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What are the drivers of eco-innovation? Empirical evidence from French start-ups

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ABSTRACT

The purpose of this paper is to identify the drivers of eco-innovation in start-ups. Firstly, a discriminant analysis (DA) is applied to study what is distinctive about eco-innovative start-ups as compared to non-eco-innovative start-ups. Secondly, a typology of eco-innovative start-ups is developed using a hierarchical ascendant clustering (HAC). Analyses are carried out using original data from a survey of 120 eco-innovative and non-eco-innovative French start-ups.

Discriminant analyses reveal that the founders of eco-innovative start-ups are differentiated by characteristics related to their environmental education and professional experience. Furthermore, eco-innovative start-ups are distinguished from the non-eco-innovative start-ups by voluntary environmental practices, such as the adoption of corporate social responsibility policies. