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Technological contribution of MNEs to the growing energy greentech sector in the early post-Kyoto period[1]

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Abstract

We consider the commitment of 946 large firms with high R&D investments and a sustained patenting activity to the development of climate change mitigation technologies related to the production or storage of energy (energy CCMT) across countries and industries. We systemically compare the situation before (1994-1996) and after (2003-2005) the signature of the Kyoto Protocol. Using priority patent applications, we give an empirical description of the corporate patenting activity and assess the contribution of corporate patenting to the overall energy CCMT across countries and sectors of energy CCMT. We find that in the decade a growing share of firms contributed to patenting in energy CCMT and that the share of greentech patents has increased (from 1.6% to 2.3%) in large firm patent portfolio. But the overall contribution of large firms to the energy CCTM patenting remains lower than that in other technologies. Large variations of corporate commitment are observed among countries and sectors of energy CCMT. A large commitment to energy CCMT is encountered in Japan where large firms account for two third of the energy greentech patenting. In western countries, the situation is more contrasted. The results suggest that US MNEs were more prone to gain skills in renewable energy technologies than most of their European counterparts. However some EU firms like public firms in the sector of energy show a high level of commitment similar to what is observed elsewhere.

[1] A part of the topics delineated in this paper have been set out in the frame of the international conference *Gouvernance of a Complex World 2014, 18-20 Jun 2014 Turin (Italy).*

Introduction

The climate change issues have become a global concern imposing pressure on decision makers in both governments and corporations. Since 1992 obligations were taken to address climate change issues through enhanced scientific and technological cooperation, assessment of sources of greenhouse gas (GHG) emissions and removals, policies and measures to mitigate GHG and to promote adaptation to climate changes (Borghesi et al., 2002). The Kyoto Protocol (1997) established emission reduction targets but was rejected in 2001 by the US arguing of the absence of obligations for all GHG emitters and possible negative effects on the US economy. Many new regional and national policies followed the signing of the Kyoto Protocol where developed countries agreed to limit emissions of greenhouse gases. Governmental incentives such as Feed-in-Tariffs and Renewable Portfolio Standard aimed to promote clean energy while grants, tax credits or preferential lending practices were designed to promote the development of renewable technologies.

The extent and scope of State support differ across countries. Several European countries emerged as early movers in promoting the supply and demand of clean energy and EU policies have reinforced member state programs (promoting high R&D levels, the pre-emption of the EU internal market with an early positioning in countries such as Germany, the UK and Italy, and public incentives and standards propelling EU technology deployment). Consequently, Europe hosts many leading clean energy companies (Germany, Spain and Denmark house some of the world leading wind and solar firms: Q-Cells and SolarWorld (Germany), Iberdrola and Acciona (Spain), Vestas (Denmark)[2]). At the national level, Denmark has established a strong technological advantage in wind technologies; Sweden and Germany have specialized in bioenergy, Germany and Spain in solar, Norway and Austria in hydropower. Japan was also an early mover in cleantech. Without national energy resources, it got engaged in environmental innovation policy after the oil shocks (the Sunshine Programme was design to introduce solar power in the 1970s). These developments were partly responsible for establishing major Japanese solar photovoltaic (PV) manufacturers and a thriving solar industry (Foster, 2010)[3]. The WE-NET (World Energy Network) project was another large project initiated in 1993 and completed in 2002 to enable the introduction of a worldwide network for development of abundant renewable energy resources, their transportation and utilization through a large government-academia-industry joint venture. Japan has promoted the consumption of renewable energy via European style FiTs (Feed-in Tariffs), although government support has not been always very consistent. On the supply side, development of renewable energy resources has benefited from strong state support and continues to be led by major integrated manufacturers. Conversely United States has suffered from the lack of a coherent national energy policy and effective legislation creating incentives for renewables development but at the state level policies to promote clean energy industries were implemented.
The correlation between political decisions resulting from the Kyoto Protocol signature and the take-off of clean-energy technologies was largely documented and many researches

[2] These firms do not belong to our firm dataset because they do not satisfy our requirements in terms of sustained patenting activity (see methological details in section II).
[3] Japan was the first country to reach 1 GW of installed solar capacity in 2004 thanks to the first subsidy programme started in 1994 for residential solar panels.

were conducted to investigate the role and efficiency of the various instruments set up to promote environmental technologies (Jaffre, 2003; Johnstone, 2010; Veugelers, 2011). In order to measure the activity in promoting greentech, many scholars used surveys[4] or patent data that provide good indications of the type of research outputs that are produced (Popp, 2005) and give detailed information on the number of patents issued over time in different countries and on applicants' name and location. They are considered to correctly reflect the level of R&D investments (Griliches, 1990) and to be adapted to investigate the consequence of the public policy framework put in place to support the development of cleantech. They also offer accessibility over long period of time, cover worldwide innovative activity (but due to different patenting rules across patent offices, the level of innovation and the propensity to apply for patents vary across countries but also across industries or firms). For example, multiple patents for the same invention can be applied for in some countries while only single patent will be applied for the same invention in others[5]. Because patents can cover inventions of substantially heterogeneous economic value (Pavitt, 1988), most studies using patents set a quality threshold by taking into account the patent family size[6] or select only patents applied for at WIPO (World Intellectual Property Organization), USPTO (United States Patent and Trademark Office), EPO (European Patent Office) or triadic patents (patents applied at EPO, USPTO and JPO). The underlined idea is to consider that only patent applications of the most valuable inventions are filed in several patent offices.
Using patents, Popp (2002) identified increasing prices of energy in the oil crisis as the significant driver of energy-saving inventions. Early empirical evidences that regulation triggers eco-innovations were given by Lanjouw and Mody (1996). They associate international patenting behaviour regarding environmentally related technologies with pollution-abatement spending in different countries. Jaffe and Palmer (1997) take the R&D process into account as well as the outcomes of inventive processes (measured with patent applications) and do not find any statistically significant effect of pollution-control expenditures on patenting activities. In contrast, Brunnermeier and Cohen (2003) find a link between pollution-abatement spending and successful patent applications related to environmental technologies. Johnstone (2010) gives evidence that these R&D programs lead to increases in patenting activity for the targeted technologies. The effect of the liberalization of the energy sector on green innovation was also investigated. Nesta (2014) shows that renewable energy policies are more effective in fostering green innovation in countries with liberalized energy markets. But according to Sanyal and Cohen (2009) and Jamasb and Pollitt (2008) R&D expenditures and patent activities declined after liberalization in the US and the UK. Similar negative effects of the deregulation on energy R&D were found for electric utilities by Sterlacchini (2012).

Several studies have already investigated the rise of greentech patenting since the end of the 1990s and put forward the leading role of developed countries, in particular Japan (plus United State, and Germany) but also the significant contribution of new comers like Korea, China or Russia at USPTO (Dechezleprêtre, 2009 and 2011; Mark and Siddharth, 2012).

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[4] Recently since 2006 the Community Innovation Survey reports information concerning the adoption of energy-saving technologies in firms. A lot of papers use now the data stemming from this survey.

[5] Patents applied at the Japanese Patent Office used to contain only one claim.

[6] Patent family size refers to the number of patent offices to which an application for a patent has been filed (Dernis and Khan, 2004).

