Measuring the technological coherence of environmental technologies with the industry knowledge base

Filiação institucional

Ana Urraca Ruiz, Professora Associada, Faculdade de Economia, UFF
Pedro Miranda, Técnico de Planejamento e Pesquisa da DISET/IPEA
Vanessa de Lima Avanci, Programa de Doutorado em Economia PPGE-UFF

Abstract

This paper evaluates the importance of environmental technologies (ET) in the base pf knowledge of 21 industries by using a new methodology based on analysis of networks. To do that, we consider that industry base of knowledge must consist not only in the addition of the technological competences of the firms, but also in the specific way by which industries combine and develop new knowledge. Inspired in the Patel and Pavitt's (1997) seminal work, we elaborate indicators of centrality and relatedness to build a hierarchical taxonomy that classifies environmental technological classes in four categories by industry: central (core), niche, background and marginal. The paper uses data from patent applications filed at European Patent Office in the 1980-2012 period by industrial companies from 21 industrial sectors. The main results are the following. First, the main creators of ET are also the main pollutant industries: agriculture, coke and petroleum, chemical and motor vehicles. Second, concentration, diversification and specialization indexes point out that investments in environmental innovation are still very low and concentrated in few technical fields, highlighting technologies related to pollution abatement and biofuels. Third, the methodology based on network analysis reinforced previous results, but extend the set of central-knowledge to which the ET are linked in, including also technologies related to renewable energy sources and GHG emissions mitigation. Thus, it reveals that knowledge relatedness matters and must be taken into account in the analysis of the industrial technological profiles.

Keywords: Environmental technologies; industry base of knowledge; relatedness; centrality; knowledge networks

JEL Classification: O30; O35; Q55

Resumo

Este artigo avalia a importância das tecnologias ambientais (ET) na base de conhecimento de 21 setores industriais a partir de uma nova metodologia baseada em análise de redes. Para isto, considera-se que a base de conhecimento industrial deve consistir no só na simples agregação das competências tecnológicas das firmas, mas também pela forma especifica em que as indústrias combinam e desenvolvem novo conhecimento. Inspirado no trabalho seminal de Patel e Pavitt (1997), o trabalho elabora indicadores de centralidade e relacionamento para construir uma taxonomia hierárquica que classifica as classes de tecnologias ambientais em quatro categorias: central, nicho, de fundo e marginal. O trabalho usa dados de patentes depositadas por empresas industriais no Escritório Europeu de Patentes entre 1980-2012. Os principais resultados são os seguintes. Primeiro, os principais criadores de ET são também as indústrias mais poluentes: agricultura, carvão e petróleo, química e veículos-motor. Segundo, os índices de concentração, diversificação e especialização apontam que os investimentos em inovações ambientais são ainda muito baixas e concentradas em poucos setores relacionados com a redução da polução e biofuels. E, terceiro, a metodologia baseada na análise de redes reforça os resultados anteriores, mas estende o conjunto de conhecimento central ao qual se vinculam as tecnologias ambientais, incluindo também as energias renováveis e a mitigação de emissões GHG. Isto revela que a relacionabilidade do conhecimento deve ser considerada nas análises dos perfis tecnológicos da indústria.

Palavras-chave: Tecnologias ambientais; inovações ambientais; base industrial de conhecimento; relacionamento; centralidade; redes de conhecimento.

ÁREA ABEIN: 5.7 Competências e capacitações de empresas

CLASSIFICAÇÃO JEL: O30; O35; Q55

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1. Introduction

Innovation on environmental technologies is an actual and relevant issue. As societies are increasingly sensitized with environmental problems [mainly linked to climate change and sustainable growth], the creation and adoption of environmental *technologies* (ET) constitutes a relevant concern at national and firm level. In terms of a research agenda, one of the more important issues about innovation in environmental technologies is the study about what determines the rhythms of adoption or the choice for more environmental-friendly technologies. This paper deals with a dimension of this matter.

Environmental *innovations* (EI) are defined by “the production, assimilation or exploitation of a product, production process, service, management or business methods that is novel to the firm [or organization] and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use)” (Kemp and Pontoglio, 2007:10). From this definition, EI acquire a very strong transversal character at least in three dimensions. First, EI refers to product, processes and organizational innovation [even simultaneously]. Second, innovators can belong to a quite large number of industrial activities. Thirdly, to use and to produce, EIs entails all competences of the firm, that is, productive, technological and managerial.

As any other innovation, creation and adoption of EI depends mostly on firm’s behavior, but also governments and related institutions act as promoters of this kind of innovations to achieve specific environmental goals. From the last decades, climate change and sustainable growth emerged as some of the most important international issues with a significant effect on the innovation policy agenda, both national and international. The main objectives for climate change policy and sustainable development are associated to the mitigation of greenhouse gases in the atmosphere (GHG) and to the migration to a low carbon economy (UNFCC, 2009). In this sense, the environmental policies act on the innovation system by promoting research and development in at least the following related technologies: reduction of GHG emissions; energy efficiency; renewable energy and biofuels (European Commission, 2011).

By the side of the firm, as a creator or an adopter of EI, the theory of the corporative coherence of the firm points out that the growth of the firm is not random, but determined by the paths of technological accumulation on a set of old and new competences that, overall, are coherent (Teece et al., 1994). As competences of the firm are productive, technological and managerial, the set of technological competences developed by firms must exhibit at least two kinds of coherence: (1) coherence with the productive activities firms are involved in; and (2), coherence between them due to the ‘knowledge relatedness’. Therefore, we can define coherence at least in two domains: productive coherence and technological coherence. Productive Coherence refers to *business relatedness*; this is, when there are economies by joint operation and/or ownership. In this sense, the range of production -products and services- follows a path of specialization/diversification strongly interrelated (Teece et al., 1994).

Technological Coherence refers to *knowledge relatedness*. At the firm level, knowledge relatedness has three dimensions referred to: (1) the learning spillovers from one technology to another; (2) the common use of specific types of knowledge, that is, the application of knowledge in more than one product; and (3) the need of combine different types of knowledge to make a single technology (Breschi et al, 2003). Considering the nature of productive coherence and the characteristics of innovation process at the level of the firm in relation to bounded rationality and uncertainty, innovations are not the result of pursuing the most profitable technologies, but the result of searching in specific knowledge domains that are complementary and interrelated. In this sense, EI happens pushed by complementary knowledge [internal, external (subcontracting) or cooperation] (Bonte and Dienes, 2013). Due to its transversal character, EI are not specifically associated to one specific industry as user or producer, but related to technologies hosted in a wide set of industries and bases of knowledge. Therefore, creation and adoption of EI depends strongly on the technological coherence of the firms' technological domains related to core activities and complementary assets as source of competitive advantage (Chiu et al, 2008).

