 2050 targets, sectors, eco-innovations

J.E.L.: L52; O33; Q58

[*] Department of Economics and Management, University of Ferrara, massimiliano.mazzanti@unife.it

[†] Department of Economics and Management, University of Ferrara, ugo.rizzo@unife.it

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1. Introduction: climate change, innovation dynamics and sector heterogeneity

In January 2014, the EU set its new binding targets for climate change mitigation policies, namely a 40% cut in CO_2 emissions with respect to those of 1990. This burden bears heavily on the shoulders of industrial sectors and transport. The relevance of industry in the green economy centres on two issues. First, even though at the moment the 2020 targets (-20% in emissions) have been achieved due to the EU's economic stagnation, a revival of economic growth in the last part of this decade could undermine this (EEA, 2014). This links to a second issue, also overlooked in 'environmental domains', namely the (non-binding) EU strategy to re-manufacture Europe: moving from the current 15% manufacturing share to 20% (of GDP) by 2020 (EC 2010). Given this, environmental and economic targets should be integrated. In the short run, re-manufacturing could well increase direct emissions. Nevertheless, manufacturing is more (eco)innovative than services (Cainelli and Mazzanti, 2013; Gilli et al., 2013). This points to the fact that composition and innovation issues are jointly relevant in explaining structural economic-environmental performances (Costantini et al., 2012; 2013). Sector and regionally oriented analyses are necessary to investigate the role of innovation and structural change in depth, since they are still somewhat hidden and unexplored, --even in macroeconomic studies that give attention to country heterogeneity and notstrictly income/time related effects (e.g. technology) as drivers of CO2 trends (Mazzanti and Musolesi 2014). It is well known that innovation is a crucial factor in achieving sustainable and competitive economic development in the long run. Technological progress has been long recognised as the only exogenous driver of long-term growth in income per capita. Economic growth theory has emphasised the role of R&D and human capital as the main forces behind country performances. Evolutionary theory poses innovation in a broad techno-organisational sense at the heart of economic systems' development. In studies of environmental and economic performances, innovations – of technological, organisational and behavioural nature – have gained increasing relevance as a key factor in obtaining sustainable transitions (Costantini and Mazzanti, 2013; Mazzanti and Montini, 2010; van den Bergh, 2007), and, more specifically, in decarbonising the economy (Edenhofer, Carraro and Hourcade, 2012). As outlined by IPAT models (Kaya identity), technological change is among the main factors that can compensate for the increasing scale of the economy as far as energy mix changes and structural change take place (Mazzanti and Zoboli, 2009).

Within techno-organisational change factors, environmental innovations (EI)[1], are crucial to creating synergies between sustainability and competitiveness towards a greener economy (Jaffe et al., 1995; 2003; EEA, 2013). It is well-known that sustainable economic growth depends upon constant investment in new technological and organisational/labour-related methods of managing production. The Stern review itself acknowledges technological change as one of the three pillars for climate change mitigation (policy and behavioural change being the others). Researchers have primarily focused on the drivers of environmental innovation and invention,

[1] "*The production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organisation (developing or adopting it) and which results, throughout its life-cycle, in a reduction of environmental risks, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives*" (Kemp, 2010). The definition comes from the EU FP7 *Measuring Eco Innovation* project. The definition of EI is not limited to specific technologies; it also includes new organisational methods, products, services and knowledge-oriented innovations.

directing their interest toward market and policy factors (Jaffe and Palmer, 1997; Brunnermeier and Cohen, 2003; OECD, 2011; Horbach 2008; Dechezlepretre et al., 2011; among others). Crespi (2013) interestingly merges EU CIS and NAMEA data to study the sector's drivers of innovation.

There is evidence that policy factors are among the levers of eco-innovative behaviour. In the EU, recent data (only available for eco-innovation adoption at a sector level) shows that carbon intensity (CO2 on value added) is pushing a higher adoption of EI. Whether carbon intensity captures policy stringency is an open question. Carbon intensity – highly heterogeneous across sectors – is a possible proxy of policy stringency at any rate (the heavier you are, the more regulated you are) and an endogenous pressure to innovate as well, in order to cut costs (Cainelli et al., 2013; Costantini and Mazzanti, 2012). It is worth noting that given the current status of the EU ETS – the only key climate change policy that is characterised by very low market prices (5€ per tonne in February 2014) and a correlated excess of supply (allowances) – sector carbon intensity is a serious driver of eco-innovation adoption. That is to say that ETS-regulated sectors are those with higher carbon intensity by definition (for EU ETS issues see among others Borghesi, 2011).

Figures 1-4 present evidence on the EI and CO_2/VA figures at the EU level by using sector disaggregated data. Figure 1 below presents the sector distribution of the two eco-innovation realms in a bi-dimensional space – energy efficiency and CO2 mitigation - with respect to CO2/VA in 2008 values. We note that though overall distribution is characterised by the presence of outliers, the fitted values show a positive link between the two factors: both innovation adoptions positively relate to CO_2/VA performances. The presence of sector dispersion and outliers is motivation for a more in-depth analysis of sector differences and idiosyncratic features, with specific attention on heavier 'agents'.

The 'positive' relationship we observed when looking at sectors merits some comment. First, it would seem that at the sector level, eco-innovation relates to CO2/VA in a way that is explainable as a 'reaction' of heavy/pollutant sectors through innovation. Whether this is more attributable to policy-making effects or market-based strategies is to be verified (Cainelli et al., 2013; Lanoie et al., 2011). It is also country specific: by using CIS data Borghesi et al. (2012) among others, show that the EU ETS stringency was not influential in supporting EI in Italian manufacturing firms, at least in its first phase where only structural features of the sector mattered.

From an evolutionary perspective, static analyses might capture the above-commented positive link between innovation and environmental efficiency over a given amount of time. Second, this might reflect differences between sectoral and national systems of innovation. A country performance is a weighted sum of many specialisations[2].

Third, the sector plot of the EU economy in 2006-2008 seems to suggest a 'policy induced' hypothesis. The sectors that present high CO_2/VA ratios are likely to be stimulated to innovate by more stringent policies. Innovation effects can then be appreciated over a dynamic scenario by different lags. Even beyond the policy effect, higher CO_2/VA ratios are likely to influence the adoption of innovation, with saving on energy costs as a main motivation.

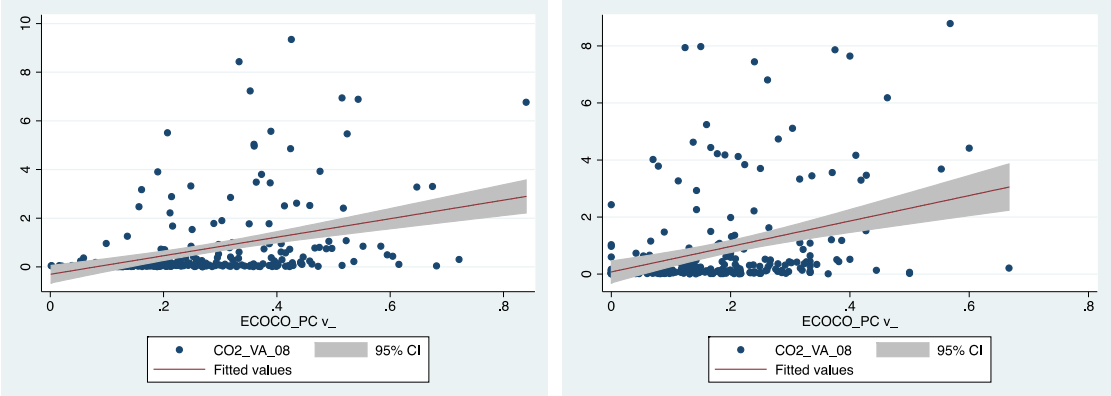
[2] There are heavy industrial sectors such as steel and ceramics that also present coherent high innovation adoptions (Cainelli et al., 2012, Borghesi et al., 2012).

The fact that this evidence is clearer for CO_2 abatement innovations and the EU12 area might be consistent with the specificity of CO_2 innovations with respect to general energy efficiency EI, and with a stronger reaction in sectors of countries which have experienced a path of convergence[3].

This is "food" for policy making, given that the climate change policy mix in EU countries is composed of energy-oriented strategies (energy taxation, renewable-energy oriented actions and subsidies) and specific carbon dioxide tools (carbon taxes, the EU ETS, carbon Funds, etc.). These policies – and their interaction – influence innovations in diversified ways. The effectiveness of policies should incorporate the innovation inducement effect, which here seems slightly larger for more specific CO_2 abatement technologies.

Again, the static 'photograph' seems to capture the fact that in the considered period, the heavier the sector performance, the higher its EI adoption, as a 'response' aimed at dynamically reducing the CO_2/VA ratio. Nevertheless, the heterogeneous picture and the rather low rates of adoption witnessed, besides in some leaders in the EU (Gilli et al., 2013), suggest that in order to achieve the 2030 targets, EU sectors should enhance their techno-organisational strategies and integrate green strategies within the package of key innovations (Antonioli et al., 2013). Without the enhancement of innovation adoption and diffusion even the 2020 targets (-20% GHG emissions) might be at risk if growth resumes its path. The year 2020 is an intermediate target that sets the pace for the achievement of relatively stringent 2030-2050 objectives. The way innovation is idiosyncratically adopted by firms in different sectors and consequently spread through sectors is important to understand. The (complement/substitute) effect of energy-environmental policies and market factors on innovations is a fundamental piece of this discourse (Antonioli, Borghesi, Crespi, D'Amato, Mazzanti, Nicolli, 2014; Antonioli, Borghesi, Gilli D'Amato, Mazzanti, Nicolli, 2013).

Figure 1 - CO_2/VA and CO_2 Innovation (EU15 and EU12)[4]



[3] Having said this, dynamic analyses are necessary in order to shed more light on the analysed performances.

[4] Data is taken from Eurostat (CIS data) and WIOD sector datasets. CO2/VA indicators and EI are over 2006-2008 (the time span of the only CIS that covers EI).

Figure 2 - CO_2/VA and energy efficiency Innovation (EU15 and EU12)

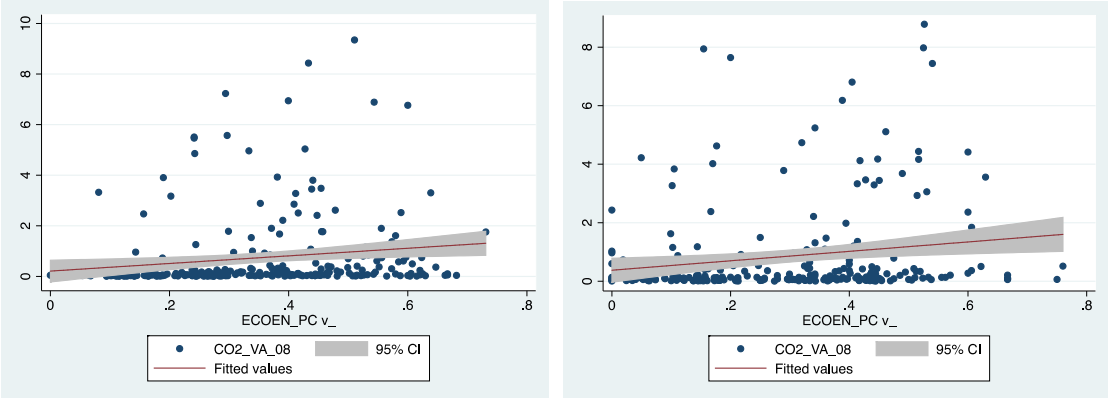


Figure 3 - CO_2/VA and CO_2 Innovation (EU, manufacturing)

