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"Environmental Innovation and Open Innovation:
evidence of collaboration from green patent data"

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Firma (signature) ……Chiara [illegible]……

Sebbene innovazione e sostenibilità siano due temi da sempre al centro del dibattito pubblico, la chiara criticità della situazione più recente ha reso l'attenzione alla sostenibilità ambientale non più soltanto un'opzione possibile, ma una vera e propria necessità.

La seguente tesi ha quindi l'obiettivo di approfondire queste tematiche, andando ad analizzare gli impatti della collaborazione tra imprese volta allo sviluppo e all'implementazione di innovazioni in campo ambientale.

Allo scopo di fornire una visione più chiara e completa su quelle che sono le caratteristiche specifiche dell'innovazione ambientale, nella prima parte dell'elaborato vengono approfondite le diverse tipologie di innovazione, i possibili modi di metterla in pratica, ed i fattori interni ed esterni che svolgono un ruolo critico nell'influenzarne lo sviluppo.
La rilevanza dell'open innovation e dei network di collaborazione all'interno del contesto green è stata empiricamente verificata tramite un'analisi dei dati riguardanti i brevetti green e non-green concessi dall'European Patent Office nel periodo 1989-2018.
I principali risultati emersi riguardano le percentuali di brevetti collaborativi sul totale dei brevetti depositati, oltre a valori indicativi dell'estensione media dei team di applicant e inventori e della composizione geografica dei network coinvolti nello sviluppo delle innovazioni.

Table of Contents

Introduction

Recently, the relevance of environmental sustainability has grown so much that it cannot be ignored by the public debate anymore. The One Planet Network suggests that today the developed world's lifestyle requires about one and a half times the amount of renewable and non-renewable resources that would be sustainable for the Earth. If no radical measures are taken, by 2050 we will need almost three planets to maintain our standards, as a consequence of the increase in the world population. (One Planet Network, 2022**).**

Growing awareness of the topic has been pushing all kinds of stakeholders, from consumers to public authorities, to put pressure on firms to implement sustainable initiatives and to then measure, monitor, and report sustainability performances (Cillo et al., 2019).

Anyway, the whole situation does not have to be looked at from a pessimistic perspective only, as responding to the environmental issue can also have some positive implications for companies. Significant opportunities could in fact emerge from the implementation of green management strategies, since the introduction of alternative goods and services, together with more efficient use of energy and resources and new forms of work organization can help open a new era of economic development (Seebode et al., 2012).

1. Understanding environmental and sustainable innovation

1.1. Definition

The Oslo Manual (OECD/Eurostat, 2005) generally defines innovation as "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations".

To go from this general one to a more specific definition of the concept of 'environmental innovation' (EI), the fact that it is not unique and that different terms like eco-innovation, green innovation, or sustainable innovation can frequently be found in the existing literature needs to be underlined. Indeed, while the latter includes a variety of economical, ecological, and social changes (the so-called triple bottom line), addressing a wide and comprehensive concept, the other three do not involve the last aspect. Nevertheless, it is also true that, despite minor differences in their descriptive precision, all terms aim at expressing the same idea and they can therefore be used interchangeably (Schiederig et al., 2012; Elkington, 1997). Another problem that needs to be taken into account when trying to find an unambiguous definition of EI, is that EI actually relies on other broader concepts such as environmental sustainability and sustainable development. These in turn are not static, as they can be seen as the result of the dynamic balancing process of the three elements of the triple bottom line. For this reason, as the spatial, temporal, and cultural context changes, the environmental challenges vary, leading to different meanings and interpretations of the word (Boons and Lüdeke-Freund, 2013).

When trying to analyze the various shades of the topic it can be pointed out that the term "sustainable innovation" was essentially coined by the Brundtland Report, a document published in 1987 by the United Nations (Brundtland, 1987, p. 24). The notion starts with the definition of the concept of sustainable development, which is described as the human ability to "meet the needs of the present without compromising the ability of future generations to meet their own". Anyway, even though sustainable development does imply limits, these limits are not absolute, as they are only "limitations imposed by the present state of technology and social organization on environmental resources" and these can therefore be managed and improved to drive economic growth.

Another institution that more recently touched on the topic is the European Commission, which proposed a view of eco-innovation that highlights its peculiarity of being characterized by "significant progress towards the goal of sustainable development", that can be reached "by reducing the impacts of our production modes on the environment, enhancing nature's resilience to environmental pressures, or achieving a more efficient and responsible use of natural resources" (EC, 2013).
The interpretation proposed by Kemp and Pearson (2007) has its roots in the initial definition of innovation given by the OECD, but it was formulated by focusing more on environmental performance. Indeed, they identify EI as "the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives".

In the end, all these definitions are just reflections of the researchers' perspective on the issue, and the idea that underlies all of them can be easily summarized by the line of thought of Carrillo-Hermosilla et al. (2010), who briefly described eco-innovation as "innovation that improves environmental performance". This interpretation is consistent with the idea that the main feature of EI is the reduction in environmental impacts, as society is generally more interested in the positive effect that the implementation of innovation has on the environment than in checking whether the motivation that pushed its uptake was purely environmental.

1.2. Peculiarities and drivers of environmental innovation

The main differences between environmental and standard innovation are two: the specific externalities that they generate, and the role played by policy interventions in driving their development (Calza et al., 2017). Regarding the former aspect, researchers pointed out how EIs are characterized by a double externality problem, both in the innovation and in the diffusion phase, that discourages firms to invest in them. Indeed, in addition to externalities induced by spillovers, as is common even for standard innovation, most of the returns on investment in EI are appropriated by general society, thus leading to market failure.
Moreover, market failures have a stronger impact in the context of sustainable innovation because, while the benefits of natural capital depletion are generally privatized, the costs are often externalized (Rennings, 2000; Arfi et al., 2018; Kobarg et al., 2020). The resulting sub-

optimal level of investment in eco-innovations requires the introduction of a strong regulatory framework. As the Porter Hypothesis states, when environmental regulations are properly designed, they can drive environmental performance improvements and, at least partially, offset the additional costs introduced by the need to comply with the regulation itself, potentially leading to a “win-win” situation (Ambec et al., 2011)
In the end, EI can be seen as an ultimate goal, an output that can be achieved thanks to the role played by companies, which are encouraged by government regulations, which are in turn influenced by society’s desire to contribute to sustainable development (Bossle et al., 2016).

By confronting the existing literature, when analyzing the drivers of EI two main categories can be distinguished: external factors and internal factors (Bossle et al., 2016; Calza et al., 2017; Chen et al., 2012; Arfi et al., 2017). Within the former classification fall government policies, which appear to be one of the most relevant drivers. Properly written environmental regulations can in fact serve at least six purposes (Porter and Van der Linde, 1995):

1. Signal companies about resource inefficiency and possible technological improvements, overcoming their incapacity to understand the full environmental picture.
2. Increase efficiency by strengthening corporate awareness when focused on information gathering and reporting.
3. Reduce the uncertainty regarding the value of investments addressing the environment.
4. Boost progress by putting outside pressure on innovation processes, making the overcoming of organizational inertia possible.
5. Level the playing field in the transitional phase by making sure that companies cannot avoid environmental investment and opportunistically gain competitiveness.
6. Improve environmental quality in case of incomplete offsets since innovation cannot completely offset the cost of compliance every time.

Together with normative pressure, even market demand is an important external factor. Firms face many different demands, as suppliers, consumers, NGOs, research centers, and financing institutes all push them towards the undertaking of EI. In addition, both the constant redevelopment of industrial technology and a shorter product life cycle force firms to increase their investments in more sustainable forms of innovation to enhance their competitiveness (Rauter et al., 2019; Huber, 2004; Bossle et al., 2016).

A third crucial external factor is the cooperation between companies and collaborative networks, and it will be extensively and thoroughly analyzed in the next chapter.

On the other hand, the internal factors are those characterized by the ability to push companies to implement sustainable innovations by taking into consideration all the costs, benefits, and risks involved. The pursuit of efficiency makes companies pay a lot of attention to the achievement of a lower cost structure, as well as to the development of a good communication strategy, which is in turn helped by the adoption of innovative information and communication technologies. Once sustainable innovations have been implemented, it is important to integrate sustainability as an explicit goal in the design process to keep the process going. This can be achieved thanks to the development of a strong entrepreneurial vision able to introduce sustainability policy and strategy, but also thanks to internal platforms and networks (human resources) that need to be enriched by continuous intra-organizational educational programs (Bossle et al., 2016; Arnold and Hockerts, 2011; Horbach, 2008). Chen et al. (2012) included even environmental leadership, environmental culture, and environmental capability within the internal features of eco-innovation. In fact, they can become not only a crucial factor in the generation of EIs but thanks to their intrinsic characteristics (they are valuable, unique, non-imitable, and non-substitutable) they can also be a source of competitive advantage for the company itself.

Moreover, it is also recurrent for researchers to include in their analysis even some control variables. For example, factors like the size of a firm, public financing, and the sector to which the company belongs have been proven to be positively associated with a greater willingness to adopt eco-innovation. In particular, for the latter has been proven that those companies that belong to high-emission sectors are more inclined to increase the adoption of eco-innovation (Bossle et al., 2016; Cainelli et al., 2015; De Marchi, 2012; Cuerva et al., 2014).

The most relevant drivers for the adoption of eco-innovation can be found synthesized in Figure 1 below.

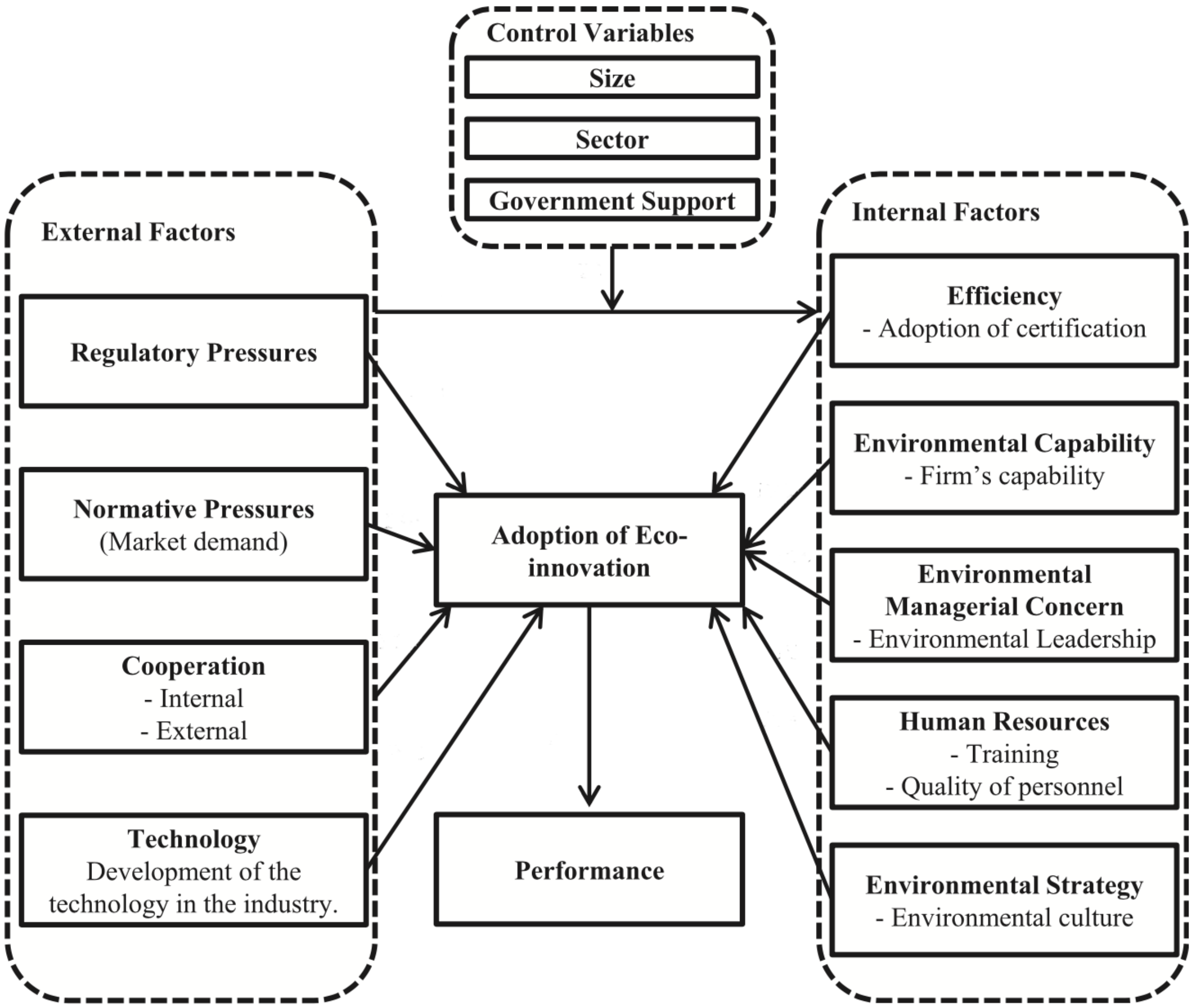


***Figure 1**. Drivers of green innovation – **Source:** Bossle et al., 2016*

1.3. Types of innovations

Since innovation and green innovation represent extremely broad topics, different researchers decided to study their characteristics by looking at them from a wide range of perspectives, therefore all focusing on different aspects of the topic.

While a first distinction between product and process innovation already appeared in the first edition of the Oslo Manual in 1992, it was only in the third edition of 2005 that the definition of innovation was expanded to include two additional types of innovations: organizational innovation and marketing innovation. This decision was taken to create a framework better able to capture the changes that affect firm performance and cover a broader range of managerial aspects (OECD/Eurostat, 2005).

Marcon et al. (2017) have synthesized these four concepts as follows:

- Product Innovations occur when “new or significantly improved goods or services are implemented in the market”, thus possibly involving changes such as variations in the materials used or in the characteristics of the product or service, but also the use of new knowledge or technologies.
- Process Innovations refer to “the implementation of changes in techniques, equipment, and software aimed to improve production methods” whose purpose is that of reducing costs while improving the quality of both products and services as well as of support activities.
- Organizational Innovations include those “features implemented in organizations with the objective to rearrange and improve firms’ aspects”, therefore referring to new or improved routines, business models, methods, and actions, that when implemented have the power to change firms’ practices, relations, and decisions.
- Lastly, Marketing Innovations regard the “implementation of new marketing methods”, and they can occur when changes take place in the areas of product design, placement, and delivery, communication, promotion, pricing strategies, or even packaging.

While these definitions are centered on the object of the innovations that are implemented, it is also possible to distinguish between different types of innovation by focusing more on how change happens and the process thanks to which new innovations are actually created.
In particular, Carrillo-Hermosilla et al. (2009) use the term Incremental Innovation to point out “gradual and continuous competence-enhancing modifications that preserve existing production systems and sustain the existing networks” and Radical Innovation to refer to “competence-destroying, discontinuous changes that seek the replacement of existing components or entire systems”. The fact that incremental innovation along established paths will not be sufficient for the achievement of environmental goals like the mitigation of climate change is now widely acknowledged by the scientific community and beyond. Indeed, the innovation required for sustainable development needs to involve drastic changes in products and processes, and it therefore has to move beyond incremental adjustments to create new markets and values (Cillo et al., 2019; Skordoulis et al., 2020).