At the industrial level, the technological coherence refers to the base of knowledge absorbed in the productive, technological and managerial activities. The industrial base of knowledge express, in aggregated terms, not only the technological core-competences of the firms that compose the industry, but also their complementary assets, their patterns of search and their paths of diversification. As a whole, the different levels of aggregation of competences at industrial level express a set of problems, methods and solutions to specific problems and, therefore, the technological micro-trajectories of technical progress by industry.

To move from the competences of the firm to the industrial base of knowledge is an aggregation matter. One way to do that is to deal with the individual technological competences as pieces of knowledge. Nevertheless, as long as those pieces are combined in specific ways to resolve specific patterns of problems, heuristics and procedures, their aggregation cannot be only by addition, but also by their interconnections like in a network. Therefore, the hierarchical categories that revealed the importance of specific types of knowledge at the industrial level have to consider at least two criteria: *centrality* and *relatedness*. The frequency and linkages of every single piece of knowledge used in an industry determines its *centrality*. In this sense, centralities at the industrial level must reveal what are core-competences at the firm level. Furthermore, the more frequent their links with other technologies are, the more *relative* that piece of knowledge will be. Relatedness indicates, in this sense, the specific way through which an industry solve problems. Centrality and Relatedness should reproduce at industrial level the technological coherence at firm level. Using both, one can observe how the pieces of knowledge are structured in specific ways by industry and how those structures evolved as new technologies are introduced within. One can expect that a structure of knowledge defined in this way can modify by introducing new pieces of knowledge, by changing the composition of the previous structures or by both.

The aim of this paper is to evaluate how knowledge engaged in ET [considered as a 'recent technology'] is central and related to the industrial technological bases in two senses: 1) by the degree of diversification and specialization of industrial sectors in environmental technologies; and 2) by the positioning of the ET as central competences. To do that, the paper elaborates an indicator that categorized the importance of specific types of knowledge by industry considering their frequency and relatedness. The positioning of environmental technologies in the industrial base of knowledge allows evaluating which is centrality of these technologies in industry, not only in terms of technological efforts, but also in terms of their connections with core-knowledge. If ET connects to the core business, they represent a source of competitive advantage; if not, they can be just technological niches, complementary assets or peripheral knowledge. The paper uses data from patent applications filed at European Patent Office (EPO PatStat) in the 1980-2012 period by industrial companies from 21 industrial sectors (NACE Classification) in all technical fields (OST Classification from IPC) and in the 8 environmental technologies.

2. Patents database

This work uses statistical data on patents as in numerous works on technological competences and bases of knowledge (OECD, 2009a; 2009b; Saviotti, 2009; Patel and Pavitt 1997). Patents database allows the treatment of information on the activities of firms without restricting the analysis to specific technological fields, sectors, countries or to a short period.

Patents represent results of formal or informal innovation efforts[1] and provide detailed data in a regular and long time series grouped by firm, country, geographic location and technical field (Patel and Pavitt 1991). Therefore, patents are appropriated to analyze technological competences at firm level and at industrial level. Nonetheless, there are some limitations of patents as indicator of competences. In first place, patents disclose distributions of competences of disembodied and codified technologies across technical fields, but not of distributions of capabilities. Technological capabilities should include embodied and tacit knowledge, as well as indicators about Generation and Diffusion of knowledge (Archibugi and Coco, 2005). Even assuming that complementarities do exist between all three categories, the use of patents alone underestimates the set of aspects that transform a competence into a capability (Brusoni and Geuna, 2003). Second, measuring technological specialization to the development of specific products and industries can involve a classification of technological fields that does not respond to the usual ones in patent classifications. Therefore, additional criteria for product aggregation can be necessary. Third, some technological competences can be underestimated when they are built on non-patentable technologies or on technologies that are not protected by patents. Furthermore, the option of patenting a certain object depends, among others, on firms' strategies, the features of the object, and the intellectual property system of the country. That is to say, not every effort involved in processes of technological change will necessarily result in the creation of patents, and the propensity to patent varies according to the country, sector, and size of the firms (Cohen et al., 2002; Arundel, 2001; Levin et al., 1987)[2]. In order to avoid distortions and inconclusive results, in this paper the statistics analysis always include a control by the total volume of patents granted to sectors and/or technical fields. Fourth, patents do not capture some categories of ecoinovations [as an extension of environmental technologies] pointed by OCDE (2009). Specifically, these are relative to methods linked to marketing strategies, organizational and

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[1] The literature presents evidence on the positive relation between the number of patents and R&D efforts (Danguy et al., 2013; Czarnitzki, Kraft and Thorwarth, 2009; de Rassenfosse and de la Potterie, 2009; Griliches, 1990). However, the activities that result in patents are not restricted to formal innovation efforts, especially in the specific case of smaller firms (Nagaoka and Walsh, 2009).

[2] For a review of the limits and disadvantages in the use of patent statistical data as a proxy for technological activities, see Nagaoka, Motohashi and Goto (2010), and Hall (2009).

management changes and institutional arrangement to promote EI. Patents applications statistics do not evaluate the environmental impact of any adopted technology. To do that, it should be better to use citations of patents.

In last place, four major methodological aspects worth to be noted in relation to the treatment given to the information contained in the patent database. First, patents are the only one source of information that synthetize national R&D efforts with potential of innovation by technical field. Second, the database for industry knowledge base includes patents filed only by companies and excludes patents filed by other applicants, as government agencies, universities and individuals[3] or that have an unknown NACE code. Third, one patent represents a technology that combines different pieces of knowledge. For this reason, a patent can correspond more than one technical field. Since this, the number of patents accounted for each technical field will be fractioned, according to the proportional stake assigned to each technical field.[4] This means that a single patent will be split as many pieces of knowledge as technical fields it is assigned to. This classification follows the International Patent Classification (IPC) codes available on the patent register, at 4-digit aggregation level.

The identification of environmental technologies takes the Urraca-Ruiz and Durán-Romero's (2013) classification which uses the eight environmental technology fields of OECD (2009) aggregating the technologies filed in the "IPC Green Inventory" of the International Patent System listed by the United Nations Framework Convention on Climate Change. Four great fields grouped the eight environmental technology fields: Energy, GHG emissions mitigation (Emissions), Environmental management and Agriculture/Forestry (table 1).

The analysis uses patents filed at the EPO between 1980 and 2012. Data was extracted using the April 2015 issue of the EPO Worldwide Patent Statistical Database (EPO Patstat). EPO database in PATSTAT represents the best source of information for international comparisons for several reasons. Firstly, because a simple patent is extensible to all Munich Convention member countries, which eliminates country bias of the domestic effect [like, UPSTO does]. Secondly, fee applications are relatively higher, which excludes from the database patents of low industrial value. Thirdly, EPO publishes grants and deposits of patents eighteen months after the application (by mean), while other bases are more delayed [for example, UPSTO only publishes after two years (by mean)] (Grupp and Schomach, 1999; Le Bas and Sierra, 2002; van Zeebroeck et al., 2006).