Dechezleprêtre (2009) looks at climate-friendly innovation using patent data for a broad range of technologies and countries. Its work includes renewable energy technologies, carbon capture and storage, and energy efficiency technologies for buildings, lighting, and cement manufacturing. The data cover the years 1978-2003 and include patents from 76 countries. Like Lanjouw and Mody, he finds that most climate-friendly innovation occurs in developed countries. US, Japan, and Germany account for two-thirds of the inventions in the sample. Emphasizing the role of policy, innovation increases after the Kyoto Protocol in all countries except the US and Australia that had not ratified the Kyoto Protocol. As a whole, emerging economies accounted for 16.3% of climate-friendly innovations in 2003.
Using a panel of patent data from 25 OECD countries, Johnstone et al. (2010) explore the development of renewable energy technologies. They examine innovations in five such technologies: wind, solar, geothermal, electricity from biomass, and ocean power. Their data show a rapid growth in wind and solar energy patent activity, particularly since the mid-1990s. Innovation with respect to biomass and ocean energy is also growing but starting from a very low level. In contrast, there have been only few innovations in the area of geothermal energy since the 1970s. Johnstone found that public funded R&D programs did lead to increases in patenting activity for the sponsored technologies. Its analysis compares the effects of these policies on innovation in renewable energy and finds important differences across technologies.

We focus our study on the sector of energy and therefore consider technologies related to the energy source and energy storage that mitigate climate change (technologies related to smart grids and capture of CO2 are not included). Mitigation refers to the reduction of the GHG emissions at the source (Hart, 1997), thereby lowering their impact on our planet climate. In the following, we will indistinctly refer to energy cleantech or energy greentech to name these mitigation technologies. If a large strand of literature investigates and compares the capacity of countries to promote greentech innovation, *only scare information can be found on the relative contribution of the different actors – and large firms in particular - from the business sector to green technology innovation*. To our knowledge no extensive and global picture targeting the commitment of large firms was ever produced. The aim of this research is to *quantify the contribution of firms with large global R&D* investments and sustained patenting activity to the global greentech innovative production from the pre-Kyoto to post-Kyoto period using a large and new set of firm patents. This paper uses a large data set related to the patenting activity from the worldwide 946 largest R&D operators mainly MNEs. We focus our attention on their technological activity in the field of energy green technologies (energy greentech or greentech thereafter) in order to quantify both their contribution and evolution. We sought to address four questions relevant to the context of R&D public policy and its linkages with firm strategy:

1. How much energy greentech technology is being patented by MNEs?

2. How is energy green corporate greentech patent activity distributed across the different countries?

3. In which type of energy clean technologies are the large firms most active (energy sources vs. energy storage, « traditional » nuclear fission vs. renewable energy production)?

4. How has the greentech technological activity progressed in large firms in the post-Kyoto period?

The paper is organized as follows. The first section delineates the likely impact of large firms in the worlwide context of energy greentech. Section 2 offers the necessary information on the data set, the characteristics of the sample of MNEs, the main indicators we use. Section 3 provides our most important results. In particular it shows new trends related to the MNE contribution to cleaner environment. In the last section we discuss our findings underlining the role of major firms from Japan, USA and Europe.

I. Large firms and the energy greentech context

Firms have low incentives to invest in green technologies as this market suffers from the well known 'double externality problem' (Beise and Rennings, 2005; Faber and Frenken, 2009; Hall and Helmers, 2011)[7]. The production of energy being generally more costly when using green technologies, public subsidies were designed to foster the development of renewable energy and make the market entry attractive. Porter and van der Linde (1995) claimed that well-designed environmental regulation could bring about a net benefit to firms subject to such regulation.

It was postulated that environmental policies could be more efficient with the entry of new players to foster radical innovation because large incumbents have little incentive to fully develop renewable technologies competing with their investments in large-scale energy production. The technology regime concept (Winter, 1984) and the industry life cycle theory (Klepper, 1996) insist on the importance of small firms to generate radical or product innovation which contest the dominant position of incumbents generally focused on process – not product – innovation, both to increase their cost competitiveness and to avoid product cannibalization. Later Aghion (2001, 2005) has developed models where an escaping competition effect counterbalances the standard appropriability effect[8]. The renewable energy innovations fit well with these explanations because they are competence-destroying for the centralized paradigm of energy production (Bergmann et al., 2006; Lehtonen and Nye, 2009). In particular, while production of energy from renewable sources, such as wind, biomass, geothermal and solar, is mainly decentralized in small- and medium-sized units, the skills of incumbents are tied to large-scale plants using coal, nuclear materials or gas as primary energy inputs. Moreover, high costs of large scale generation exacerbate the lock-in of existing incumbents (Neuhoff, 2005; Jacobsson and Bergek, 2004; Nilsson and al., 2004; Lauber and Mez, 2004). As a result, one should expect that new entrants have a comparative

[7] The first externality relates to market imperfection and public goods nature of knowledge and the second one to the fact that the greatest benefits from green inventions are likely to be public rather than private.

[8] In order to retain their market shares, incumbents are induced to invest more in R&D if the competitive pressure of new entrants is higher and they are close enough to the existing technological frontier. On the other hand, higher pressure of new entrants discourages R&D investments of incumbents far from the frontier, whose competences are too distant from the ones needed to imitate leading-edge technologies.

advantage in renewable energy technologies and in related infrastructures (i.e. smart grids).

The quest for social and environmental sustainability has transformed the landscape of global competition (Nidumolu, 2009) and managers are increasingly re-evaluating the impact of their business activities on the climate system and, more importantly, finding ways to mitigate the impact (Okereke, 2012; Reid and Toffel, 2009). In particular, MNEs accused of being major contributors to various environmental problems as a result of their worldwide operations (Christmann, 2004; Christmann and Taylor, 2001; Strike, Gao and Bansal, 2006) give a high priority to the reduction and eventual elimination of GHG emissions. Considering climate change mitigation can positively affect sales effectiveness mitigation efforts by MNEs are also positive signals towards the consumers (McWilliams and Siegel, 2000) and improve product leadership (Cohen and Levinthal, 1990; Grant, 1996). According to Chakrabarty and Wang « *MNCs that implement climate change mitigation are likely to see significant increase in sales effectiveness and product leadership but no significant increase in return on equity. Further, the positive influence of mitigation on sales effectiveness and product leadership is found to be more strongly positive when the MNC's internationalization is high ».* Many companies also see potential market opportunities in new high-margin, low-emission products and technologies, as well as cost savings from lower energy use (Begg, van der Woerd and Levy, 2005; Margolick and Russell, 2001; Reinhardt, 2000)[9]. The rapid growth of markets for renewable and clean energy, and for energy efficiency, is one example. Global markets for wind, solar photovoltaic (PV), and fuel cell power are growing at an annual rate of approximately 20%, and are forecast to reach $115 billion by 2015, from a 2005 base of only $24 billion » (Makower, Pernick and Wilder, 2006).

Despite the common threat and opportunity, there has been a striking variation in the responses of companies across sectors and countries (Falkner 2010). As a whole European industry displayed a readiness to invest in technologies that might reduce greenhouse gas emissions. During the 1990s, US-based companies were particularly active in challenging climate science, pointing to the potentially high economic costs of greenhouse gas controls, and lobbying government at various levels. By 2000, a convergent trend emerged and key firms on both sides of the Atlantic appeared to move toward a position that acknowledged the role of GHGs in climate change and the need for some action by governments and companies, despite continuing uncertainty. The impact of the MNE home country on corporate strategies is likely to diminish over time as industries become more international in scope. (Levy and Kaplan, 2007).