By looking at things from another point of view, Chen et al. (2012) focused on the resourcefulness exhibited by companies in the innovation process and underlined a distinction between proactive and reactive green innovations. In their study they define Proactive Green Innovation as “active environment-related innovation in order to take initiatives new practices or products ahead of competitors, to decrease cost, to seize opportunities, to lead in the market, or to obtain competitive advantages”, while Reactive Green Innovation is instead identified as “passive environment-related innovation in order to comply with environmental regulations, to adapt to stakeholders’ requests, to react on the changing environment, or to respond to competitors’ challenges”. As shown in Figure 2., the two are clearly different, and the authors aimed at demonstrating that even the drivers that influence them will not always be the same. Indeed, the research that they conducted led to the finding that, while the firm’s internal features – environmental leadership, environmental culture, and environmental capability – can push the development of both, external drivers like environmentalism of investors and clients and environmental regulations can only generate reactive green innovations. In conclusion, Chen et al. argued that companies should decide how to invest their resources by considering the internal factors rather than the external ones since they would allow them to take the initiative, seize market opportunities, and generate a sustainable competitive advantage.

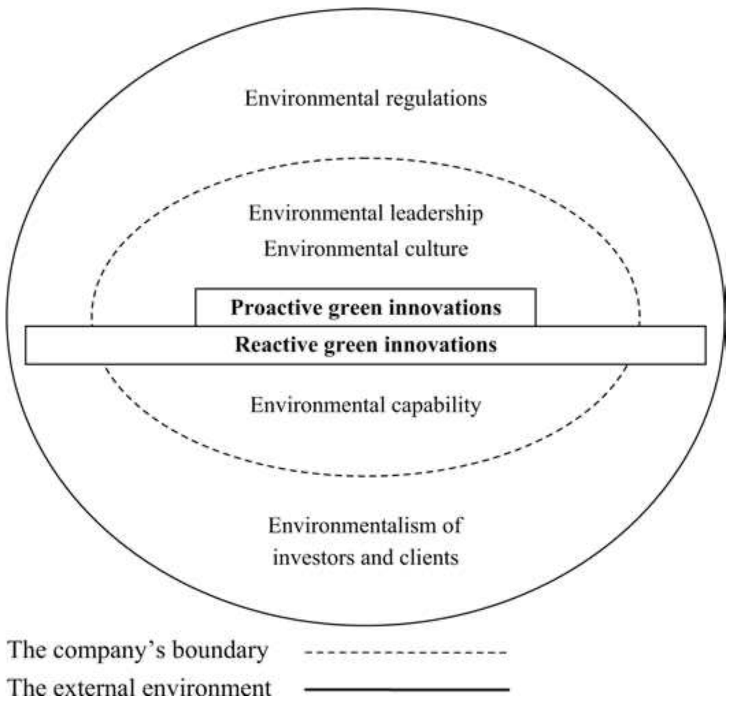


Figure 2. *Factors that influence proactive and reactive green innovations –* ***Source:*** *Chen et al., 2012*

1.4. Sustainable Innovation Management

Instead of prioritizing the more specific concept of environmental innovation, Angelo et al. (2012) looked at the bigger picture, and they focused on analyzing the moments that precede the development of an innovation, defining the concept of environmental management as "a process of organizational implementations that involves adaptation and internal change to reduce environmental impacts". Investing in environmental management would not only allow firms to avoid both environmentalists' complaints and unexpected consequences, but it would also make them more efficient, allowing them to expand in new markets, and increase their green know-how (Chen et al., 2012). When analyzing the way in which this process evolves, Angelo et al. were able to identify three different evolutionary stages of environmental management:

- Reactive Environmental Management is limited to the exercising of prescribed functions and the implementation of environmental regulations.
- Preventive Environmental Management is more evolved than the reactive one, but it is still not strategic as it never crosses the line of the existing framework, respecting the standards posed by organizations, demand, markets, and legislation.
- Proactive Environmental Management concerns a more complex organizational concept characterized by internal and external influence. This stage is able to generate a great competitive advantage, as environmental activities are integrated strategically to exploit new opportunities with wider applicability.

On the one hand, proactive environmental management can conduct to the development and adoption of sustainable innovation but, on the other, innovation can also give a boost to the evolution of organizational environmental management and promote proactivity. Therefore, the study concludes that environmental management and innovation are characterized by bilateral relations and a process of mutual reinforcement (Chen et al., 2012).

Calza et al. (2017) recognized that the existing classifications – like e.g. the one proposed by Chen et al. that was previously described – only considered the firm's attitude towards environmental engagement, and they lacked a focus on how companies can effectively implement green innovations. For this reason, they decided to introduce a new classification method that responds to the need of measuring the impact of green innovations on the implementing firms with respect to the way in which they decide to invest in these activities.

In order to do this, they decided to build on an existing framework, borrowing "The Innovation Landscape Map" elaborated by Pisano (2015) for standard innovation, and developing a taxonomy of green innovation.
Pisano introduced the matrix reported in Figure 3. as an instrument to help companies realize whether a potential innovation is consistent with their existing business model and technical capabilities, and to assist them in the choice of how much to focus and invest in their prospective renovation. Therefore, this model becomes very useful even when trying to explain how green innovations are implemented in non-green industries. In order to do this, companies working in non-green sectors will face the need to invest to change both their technology and their business model, since new aspects like the formation of eco-systems and networks become critical in supporting environmental sustainability (Calza et al., 2017).

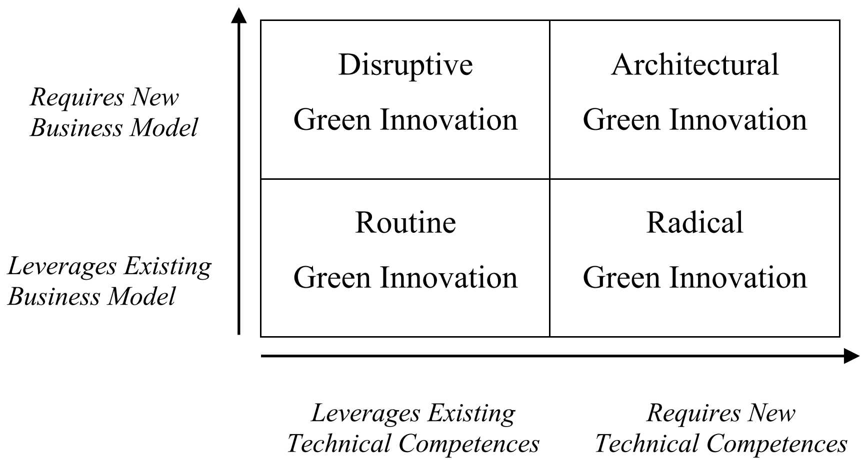


Figure 3. *Green Innovation Landscape Map –* ***Source:*** *Calza et al., 2017*

Despite the fact that both dimensions exist on a continuum, Pisano's "Innovation Landscape Map" still identifies four quadrants, or categories, of innovation (elaboration of the matrix by Calza et al.):

I. Routine Green Innovation is built on a company's existing technical competencies and coherently with its current business model – and hence its market base.
II. Disruptive Green Innovation requires a new business model, but it does not involve drastic technological breakthroughs. Additionally, this kind of innovation has been proved to have strong impacts even on the business model of competing companies, thus extending the challenge.

III. Architectural Green Innovation combines both technological and business model disruptions.

IV. Radical Green Innovation is the opposite of the disruptive type, as it only involves a pure technological change, maintaining the existing business model.

The case study built on this model's framework that was then conducted by Calza et al. showed that, while with routine green innovations companies usually focus on internal R&D, existing knowledge, or supply chain partners, when the aim is that of developing disruptive, radical and architectural green innovations, companies tend to implement an open innovation approach. This involves the establishment of inter-organizational relationships to in-source external ideas that come from multiple sources and fall outside the firm's current business model or technical capabilities.