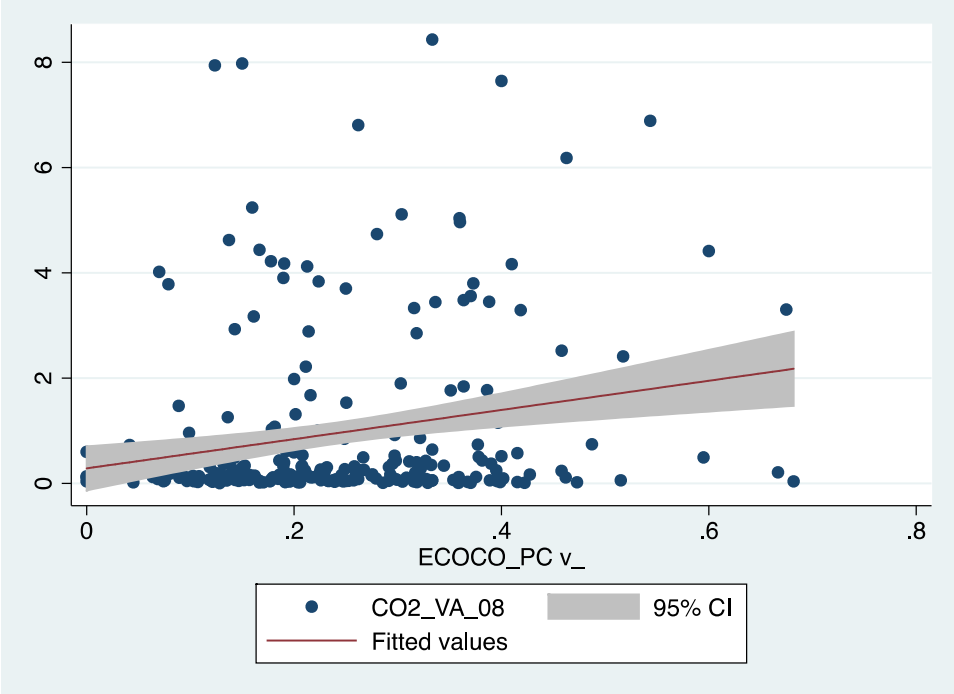
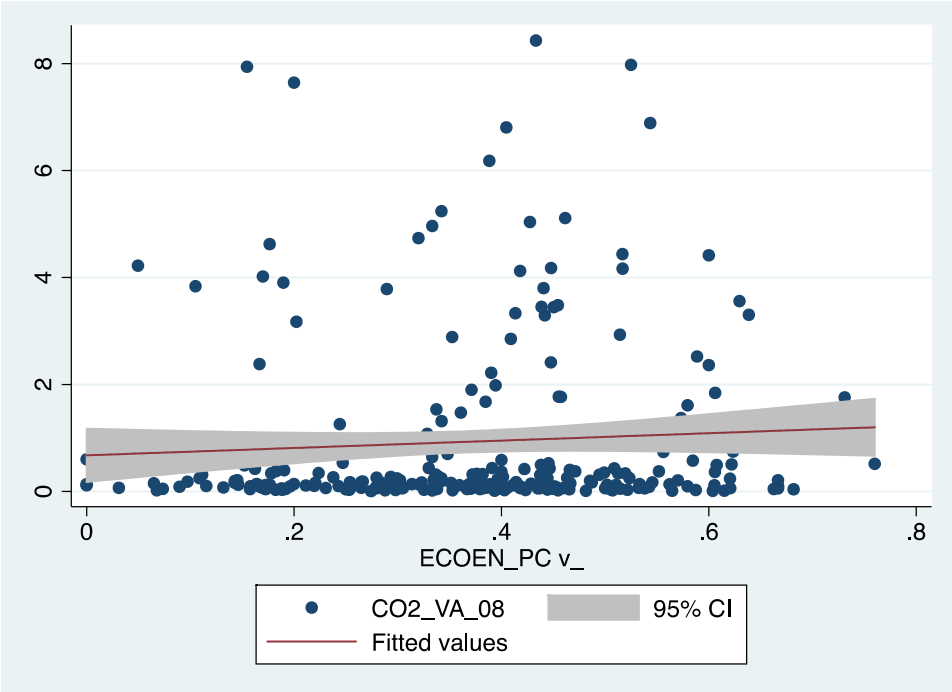


Figure 4 - CO_2/VA and Energy Efficiency Innovation (EU, manufacturing)



Sectoral issues have gained considerable consideration since the Pavitt (1984) taxonomy was introduced into the economics of innovation. From a conceptual point of view, we mainly refer to the integrated concepts of sectoral and national systems of innovation, which have been consolidated into an innovation-oriented evolutionary theory (Malerba and Orsenigo, 1997) and have been exploited in environmental economics literature examining EI and policy (Jaffe et al., 1995; 2003; 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, the complementarity they show between innovations and their market demand. Regarding policies, both from a strict innovation/industrial aspect and from an environmental aspect, these arguments matter: A 'one size fits all' approach may be not effective in supporting innovation diffusion and, consequently, economic and environmental performances. This is a hot-button issue in the EU, where 'mainstream economics' have probably influenced the implementation of policies that were constructed on the one-size-fits-all paradigm. The alternative is to shape policies according to sectoral and regional features following more bottom up and diversified approaches (Epicoco et al 2014).

Along such lines of thought, Peneder (2010) analyses the differences between firm level studies and sector analyses: firms' heterogeneity is crucial, but differences between sectors and their regularities are also important. Sectors represent a crucial and unique 'place' where innovation is developed and diffused: 'Industry characteristics matter and cannot be ignored […] [in designing policy programs and tailor[ing] them more effectively to the needs of targeted firms' (Peneder, 2010).

We here propose to complement (i) quantitative-oriented literature that assesses ex post the

drivers of innovation and performances; studies that econometrically focus on sector specificities (Marin and Mazzanti 2013) are also limited in terms of the way they can explore innovation issues; (ii) the macro modelling body of works (integrated assessment models, GTAP-energy models, agent based models) that aims at generating medium /long-term scenarios for GDP, CO2 and other variables of interest by coping with the challenge of making plausible and effective assumptions to endogenise technological change and innovation in a broader sense (Costantini and Mazzanti, 2013, Durance and Godet 2010). Even though sector issues have gained interest, especially in the integration between evolutionary and environmental economics (Borghesi et al., 2013; van den Bergh, 2007), one of the most effective ways to shed light on specific potential technological options is to gather experts' opinions and involve industrial actors (Mazzanti and Zoboli, 2006,). This is highly relevant to understanding what are the potential techno-organizational trajectories towards the achievement of medium and long run climate (and competitiveness) targets, with emphasis on feasibility and efficiency features (Svenfelta et al 2011).