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[3] As a reference for the nature of the applicant, it was used the classification available on ORBIS - Bvd for stakeholder and affiliate types, and the following applicant categories were disregarded: Foundation/Research Institute, Employees/Managers/Officers, Individuals/Families, Public Authorities/State/Government, or Not Identified. As for the industry sectors in which each firm acts, it was used the classification created by ORBIS - Bvd based on the revised Statistical Classification of Economic Activities in the European Community (NACE Rev.2), and were included only the companies listed in sections A to L

[4] An alternative to this method of fractioned counting, where the share of each technical field is inversely proportional to the total fields concerned, would be multiple counting. It allows for the register of one unit every time a patent features at least two technical fields. That is to say, patents featuring more than one technical field would be accounted for *n* times, where *n* = (number of different technical fields). Unfortunately, patent documentation does not include any information regarding the importance of the share by each mentioned technical field. Therefore, both methods will generate imprecise measurements and a bias.

Table 1. - Description of environmental technological groups

	Environmental Technology	Description
Energy	Energy generation through renewable energy sources (RE)	Geothermal energy - use of geothermal heat Hidroenergy - Water power plants Machines or engines for liquids Ocean Thermal Energy Conversion Photovoltaics (PV) Solar ernegy - use of solar heat Propulsion of vehicles using solar and wind power Structural association of electric generator with mecanical driving motor
Energy	Technologies for the production of fuel of non-fossil origin - Biofuels (NF)	Solid Fuels Liquid Fuels
Energy	Energy conservation (EC)	Storage of electrical energy Electric consumption measurement devices Storage of geothermal energy - Heat storage materials Low energy lighting - Light Sources Thermal building insulation Recovering mechanical energy - Mechanical devices
Emissions	Combustion technologies with mitigation potencial (CT) Technologies with potential or indirect contribution to GHG emissions mitigation (MG) Emissions Abatement and Fuel Efficiency in Transportation (ET)	Combined cycle power plant or combined cycle gas turbine Integrated gasification combined cycle (IGCC) Electrodes Fuel cells Hydrid cells Integrated emissions control (NOX, CO, HC, PM) Post-combustion emissions control (NOX, CO, HC, PM) Propulsing using electric motor Hibrid propulsion Fuel efficiency - improving vehicle design
	General Environmental Management (EV)	Air pollution abatement Water pollution abatement Solid waste collection Material recovery, recycling and re-use Incineration and energy recovery Landfilling and Waste management Reclamation of contaminated soil Environmental monitoring
	Agriculture/Forestry (AF)	Alternative irrigation techniques Forestry techniques Pesticides and biocides Soil improvement

Source: Urraca-Ruiz and Durán-Romero's (2013) and OECD (2009)

EPO database recorded 2,474,208 applications between 1980 and 2012; 1,444,990 patents were filed by industrial companies (58.4%); 130,946 patents were identified as ET, with a huge concentration in the energy technical fields and General Environmental Management technologies (Table 2). The contribution of the industry for environmental technologies was about 54.9%, with higher participation in the Emissions mitigation (from 60.7% up to 67%) and agriculture/forestry technologies (66.8%).

Table 2 – Patent distribution by technical field and applicant – 1980-2012

Technical fields	Total (a)	Industry (b)	Industry contribuition [100*(b)/(a)]
Environmental technologies	**130945,5**	**71828,8**	**54,9**
Energy	66837,3	34843,6	52,1
Energy generation through renewable energy sources (RE)	21429,5	10350,7	48,3
Technologies for the production of fuel of non-fossil origin - Biofuels (NF)	28824,2	15090,2	52,4
Energy conservation (EC)	16583,6	9402,7	56,7
Emissoins	23445,3	15539,0	66,3
Combustion technologies with mitigation potencial (CT)	672,3	408,1	60,7
Technologies with potential or indirect contribution to GHG emissions mitigation (MG)	6169,9	4002,8	64,9
Emissions Abatement and Fuel Efficiency in Transportation (ET)	16603,2	11128,2	67,0
General Environmental Management (EV)	26147,4	11745,3	44,9
Agriculture/Forestry (AF)	14515,4	9700,8	66,8
Other technical fields	**2343262,4**	**1373161,5**	**58,6**
Total	**2474207,9**	**1444990,3**	**58,4**

Source: author calculations based on data from EPO PATSTAT / EPO (2015) e Orbis / BvD (2013).

3. Industrial Diversification, concentration and specialization in environmental technologies

First step to evaluate how ET compose the industrial technical base is to identify the relevance of ET creation by industry. As a whole, ET represent only about 5.29% over the total technological base. Decomposing this share by technology, only two ET represent achieve than 1% of the total technologies in the database, which is very low (table 3). These ET are Environment and Non-fuel technologies. The low activity in ET is due to they are still quite recent and there are few incentives to incorporate them. The Kyoto Protocol that affect the ET related to Climate Change technologies [Combustion; Energy conservation; Emissions transport; Mitigation GHG; and Renewable Energy] does not seem to have had the expected results in terms of rhythms of ET creation and adoption. Several reasons could explain why, but may be the most important is the resistance to alter the actual techno-economic paradigm that affects such relevant transformations as new sources of energy, new consumer habits and new institutions; all of them with elevated direction changing costs.

At the sectoral level, some observations are worth noting. In first place, ET are more relevant in the most contaminant industries (Agriculture; Mining and Quarrying; Coke and Petroleum; Chemical; Motor-vehicles; Other non-metal products) (Table 3). Other still quite important like Pharmaceutical or Other Services have other kind of relationships with ET. Pharma industry, as well as Chemical, take some advantages of its technological competences developed their firms in productive divisions of agrochemicals and chemistry. These explain their inventive activity in Agro-forestry and Non-Fuel Technologies (Biofuel). Other Services includes Real State activities, Administrative and support services activities, education and Human Wealth.

The contaminant industries focus their environmental technological activity in technologies that try to reduce their pollutant action. Therefore, Agriculture, Mining, Coke and Petroleum and Chemical concentrates in non-fuel technologies (Biofuel); Other non-Metal products concentrates in energy conservation, given it is a high-intensive user of energy in their productive processes; and Motor-vehicles focus in Emissions Transports. Other relevant contributions of these industries are Agriculture to Agro-Forestry; Mining and Quarrying to Environment; Food, Beverage and Tobacco to Biofuel; Wood and Furniture to Energy conservation; Rubber and Plastic to Emission Transport; Motor-vehicles to Environment; Other transport equipment to Emission Transport. No significant contributions are made by any specific industry to the generation of renewable technologies.