Since the beginning of the 2000s many examples of the commitment of MNEs in greentech are given in the literature and in the media. Pernick and Wilder (2007) present examples that show that the "clean tech revolution" is already under way. Very large corporations such as Intel, General Electric, Toyota, Sharp, Total, Chevron, Daimler reported large investments in clean technology, in R&D programmes, partnerships or start-ups acquisitions. Traditional energy companies like Total became involved in solar power (acquiring SunPower, Silicon Valley's dominant solar-panel maker). Among the dominant players in

[9] However, there are often managers at MNEs unconvinced about the feasibility of attempts to mitigate the destructive effects that their business operations have on our planet's climate (Porter and Kramer, 2011) or that "the more environment friendly they become, the more the effort will erode their competitiveness" (Nidumolu, Prahalad and Rangaswami, 2009).

corporate cleantech are ABB (world leader in power grids), Siemens, Schneider Electric that specializes in energy management. The trend of corporate investments cuts across several cleantech sectors from biofuels to batteries. The adaptive responses of firms to the climate change challenge also depend on the industry. Companies from petroleum-gas, automotive, energy, home appliances and metal/mining - industries in close relation with the climate change by their energy needs, their processes and their created outputs - are more sensitive to the climate change (Deegan and Gordon, 1996; Lang and Lundholm, 1993). But Frankhauser (2013) shows that the ability of sectors to develop a green competitiveness based on their existing comparative advantages, skills and production patterns was uneven across countries. At last, multinational companies are more responsive to the climate change when compared with the national enterprises (Kaya, 2008). However it also has to be kept in mind that R&D investments in the field of energy/electricity have declined dramatically over the last decades in the developed countries. Although even public research efforts have been reduced, the key area of concern rests on the behaviour of electric utilities. Investments in energy R&D by US utilities fell by 72% between 1990 and 2004. Over the same period, the electric companies of the EU reduced the R&D expenditures by 62% while in Japan the decrease, although remarkable, was less pronounced. Sterlacchini (2012) found that the only companies that did not reduce substantially their R&D investments are state-owned enterprises.

II. Data, sampling and indicators

This research uses patent information extracted from the Patstat database (2011), which includes all patents applied for through the world in one of the 180 patent offices. We select priority patent applications. i.e. the very first patent application for a novelty without any patent office restriction for two periods of time, 1994 to 1996 and 2003 to 2005, and use information pertaining to applicant names and application filing date.

In order to assign patents to countries, the applicant's country of residence or the inventor's country of residence may be chosen. In this study, patents are assigned to the country of the headquarters of the firm to whom the applicant belongs. For example if the applicant of a patent is located in country B and is a subsidiary of a large firm with headquarters in country A, the patent is attributed to the corporate patent portfolio of country A. Most of published studies select valuable patents (i.e. PCT patents or patents applied or granted at USPTO) but we adopt a different and broader approach considering all applications of priority patents applied without any patent office restriction in order to encompass all greentech activity. We consider that a defence patent or a low quality patent only applied in the applicant's country is a signal of activity in the green field and should be included in our data[10]. Moreover, for dealing with corporate innovative activity and therefore possibly incremental innovation rather than radical one, considering all priority patents seems to better reflect this type of activity.

The energy cleantech patents were identified using the new CPC classification (Y02) set up by EPO in 2010 to tag technologies which "control, reduce or prevent GHG emissions of anthropogenic origin" as set forth by the Kyoto Protocol. We select in the Patstat database the priority patent applications included in the T02E subclass that covers technologies

[10] Another option would have been to include all priority patents and to ponderate each patent according to its value by considering either its citations or the number of patent offices where the patent was applied for.

dealing with the reduction of GHG emission, related to energy generation, transmission or distribution (Veefkind, 2012). Main sectors in T02E class include: *Technologies with contribution to GHG emissions mitigation* that towers with 64% of T02E patents and includes the energy storage (batteries) (39%), fuel cells (18%), hydrogen technology (2,9%); *Renewable energy sources* (23%) with photovoltaic (10%), wind (4,6%), thermal solar (3,9%), hydro (3,2%), oceanic (0,6%) and geothermal (0,5%) energies, -*Technologies for the production of fuel of non-fossil origin* (4,1%) (biofuel 1,6%), from wastes (2,5%); *Combustion technologies with mitigation potential* (Combined Heat and Power, …) (3,4%), -*Nuclear Energy* (3%); *Technologies for efficient electrical power generation, transmission or distribution* (1,8%).

Firm patents are priority patents applied for by a legal entity that belongs to a set of 946 large firms with sustained patenting activity (sustainability was defined by a threshold of 5 patent applied for during each of the two periods of time (1994-1996 and 2003-2005)). These firms were selected from a list of more than 2000 large industrial companies with the highest annual R&D investments mainly provided by the Industrial R&D Investment Scoreboard 2008 (1 000 European firms and 1 000 non European firms)[11]. For each firm, using the Orbis database edited by Bureau van Dijk Electronic Publishing the patent portfolio was built including applications originating from the firm and all identified subsidiaries in which the firm had more than 50.01% of shares (see Laurens et al., 2013) for methodological details on the corporate patents delineation). Each firm is assigned to a country according to the location of its headquarters.

Information concerning patent numbers is shown in table 1 for the two periods of time. The 946 firms are roughly equally distributed between the US (34%), Asia (27.2%) and Europe (35.7%) (see column 2 in table 3,). The 946 firms have applied for 706 524 priority patents (62% of all priority patents applied for in the world) in 1994-1996 and 882 895 in 2003-2005 (50% of worldwide priority patent applications). In 1994-1996, 11 445 patents of firm patents were related to energy greentech (among 17 087 overall energy greentech patents). They were 20 273 patents in 2003-2005 (among 36 147 overall energy greentech). In the decade the number of energy greentech patents of firms has almost doubled, the percentage of energy greentech patents in their patent portfolio has grown from 1.62% to 2.30% and the distribution of greentech patents by greentech sectors has evolved: the sector of “Energy storage, fuel cells and hydrogen technologies” that concentrated 62% of the energy greentech patents in the mid-1990s received more and more attention from large firms and has gained 13 points (to concentrate ¾ of all energy greentech patents). The second largest sector “Renewable energy” has lost 4 percentage points; its share has declined from 20% to 16%. To the exception of “Fuel of nonfossil origin” whose share remained stable to 2%, the shares of other sectors have decreased. The drop was most marked in “Nuclear energy” (from 7.9% to less than 1%) and “Technologies for efficient electrical power generation, transmission or distribution” (4% to 1%).

[11] This initial list produced yearly by the Institute for Prospective and Technology Study (IPTS) was complemented with Indian and Chinese firms declaring R&D investments between 1999 and 2009 in the Computstat database and with name of the most important firms as assignees of WIPO, EPO and USPTO patents.