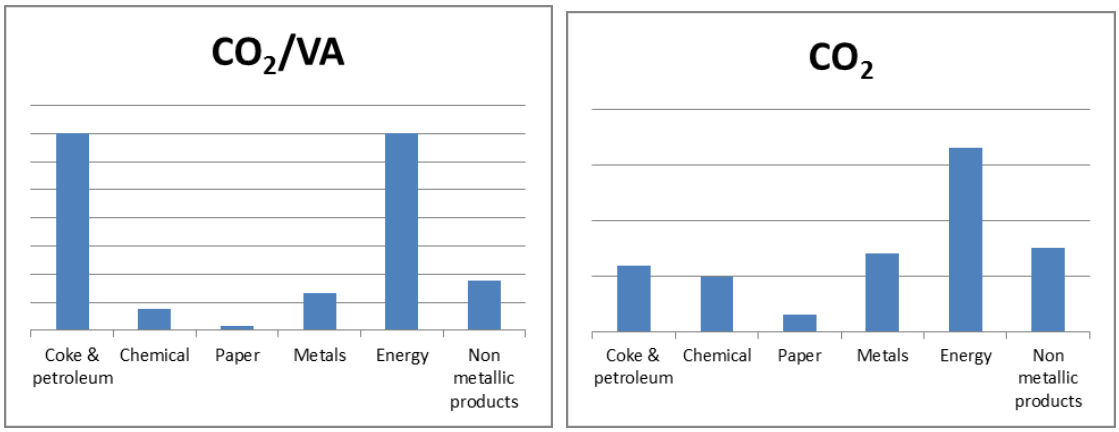
The paper is structured as follows: Section 2 describes the research design and the survey on sectors/experts. Section 3 narrates the main evidence. Section 4 concludes.

2. Research design

The exercise proposed here regards the assessment of future dynamics. An alternative option to ‘modelling techniques’, which is widely diffused to inform policy makers about uncertain future events, and particularly used in the realm of climate change, is to gather experts' opinions (Arnell et al 2005, Nordhaus 1994, Morgan and Keith 1995, Zubaryeva et al 2012, Varho and Tapio 2013). In order to answer the research questions advanced above, we thus conducted several interviews with selected experts, representative of the main ETS sectors in Europe. We specifically focus our analysis on three main industrial sectors: ceramics, energy and steel. Their interest lies in their relatively larger impact in terms of direct carbon dioxide emissions (Marin and Mazzanti, 2013, and Figure 5) and their inclusion in the EU ETS since the appearance of the policy (the chemical sector entered in the second phase). Though one aim of the paper is to highlight sector heterogeneity with regards to technological and organisational innovations dynamics, it must be noted that these three sectors are all heavy and regulated thus they share some common structural features.

In order to clarify the basis and objective of the analysis, the interviews started by providing a definition of Eco-Innovation, as cited in footnote 1 (Kemp 2010). The questionnaire investigated the techno-organisational dynamics that could potentially lead sectors to reach European GHG reduction targets. Questions regarded the investigation of which innovations, both technological and organisational, could be developed to reduce GHG emissions in the EU by 2030 and by 2050. Both market and policy factors were considered as drivers of the changes sectors need to introduce to fulfil the expectations of EU strategy.

Figure 5: CO_2/VA and CO_2 emissions in EU27 by sector, year 2009



Source: authors' elaboration on Eurostat data

The questionnaire was semi-structured, and half of the questions were left open-ended in order to avoid imposing constraints to those interviewed (Bostrom et al 1994, Read et al 1994). Our aim was not to collect data and elicit information in order to formalise and quantify probability distributions for a number of different scenarios (e.g. Morgan and Keith 1995, Keith 1996). Rather, we aimed to collect the opinions of a set of experts, taking into account their variability, in order to identify solutions that may inform policy makers (Keith 1996, Arnell et al 2005, Baker et al 2014).

Experts were contacted and selected through different channels. The questionnaire was developed for technical directors of the industrial associations across European countries and of the European Union. We therefore initially contacted these associations and asked their technical directors to take part in our study on future dynamics perceived with respect to their sector of reference. In order to provide a more comprehensive picture on future possibilities (Keith 1996) and to assure data triangulation (Jick 1979, Yin 2008), we also interviewed expert academics and technical directors of major multinational companies which are leaders in their sector of reference.

We contacted several selected experts across Europe and asked them to take part in the questionnaire by agreeing to be interviewed by phone. Interviews lasted an average of 45 minutes. In order to collect a higher number of answers, we also allowed the experts to fill out an online form in the case the (s)he preferred this format. Overall, we conducted 10 direct interviews and received 13 web-answers. The direct interviews were also characterised by the use of 'follow-up' questions, when needed, in order to gain a more detailed comprehension of critical issues. We collected 10 opinions from energy experts, six from the ceramics sector and nine from the steel sector.[5] Some details about the people interviewed is given in Table 1. The information collected was then integrated with the analysis of literature and reports, in particular with the Roadmap to 2050 GHG reduction that various sectoral European associations edited.

[5] Experts were based in: Italy (10 experts), Spain (3), Belgium (2), Netherlands (2), UK (1), Germany (1)

Table 1: The set of interviewed Experts

	Energy	Ceramics	Steel
Interview type			
Direct interview	3	3	5
Web-answer	7	3	4
Respondents nature			
Sectoral Associations	5	2	4
Academia	3	0	0
Companies	2	4	5

3. Technological trajectories towards 2030 and 2050 climate targets: evidence from three industrial EU sectors

In the following we describe the results of the interviews together with the analysis of reports and specific literature on each sector. We treat all of this as complementary information and evidence. For a new assessment of GHG emission trends we refer to the EC's (2014) 'EU energy, transport and GHG emission trends to 2050'.