The industries where ET presents higher participation in its competences base distributes their efforts in the ET generation as follows:

- *Agriculture, Forestry and Fishing* concentrates 21% of its ET generation in Agroforestry (15% in Biocides); 46% in Non fuel (fully concentrated in Liquid fuels); and 20% in Environmental (which is 7% in Water pollution abatement and 6% in Material recovery, recycling and re-use);
- *Mining and Quarrying* concentrates in Environmental 30% (which is 14% in Air Pollution and 7% in Water pollution abatement);); in Non fuel 32% (which is 31% for Liquid fuels);
- *Coke and Petroleum* concentrates in Non fuel 42% (which is 41% for Liquid fuels);
- *Chemical* concentrates in Agroforestry 34% (which is all 34% in Biocides); and in Non fuel 31% (which is all 31% for Liquid fuels);
- *Pharmaceuticals* concentrates in Agroforestry 31% (which is 30% in Biocides); and in Non fuel 59% (which is all 59% for Liquid fuels);
- Motor vehicles concentrates 63% in Emission transport (which is 32% in Integrated emissions control; 11% in Post-combustion emissions control; and 11% in Fuel efficiency).

Table 3. The industrial creation of environmental technologies – 1980-2012

Sector	Environmental Technical fields									Other technical fields (b)	TOTAL (a+b)
	Agriculture/Forestry (AF)	Combustion technologies with mitigation potencial (CT)	Energy conservation (EC)	Emissions Abatement and Fuel Efficiency in Transportation (ET)	General Environmental Management (EV)	Technologies with potential or indirect contribution to GHG emissions mitigation (MG)	Technologies for the production of fuel of non-fossil origin - Biofuels (NF)	Energy generation through renewable energy sources (RE)	Total (a)		
Agriculture, Forestry and Fishing	2.16	0.02	0.24	0.12	2.03	0.11	4.71	0.79	10.17	89.83	100.0
Mining and Quarrying	0.77	0.19	0.25	0.77	2.52	0.41	2.66	0.88	8.44	91.56	100.0
Food, beverage and tobacco	0.46	0.00	0.03	0.06	1.01	0.01	2.94	0.11	4.62	95.38	100.0
Textil, wear and leather	0.19	-	0.59	0.75	0.78	0.23	0.25	0.46	3.26	96.74	100.0
Wood and Furniture	0.15	0.01	3.09	0.13	0.60	-	0.48	0.73	5.19	94.81	100.0
Paper and printing	0.23	0.00	0.26	0.03	0.90	0.09	0.16	0.24	1.91	98.09	100.0
Coke and petroleum	0.70	0.15	1.67	0.75	2.11	0.38	5.31	1.49	12.57	87.43	100.0
Chemical	2.87	0.03	0.45	0.38	1.30	0.25	2.63	0.46	8.37	91.63	100.0
Pharmaceutical	2.08	0.00	0.10	0.09	0.37	0.02	4.01	0.10	6.77	93.23	100.0
Rubber and Plastic	0.12	0.00	0.68	1.90	1.25	0.17	0.13	0.73	4.98	95.02	100.0
Other non metal products	0.20	0.00	2.17	0.25	2.21	0.67	0.32	1.22	7.04	92.96	100.0
Basic metals	0.15	0.02	1.17	0.23	1.41	0.28	0.26	1.05	4.58	95.42	100.0
Metal products	0.10	0.01	0.85	0.20	1.10	0.20	0.09	1.00	3.55	96.45	100.0
Computer, electronic and optical	0.02	0.02	0.80	0.27	0.26	0.21	0.16	0.97	2.73	97.27	100.0
Electrical equipment	0.01	0.01	1.44	0.30	0.37	0.71	0.04	1.06	3.94	96.06	100.0
Machinary and equipment	0.17	0.05	0.30	0.58	1.26	0.10	0.22	0.86	3.53	96.47	100.0
Motor-vehicles	0.01	0.01	0.69	6.34	1.70	0.85	0.05	0.37	10.01	89.99	100.0
Other transport equipment	0.01	0.26	0.39	1.51	0.77	0.63	0.14	1.11	4.82	95.18	100.0
Other manufacturing	0.12	0.00	0.16	0.05	0.31	0.13	0.59	0.20	1.56	98.44	100.0
Industrial services	0.35	0.03	0.55	0.68	1.26	0.26	1.22	0.91	5.25	94.75	100.0
Other services	0.51	0.01	0.54	0.38	0.96	0.24	3.09	0.92	6.65	93.35	100.0
TOTAL	**0.59**	**0.03**	**0.67**	**0.67**	**1.06**	**0.25**	**1.16**	**0.87**	**5.29**	**94.71**	**100.0**

Source: author calculations based on data from EPO PATSTAT / EPO (2015) and Orbis / BvD (2013).

Table 4. Related and Unrelated Variety, Concentration and industrial Specialization in Environmental Technologies.

	Diversity or Variety		Concentration	Revealed Technological Advantage							
	Unrelated Variety	Related Variety	HHI	Agro Forestry	Combustion Technology	Energy Conservation	Emissions Transport	Environ ment	Mitigation GHG	Non Fuel Techs	Renewable Energy
AGRICULTURE, FORESTRY AND FISHING	2,03	0,99	0,31	0,56	-0,18	-0,50	-0,71	0,29	-0,42	0,59	-0,07
MINING AND QUARRYING	2,50	1,11	0,22	0,12	0,74	-0,47	0,05	0,40	0,23	0,38	-0,01
Food, beverage and tobacco	1,51	0,55	0,46	-0,12	-0,76	-0,90	-0,83	-0,02	-0,96	0,43	-0,77
Textil, wear and leather	2,62	1,53	0,18	-0,50	-1,00	-0,06	0,07	-0,14	-0,03	-0,64	-0,29
Wood and Furniture	1,82	0,85	0,40	-0,59	-0,66	0,64	-0,67	-0,28	-1,00	-0,41	-0,08
Paper and printing	2,26	1,46	0,28	-0,43	-0,80	-0,43	-0,90	-0,06	-0,47	-0,76	-0,55
Coke and petroleum	2,41	0,89	0,25	0,05	0,68	0,40	0,02	0,30	0,17	0,62	0,23
Chemical	2,31	0,56	0,25	0,65	0,01	-0,21	-0,29	0,09	-0,01	0,37	-0,32
Pharmaceutical	1,49	0,17	0,45	0,55	-0,85	-0,75	-0,76	-0,49	-0,84	0,54	-0,79
Rubber and Plastic	2,26	1,58	0,25	-0,67	-0,78	0,00	0,48	0,08	-0,19	-0,80	-0,08
Other non metal products	2,33	1,28	0,24	-0,51	-0,82	0,52	-0,47	0,35	0,45	-0,57	0,16
Basic metals	2,41	1,63	0,22	-0,60	-0,12	0,27	-0,48	0,15	0,07	-0,63	0,10
Metal products	2,31	1,72	0,24	-0,70	-0,32	0,12	-0,54	0,03	-0,10	-0,85	0,08
Computer, electronic and optical	2,34	1,09	0,24	-0,93	-0,10	0,10	-0,41	-0,59	-0,07	-0,75	0,07
Electrical equipment	2,22	1,35	0,25	-0,95	-0,31	0,37	-0,38	-0,48	0,48	-0,93	0,11
Machinary and equipment (incl reparing)	2,44	1,93	0,23	-0,55	0,26	-0,37	-0,07	0,10	-0,44	-0,68	0,00
Motor-vehicles	1,65	1,57	0,44	-0,95	-0,58	-0,01	0,80	0,21	0,53	-0,93	-0,42
Other transport equipment	2,51	1,67	0,20	-0,97	0,81	-0,26	0,39	-0,15	0,44	-0,78	0,12
Other manufacturing	2,46	1,13	0,22	-0,65	-0,85	-0,60	-0,86	-0,53	-0,31	-0,31	-0,62
Industrial services	2,66	1,53	0,18	-0,26	0,10	-0,10	0,01	0,09	0,02	0,02	0,02
Other Services	2,31	0,97	0,27	-0,08	-0,48	-0,11	-0,28	-0,05	-0,03	0,45	0,02
Non classified	2,57	1,23	0,19	-0,02	-0,14	0,12	-0,27	0,23	-0,25	-0,04	0,18
Pervasivess across industrial sectors				7,54	15,50	23,04	12,69	18,83	19,10	27,25	12,12
Maximum value	3	3	1	1	1	1	1	1	1	1	1
Minimum value	0	0	0,13	-1	-1	-1	-1	-1	-1	-1	-1

Source: author calculations based on data from EPO PATSTAT / EPO (2015) and Orbis / BvD (2013).

A second step in the analysis is to qualify how the industries diversify, concentrate and specialize in ET. One appropriated methodology to measure diversification is the index of related and unrelated diversification –or variety- (Frenken et al 2007). Unrelated Variety (UV) is the entropy index of the two-digits distribution per industry. The two-digit shares can be denoted by summing the four-digit share as follows:

$$P_g = \sum_{i \in S_g} p_i$$

And the Unrelated Variety is defined as;

$$\text{UV} = \sum_{g=1}^{G} P_g \, log_2 \left(\frac{1}{P_g} \right) = - \sum_{g=1}^{G} P_g \, log_2 \left(P_g \right)$$

The UV index vary between zero and $log_2(n)$ that takes a maximum value when all the shares are equal ($P_g = 1/n$). As the number of ET is eight, the maximum value for UV=3.

Related Variety (RV) indicates the spillovers from participate into a variety of technologies within each of the two-digit classes. RV is measured as the weighted sum of the entropy at the four-digit level within each two-digit class and it is calculated as follows:

$$\text{RV} = \sum_{g=1}^{G} P_g \, H_g, \qquad G = 8$$

Where H_g is the weighted factor calculated as $H_g = \sum_{g=1}^{G} \frac{p_i}{P_g} log_2 \left(\frac{1}{P_i/P_g} \right)$. The RV index also vary between zero and $log_2(n)$=3 for the maximum value of variety when $P_g = 1/n$, this is, when all the shares are equal.

Table 4 reports the results for unrelated and related. Unrelated variety is a measure of diversification and then highly correlated with the Herfindahl-Hirschman index (HHI) –also reported in Table 4–, which defines as follows:

$$\text{HHI} = \sum_{g=1}^{G} P_g^2 \, , \qquad G = 8$$

A first result that call the attention is that a large number of industries diversify their inventive activity among most of the ET at two-digits level. For a maximum value of diversification equal to 3, the UV index takes values superior to 2 in 18 of all 21 sectors. Only four industries concentrate highly their inventive efforts in ET: Food, beverage and tobacco (HHI=0,46) in Biofuel; Wood and furniture (HHI=0,4) in Energy Conservation; Pharmaceutical (HHI=0,45) in Agro-Forestry and Biofuel; and Motor-vehicles (HHI=0,44) in Emission transport. This apparent diversification observed at two-digits levels disappears at four-digits level. The Related Variety index shows that the diversity of related knowledge at four-digit level within the same technology is quite low. None of sectors achieve values for RV superior to 2 and only seven industries show RV values superior to 1.5.

Last indicator used to characterize the industrial invention in ET is Revealed Technological Advantage (RTA), which compares the technological effort of an industry in a specific technology (p_{ij}) with the total technological effort in the same technology (p_{iw}) $RTA_{ij} = \frac{p_{ij}}{p_{iw}}$. RTA-values run from 0 to ∞. Normalized RTA (NRTA) run between -1 and 1 by doing the following transformation: $NRTA_{ij} = \frac{RTA_{ij}-1}{RTA_{ij}+1}$.

Table 4 reports the normalized values of industrial specializations in environmental technologies, confirming previous results. That means that, in so many cases, the technologies which the industries are specialized in, are those ones the concentrate their principal efforts. In this sense.

- *Agriculture, Forestry and Fishing* specialize in Agroforestry, Non fuel and Environmental Technologies;
- *Mining and Quarrying* specialize in Combustion Technologies, Environmental and Non fuel technologies;
- *Coke and Petroleum* specialize in Combustion Technologies, Energy conservation, Non fuel technologies, Environment and GHG Mitigation;
- *Chemical* and *Pharmaceuticals* specialize in Agroforestry and in Non fuel Technologies;
- *Motor-vehicles and Other transport equipment* specialized in Combustion Technologies, Emission transport and GHG Mitigation.

4. Centrality and Relatedness of environmental technologies in the industrial structure of knowledge.

All general results presented previously points out that the environmental technologies are related to the core business activities of the each sectors. That is the reason of the close relation between create clean technologies and be a pollutant. As technological efforts of ET are low in relation to other technologies, measures based in frequency would underestimate the importance of ET inside the industrial structure of knowledge. So, the methodology adopted uses analysis of networks including not only the frequency of use of each piece of knowledge, but also their links and interactions.

The methodology departs from the Patel and Pavitt´s (1994) work in which the technological competences of the firm aggregated to the industrial level were classified hierarchically as core, niche, background and marginal. Those categories depend on two criteria: the importance the technology has for the industry [measured as the share of the technology in the industrial knowledge base]; and the relative contribution of the technology in an industry in relation to all industries. When a technology distinguishes in an industry from others and at the same time it has a high participation in the industrial base of competences, it will be a core-technology. When a technology distinguishes in an industry, but it does not represent an important investment area in that industry, it is a niche-technology. In the opposite situation, a technology that is important for an industry but does not distinguish in the industry from the others, it is a background-technology. Finally, when a technology neither is important in the industry nor contributes to distinguish it, it is marginal.