Table 1: Distribution of energy greentech patents of firms across greentech sectors (%)

Energy greentech subsectors	**1994-1996**	**2003-2005**
Technologies for the production of fuel of non-fossil origin	2.1	2.5
Renewable energy source	20.1	16.5
Energy storage (batteries), fuel cells, hydrogen technologies	62.1	75.4
Combustion technologies with mitigation potential	3.2	2.8
Technologies for efficient electrical power generation, transmission or distribution	4.1	1.2
Nuclear Energy	7.9	0.9
Total	100.0	100.0
Number of energy greentech patents	11 445	20 273

We calculate four indicators at the country level:

- The greentech patenting of the set of large firms of a given country as a share of the total country green patenting. It quantifies the green contribution of the large firms to their home country,
- For a given country the share of large green firms, i.e. the number of large firms having applied for greentech patents over the total number of large firms. This indicator allows us to follow the diffusion of the firm greentech inventive activity,
- The share of energy greentech patents (or sectors of greentech) of large firms aggregated by firm country. It is the number of greentech patents of large firms from a given country over the total number of greentech patents of the 946 firms. This enables us to map the worldwide large firm greentech activity,
- The greentech specialization index (GSI). It is defined for the set of large firms for a given country as the ratio of two shares: the share of greentech patents of large firms over the share of the overall large firm green patents at the world level. It enables to compare the corporate relative greentech effort avoiding institutional bias and to follow their evolution over time across countries. When GSI>1, the firms are specialized in greentech (compared to the corporate world average) at the country level.

These indicators allow us to follow the evolution of firm greentech activity, intensity and specialisation over time.

III. Results: trends related to the technological contribution of MNEs to energy greentech

The first section explores the extent of the contribution of large firms to the overall green patenting activity in their home country while the following sections focus on the large firm patent dataset detailing the trends of the corporate greentech activity.

3.1 Contribution of firms to the overall corporate greentech activity

Table 2: Share of firm patents in the overall energy greentech patents of the home country (%)

Country of firms	Share of greentech patents of corporate origin (%)	
	1994-1996	**2003-2005**
Japan	105.0	100.5
France	55.7	50.5
Switzerland	169.7	44.6
Netherlands	30.5	37.6
Germany	29.8	33.0
Belgium	12.2	32.0
Sweden	24.8	30.0
United States	29.5	29.7
Finland	33.8	26.3
Norway	7.3	23.3
Korea	29.9	22.5
Italy	31.1	21.7
United Kingdom	39.3	14.8
Canada	26.3	10.8
Taiwan	6.6	9.6
Denmark	13.4	7.1
Austria	18.6	4.3
Brasil	0.0	2.8
China	0.4	1.9
Total	72.4	60.3

Note: contribution of firm patenting to the overall firm country patenting can exceed 100% because applicants belonging to the firm perimeter can be located in country which is not the firm HQs country; according to our methodology its patents are allocated to the firm in the firm country.

The contribution of large firms to their home country greentech patenting shows strong variations according to countries and greentech sectors (Table 2). In Japan all the greentech technological activity originates from large firms. This country differentiates from the US and Europe where large firms are involved only in approximately ¼ to 1/3 of all the greentech patents but the level of commitment varies across EU countries. The largest presence is observed in France where large firms contribute to approximately 50% of greentech (the largest share after Japan) but it stays below 10% in countries like Denmark or Austria. If the overall contribution of large firms to greentech has decreased in the post-Kyoto period (-12 percentage points) - a trend not specific to greentech patenting and even more prominent when considering large firm patents in all fields of technology - it has progressed in small EU countries (Norway, Belgium, Netherlands or Sweden) and in Germany. This indicates that large firms have contributed to create the dynamics of this sector but that other types of actors (small independent firms, organizations from the public sector…) have been more intensively committed. The contribution of large firms differs according to sectors of greentech (see table 6 in the Appendix for detailed data). In most countries the largest firm commitment is in the transport energy (batteries, fuel cell and hydrogen technologies) where it exceeds that of the total greentech, which means that the firms are relatively specialized in this sector (with the exception of Japan where firms are most committed to renewable energies). Most often European firms contribute to a high level to technology development in Combustion (Germany, France, UK, Sweden…), Efficient Electrical Power (France, Germany, Italy, Switzerland, Netherlands) and Nuclear Energy in France or Italy but their share in the latter sector has strongly declined or even dropped to zero in most other countries (Germany, UK, Italy, Japan). France remains an exception with a constant and substantial contribution of firms (>50%) in Nuclear energy. US firms are first specialized in Efficient Electrical Power and then in Renewable Energy. In that latter sector the contribution of US firms has doubled (from 14% to 28%) in the decade and it became the sector with the second highest firm contribution in 2003-2005. No other country has followed such a positive trend (except in Sweden but with a low number of patents): in most EU countries the share of large firms has dropped below 20%.

From this section we conclude that the decommitment of firms to greentech is a trend frequently observed among countries after the Kyoto Protocol. However this trend participates in a more general evolution encountered in all sectors. It evidences that a few large firms (946 firms) remain the major actors of the R&D technological activity but that the competition with other actors has increased.

3.2 Share of firms involved in energy greentech patenting across countries: distribution and evolution

Table 3: Share of firms active in energy greentech across country (%)

Country of firms	**Share of green firms (%)**	
	1994-1996	**2003-2005**
Korea	57	86
Taiwan	9	82
Japan	70	77
China	*25*	*75*
Austria	*40*	*60*
Norway	*20*	*60*
Italy	45	55
Brasil	*0*	*50*
France	36	46
Switzerland	22	44
Germany	29	44
Finland	22	33
Netherlands	25	33

United States	27	32
Canada	27	27
Denmark	27	27
United Kingdom	19	27
Sweden	11	26
Belgium	8	17
Total	36	46

Note: in italic countries with 5 firms or less

In the pre-Kyoto Protocol period 36% of the large firms were green firms (i.e. who applied for greentech patents) (Table 3). This share has gained 10 points and reached 46% in 2003-2005. Despite an uneven commitment to greentech of large firms in countries, the presence of new entrant MNEs in energy greentech among large firms is a common trend. The diffusion of greentech inventive activity among firms is more pronounced in European countries (+50%) than is US (+12%) or Asia (10%). With 70% of its large firms already active in energy greentech in the 1990s and ¾ of firms in the mid-2000s, Japan is a special case. This large Japanese firm share is about twice what is observed in western countries where approximately 1/3 of large firms are committed to green patenting. France and Italy are countries where the green activity of large firms is high, compared with other European countries. Conversely, Nordic countries and UK show a low share of large firms in greentech patenting, similarely to that observed in the US.

3.3 Distribution of firm energy greentech across firm countries

Table 4: Distribution of firms, firm patent shares in energy greentech and firm greentech specialization index across countries (%).