3.1 Energy

Energy is the key sector on which European climate policy depends in order to accomplish decarbonisation of the economy. In 2009, the CO_2 produced by electricity and heat accounted for 36.5% of the total CO_2 emitted in the EU (IEA 2011). The DG Climate road map (EC 2011) estimates that the least cost effective solution for decarbonising the economy would call for a 93-99% GHG emission reduction in the power sector, and one of 88-91% in the residential and tertiary sector.

According to various reports and articles (Think 2011, Lund and Mathiesen 2009, Ruester et al 2014, ECF 2010, Meeus et al 2012), there are three broad points of interest upon which the energy sector may lean in moving towards a low carbon European economy: energy savings and efficiency, the development and diffusion of renewable energy technologies, and the development of energy infrastructure and an energy market. In order to support these pillars, two transversal points of intervention have been identified: investment in R&D and technology development, and in fuel and CO2 prices, that is carbon pricing (Pearce, 2003; Meeus et al 2012).

For what concerns technological innovation mechanisms, 'the key challenge that is implicit in all the visions is to develop the technologies that are not yet available, and to reduce the costs of

technologies that are already available' (Meeus et al 2012). According to the ECF (2010, p. 10) Europe could reach the 80% GHG emission reduction target by 2050 'by deploying technologies already commercial today or in the late development stage'.

Interviewed experts argue that renewable energies together with energy efficiency, especially in the building sector, are the main issues on which to start the GHG reduction toward 2030. Such technological innovations, however, could make a significant step only if coupled with organisational and societal initiatives. The statement of one interviewed expert serves as the example of a widely shared opinion within the sample we surveyed:

'a main challenge now will be to plug all these renewable energy sources into the grid, especially in view of the incumbent production profile which differs very much from the consumption profile. In my opinion, smart grid developments (both electrical and thermal) will accelerate. A main organisational innovation will be the enforced involvement of citizens. Co-operative organisations have demonstrated themselves as the driving force behind renewable energy deployment in Germany. Traditional companies running classic power stations now experience that the business models they relied on are starting to fail. There will be a need for new business models.'

As could perhaps be expected, emerging clearly from the investigation was the idea that in order to accomplish European targets, clear cut and complementary policies need to be designed and implemented. These policies regard innovation and R&D subsidies on the one hand, and on the other incentives to adopt renewable and energy efficiency measures. These considerations are particularly valuable in the short-term, since fossil fuels continue to be cheaper to produce than renewable energy[6].

As regards the reduction target the EU envisages for 2050, experts pointed to the need of developing capabilities for storing the excess electricity produced by means of renewables, together with smart grid development to foster the transition toward a decentralised energy production.

At the same time, a radical technology that could become available by 2020-2030, but whose development (cost) feasibility and social acceptance remain uncertain (Lovelace and Temple 2012), is Carbon Capture and Storage (CCS). The EC (2014) revises difficulties and delays upward in the development of CCS in the new 2050 scenario development. CCS consists in the development of mechanisms to capture and store, deep below earth, the CO2 produced in a wide variety of productions, from the power sector to industry. Although studies forecast it will be commercial only in the next 10 to 20 years, according to different sources (e.g. IEA 2011, EFC 2010), it is acknowledged that such a development needs to be driven by large amount of R&D spending (Haszeldine 2009). Moreover, the great uncertainty behind an adequate development of this technology has led some future scenario models not to even take it into account (e.g. EREC Greenpeace 2007). However, the majority of possible paths forecasting models leading toward a zero carbon energy sector always rely on the development and use of this technology (e.g. IEA 2011, EFC 2010, Meeus et al 2012).

[6] EC (2014) notes that strong cost reductions have been experienced mainly for solar photovoltaics while remote offshore wind capital costs have increased. This illustrates the high dynamic uncertainty over the set of relative prices (e.g. fossil fuels vs. renewables and across fossil fuels and renewables), due to the joint effect of market and policy factors.

Similarly, although experts often point to the uncertainties of a feasible development and deployment, they still tend to cite CCS as a major tool that could help reach the 2050 EU targets. More specifically, together with the development of smart grids, CCS is the main technological breakthrough that could create a steep increase in the decarbonisation trend. On the policy side of things, together with investment in R&D[7], a significant cost reduction of renewables is particularly important in the long term.

A policy initiative that is considered vital to developing eco-innovation activities regards the increase in carbon and oil prices. Such a policy strategy, differently from R&D and innovation subsidies, does not pick out "winning" technologies, and therefore represents a 'technology-neutral financial support to innovation' (Ruester et al 2014). Such an initiative, if centrally managed at the European level, could, however, simply lead to the de-localisation of high carbon emitting production toward countries with cheaper carbon and fuel prices.

The adoption of higher carbon and oil prices should thus be combined with policies with a greater technological push. Some experts interviewed, however, expressed different opinions on the usefulness of both carbon taxes and of an increase in fuel and oil prices; others considered such pricing policies important but had different visions as to "right" carbon and oil prices that could lead to the adoption of radical innovative technologies. Such results are in line with the various forecast models proposed in the literature (e.g. Capros et al 2012). More specifically, from both interviews and literature, prices should increase by two or three times their actual amount for oil, and move toward 30 to 60 Euro per ton of CO_2 emission. As one interviewed expert stated: 'certainly the price of CO_2 cannot be lower than 30-50 Euros per ton if it is to become relevant in firms' decisions'. However, various experts also pointed out that the most important element is not price per se, but the 'relative price difference between oil products and alternative products'. In addition, specific sector-oriented earmarked funding inspired by the recycling of carbon taxation and/or EU ETS auction revenue often emerged in interviews as a key policy package, which would integrate pricing and R&D/EI adoption funding.

3.2 Steel

The steel industry is one of the highest in CO_2 emissions. From 1990 to 2010 a 25% decrease in absolute emission of CO_2 has been registered in Europe, mostly because of a decrease in production, and only partly due to a technological upgrade in the industry. In fact, CO_2 emissions per ton of crude steel only decreased by 14% in the same time frame (BCC-VdeH 2013, Eurofer 2013).

The European steel industry is mostly based on two production cycles (Flues et al 2013, BCC-VdeH 2013): use of a blast furnace to remove the oxide from iron together with a basic oxygen furnace used to produce steel (BF-BOF), or a scrap-electric arc furnace (Scrap-EAF). The first method is used in the production of steel from extracted iron from mines, and in 2010 represented 59% of EU27 production; while the second is followed to make steel starting from scrap metal, and accounted for the other 41% of production in the same year. While BF-BOF allows for the production of high quality steel, the Scrap-EAF steel output largely depends on

[7] We recall that the EU 3% of GDP target set in the Lisbon agenda is not fulfilled yet. The average is about 1.75%. even Germany does not reach 3%.

the quality and types of scrap, as well as on their availability. As a consequence, BF-BOF produced steel is directed toward high quality products, such as vehicles, while scrap-EAF is usually used for products with a lower demand for quality, such as construction. BF-BOF production generates higher CO_2 emissions, and in Europe a shift from this production toward scrap-EAF is taking place: the latter represented only 28% of steel production in 1990. However, scrap-EAF requires a higher volume of energy input, also because in BF-BOF allows for the reuse of gases generated along the production chain to generate electricity and heat (integrated plant). On the contrary, scrap-EAF does not allow for reuse of the energy input.

Scrap-EAF is highly energy intense, especially for what concerns electricity: roughly half of its CO_2 emissions indirectly derive from the production of electricity employed in steel production. As a consequence, an important share of CO_2 emission reduction has been obtained by supplying electricity through renewable energy (Eurofer 2013). However, electricity and energy prices in Europe more generally are far higher compared to those in the US and Asian countries, and have been increasing significantly in the last decade. For this reason the economic feasibility of EAF is largely dependent on energy prices, which are also highly volatile.

From a technological point of view, several future scenarios have been recently outlined in order to assess the feasibility of GHG emission reduction. Although a significant number of technologies are in development, both of an incremental and radical nature, it seems that 2050 EU reduction targets for GHG emission will hardly be obtainable in the steel sector. As an illustrative example, when asked: 'Will your sector achieve 2030 EU targets?', an industry association respondent stated: 'There is no technology available to do so nor is it thermodynamically possible'. The same point is clearly expressed in the opening lines of the BCC-VdeH (2013) report as well:

'For the time being there are no economically feasible steel making technologies available that have the potential to meet the CO2 reduction pathway envisaged in the Commission Roadmap for moving to a competitive low carbon economy in 2050. At best, a 15% decrease in the overall CO2 intensity of the sector could be achieved between 2010 and 2050 through the widespread dissemination of technologies that could reasonably become cost-effective in the future.'

Among the main strategies to maximise GHG reduction is an 'improvement in the CO2 load of electricity consumed' and a shift from BF-BOF to scrap-EAF (BCC-VdeH 2013, p. 16). These two strategies are clearly very interconnected, although such a shift also has to deal with the scrap availability. The problem of the cost of electricity may however once again lead to a de-localisation of steel production toward countries with lower energy prices.

From a technological perspective, as stated above, several incremental technologies are regarded as having an impact on future GHG reduction. For example, Sinter-Plant-Cooler heat recovery or the Optimization of Pellet Ration to BF-BOF. However, while resulting in most of the efficiency and emission reduction gained since 1970 (Rynikiewicz 2008), such technologies are considered to be able to produce at best a 28% cut on CO_2 emissions per ton by 2050, and to lead to a reduction in absolute CO2 emissions of 13% from the 1990 level, assuming an increase in the demand and production of steel.

A larger GHG reduction may be reached through the adoption of radical technologies (Moya and Pardo 2013). Various reports and scenarios about the European steel industry again point to CCS as an important technology that may be developed in the next 15-20 years. In the words of

a stakeholder representing an international steel association: 'Only Carbon Capture and Storage is likely to be able to make a difference'.

In 2004, Ulcos, a European consortium formed by the main European steel producers, was developed to assess what possible technologies could lead to a reduction in CO2 emissions in the steel industry by 50%. This consortium concluded that four different technologies could lead to such an improvement. However, in order for any of these technologies to make a real impact on emission abatement, they needed to be coupled with CCS. CCS emerges therefore as the only radical change which could possibly lead toward the 2050 EU GHG reduction target. But this breakthrough technology development will not be in place before 2020-2025, and at the same time both its feasibility and its level of acceptability are regarded as rather questionable (e.g. EREC Greenpeace 2007). Moreover, this technology is not steel specific, and in the steel industry it may only be applied to BF processes.

Although uncertain, the route to maximising CO2 reduction is thus regarded to be mostly a matter of technological development (Pardo and Moya 2013)[8]. The stakeholders we interviewed stated that two main sets of policies are important in order to increase GHG reduction. The first policies have to do with R&D and innovation subsidies, and the second regard the definition of standards. Among the main obstacles to moving toward a low carbon steel industry is in fact the lack of financial resources to invest in technological innovation and the price volatility of input, especially electricity prices. The adoption and shift to EAF is therefore limited by the volatility of electricity prices along with the availability of scrap.

Summing up, according to the interviewed experts, the steel industry will not reach or even near both 2030 and 2050 EU targets. At the same time policies are needed to avoid a massive de-localisation process to countries with less environmentally stringent laws and with lower energy prices. In line with this reasoning, several reports claim that this type of de-localisation would produce a carbon leakage phenomenon, therefore not improving the efficiency of the industry, and would not take the complementarity of the steel industry with other sectors into account, such as the automotive sector, construction, wind farms, and so on. In the words of a stakeholder: 'There is a need for a global climate convention with equal requirements for all effected stakeholders that guarantees a level playing field'.

At the same time, it has been argued that steel is a mitigating enabler: developing innovative steel grades can enhance CO2 emission savings in other industries. Steel associations therefore claim that in order to assess CO2 emission in the steel industry it is necessary to consider the complementarity of steel with other sectors and the impact of steel in other industry emission reductions, thus taking into account indirect inter-sector effects (Marin et al., 2012).