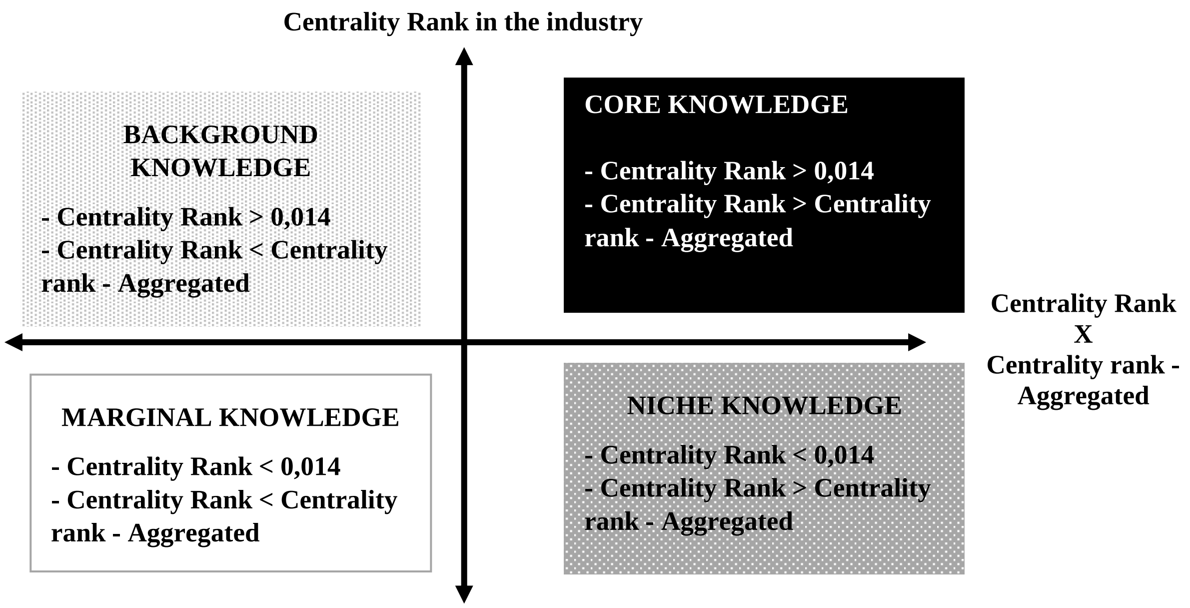
The aggregation of competences to build an industrial base of knowledge using the analysis of networks also will permit to create hierarchical categories, but in a different conceptualization. In first place, technical fields by IPC classification at any level of aggregation represent *units of technical knowledge (UTK)that respond to the same heuristics, this is, the same patterns of problems, methods, procedures and solutions*. In second place, the way in which this units or pieces of knowledge are connected matters, because it varies from one industry to another. Thus, as the links of every UTK are specific for each industry, the centrality indicator must take into consideration the number of relations each UTK is linked in the industrial structure of knowledge base, as well as the importance of each UTK is linked in. The more connected a UTK is to others in the industrial network of knowledge; the higher will be its relevance.

The UTKs are technical fields [IPC codes] at 4-digit level of aggregation assigned in each patent. As it is usual that a patent registers more than one 4-digit IPC code, the relatedness between UTKs is measured by the co-occurrence of different UTKs in the same patent register. The co-occurrence network has three components: nodes or UTKs [IPC code at 4 digit level]; edges which link nodes when these nodes co-occur on same patent; and co-occurrence frequencies of pairs of nodes as weights for the edges. The more frequent two nodes [UTKs] are linked in, the stronger the relationship between them will be. The co-occurrence network forms an undirected and weighted graph and the UTK centrality in this network will be calculated using the PageRank algorithm. PageRank is a graph-based ranking algorithm used to determine a rough estimate of importance [centrality] of a UTK by considering both its inbound links and outbound links (Perra & Fortunato, 2008; Ding, 2009). Nodes with more links and higher weights will get high PageRank scores. From this it may be interpreted that UTKs that co-occur with many other UTKs [which indicates “more links”] and co-occur many times with these UTKs [which indicates “high weights”] will get higher PageRank scores. Also, nodes linked with important nodes will get higher PageRank scores.[5]

The centrality rank is calculated using 671 UTKs for each one of the 21 industries analyzed and for all industries aggregated. The reference value is the centrality rank observed in a base of knowledge where all the UTKs have the same participation [the same rank]. Considering the number of UTKs and the PageRank algorithm, this reference value is a centrality rank of 0.014. The distinguished UTKs in an industry are those whose centrality rank in the industry is higher than its centrality rank in the whole of aggregated industries. When a UTK has a centrality rank in a industry higher than 0.014 and higher above the value for the aggregate industry, this UTKs represents Core-Knowledge in that industry (Figure 1). If the centrality rank of the UTKs is higher than 0.014 in the industry but bellow the value for the aggregated industry, the UTKs represents Background-Knowledge for the industry. If the UTKs has a centrality rank in the industry lower than 0,014 but higher than the value it takes in the aggregated base of knowledge, it represents Niche-Knowledge. In addition, UTKs with centrality ranks lower than 0.014 in the industry and lower than its value for the aggregate base of knowledge represents Marginal-Knowledge.

Figure 1: Hierarchical categories to classify the UTKs of an industrial base of knowledge.

[5] Gephi was the software used to estimate the centrality rank.



Source: Own criteria based on Patel and Pavitt ‘s (1997) methodology.

Table 5 reports how the 38 environmental UTKs [units of knowledge related to environmental issues at 4-digits level of aggregation] were categorized [marginal, background, niche or core] in each industry. Results confirms that a large number of environmental UTKs are marginal or are not included in the knowledge base for most of industries. UTKs in energy generation from renewable sources related to water power plants, machines for liquids and ocean thermal energy conversion are marginal or absent in more than 15 industries and they do not play a central role in any industry. The same pattern is observed in others UTKs in agriculture/forestry [forestry and alternative irrigation techniques] and general environmental management [solid waste collection, reclamation of contaminated soil and environmental monitoring].

In despite of that, some environmental UTKs play a central role in the knowledge base of some industries. In Environmental management, environmental UTKs applied to Waste management, Recycling and Air and water pollution represent Core-Knowledge in at least 10 industries. Other UTK should also be highlighted for their core role, Fuel Cells technologies in the GHG emissions mitigations technical field and technologies for propulsion of vehicles using solar and wind power in the renewable energy sources fields were considered core-technologies in 14 and 11 industries respectively.

Additional observations are worth noting when analyzing the results by industrial sector. Core-knowledge in Agriculture, Forestry and Fishing and Mining and Quarrying, are UTKs located in Agriculture/forestry [biocides and soil improvement], Environmental management [water and air pollution abatement and waste management, recycling and incineration]; Biofuels and some from Renewable energy [technologies related to for propulsion of vehicles and mechanical driving motors]. In Coke and Petroleum, core UTKs are related to Energy conservation, Environmental management; Biofuels and GHG emissions mitigation. The Other transport equipment industry has its core UTKs concentrated in Emissions abatement and fuel efficiency in transportation has some core-technologies in GHG emissions mitigation [fuel cells] and energy conservation and renewable energy sources. In other industries where ET has some relevance, the results reinforce the previously presented ones.

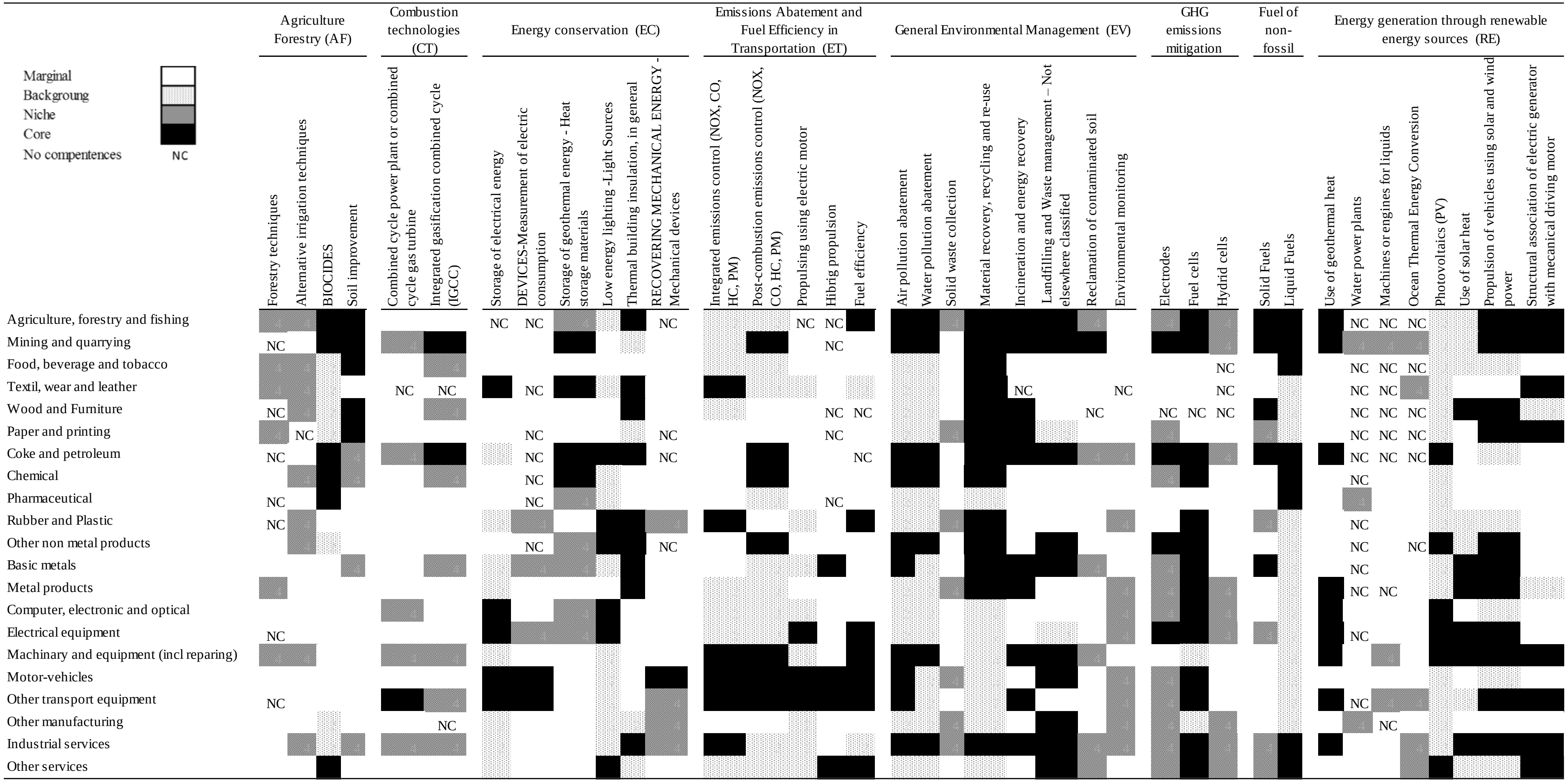
All the UTKs included in Emissions abatement in transportation are core in the Motor-vehicles industry. In the Chemical and Pharmaceutical industries, core UTKs are Biocides and other related to Biofuels. In Chemical, some technologies in Environmental management field also showed to play the same role.

Finally, table 6 compares the industrial distribution of core, niche, background and marginal resulting of using the page rank-meth and the frequency-meth. First method uses the centrality matched by the page rank and the second meth uses the same kind of information as in tables 3 and 4, but for UTK at 4-digit level, to reproduce the Patel and Pavitt's (1997) taxonomy, based only in the frequency of the technological classes, with a benchmark for VTR value =1. As we expected, the analysis of the industrial base of knowledge, based on the frequency of the technological competences of the firm, under-estimate the role of environmental technologies in the industry base of knowledge. As ET are transversal to a set of sectors, [they are not concentrated in a specific industry], and as they still represent low innovation efforts, they tend to be marginal in most of industries. Considering that the maximum value that each category can achieve is 798 (in the extreme case that all 38 competences correspond in a specific category to all 21 industries), environmental UTKs are: Marginal in 446 events (56%); Core in 115 events (14.4%); Niche in 122 events (15.3%) and Background in 49 events (6.1%). Nevertheless, when used the page-rank meth, the representability of ET increase significantly. The marginality of environmental UTKs decrease to 303 events (38.1%), meanwhile the importance to Core-knowledge increases to 190 events (23.8). The same effect is observed for Background environmental UTKs, that goes from 49 (6.1%) to 137 (17.2%). Only the Niche environmental UTKs are lower when measured by page rank, going from 122 events to 102 (12.8%).

In this sense, the more linked to the central knowledge environmental UTK are, the more coherent with the industrial base of knowledge they will be. The page rank centrality allows identifying coherence considering the connections of environmental UTKs to the central base-knowledge by industry. It is worth to mention the following cases:

- *Fuel efficiency (Emissions abatement),* that goes from being Core in 2 industries to be in 7;
- *Incineration and energy recovery and Landfilling and Waste management (general environmental management),* that go from being Core in 1 industry to be core in 10;
- *Fuel cells (GHG emissions mitigation),* that goes from being Core in 6 industries to be in 14;
- *Use of geothermal heat (renewable energy sources),* that goes from being Core in 1 industry to be in 9;
- *Propulsion of vehicles using solar and wind power (renewable energy sources),* that goes from being Core in 6 industries to be in 11.