Some other crucial aspects of the sustainable innovation challenge are the process of searching for innovation trigger signals, selecting (resource allocation), and implementing. While well-established firms have developed fixed routines for this kind of operations and are therefore constrained within their defined framework, innovative firms are characterized by ambidexterity and an ability to "think outside the box" that allows them to manage different degrees of novelty. To succeed, innovative firms need to develop the capability to acquire, assimilate and exploit different knowledge components – new technologies, new markets, new environmental regulations, etc. – to then be able to work at a system level and put them together to determine the architecture of innovation. Existing incumbents often fail in this process because they have to face two twin challenges: learning and configuring a new knowledge system and "unlearning" the old and established one (Seebode et al., 2012).

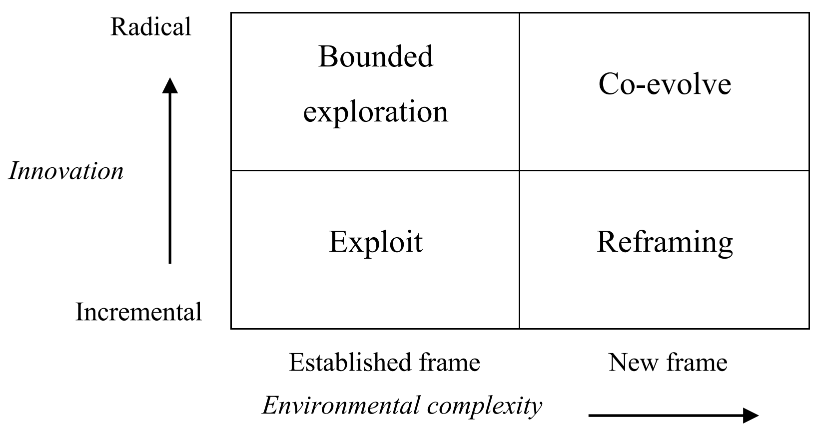


Figure 4. *Innovation Management Challenge Map –* ***Source:*** *Seebode et al., 2012*

In Figure 4., Seebode et al. mapped the innovation management challenge by considering two dimensions: the environmental complexity (number of elements and potential interactions) and the incremental/radical dimension. On the left-hand side firms innovate at the component level, implementing innovations within the existing configuration of technological and market elements, and therefore still within the 'business as usual' framework. On the right side, instead, the introduction of complex elements requires a change in the dominant architecture to support them, and it therefore identifies the framework in which most of the innovative activity around EI will take place. In the "reframing" zone reconfiguration is incremental, and it basically consists in finding new ways of doing what companies are already doing. In terms of sustainability outcomes, this zone is characterized by the "'co-efficiency' concept, that relies on the 'doing more with less' idea that is intrinsic to the '3 Rs' principle: reduce, re-use, recycle. In the "co-evolution" zone, innovation can be seen as the result of complex interactions between independent elements. For this reason, it involves significant system-level changes that require a rethinking of the way in which we produce and consume, as well as a deep understanding of the interdependencies between system components and how to leverage them. Since one single company cannot know everything or keep everything under control, even such innovations, just as the radical and architectural innovations seen before, frequently involve collaborations between many different partners in a context of open innovation.

1.5. Business models

Until not so long ago the concept of innovation was associated solely with companies' massive investments in internal research labs where the most brilliant experts in the field would be hired to develop novel products. Recently though, the cost of this process chain has increased tremendously, and the generalized shortening of products' lives meant that even great technologies cannot be relied upon to earn an acceptable profit before they become obsolete. Today, innovation must go beyond just technology and R&D, as innovative business models are becoming increasingly decisive (Chesbrough, 2007).

Whether explicit and articulated or not, a business model is something that characterizes every company, and it thus constitutes an extremely relevant aspect for their pursuit of competitive advantage. According to Boons and Lüdeke-Freund (2013), the main elements of which the generic business model concept is composed are:

1. Value Proposition: what value is created for users by the product/service offered by the firm;
2. Supply Chain: how the upstream relationships with suppliers are structured and managed;
3. Customer Interface: how the downstream relationships with customers are structured and managed;
4. Financial Model: costs and benefits from the previous points and how they are distributed across business model stakeholders.

When companies want to implement sustainability within their business model, they have to respect certain basic normative requirements in order to be able to successfully market EIs. In particular, the value proposition will have to provide measurable ecological and/or social value in accordance with economic value, reflecting society's need to balance the components of the triple bottom line. Secondly, with regard to the supply chain, companies will have to actively engage suppliers in sustainable supply chain management, making sure that they take responsibility for both their own and the focal company's stakeholders. The customer interface will have to focus on relationships that recognize the sustainability challenges faced by differently developed countries, motivating customers to take responsibility for their consumption as well as for the focal company's stakeholders. Lastly, the financial model has to ensure that the distribution of economic costs and benefits among the actors involved in the business model is appropriate, and it has to actually account for the company's ecological and social impacts. Following these requirements is essential for companies, as it allows them not to waste their potential. Indeed, innovation can only bear a presumed sustainability potential, while the business model is the device that actually allows to unfold it.

1.6. Barriers and success factors

While developing a sustainably innovative product can be difficult, the true challenge of the process can be found in the innovations' implementation and diffusion. In fact, while standard innovations only need to be economical and fit from a technical or organizational perspective, EIs also need to introduce novelty in the environmental field (Boons and Lüdeke-Freund, 2013). The road to EI is thereby not easy, and even though its presence is expanding, in order to be developed and implemented effectively it still has to overcome many different barriers. Some of the main barriers that can be identified by confronting existing studies are (Angelo, 2012):

- inefficiencies in the internal communication process;
- lack of environmental training for companies’ employees;
- managerial limitations to understanding the relevance of green issues;
- difficulties to build networks between partners and green teams;
- unskilled green team for research and development (R&D);
- poor economic perspective with a low perception of green innovation gains;
- investment with long-term return;
- difficulties in obtaining financial resources;
- sluggish environmental regulatory system based on governmental inefficiencies.

On the other hand, some success factors, that is to say, some elements that when present can favor the development of sustainable innovations, can also be identified. Indeed, Dangelico (2015) divided them into four categories, according to the specific aspects that they relate to: management, relationships, resources and capabilities, and the development process. With regard to the management category, it becomes a relevant factor when the focal company and its top management include the environment as a truly crucial aspect of their strategy from the start, formalizing environmental policies and strategies, and widening the focus of a sustainable strategy to the whole organization. When it comes to relationships then, it is proven that collaborations with different types of actors, from customers and suppliers to NGOs and institutions, can be identified as a success factor for sustainable innovation. In fact, extensive communication between the firm and its stakeholder, the education of users, the exploitation of the local knowledge base, and the creation of local innovation clusters can also really help to achieve the goal. Third, the factors that benefit the development process of sustainable innovation can be identified in the presence of cross-functional teams who facilitate integration and coordination, the implementation of eco-design and life cycle assessment practices, accompanied by market orientation, effective groundwork, and dedicated employees. And lastly, when resources and capabilities are valuable, rare, non-imitable, and non-substitutable, they become a source of competitive advantage, and it therefore becomes a managers’ responsibility to identify, enhance, protect, and exploit them. In fact, within this category fall strategic factors like internal R&D, human resources, a company’s innovative capacity, and its innovation management skills.