Finally, oil and carbon prices are considered not to be important in fostering innovation

[8] Though some leaders in the sector (multinational Italian firms) presented the case of integration between technological change, organisational change and training. As an example, the role of organisational change, or better, high performance work practices (HPWP) is interestingly highlighted as a key innovation. Within such practices, training programmes dominate. The chain seems to start at the technological level, then training complements the EI adoption. Training is key to making the technological options concrete: energy efficiency improvements highly depend upon the behaviour of factory workers at the production level, and also on their feedbacks on further marginal efficiency improvements to machinery functioning/timing . Some leading firms in the sector have current training goals that should cover 95% of the workforce and 2% of their working hours as formal training. The role of training has recently been noted by Cainelli et al. (2012) in econometric EI studies.

activity in the steel sector[9]. More specifically, there was agreement among the experts interviewed that significantly increasing oil and carbon prices would mostly lead to the de-localisation of steel production, causing negative consequences for the European steel industry[10]. This is an historically debated issue, linked to the 'Pollution Have' debate. Empirical evidence is mixed (Wagner and Tiimins, 2009). In addition, the pollution have hypothesis should be treated in integration with the Porter Hypothesis and the Innovation Leakage Effect (Costantini and Mazzanti, 2012). Environmental policies risk inducing de-localisation as well as innovation. Again, this might be a very specific sector effect (Wagner and Timmins, 2009) which cannot be analysed at only a macroeconomic scale. Policy design therefore also matters. As an example, implementing a given policy upstream or downstream, such as R&D subsidy, may influence invention and innovation adoption in different ways (Fischer and Salant, 2013) for the country's economic performance. In a nutshell, environmental policy is a possible driver of de-localization. Nevertheless, the innovation / competitiveness aspect should not be overlooked: well-designed policies might induce higher innovation and economic performances. Which stage in the production chain a fiscal policy impacts is also relevant for innovation inducement and competitiveness targets. This is clearly crucial for the current and future design of environmental EU policies.

3.3 Ceramics

The European ceramic sector accounts for 23% of the total world production (Cerame-Unie 2013). Similar to the steel sector, it is experiencing a decrease in production. As a consequence, a decrease in CO2 from 1990 to 2010 has also been registered (Cerame-Unie 2013). At the same time most of the interviewed experts expressed the conviction that it is highly likely that the GHG reduction targets will be reached by 2050. In contrast to this, the European Ceramic Industry Roadmap (Cerame-Unie 2013) considers a significant increase in the demand for ceramics, and, in line with one of the experts we interviewed, states that the EU GHG reduction targets will hardly be reached by 2050. This shows how assumptions about demand and GDP growth are crucial. In addition, the 're manufacturing' scenario is critical in assessing future dynamics, as it influences economic and environmental performances through composition and innovation effects (EEA, 2014).

Several improvements have taken place from a technological point of view in the processes of ceramics production, and significant CO2 reduction mechanisms have been put in place in the last 30 years. These emission reduction processes have above all regarded the reduction in energy consumption in some phases of ceramics production processes. In 2011, the energy

[9] It might be true that the indirect effects of high energy taxation are more effective than CO2tailored economic instruments. All in all, in the case of steel, only higher CO2 prices – even higher than 25-30€ per tonne - would significantly change technological behaviour with specific respect to the carbon content (and not only the energy content) of options.

[10] Other respondents nevertheless stated that policies have so far marginally increased the value of already existing 'low hanging fruits' in energy efficiency. More costly and problematic actions, such as cutting CO2 through a full closure of the material loops and enhanced recyclability of materials along the process, are (thus far untaken) paths for the future. A clear distinction is therefore made between energy saving strategies (more appropriable by firms in terms of rents) and CO2 (a mixed or full public good for a firm, see Corradini et al., 2014 for innovation and abatement analyses taking mixed goods into account) and – as a correlated issue – between past achievements and more stringent 2030-2050 targets.

sources used in ceramics production were natural gas for 85% and electricity for 15% (Cerame-Unie 2013). In the last decades a substitution of solid fuel energy sources toward the use of natural gas led to important energy efficiency improvements, and a consequent reduction in CO2 production. For example, 'the energy used to produce the bricks for a 1m brick wall decreased by 39% from 1990 to 2007. For one tonne of wall and floor tiles, the energy used decreased by 47% from 1980 to 2003' (Cerame-Unie 2013, p. 11). Energy saving mechanisms such as co-generation represent an important incremental improvement that could enhance GHG reduction in the future.

A method which would significantly reduce emissions in ceramics production would be the 'electrification of kilns using low-carbon electricity' sources (Cerame-Unie 2013, p. 12). This point was also raised, together with other measures, by two of the experts we interviewed. However, according to Cerame-Unie (2013), such a path is not economically feasible, also because several gas-based 40-year- life kilns have recently substituted the older solid fuel kilns. Other possibilities that could lead to reducing emissions by 2030 have been proposed by stakeholders in the ceramics industry. For example, one company's technical director affirmed: 'We have developed a new mixture of porcelain which reduces cooking by 40% in consumption thanks to the use of glass, which cooks the mixture at lower temperatures. […] We also need new kilns that reduce consumption". Along the same lines, an expert stakeholder stressed that important aspects regard '[a] change in the formulation of the mixtures in order to decrease the cooking temperature […] and […] study[ing] and build[ing] new plants, kilns and atomizers that consume less gas'. According to the experts interviewed, these innovative processes could mostly be favoured by the creation of a competitive environment and by operating on "energy costs" and on "green demand".

Shifting his attention onto the 2050 GHG reduction targets, the expert interviewed continued to state that the main techno-organisational dynamics to be incentivised would be energy saving, energy efficiency and the electrification of kilns. In other words, the factors on which to build a GHG emission reduction path in the ceramics industry remain for the most part consistent. However, one expert also claims that technological breakthrough could play an important role, specifically development of the smart grid.

None of the experts interviewed cited the development of CCS. On the contrary, according to the European Ceramic Industry Roadmap report, CCS could play a role if the target is that set by the European Commission under the ETS reduction targets. As a consequence the experts we interviewed did not really seem to push for any policy initiative towards the investment in innovation technologies. Only two experts (one of which claimed the need for the development of the smart grid) think that subsidising R&D and innovation activities could have a relevant effect on CO2 reduction.