Country of firms	**Distribution of firms**	**Distribution of firm greentech patents**		**Firm greentech specialisation index**	
		1994-1996	**2003-2005**	**1994-1996**	**2003-2005**
United States	34.00	7.26	5.74	0.62	0.50
Japan	23.20	83.73	83.14	1.13	1.34
Germany	9.20	3.45	3.87	0.91	0.66
United Kingdom	6.20	0.31	0.18	0.40	0.38
France	5.30	1.47	1.84	0.88	1.13
Switzerland	2.90	1.11	0.22	1.78	0.47
Sweden	2.90	0.20	0.12	0.44	0.24
Netherlands	2.50	0.15	0.26	0.33	0.59
Finland	1.90	0.12	0.06	0.43	0.16
Korea	1.50	1.23	3.37	0.25	0.25
Belgium	1.30	0.01	0.06	0.08	1.12
Canada	1.20	0.38	0.23	3.14	0.95
Denmark	1.20	0.03	0.03	0.51	0.61
Italy	1.20	0.20	0.13	1.38	0.93
Taiwan	1.20	0.03	0.20	0.18	0.21
Austria	0.50	0.05	0.02	1.17	0.41

Norway	0.50	0.01	0.08	0.36	2.25
China	0.40	0.01	0.31	0.16	0.24
Brasil	0.30	0.00	0.02	0.00	0.95
Total	100.00	100.00	100.00	1.00	1.00
Total Nber	946	11445	20273	-	-

Japanese firms that represent about 23% of the firms in our dataset dominate the worldwide corporate greentech priority patenting: since the 1990s more than 83% of greentech patents produced worldwide originate from Japanese firms (Table 4). This overwhelming contribution of Japan priority patents suffers from a bias due to the heterogeneity in patent office rules that is particularly striking when considering patents at the Japan Patent Office[12]. Using transnational priority patents (patents that were applied for at least two distinct patent offices) provides a less biased picture and alleviates the contribution of Japanese firms. However, Japanese firms still dominates to a large extend (56%) the worldwide corporate energy greentech invention.

The share of greentech patents being higher than their contribution to the global firm patenting shows that Japanese firms have a pronounced and durable specialization in greentech that has intensified over time: Japanese firm greentech specialisation index has grown from 1.13 to 1.34. Conversely Korean or Taiwanese firms show a very low greentech specialisation that has hardly progressed in the decade (0.20-0.25).

Europe and US, housing each about 1/3 of the firms, contribute to 6%-7% of worldwide corporate greentech patenting each; their contribution to greentech patenting being lower than their contribution in all patents, US firms were not specialized in greentech in the first period and did not intensify their efforts over time. The US firm share in greentech has decreased from 7.3% to 5.8% and the greentech specialization index from 0.68 to 0.50. In Europe, diverse trends are visible. German firms contributing approximately to half of European corporate greentech patents (around 3.5%) have had a stable greentech patent share but a specialisation index reduced by 1/3 in a decade (energy greentech was not among their main priorities). Such a drop in greentech specialization is also observed in Italy and in most of the small or Nordic European countries (except Belgium, Netherlands and Norway). Conversely, French firms have significantly reinforced their overall greentech specialisation and slightly increased their contribution to the global corporate greentech patenting (from 1.5% to 1.8%).

This section first shows the leading position of Japanese firms both in terms of their net contribution of greentech patents compared with their foreign competitors. It reveals as well that Japanese firms gave green technological activity a high priority as shown by their relative higher specialization index. Being the greenest firms and still reinforcing their

[12] Until recently, patents applied for at JPO had only one claim while in main patents western patent office, each patent include several claims. Besides, there were strong incentives for researchers to heavily patents. Extending patents in other countries usually requires to group several patents applied for at JPO into a single patent to applied for in another country. The ratio was estimated to be 3 :1 or 5 :1 according to studies (de Rassenfosse (2013)).

commitment (the percentage of energy green patent in patent portfolio has risen from 1.8% to 3.1%) Japanese firms are responsible for most of the progression of the worldwide technological activity in energy greentech in firms after the signing of the Kyoto Protocol (the overall share of greentech patenting in firm patent portfolio has increased from 1.6% to 2.3%). Large firms from a few other countries also performed well in greentech like France, Italy, Belgium, Canada or Brazil. Besides, in these countries large firm greentech specialisation exceeds that of their home country. Among large countries, France and Italy that have a large set of diversified large firms show such an atypical, continuous and pronounced trend that could stem from their sectorial industrial profile.

At last, in countries where large firms are not specialized in greentech, the firm greentech specialization is also lower than that of the home country: in US, Germany, Korea and small EU countries, firms have a lower specialisation than firms from other countries but also than their overall home country - on average US firms are less green than French firms but also less green than the US as a whole.

Table 5: Distribution of firm and firm patents by sectors of energy (%)

Country of firms	Renewable energy		Combustion		Nuclear energy		Efficient Electrical Power		Non fossil fuel		Batteries, fuel cell, hydrogen	
	94_96	03_05	94_96	03_05	94_96	03_05	94_96	03_05	94_96	03_05	94_96	03_05
United States	3.94	8.61	14.30	12.47	18.72	5.87	5.40	9.47	1.78	2.28	6.78	6.63
Japan	90.40	82.93	50.66	59.35	53.61	60.68	77.78	58.70	92.90	88.71	86.72	81.57
Germany	2.57	2.96	13.58	8.60	11.15	0.00	7.28	11.53	2.90	3.07	2.22	4.64
United Kingdom	0.39	0.37	2.08	0.60	0.48	0.17	0.75	0.00	0.33	0.00	0.17	0.06
France	0.60	1.36	6.53	7.80	6.43	18.56	2.76	3.91	0.45	0.44	0.73	1.64
Switzerland	0.56	0.28	8.65	0.17	7.26	0.00	3.77	7.20	0.30	0.39	0.28	0.11
Sweden	0.00	0.43	0.58	1.31	0.27	0.00	0.00	0.00	0.00	0.00	0.22	0.03
Netherlands	0.29	0.36	0.29	0.34	0.00	0.00	0.25	0.41	0.00	0.20	0.10	0.33
Korea	1.01	1.60	0.00	7.33	0.64	14.04	0.50	4.12	0.00	0.00	1.55	3.82
Canada	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.41	0.00	0.00	0.62	0.30
Italy	0.00	0.08	0.00	0.09	1.07	0.00	1.26	0.41	0.45	0.13	0.14	0.18
Taiwan	0.14	0.32	0.00	0.00	0.00	0.00	0.00	1.24	0.00	0.00	0.00	0.18
China	0.00	0.15	0.00	0.31	0.00	0.17	0.00	2.20	0.00	1.73	0.01	0.25
Other countries*	0.10	0.19	1.96	0.5	0.00	0.00	0.00	0.47	0.90	2.64	0.79	0.43
Total	100	100	100	100	100	100	100	100	100	100	100	100

*Other countries include Brazil, Norway, Austria, Denmark, Finland, and Belgium

The distribution and its evolution over time of corporate greentech patenting across countries differ according to sectors of greentech (Table 5). Technological activity of large firms is highly concentrated in energy transport. In this sector the mid-2000s saw emerging competitors emerging from large countries (Germany, France and Korea that has doubled their contribution) and challenging Japanese firms (US firms were already active in the mid-1990s and maintained their position around 6.5%-7.0%). In renewable energies, a similar start has occurred, not due to European firms, but mostly under the pressure of US firms whose share has more than doubled from 4% to 8.6% in a decade (the highest share evolution among greentech sectors and US share in renewable energy largely exceeded their global contribution to energy greentech in the mid-2000s) while their global contribution in energy greentech has declined. A similar but less pronounced trend is also observed in France (whose share doubled to 1.36%). German firms already committed to renewable energy have maintained their contribution (2.5%-3%) but did not progress. Firms from small countries like Sweden, Norway, Netherlands or Italy, China and Taiwan have started to apply for patents in this sector after the signature of the Kyoto Protocol but their contribution remained marginal. The largest increase of market shares in energy production of main European countries in greentech patenting remained in traditional sectors: Nuclear Energy (France), Efficient electrical power (Switzerland, Germany). Another common feature to large countries previously engaged in Nuclear Energy is their pronounced decommitment to Nuclear Energy (Germany, US and France to a lower extend). It is also worth noting that firms from Brazil and China became challengers in non-fossil energy.