Table 5. Technological profile of Environmental technical fields



Source: Own elaboration based on EPO PATSTAT / EPO (2015) e Orbis / BvD (2013).

Table 6. Comparing methods to reveal the importance of environmental technologies in the industry base of knowledge

		Agriculture Forestry (AF)				Combustion technologies (CT)		Energy conservation (EC)					
		Forestry techniques	Alternative irrigation techniques	BIOCIDES	Soil improvement	Combined cycle power plant or combined cycle gas turbine	Integrated gasification combined cycle (IGCC)	Storage of electrical energy	DEVICES-Measurement of electric consumption	Storage of geothermal energy - Heat storage materials	Low energy lighting -Light Sources	Thermal building insulation, in general	RECOVERING MECHANICAL ENERGY - Mechanical devices
By page-rank meth	Marginal	8	11	8	12	14	10	7	9	11	5	8	12
	Background	0	0	7	0	0	0	8	0	0	10	4	0
	Niche	6	9	0	4	5	7	0	3	6	0	0	4
	Core	0	0	6	5	1	2	5	2	4	6	9	1
	No- competence	7	1	0	0	1	2	1	7	0	0	0	4
By frequency meth	Marginal	9	17	10	16	15	13	15	10	15	12	12	12
	Background	0	0	6	0	0	0	0	0	0	4	1	0
	Niche	4	3	0	4	4	5	2	4	5	0	0	5
	Core	1	0	5	1	1	1	3	0	1	5	8	0
	No- competence	7	1	0	0	1	2	1	7	0	0	0	4
Maximum Value		21	21	21	21	21	21	21	21	21	21	21	21

		Emissions Abatement and Fuel Efficiency in Transportation (ET)					General Environmental Management (EV)							
		Integrated emissions control (NOX, CO, HC, PM)	Post-combustion emissions control (NOX, CO, HC, PM)	Propulsing using electric motor	Hibrig propulsion	Fuel efficiency	Air pollution abatement	Water pollution abatement	Solid waste collection	Material recovery, recycling and re-use	Incineration and energy recovery	Landfilling and Waste management – Not elsewhere classifed	Reclamation of contaminated soil	Environmental monitoring
By page-rank meth	Marginal	7	4	9	12	10	0	0	14	0	10	9	13	11
	Background	8	10	8	0	2	11	14	0	8	0	2	0	0
	Niche	0	0	0	0	0	0	0	7	0	0	0	6	9
	Core	6	7	3	4	7	10	7	0	13	10	10	1	0
	No- competence	0	0	1	5	2	0	0	0	0	1	0	1	1
By frequency meth	Marginal	14	15	15	12	16	8	5	15	7	12	13	13	10
	Background	2	0	0	0	0	5	6	0	2	0	0	0	0
	Niche	0	0	3	3	1	0	0	4	0	7	7	7	10
	Core	5	6	2	1	2	8	10	2	12	1	1	0	0
	No- competence	0	0	1	5	2	0	0	0	0	1	0	1	1
Maximum Value		21	21	21	21	21	21	21	21	21	21	21	21	21

		GHG emissions mitigation (MG)			Fuel of non-fossil origin - Biofuels		Energy generation through renewable energy sources (RE)								
		Electrodes	Fuel cells	Hydrid cells	Solid Fuels	Liquid Fuels	Use of geothermal heat	Water power plants	Machines or engines for liquids	Ocean Thermal Energy Conversion	Photovoltaics (PV)	Use of solar heat	Propulsion of vehicles using solar and wind power	Structural association of electric generator with mecanical driving motor	TOTAL
By page-rank meth	Marginal	5	4	9	11	0	12	5	10	10	0	8	4	11	303
	Background	0	2	0	0	13	0	0	0	0	15	7	6	2	137
	Niche	11	0	9	5	0	0	3	3	5	0	0	0	0	102
	Core	4	14	0	5	8	9	0	0	0	6	6	11	8	190
	No- competence	1	1	3	0	0	0	13	8	6	0	0	0	0	66
By frequency meth	Marginal	9	6	12	14	6	16	5	8	11	5	16	13	14	446
	Background	0	6	0	0	7	0	0	0	0	10	0	0	0	49
	Niche	11	0	6	6	0	4	3	5	4	0	0	2	3	122
	Core	0	8	0	1	8	1	0	0	0	6	5	6	4	115
	No- competence	1	1	3	0	0	0	13	8	6	0	0	0	0	66
Maximum Value		21	21	21	21	21	21	21	21	21	21	21	21	21	798

Source: Own elaboration based on EPO PATSTAT / EPO (2015) and Orbis / BvD (2013).

5. Final remarks

Environmental problems and sustainable growth are important issues in innovation policy agendas, especially in regard to the creation and adoption of environmental technologies (ET). Due to its pervasive character ET are present in several industries and due to their recent apparition, they are still quite unimportant when compared to other technologies more mature. Nevertheless, more relevant than its relative importance is to know how they connect to other technological assets in the industrial bases of knowledge. If they are connected to the core-competences and the core-business of the industries, they represent a strategic asset for developing technological trajectories in the future and there will be a natural path of adoption coherent with the growth of the firm. It they are connected to complementary assets or represent niches of technological opportunity, their prevision for adoption is slower and uncertain. Thus, the aim of this paper is to evaluate the centrality of ET in relation to the industrial bases of knowledge considering their frequency and relatedness.

Aggregated indexes of concentration, diversification and technological specialization point out that investment in environmental innovation efforts are still low. For the period 1980-2012, ET share in industry competence base was around 5%. Its participation was also concentrated in a few technical fields, as environmental management, biofuels, agroforestry (biocides). That means that the Kyoto Protocol was just an initial move. Economic and market incentives are more powerful and there are still resistance to changing the actual techno-economic paradigm. Usually, ET are present in the most contaminants industries: Agriculture; Mining and Quarrying; Coke and Petroleum; Chemical; Motor-vehicles; Other non-metal products. In those industries, diversification in ET is low and tend to be concentrated and related to the core productive activities (for example, biocides in Agriculture/Forestry and Chemicals; and emissions abatement and fuel efficiency in motor-vehicles). That is the reason of the close relation between create clean technologies and be a pollutant.

The analysis of the technological profiles of the different industrial sectors based on centrality index of network analysis strengthened those results. Most of ET still play a marginal role in the industries competence base. However, considering relatedness some environmental technologies reveals pervasive and coherent with the base of knowledge in a quite elevated number of industries, especially technologies associated with renewable energy sources and the mitigation of GHG emissions. In this sense, the centrality indicator, based on the network analysis, seem to be more comprehensive indicator to hierarchize knowledge into an industrial network.

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