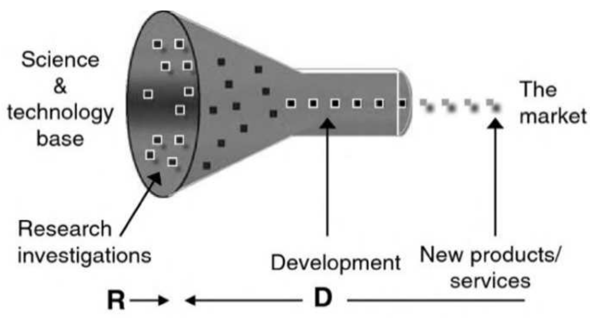
2. Environmental innovation and collaborative networks

2.1. Innovation Ecosystem and Open Innovation

At the end of the twentieth century, factors like the ease of mobility of skilled and competent workers, the acceleration of the time to market for most products and services, and the greater number of ways in which customers and suppliers can obtain relevant information started to affect companies' ability to profit from their internal knowledge, pushing them towards the implementation of new competitive strategies (Chesbrough, 2003).
In the context of EI, another obstacle is represented by the fact that, even when considered on its own, the challenge of environmental sustainability is often too large and complex to be tackled by individual and isolated companies, with the difficulty being even greater in the case of small and medium enterprises (SMEs) (Costa and Matias, 2020; Kahle et al., 2020)
To address these issues, new innovation paradigms started being introduced to create a new shared value, and in today's modern world innovative ecosystems characterized by collaboration and co-creation among different players are becoming key to the development of innovation (Costa and Matias, 2020).

The concept of a business ecosystem was first outlined by Moore, who suggested that every company should be considered as part of a wider system that encompasses a variety of industries. Within this framework, they thus have the chance to "work cooperatively and competitively", benefiting from the extended web of relationships that emerges and mutually strengthening their innovation process (Moore, 1993).
The collaboration between agents will be focused on "sharing common goals, trust, respect, resources, green knowledge, risks, and rewards" so that all parties involved will be able to achieve a competitive advantage more solid than what they would have been able to create on their own (Li et al., 2020).
A concept that clearly emphasizes the need for external points of view in the innovation process is Open Innovation, a paradigm that underlines the role of the synergy between both external and internal ideas, as well as internal and external paths to the market, in those situations where firms' purpose is to innovate their technology (Chesbrough, 2003). In Figure 5.1 a Closed Innovation model is pictured, and it is characterized by the fact that there is only one way in and out for research projects, as they can be launched only from the scientifical and technological base of the company, and their only way out is through the market. On the other hand, Figure 5.2 represents an Open Innovation model, where projects can be started by

either internal or external sources, and multiple paths could facilitate their circulation on the market (Chesbrough, 2006).
Even when explicitly focusing on EI, many studies point out the existence of a general tendency for companies to seek on the outside for specific knowledge and resources that go beyond their core competencies, looking for alliance partners that can widen their perspectives and help fill their gaps in key areas (Yang et al., 2021; Horbach et al, 2013; Teece et al., 1997). To emphasize this link between EI and open innovation, the term Open Environmental Innovation can be used whenever the aim of the open innovation model is that of using the know-how acquired by the company from the multiple stakeholders to create value not just for itself, but also for society and the environment (Skordoulis et al., 2020).



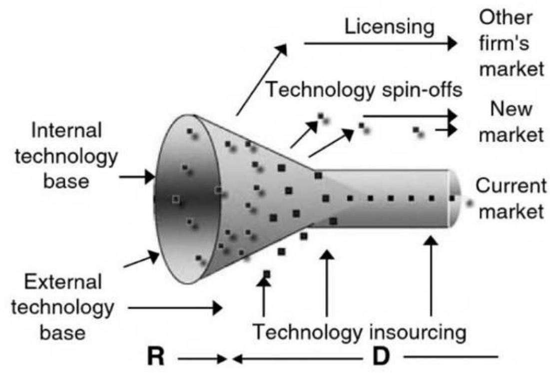


Figure 5.1. *Closed Innovation Model;* ***Figure 5.2.*** *Open Innovation Model –* ***Source:*** *Chesbrough, 2006*

With the world's ecosystem changing faster than ever before and an equally rapid pace of globalization and technological change, unexpected circumstances are becoming the norm, with companies having to learn how to deal with environmental uncertainty (Meidute-Kavaliauskiene et al., 2021; Rycroft, 2007). Because of their flexibility, extended innovation networks based on alliance and collaboration are often the best way to respond to the challenges posed by uncertainty. Relying on cooperation in the innovation process can in fact help overcome its complexity, sharing risks and costs by combining different knowledge, skills, and experiences (Rycroft, 2007; Kobarg et al., 2020; Belderbos et al., 2004).
In the end, the intrinsic intricate nature of environmental innovations and the higher uncertainty that characterizes them are all indicative of a higher propensity to resort to co-innovation and external partnerships (Cainelli et al., 2015; Kobarg et al, 2020), but the empirical evidence on the topic is ambiguous. Anyway, even though the survey launched by Cuerva et al., (2014) showed non-significant results for cooperation with both external stakeholders and research centers and Bönte and Dienes (2013) showed how companies that are more active in environmental innovation usually follow an 'in-house strategy', most of the

other researchers found opposite results. In fact, many studies point out how collaborating with an extended network that involves various agents in the R&D process actually promotes environmental innovations more than other innovations (De Marchi, 2012; Cainelli et al., 2015; Horbach, 2008; De Marchi and Grandinetti, 2013), and some deeper analyses found this to be true even when considering the implementation of a green supply chain, as it can increase the value of EI and strengthen the environmental performance (De Marchi, 2012; Seman et al., 2019).

This connection between EI and open innovation will be tested in the next chapter by analyzing the existing ratio between the number of green patent applications and how many of these show evidence of collaboration by being characterized by the presence of more than one applicant.

Q1: What is the percentage of collaborative green patents on the total amount of green patents?

2.2. Firm size and collaboration

In addition to the internal drivers of EI that were described in Chapter 1, the size of a company is another factor that was often found to strongly incentivize the environmental innovation process (Triguero et al., 2017; Cleff and Rennings, 1999; Cuerva et al., 2014; De Marchi, 2012; Triguero et al., 2013). This could be due to larger companies' greater willingness to take risks, explained by the fact that, thanks to the greater sales and financial resources at their disposal, they can afford to spend more time focusing on environmental practices with long-term returns (Andries and Stephan, 2019; Triguero et al., 2017; Rogers, 2004).
On the other hand, though, a study conducted by Wagner (2008) found the variable "Firm size" to have a non-significant influence on the probability of innovation, and Costa and Matias (2020) found evidence of a negative correlation between the size of a firm and the propensity to develop product and marketing innovation in an ecosystem of sustainable innovation. Rogers, (2004) proposed that these conflicting results could be explained by the flexibility associated with being small firms, and their greater ease in adjusting incentives and management structure to exploit opportunities. Moreover, Triguero et al., (2017) assumed that this could also be caused by the stronger effect that factors like open innovation, training, and

collaboration with the user community, the suppliers, and universities have on influencing the pursuit of environmental innovation, an impact that outweighs that of the firm size (De Marchi, 2012; Triguero et al., 2013).

Regarding this, although Roger (2004) showed that SMEs would benefit more from the participation in external knowledge networks, Martínez-Ros and Kunapatarawong, (2019) and Del Brío and Junquera, (2003) were able to prove that, in practice, small firms usually rely more on internal knowledge to develop new environmentally friendly products or processes, whereas larger firms tend to focus more on the exploitation of external sources. In addition to the lack of available resources that limits the firm's possibilities, this contradiction can also be conditioned by the need for a firm of having developed strong negotiating power and consolidated competencies to integrate its knowledge base by absorbing external ideas effectively, since the risk would otherwise be that of losing control over the networks' partners and, eventually, the whole process (Martínez-Ros and Kunapatarawong, 2019; Cohen and Levinthal, 1990; Del Brío and Junquera, 2003). It is only if the SME's top management is willing to cede some control and hire new skilled managers to facilitate the growth process that the company will be able to open up and successfully boost its EI activities (Wynarczyk et al., 2013).