These data show that the post-Kyoto period is all over the world a period of growing commitment of firms to all sectors of energy greentech. However most European firms remained more active in traditional energy sector (except in a few small countries) and increased their activity in transport energy while US ones were more prone to develop technological skills in renewable energy.

IV Discussion of findings: role and strategy of major firms

This article describes the commitment over time of large firms with high R&D investments and sustained invention activity in energy greentech that is of foremost importance in the eco-innovation context. It uses basic indicators at the country level to follow over time the contribution of the large firms to the greentech effort in their home country and also the progress of energy greentech within firm patent portfolios. According to our knowledge, this contribution of large firms had not yet been quantified at such worldwide large scale. In the following, we classify our results according to the firm home location. We first discuss salient differences between Japanese firms and their western competitors. Less striking but still obvious, various behaviours are also evidenced among western countries. We expect to detect evidence that large firm commitment to energy greentech is linked to regional strategic policy regarding climate change issues. Taking into account that energy cleantech innovation is a global challenge we consider that business competition for international market between large firms may be the major incentive for large firm involvement. Depending on the sector of energy cleantech the reasons for commitment may vary. In some cases firm main responsibility could be linked to its capacity to propose technological solutions for the home country to respect its engagement towards greenhouse gas emission restriction (for example in the case of large public firms); in other cases, intensive competition for international market may be the dominant incentive (like the race for electric vehicles in the car industry).

1) Japanese large firms leaders of energy greentech

In the mid-1990s Japanese large firms had an obvious advantage in the competition of large MNEs for cleantech innovation leadership over European and US corporations. As already discussed, measuring the filing of priority patents overestimated this overwhelming role played by the Japanese firms but selecting only transnational priority patents simply lowers the Asian predominance; still more than 50% of worldwide greentech transnational priority patents of worldwide MNEs originated from Japan. The leadership of Japanese MNEs in the energy greentech race stems from: -i) a high greentech specialisation within firm patent portfolio (the share of the energy green patents in Japanese patent portfolios exceeds that of European and US firms), -ii) a high propensity of Japanese MNEs to be committed to greentech technologies in all manufacturing industries (in Japan the share of MNEs that includes energy cleantech in their patent portfolios by far exceeds that measured elsewhere), -iii) greentech innovative capacities concentrated in MNEs that contribute to 70% of the national greentech portfolios while this contribution is 2.5 times lower in most western countries.

Another striking difference among Japanese MNEs and their foreign competitors relates to their specialisation among energy greentech technologies. In the mid-1990s - the pre-Kyoto period when the prices of energy were low -, Japanese MNEs were already specialized in new energy greentech technologies for energy production and energy storage (renewable energies, biofuel, batteries, fuel cell and hydrogen technologies) while western MNEs relied on traditional energy greentech (Enhanced Combustion, Nuclear Energy or Improving Electrical Efficiency). This early and massive commitment of Japanese MNEs to greentech is at the origin of the leading role of the country in greentech already evidenced in the literature. It finds its roots in early strategic national R&D programmes (as Sunshine or WE-NET programmes for photovoltaic or hydrogen technologies) set up to limit the country dependence on petroleum but also to maintain Japan as a high-tech superpower in the green XXIth century. In this perspective, MNEs technological greentech capacity fulfils both national strategic objective (Japan had taken engagement in reducing greenhouse gas by 6% in 2010) and a dominating position in the new and promising international market of energy greentech. This leading position of Japanese MNEs in the pre-Kyoto period had not been challenged in the following decade. Neither European nor US firms have reinforced their contribution that stagnated to 6%-7% of the total large firms production after the signing of the Kyoto Protocol; the US firm share has even declined.

While Japanese firms reinforced their greentech capacity and their relative green specialisation, European and US firms have followed a reverse trend. In 2003-2005, the specialisation index of Japanese firms in greentech was twice that of European firms and 2.7 that of US firms. In 1994-1996, Japanese specialisation was only twice that of US firms and 1.5 that of European firms. This shows that climate change issues and greentech development were not prioritized to the same level in large firms of western countries as in Japanese ones in the beginning of the 2000s. However in western countries the commitment to greentech has progressed among MNEs: the share of firms filing greentech patents has significantly increased in most industries.

2) US large firms: the followers

US large firms reveal a contrasted picture and diverging trends among energy greentech sectors over time. Two main evolutions are evidenced: an increasing involvement in

Renewable Energy and a massive decommitment from Nuclear Energy. To the contrary, the level of US firm commitment to transport energy, which grew already significantly in the mid-1990s (6% of the worldwide corporate activity in the sector), has remained stable.

After the early specialisation of Japanese firms in new renewable energy greentech technologies already noticeable in the mid-1990s, US firms followed the same trend ten years later and became specialised in renewable energy. Within large firm overall inventive activity, the share of US firms in Renewable Energy has more than doubled (from 3.9% to 8.6%) and has become higher than their contribution to the corporate overall inventive effort (6.6% in 2003-2005). Besides, the contribution to technological development in Renewable Energy of US large firms to the overall US effort in this sector also doubled in the decade, increasing from 14% to 28% (the largest corporate contribution after that observed in Japan (95%) and Sweden (40%)). Therefore, despite the fact that the US government rejected the Kyoto Protocol in 2001, US firms clearly adopted a strategy aiming at developing technological skills in alternative energy to comply with the climate change mitigation objectives. This is in accordance with the situation at the end of 1999 when many large US companies (Ford, Chryler, General Motors, Texaco) started to align their strategies by taking into consideration the signature of the Kyoto protocol despite the official opposition of the US government (Falkner, 2010). This overall evolution of US large firms could suggest that large firms are less sensitive to the fluctuating regional political signals in terms of engagement of the government fostering local technological choice and more prone to investigate new technological sectors as soon as they detect international market opportunities. This is the competitive risk linked to regulatory risk in the global and domestic marketplaces described by Cogan (2006) who cites the struggle of Ford and General Motors with their Japanese competitors for hybrid or electric vehicles.

The disengagement of US large firms from Nuclear Energy in the mid-2000' was massive: in 1994-1996, 50% of the American patents were applied for by US large firms and this share dropped to 7% ten years later. In this globally declining sector, US large firm contribution has decreased faster than the rest of the world (their contribution to the sector was divided by 3.5 in the decade but this is also the result of the emergence of new countries, i.e. firms from Korea and China). The observed movement of US firms phasing out the sector of nuclear energy is similar to that obtained by Albino (2014) using patents granted at USPTO by applicants located in the US. This author explains how in this period opposite trends coexisted: one the one hand, nuclear accidents (Three Miles Islands (1979) and Tchernobyl (1986)) had conducted countries like Italy, UK or Germany to reconsider their programme in Nuclear energy but, on the other hand, oil prices, interest of developing countries and environmental concerns lead to a nuclear renaissance in the late 1990s. In this context, our results indicate that in 2003-2005, US large firms followed the first movement despite the fact that « in 1999 the Nuclear Energy Research Initiative (NERI) was established in the U.S. in order to foster collaborative researches in innovative technological nuclear solutions » (Albino, 2014).