For what concerns the pricing issue, our investigation revealed a disparity of views. While some experts do not consider the price of oil as important for this sector, since the main energy source in this case is gas, others think that raising the price of oil by two to three times the current price could have a positive effect. Conversely, only one expert does not consider CO2 pricing as important in driving innovative improvement in the industry. This expert claims that increasing the price of CO2 would only lead to a major de-localisation of the production processes in countries with cheaper prices and less environmental stringencies. The other experts, on the contrary, claim that the price of CO2 which could stimulate the adoption of

radical innovation would be from 30 to 100 USD per ton of CO2.

Finally, it is important to note that from the interviews conducted, also highlighted in the Cerame-Unie (2013, p. 4) Roadmap, it emerges that ceramics, like steel, can be considered a 'mitigation enabler':

Ceramic products are designed to be durable. This is achieved through high-temperature firing of a wide range of minerals, from locally-sourced clay to natural or synthetic high-quality industrial minerals, to produce carefully-controlled materials. The contribution of such products to resource and energy efficiency can only be appreciated with a holistic approach that considers the complete life-cycle of the product, including its durability and impact over the use phase. This approach should also take into account all relevant environmental indicators, such as biodiversity, ecological and human toxicity and water use. This holistic approach is required to ensure the responsible promotion of ceramic products made in the EU instead of less durable products or other ceramic products imported from less environmentally-regulated countries.

The Spire Roadmap (Spire 2010) conducted a study on the industry's GHG emission scenarios toward 2030 and the results revealed that 'indirectly, as energy consumption will be reduced, lower CO2 emissions and other greenhouse gases will be emitted. In the ceramics sector this is expected to allow feedstock savings greater than 11%, operating cost reductions of at least 19%, and productivity increases of at least 22%.'

As a consequence, the argument stressed by the Cerame-Unie Roadmap is that too stringent policies on CO2 and energy prices could lead to the de-localisation of an industry that could otherwise contribute to building a decarbonised economy. The main point raised by the experts we interviewed is that the innovative products emerging in the ceramics sector should be better exploited. This highlights the need of integrating value creation and emission cuts as unavoidably integrated aims in CO2 abatement. CO2 cannot be cut through end of pipe technologies. It requires a deep reshuffling of energy components within sectors together with radical innovations. These goals cannot be achieved without a full integration of economic and environmental concerns to further abate CO2/value added indicators and CO2 in and of itself.

In this regard, while explaining a new product development project his company was working on a technical director asked: 'Will there be a market for these products? In the end a brick is just a brick".

4. Conclusions

This work investigates potential techno-organisational dynamics in three main polluting EU sectors towards the reduction of GHG emissions in the EU by 2030 and 2050. The analysis on the one hand highlighted considerable differences among the sectors analysed, and on the other revealed some important elements of common perspective in these sectors.

First of all, innovations, of both radical and incremental natures, remain fundamental in moving toward the GHG reduction targets in all sectors. However, in order to reach the prospected targets, it is not sufficient to continue down the present path mostly based on incremental improvements dedicated to improving energy efficiency and adopting incremental

technical innovation, but requires radical technologies to get close to EU targets. As a consequence, if the objective is to develop some breakthrough technologies in the relatively short term, important public investments in R&D are needed to achieve at least the EU Lisbon agenda 3% target. This funding might be tailored to green economy pathways and foster new EU specialisation within the 're-manufacturing' policy agenda.

The most cited radical innovations that could help move towards the reduction target are CCS and the development of smart grids. However CCS is still in very early stages of development, it requires an important level of expenditure to move its feasibility forward, and is not largely socially accepted. On the contrary, smart grid development seems to represent a feasible option in the relatively short term. It is not only a major innovation, but also represent a tool with which to implement a unified electricity market in the EU, allowing for increasing efficiency returns.

Technical innovations, though, emerged from the analysis as only one side of the coin. The large majority of experts and stakeholders supported the idea that the potential of technological innovation may have an impact only if coupled with organisational and societal innovations. The creation of a unified energy market is in addition a key economic/institutional leverage condition.

Regarding differences across sectors, this work highlighted some of key relevance. A certain usefulness of R&D and innovation subsidies emerges in both the energy and steel sectors, while in the ceramics sector innovation subsidies are not seen as related to large GHG reduction. Ceramics is overall – from ex post and ex ante views – the most policy-detached sector. As they are highly polluting (and also highly innovative), this is to be taken under consideration from a policy perspective.

In the ceramics and in the steel sectors an important problem to face is a loss in production volumes: while this element seemingly improves the reduction trend in the sector, it has a negative impact on this sector's development in Europe and on its capability of generating innovations. More specifically, the high reduction targets imposed by the EU may end up mostly producing a de-localization of production rather than significant improvements in sectoral efficiencies. As a consequence, while experts in the energy sector claim that policy initiatives of various nature may represent a main driver in reaching the EU targets; in the other sectors the most important options regard an understanding of the strategic roles of ceramics and steel production in the European economy. In other words, ceramics and steel experts assert that it is important to consider the complementarities between these productions and other sectors: improving the quality of materials could enhance energy savings across a wide variety of economic production processes. This factor seems particularly important, especially with respect to the willingness of the EU to increase its manufacturing activities share. It also highlights the need to analyse a given sector's economic and environmental performances under a broad and integrated inter-sector approach, which encompasses both manufacturing itself and also considers the reality linking services and manufacturing.

Finally, the role of oil and carbon prices are also perceived very differently from sector to sector. While these prices may represent a major strategy of action for reducing GHG emissions in the energy sector, they are seen as negatively impacting the steel sector, and regarded as mostly neutral in the ceramics sector. It must be specified that pricing issues are often considered in a very diverse way even within the same sector by the experts we interviewed.

This reinforces the necessity to reflect upon a potential complementarity between economic tools based on pricing and more extensive innovation and industrial policies, in order to enhance the efficiency and effectiveness of these policies through innovation creation and diffusion in the medium-long term.

When setting the policy agenda for the future path towards a green economy, great consideration is to be given to the integrated policy package that might support innovation – environmental, innovation, industrial. EU, national and regional policy packages should also consider both idiosyncratic sectoral responses involving innovation and how (increasing) sector integration influences a given sector's techno-organisational trajectories.

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