2.3. Size and heterogeneity of the cooperation networks

Having assumed that larger firms are both the most likely to undertake a process of EI and the more inclined to turn to external knowledge sources to enhance their innovative capacity, the wide spread of open innovation networks becomes evident, and its structure should therefore be deepened.

Regarding the composition of the cooperation networks, the literature on the topic distinguishes several types of partners, ranging from commercial sources like i) suppliers and ii) customers to, iii) public and iv) private research centers, v) universities, and vi) technological centers, but they could also include the company's vii) competitors and all kinds of companies that could significantly influence the firm's decisions (OECD/Eurostat, 2005; Cainelli et al., 2015). Because of the great variety of possible partners, many researchers tried to analyze in which ways their impact could differ, all coming to the conclusion that the effectiveness of collaboration on EI depends on the specific combination of external partners (Kobarg et al., 2020; Marzucchi and Montresor, 2017).

In relation to this, Cainelli et al., (2015) were able to show that it is easier for companies to successfully implement EIs when they are part of a varied network, as the likelihood increases as a greater number of types of cooperating partners are included. Moreover, De Marchi and Grandinetti (2013) found evidence of the greater tendency that environmental innovators generally have to cooperate with a broader network of partners when compared to other innovators. When put together with the fact that larger teams are more likely to get involved in more extended networks thanks to their high reputation and better connections (Kim et al., 2015), these two hypotheses could lead to the assumption that bigger teams of collaborating partners are more effective in the development of EI.

Q2: Does the development of environment-related innovations tend to attract larger teams of innovators compared to non-green innovations?

2.4. Internationalization of collaborative activity

In today's everyday reality it seems unlikely to think that all these possible collaborative relationships could remain exclusively within a region's or a country's borders. The expansion of the phenomenon of globalization concerns the strengthening of the interdependencies between economies, cultures, and communities around the world (Kolb, 2018). Moreover, the shortening of product lifecycle pushes firms to strengthen their presence in international markets to take advantage of the opportunities arising from participation in global networks (Herstad et al., 2014). To better navigate in this fast-changing and interconnected world, lower R&D costs, and gain market access, companies have been building partnerships to facilitate cross-border movements and achieve a wider and deeper knowledge of key factors that could be otherwise missed because of their distance (Kolb, 2018; Haseeb et al., 2019; Kim and Park, 2010). Putting together resources and knowledge sources that were originally spread out around the world can therefore strongly enhance a firm's ability to deal with environmental challenges, incentivizing it to respond to the market's demand for increasing investments in EI (Chiarvesio et al., 2015).
In this regard, a study conducted by De Marchi and Grandinetti (2013) showed that, as a consequence of their propensity to attract a large network of cooperating partners, environmental innovators are more inclined to collaborate with foreign partners. To prove this, the authors analyzed the peculiarities of environmentally innovative firms by drawing information from the Italian Community Innovation Survey (CIS), eventually coming to a

conclusion pointing out how 13.3% of these firms collaborated on an international level, while the percentage for other innovators was just 6.6%. In addition to finding consistent evidence on this, Chiarvesio et al., (2015) also showed the existence of a positive correlation between being part of an international group of firms and the development of both product and process EIs, remarking how valuable a firm's openness can be when it comes to green strategies, even when looking at things from a multinational perspective.

On the other hand, it is also true that managing EI in such a complex and varied network poses significant challenges to the companies involved, possibly undermining its positive effect. The most relevant difficulty is considered to be the transfer and acquisition of knowledge, but of great importance are also the distribution of innovation appropriability and the need to maintain the network stable and avoid internal disruptions (Bullinger et al., 2004; Levén et al., 2014)

With regard to standard innovation, Picci (2010) adopted a gravity model to conduct a study aimed at identifying those factors that prevail in determining the level of international collaboration between pairs of countries in the field of innovation. One of its most interesting results was the confirmation of the fact that, as expected, there is a positive correlation between the physical proximity of the countries, especially in the case of countries with a border in common, and the intensity of their collaboration. Being geographically close can in fact facilitate communication between the partners, making the exchange of knowledge much more immediate, even when the transferred knowledge is environmentally related (Ardito et al., 2019).

Q3: Are collaborations in environment-related innovations taking place more within the same region or the same country, or are they more commonly happening on an international level?

3. Analysis of patent data and discussion

3.1. Methodology

Together with large-scale statistical innovation and R&D surveys, patent data, despite all of its flaws and limitations, can turn out to be quite useful when measuring innovation-related activities (OECD, 2009). In this regard, Haščič and Mingotto (2015) summarized a number of possible advantages and shortcomings by comparing this method to the alternative measures of innovation.

Looking at patent data can be considered a good choice because they are:

- commensurable, since the patented invention has to be well-defined and based on an objective standard
- comprehensive, considering that they allow the measurement of the intermediate outputs of the process
- quantitative
- publicly available
- dividable into specific technological fields

On the other hand, the method still has some deficiencies caused by the fact that not all innovations are patentable, that not all patentable innovations are patented, and that even those inventions that are patented can vary in quality. Anyway, despite all these assumptions, it is also true that in reality there are only a few examples of non-patented inventions that can be considered economically significant (Dernis et al., 2001; Dechezleprêtre et al., 2020). Hence, because of this and the fact that several econometric methods and indicators have been developed to contrast these limitations, it has become standard in the literature to use the available data on green patents as a measure of the output of green innovation processes (Fabrizi et al., 2018).

The following analysis was conducted by taking into consideration all green patent applications registered at the European Patent Office (EPO) over the 30-year period 1989-2018. Among all the considered patents, the study is mostly centered on green patents' data, which makes up about 7,26% of the total amount (118.437 of 1.630.355).
The extracted data is classified according to the NUTS-2 classification scheme used by the European Union, a system that divides the European territory into 242 basic regions for the

application of regional policies (EU, 2020). The considered patents are all expressed as integers so that both individual patents and those characterized by the involvement of two or more inventors from different NUTS-2 in the application will still be weighted in the same way.
The column “Patent.int” included in the tables below reports the total number of patents that were filed in a given year, and it can thus be broken down into two main other columns: “Indiv.pat.int”, pointing out how many of the patents registered in that region for that specific year were individual, and “Copat.int”, reporting the total amount of collaborative patents. The analysis can be further deepened by breaking down even this latter column into four other ones to investigate the specific characteristics of collaboration and the geographical distribution of the network. Indeed, “Intra.copat.int” reports the sum of all collaborative patents whose team was composed of companies located in the same NUTS-2 region, while “Intra2.copat.int” does the same thing by including all those patents where the collaborating partners were companies located in the same country but not in the same region. Along the same line, “Inter,copat” measures how many collaborations took place among partners located in Europe but in different countries, and “ExtraEU,copat” reports how many collaborative patents were characterized by a network of international companies all located outside European borders.

3.2. Descriptive statistics

In order to find an answer to the question posed by Q1, Table 1 reports a general measure of the diffusion of collaboration in the context of EI. The reported results were obtained by confronting the total amount of green patents that were filed by each country with the respective number of collaborative green patents registered in that given 5-year period. Figure 6 reports the trends followed by these two variables between 1989 and 2018. It can be noted that the above-mentioned percentage of collaboration is relatively stable, and it fluctuates around an average of 16,17%. As is reported in Figure 7, a peculiarity that should be pointed out is that these values tend to be higher for those countries that are less technologically and industrially advanced, with the highest ones being Greece (41,72%), Slovakia (38,61%), and Hungary (37,23%).