3) European firms: contrasted specialization trends

While US firms got committed to renewable energies, European firms lagged behind in these technologies. In the mid-2000s, at the continent level European firms still relied on their overall specialisation[13] in Nuclear Energy (specialization index = 2.39) rather than on Renewable energy (specialization index = 0.83) to comply with the climate change mitigation objectives. However the context varies across European countries and the overall apparent lack of commitment to new energy greentech needs to be further examined at the country level.

In the 1990s, a large group of European countries including France, Germany, the UK, Switzerland and Sweden saw their MNEs specialised in Nuclear Energy, Combustion and Electrical Efficiency (their share in Nuclear Energy exceeds that of their overall greentech) and under-specialised in Renewable Energies (except the UK [14]). Ten years later, different trends have come out. At first and as already mentioned, in the 1990s several EU countries have exited (or planned to exit) from the nuclear energy (Italy, Germany, UK and Sweden) while other like France had not (its world share has tripled in the decade). In the first group of countries, all large firms have stopped or significantly reduced their technological development in the sector: the world share of German firms in Nuclear Energy has dropped from 11% in 1994-1996 to 0% in 2003-2005, in the UK it has declined from 0.5% to 0.17%. A similar situation is observed in Switzerland[15].

As far as Renewable Energies are concerned, the commitment of European firms at the European level is less impressive than for US firms: while the world share of the latter doubled in the decade, the share of EU firms increased by one-third. In Germany and in the UK, large firms started early to invest in Renewable Energy but then hardly progressed in this sector. In the period, French large firms have made noticeable efforts to catch-up (and doubled their world share) but this sector remained of minor interest. The specialisation in traditional energy greentech sources still dominates in large firms giving to France its globally high specialisation in greentech and we witness among French firms the low motivation to invest in new energy greentech for energy production due to the country strong reliance on nuclear resources described by Cosatea (2014). It is only in small and Nordic EU countries that a nascent or growing corporate technological activity (Netherlands, Sweden, Norway, Finland) in renewable energy and an increasing contribution of large firms to the national commitment is detected[16]. The investments of large firms in Germany, France and Italy are balanced between wind energy, PV and solar energy. In smaller countries, large firms are more specialized: wind energy in Sweden, Switzerland or Norway; solar energy in the Netherlands, hydro energy in Austria. In Europe, the most impressive evolution concerns the sector of transport energy (batteries, hydrogen technology and fuel cell) where large firms from most countries significantly reinforced their contributions compared to their foreign US and Asian competitors but also reinforced their participation in the commitment of their home country. The specialisation of EU large firms differs in this sector from US and Japanese firms: the former lead technological development for hydrogen

[13] The specialisation index aggregated at the European level is the worlwide share of all European firms' patents in a given sector or greentech (here Nuclear energy or Renewable energy) divided by their worldwide share in all energy greentech patents.

[14] The UK (like the Netherlands) hosts several international MNEs that just locate in UK or in Caraïbian countries of the Commonwealth their headquarters to benefit from fiscal incentives (Shell, Tyco International …) that may have strategies that differ from continental EU firms.

[15] ABB, the swiss firm involved in nuclear energy (instrumentation, control, electrical systems) ceased this activity in 2000 (and sold to BNFL (UK) to be further merged into Westinghouse (US)).

[16] Except in Denmark where no large firms have ever explored this field maybe because our firms set contains only eleven Danish firms with none in the sectors of Utilities or Chemical.

technology and fuel cells, the latter ones being more focused in the technologies of batteries. Of course German firms took the lead and the new specialisation in batteries, fuel cells and hydrogen technologies emerged from the car industries, a sector of growing importance in patenting in the 2000s (Laurens et al., 2013). However among all energy greentech, it is in the most traditional and mature sectors that European large firms are the most committed to. Besides Nuclear Energy, EU large firms heavily contribute to the technological development related to combustion or to improving the efficiency of the use of electrical power (except in the UK where firm contribution to technological production has noticeably decreased as a possible consequence of reduced R&D investments after the privatisation of the energy sector (Sterlacchini, 2012).

We conclude that in the period 2003-2005 issues of the impact of energy on climate change has not yet been addressed on a large scale by European large firms. Our data feed well the statements of Aghion and Veugelers (2009) according to which the "private innovation machine" has not taken off in the case of EU MNEs due to the design of political instruments that do not provide enough incentives to invest in clean innovation fragmentation and due to the lack of coordination among EU countries[17]. Additionally, a lack of coordination at the EU level in the sector of energy that contrasts with the focused energy technology policy in the US (through the Department of Energy) and Japan (through the METI) (Wiesenthal, 2011) could have delayed the EU large firm commitment to new energy cleantech. However our findings showing that US firms have taken on the issues of renewable energy before most of those from EU countries may somehow contradict Cogan (2006) who states that in the mid-2000s American firms addressing climate change at the governance level were catching up with their international competitors. Besides this notable difference, Europe and US firms also shared more or less similar trends at the regional level: the contribution of corporations to regional greentech activity is quite similar: around 1/3 of the regional greentech patents originate from large firms' activity and this contribution has noticeably progressed since 10 years.

The answer of firms to the climate change challenges depends also on the industrial sectors. We did not yet consider this dimension in our geographical analysis at the country level. Different national industry profiles could explain the different observed behaviours concerning the greentech commitment of large firms aggregated by country. The commitment of industrial sectors among countries was already the subject of an extensive study carried out by Frankhauser (2013) analysing 500 000 firms commitment in all greentechs (i.e. not only in the sector energy) between 2005 and 2007. Our study, which is restricted to the energy greentech sector, covers a previous period of time and uses a broader set of patents. But we evidence similar results [18].

It is for example well documented that Utility industries or other industries extensively relying on energy are more prone to be committed to greentech. We have observed similar trends in our data and the sectorial profile of countries matters, more strikingly in small

[17] Using data from CIS 2006 survey they have found that among possible motives for innovation, those related to improving energy effiency and reducing the enrironmental impact were the less often cited motives for explaining innovation.

[18] However one main difference relates to the predominent role of Utilities in our study that did not emerge in their multisector greentech work.

countries with a small number of large firms - for example the dominating Industrial Machinery sector in Austria, Norway or Sweden gives those countries their green affinity - but also in larger ones where leading firms with a strong patenting activity set the green tone for the country. This is the case of the energy supplying industry where large public firms like Electricité de France, Areva (France), Vatterfall (Sweden) or Hydro-Quebec (Canada) with more than 15% of energy greentech patents but also for Chemistry (Air Liquide in France) or car industries (General Motors in the US, Ballard Power Systems in Canada, Elringklinger in Germany), in Electrical components and equipment (Morgan Crucible Company (GB), Energizer Holdings (US) or SGL Carbon (DE)). However at the continent level, the percentage of firms from the two main sectors applying for energy greentech patents – Industrial goods and services and Technology (each sector apply for 20% to 25% of greentech patents) – is similar[19].

Our study targeting large firms does not give information on countries overall activity in energy greentech nor allow any comparison between countries since our set of firms contribute to various degree to the overall national greentech innovative effort in their respective country. In particular, our study does not evidence the countries specialisation that has been put forwards in other studies like the importance of wind energy industries in Germany or Denmark. In western countries large firms contribute on average to 1/3 of the national green patenting activity whereas in Japan this share doubles. This difference is not specific to the greentech sector since very large companies have always dominated the Japan industrial sector during all the country industrial development but this discrepancy is enhanced in greentech.

Conclusion: the role of policies and firm strategies

The developments of greentech inventions across countries and in different technologies were already reported (Johnstone, 2010 and 2011; Dechezleprêtre,2009). In this strand of literature our contribution focuses on the role played by large firms. The leading role of multinational companies in the growth of the green sector was assessed by OECD (Kalamova et al., 2011; Corsatea, 2014) as well as the importance of clear and continuous national public policies to promote both greentech technology development and market demands. However to our knowledge, no research has ever studied to which extend such large contributors to the technological progress have participated to the launching of the “green innovation machine” (Aghion and Veugelers, 2012). Of course we do not provide any assessment of the enviromental benefits of the MNEs technological activity in clean energy sector (as realized for instance by Gilli et al., 2013; Ghisetti and Quatraro, 2014; Mazzanti and Zoboli, 2009). We use a unique set of corporate patent data applied for by the firms with the largest R&D investments among the world and restrict the study to those that have a sustainable patenting activity. Conversely to most studies that used restricted sets of patents meeting a certain quality threshold when selecting triadic patents, PCT patents, patents applied at USPTO or EPO for monitoring technological developments, we consider a broader range of patents by including all priority patents applied for without any restriction. Therefore our study also includes patents of low value or protective patents that are usually discarded. This enable us to “capture different dimensions of inventive activity” stressing the

[19] 27% of the EU firms and 24% of the US firms are in Industrial goods and services. For Technology the respective share are 8% and 12%.

"local and entrepreneurial natures of inventive activity" and "better reflect the inventive activity of developing countries and countries with a strong entrepreneurial base" (de Rassenfosse, 2013) as a measure of greentech innovation among large firms. In order to deal with institutional bias associated to priority patent, we most often use relative specialization index and compare corporate activities in greentech and non greentech to assess the issues of the distribution of greentech innovation among large firms depending on the firm country industries and on the contribution of large firms innovation to the global greentech innovation in the firm's country.

Nevertheless, the volume and the percentage of greentech patents in firm patent portfolios indicate the level of commitment of the firms to innovation in environmental technologies and provide documented evidences for our initial four questions:

1. The contribution of large firms to greentech patenting varies according to countries and greentech sectors. In Japan all the greentech technological activity originates from large firms. In US and Europe, large firms are involved in ¼ to 1/3 of the greentech patents.
2. More than 83% of corporate greentech patents produced worldwide originate from Japanese firms while US and European firms contribute to 6%-7% of corporate greentech.
3. The sector of the transport energy is the sector where the firm commitment is the strongest. However Japanese and US firms are highly committed to renewable energies.
4. The post-Kyoto period is a period of growing commitment of firms to all sectors of energy greentech. European firms tended to remain more active in traditional energy sector and transport energy while US ones develop skills in renewable energy.

With no doubt, Japanese large firms from all industries follow and benefit from the policy in environmental program; moreover they were already largely committed to greentech when international discussion started to mitigate climate change due to human activity. What is particularly striking concerning Japanese firms patenting activity is the fact that it includes all industrial sectors. However we cannot exclude that the national policy aiming at promoting environmental technologies has lead firms to label green every research program in order to be in line with the national policy and benefit from funding. According to Lambrecht (2014), in Japan, clean energy is often classified under the label "new energy", which makes no differentiation of whether the technology is clean. We should of course also keep in mind that Japanese greentech patenting covers a high level of incremental inventive technology with very a low inventivity level. In order to address this issue, complementary research using patent citations, or characteristics of the patent family should be conducted. If such research provides quantitative estimates on the contribution of the main innovative large firms to the greentech field, it does not assess the mechanism of greentech knowledge acquisition in the large firms (internal vs. external greentech knowledge acquisition). In particular it cannot assess whether technological content of the firm greentech patent portfolio results from R&D conducted within the large firm or whether it was included in the firm patent portfolio after acquisition of subsidiaries and/or merging of firms. Consequently our results may not only reflect large firm greentech innovation capacity but also integrate an undetermined contribution of technology development conducted in smaller entities further incorporated in large firms.

At last, in our future work we expect to follow better the evolution of firm commitment to energy greentech in the post-Kyoto period by enlarging the time period to the late 2010s and by studying firm greentech commitment according to sectors of energy as well.

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Appendix: Contribution of firm to country greentech patents by greentech sector

Table 7: Share of firm patents (%) in country greentech patents by green subsectors across countries.

Country	Renewable energy		Combustion		Nuclear energy		Efficient Electrical Power		Non fossil fuel		Batteries, fuel cell, hydrogen	
	94_96	03_05	94_96	03_05	94_96	03_05	94_96	03_05	94_96	03_05	94_96	03_05
Austria	5,2	5,7	100,0	31,4	0,0	-	0,0	-	0,0	0,0	0,0	2,1
Belgium	0,0	0,0	0,0	0,0	-	0,0	-	-	0,0	28,6	25,0	49,8
Bazil	0,0	0,0	0,0	-	-	-	-	0,0	0,0	12,7	0,0	0,0
Canada	0,0	0,6	0,0	0,0	0,0	0,0	0,0	15,4	0,0	0,0	33,4	13,7
Switzerland	59,0	19,5	168,8	8,8	6808,6	-	333,3	350,0	6,2	40,2	65,3	26,6
China	0,0	0,4	0,0	1,5	0,0	1,9	0,0	3,4	0,0	3,0	0,6	2,3
Germany	9,6	8,3	30,1	37,3	82,8	0,0	66,9	55,9	7,4	9,3	28,3	43,8
Denmark	0,0	0,0	0,0	13,3	-	-	-	-	33,3	40,5	13,7	6,1
Finland	5,6	12,5	20,8	25,0	-	-	0,0	0,0	25,0	25,0	154,2	31,6
France	22,7	17,1	99,3	80,7	58,1	52,7	91,7	135,7	10,9	6,3	34,6	47,9
United Kingdom	18,1	5,7	69,6	24,4	900,0	13,3	27,3	0,0	25,0	0,0	37,6	11,3
Italy	0,0	5,6	0,0	3,9	71,4	0,0	100,0	50,0	11,8	4,7	22,7	35,9
Japan	93,8	95,1	91,3	86,4	106,1	67,6	86,1	86,8	95,5	89,0	94,1	84,0
Korea	50,6	9,1	0,0	73,3	50,0	67,1	50,0	21,7	0,0	0,0	27,0	23,8
Netherlands	16,4	11,6	33,3	25,0	0,0	0,0	-	100,0	0,0	5,8	33,2	91,7
Norway	0,0	15,6		130,0	-	-	-	0,0	-	50,0	0,0	24,5
Sweden	0,0	40,2	18,3	61,1	3,8	0,0	0,0	0,0	0,0	0,0	134,2	27,4
Taiwan	9,0	9,6	0,0	-	-	-	-	40,0	-	0,0	0,0	7,4
United States	14,6	28,4	22,9	27,8	49,2	6,8	26,2	35,5	3,2	7,8	25,6	27,6
Total	52,1	35,4	48,1	50,1	77,7	29,7	71,2	41,7	36,2	32,5	69,2	57,9

Note: contribution of firms patenting to the overall firm country patenting can exceed 100% because applicants belonging to the firm perimeter can be located in country which is not the firm HQs country; according to our methodology its patents are allocated to the firm in the firm country.