	Sum of Patent.int	Sum of Copat.int	Avg. of Copat.int/Patent.int
1989-1993	7065	1059	15,63%
1994-1998	9034	1145	16,03%
1999-2003	13804	1683	16,39%
2004-2008	21801	2761	16,39%
2009-2013	35042	4213	15,95%
2014-2018	31691	3665	16,47%
Tot.	**118437**	**14526**	**16,17%**

Table 1. *A measure of the diffusion of collaboration in environmental innovation*

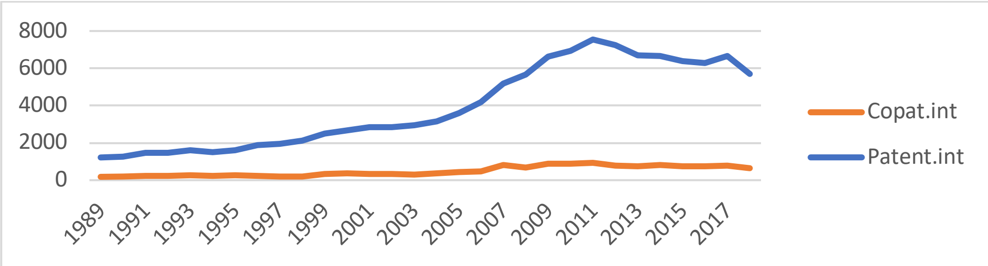


Figure 6. *Collaborative green patents in relation to the total amount of filed green patents*

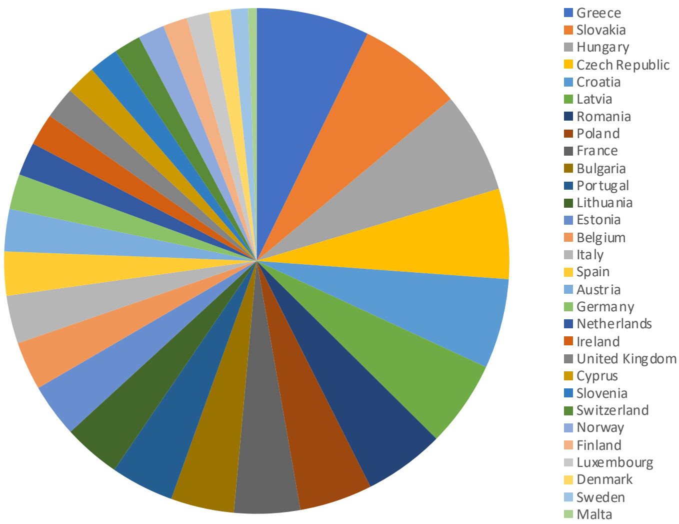


Figure 7. *Evidence of collaboration by country in green patents*

Table 2 reports the results obtained by conducting the same analysis, now focused on non-green patent data. Even in this case, the trend tends to be consistent over the considered periods of time, as no significant fluctuations can be outlined. The average of the "Copat.int/Patent.int" variable is 15,15%, and it is therefore lower than the one identified for green patent data. In line with the evidence above exposed, even for general innovation can be identified a diffused tendency for less wealthy countries to participate more in external networks. Anyway, when leaving EI out of the analysis, the likelihood of cooperation turns out to be lower, as the most open country among those examined is Latvia, with 35,73% of collaborative patents on the total amount of the filed ones.

	Sum of Patent.int	Sum of Copat.int	Avg. of Copat.int/Patent.int
1989-1993	146103	18092	14,20%
1994-1998	190037	20581	16,01%
1999-2003	269814	28966	15,43%
2004-2008	304299	33586	14,73%
2009-2013	301286	34710	15,33%
2014-2018	300379	33858	15,13%
Tot.	**1511918**	**169793**	**15,15%**

Table 2. *A measure of the diffusion of collaboration in general innovation*

Table 3 summarizes the analysis that was conducted to collect evidence on the average size of the teams involved in the development of EI. The variable "Applicant.involved" describes the number of organizations or individuals that filed a specific patent application. When considering green patent data, it can be pointed out that an average of 0,9995 applicants generally file for a single green patent. This value can be explained by the fact that, while many registered patents are the result of a collaboration process and are characterized by the presence of more than one applicant, there are also many cases in which the same applicant files for more than one patent, thus lowering the average. The other relevant variable that needs to be considered when looking into the extension of external networks is "Inventor.involved", as it represents the number of individuals that contributed to the R&D process of an invention. When confronted with the number of green patents that were filed in a given period, it is evident that a situation in which a single person works alone on an innovative project is quite rare, as the average value of the variable "Inventor.involved/Patent.int" is of 2,049 inventors.

While they may be thought to be similar, the trends of these variables are completely opposite to each other. Indeed, by comparing the data collected over the 5-year periods that go from 1989 to 1993 and from 2014 to 2018, it can be seen how the value of "Applicant.involved/Patent.int" decreased from 1,074 to 0,922, while the average of the number of inventors increased from 1,852 to 2,252. Regarding the different countries' peculiarities, it can be observed that even in this case the most extended teams are likely to be located in Eastern Europe, as reported in Figure 8.

	Sum of Applicant.involved	Sum of Inventor.involved	Avg. of Applicant.involved/Patent.int	Avg. of Inventor.involved/Patent.int
1989-1993	72670	251301	1,07	1,85
1994-1998	93256	334913	1,07	1,96
1999-2003	120709	488522	1,06	2,09
2004-2008	128253	560510	1,01	1,99
2009-2013	124845	562846	0,93	2,06
2014-2018	120215	563239	0,92	2,25
Tot.	**659948**	**2761331**	**1,00**	**2,05**

Table 3. *Size of the cooperation networks in non-green patents*

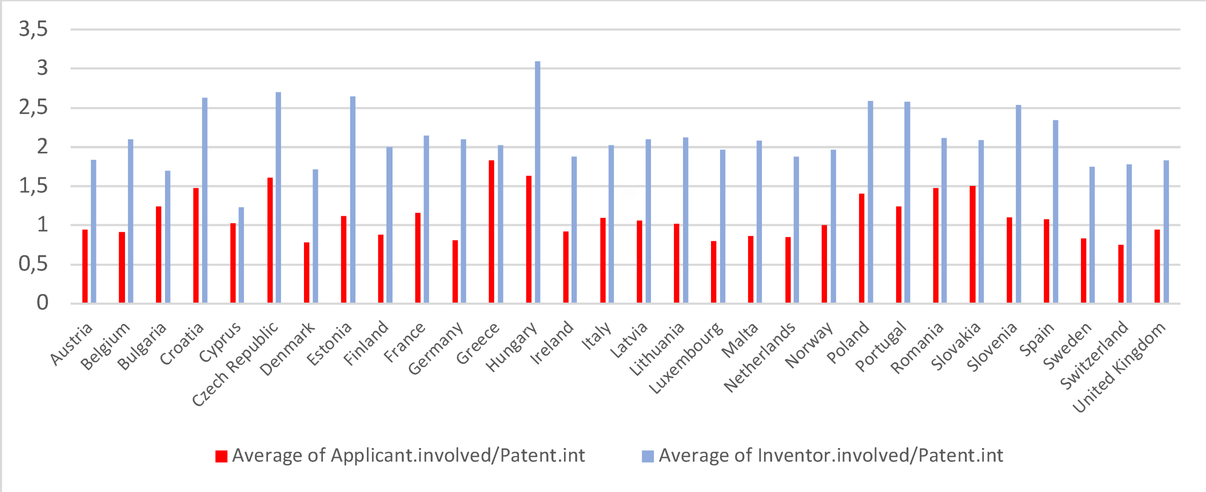


Figure 8. *Average number of involved applicants and involved inventors in green patents by country*

To be able to verify the peculiarities of the collaboration networks that characterize EIs and respond to Q2, even the data on non-green patents were analyzed, and the results are reported in Table 4.

While the general trends of the variables show the same characteristics as those highlighted by the analysis of green patents, the average values of the considered variables are instead lower. In fact,

"Applicant.involved/Patent.int" has an average value of 0,851 applicants, and "Inventor.involved/Patent.int" of 1,935 inventors, adding evidence to the thesis supporting the existence of less cooperative tendencies for non-green inventors.

	Sum of Applicant.involved	Sum of Inventor.involved	Avg. of Applicant.involved/Patent.int	Avg. of Inventor.involved/Patent.int
1989-1993	72670	251301	0,86	1,74
1994-1998	93256	334913	0,90	1,83
1999-2003	120709	488522	0,88	1,92
2004-2008	128253	560510	0,84	1,95
2009-2013	124845	562846	0,84	2,04
2014-2018	120215	563239	0,79	2,08
Tot.	**659948**	**2761331**	**0,85**	**1,94**

Table 4. *Size of the cooperation networks in non-green patents*

Table 5 reports the results of an analysis aimed at developing a deeper understanding of another aspect related to the composition and heterogeneity of the collaboration networks focused on EI: the geographical localization of the partners. The data-based evidence showed that the majority of the collaborations (43,60% on average) took place among partners that were all located within the same country's borders, even though all in different NUTS-2 regions, clearly responding to the question posed by Q3. Cooperation at the regional and at the European level respectively make up 19,46% and 24,17% of the total number of collaborative green patents. The most open form of collaboration is that involving partnerships that go beyond European borders, but, with an average of 12,77%, it still represents the lowest percentage share. While no significant trend can be identified for either the "Intra2.copat.int" or the "Inter.copat.int" variables, it is evident how in the most recent years there has been a clear decrease in regional-level collaborations, while the participation in international networks is becoming more and more appealing and thus frequent. Moreover, when focusing on single countries' data, it can be noticed how there is no dominant strategy in the choice of partners, as each country's situation is different. For example, bigger countries like Germany, France, the Czech Republic, and Poland tend to rely more on internal partners, taking advantage of the large number and variety of companies that are located on their national territory. Instead, smaller countries like Luxembourg, Switzerland, and the Netherlands do not have the same internal resources, and they are therefore pushed more towards collaborating with other European and international partners.

	Sum of Copat.int	Avg. of Intra.copat.int	Avg. of Intra2.copat.int	Avg. of Inter.copat.int	Avg. of ExtraEU.copat.int
1989-1993	1059	24,71%	39,79%	25,51%	9,99%
1994-1998	1145	20,90%	38,94%	26,29%	13,87%
1999-2003	1683	19,17%	45,03%	24,67%	11,13%
2004-2008	2761	20,91%	44,16%	22,11%	12,83%
2009-2013	4213	17,49%	47,15%	21,99%	13,37%
2014-2018	3665	17,06%	42,90%	26,08%	13,96%
Tot.	**14526**	**19,46%**	**43,60%**	**24,17%**	**12,77%**

Table 5. *Geographical localization of collaborations in green patents*

Table 6 shows how, when moving the focus of the analysis to non-green patents, all the new identifiable percentage shares point out a different situation. In fact, the collected data indicates that, with an average of 39,15% and 23,34% respectively, non-green innovators generally rely less on nationwide networks and on European partners, while both the percentage shares of "Intra.copat.int" and "ExtraEU.copat.int" (23,61% and 13,90%) are found to be greater in this more general context. Anyway, consistently with what was seen for green patents, the weight of "Intra2.copat.int" and "Inter.copat.int" tends to be relatively stable over the years, while the frequency of international collaborations is clearly increasing.

	Sum of Copat.int	Avg. of Intra.copat.int	Avg. of Intra2.copat.int	Avg. of Inter.copat.int	Avg. of ExtraEU.copat.int
1989-1993	18092	26,72%	39,44%	23,96%	9,88%
1994-1998	20581	25,44%	36,97%	24,82%	12,78%
1999-2003	28966	25,29%	38,30%	22,16%	14,24%
2004-2008	33586	23,75%	39,11%	23,02%	14,12%
2009-2013	34710	21,85%	39,87%	23,45%	14,83%
2014-2018	33858	19,73%	40,88%	22,91%	16,48%
Tot.	**169793**	**23,61%**	**39,15%**	**23,34%**	**13,90%**

Table 6. *Geographical localization of collaborations in non-green patents*

3.3. Discussion

Consistently with the opinion of most of the researchers presented in Chapter 2, the result that is most frequently recurring in the above-exposed analyses is the higher propensity that environmental innovators have to rely on external knowledge sources in the innovation process. Even though the two percentages of collaboration are not too considerably different (16,17% for green patents against 15,15% for non-green patents), this finding was shown to be true even by the study of team sizes.

Moreover, the fact that the countries that tend to be more active in the collaboration networks are those characterized by the highest number of both applicants and inventors per patent should not come as a surprise either. Indeed, both aspects are indicative of higher levels of openness in the innovation process, pointing out the attempt of green companies located in these countries to make up for their scarcity of internal resources, including their lack of specific technical and scientific knowledge.

In this regard, the tendency to look on the outside for targeted and more efficient solutions that companies generally show has recently been emphasized by the technological development and the lower costs that facilitate long-distance transportation and immediate communication. In fact, since vast and extended networks have always been naturally more costly to manage, these improvements can at least partially explain the steady increase in the weight of international collaborations that occurred from 1989 to 2018 (Viticoli, 2021; De Backer et al., 2008).

Another possible explanation for this extended openness can be found by looking at the data on the average size of the teams working on the development of innovation. The general decrease in the registered number of applicants per patent, consistent with the increase in average filings per applicant pointed out by Hingley and Bas (2009), could, at least partially, be due to companies' willingness to reach greater appropriability and individual returns from the filings. Its decline is in fact even more evident for non-green innovations, underlining the greater attention to profit that general innovators usually show when compared to environmental innovators, who instead tend to integrate even social profit into the equation (Boons and Lüdeke-Freund, 2013). Along the same line, the average number of involved inventors increased over the years for both green and non-green patents, but the escalation was much more pronounced in the former case. When putting these two pieces of evidence together, the outlined trends can be explained by the fact that the organizations that decide to spend time and money working on risky R&D processes are becoming fewer, and thus plausibly bigger. The resulting concentration of innovation culture and fresh ideas tends to

make these remaining companies a lot more attractive to the eyes of brilliant and motivated talents, making them want to play a role in their challenging projects, even if this means moving to another country (Sommer et al., 2016).
Despite this, this need to go abroad to find competent companies that are active in collaborative networks is less pronounced in the case of green patents. Indeed, when it comes to EI, the weight of national collaboration is much more relevant than for standard innovation (43,60% against 39,15%) and, while regional level networks have been decreasing, those at a national level have been increasing steadily. This can be further enhanced by the strengthening of the so-called national systems of innovation, which can be defined as “the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies” (Freeman, 1987). In fact, institutions play a crucial role when it comes to encouraging the development and the implementation of EI, since countries with fewer administrative requirements, stringent intellectual property protection, high-quality education, and stable prices tend to be more innovative and experience better innovation performances (Hollanders and Arundel, 2007; Arundel, 2003).

Conclusions

In conclusion, the world of environmental innovation is extremely complex and interconnected, and the aim of this study has been to focus on its connection to open innovation.
The factors that could possibly influence the development and implementation of EI are many and varied, as they range from intrinsic characteristics of the individual company to external drivers like environmental regulations, market demand, and external collaborations.
This last aspect was thoroughly investigated in Chapter 3 to show the cooperative tendencies that specifically characterize EI, differentiating it from standard innovation.
What emerged from the patent data analysis is that companies tend to open more to external knowledge and collaborate more with larger networks when their focus is on developing environment-related innovations. In doing so, in the last few years, innovators have been working more and more with partners who are located in the same country as them, and that thus face the need to comply with the same national regulations. Anyway, this is not the only novelty, as even international collaboration has been increasing, with companies exploiting the ease of transport and communication to take advantage of the best available opportunities to optimally respond to market demand and truly aim at excellence.

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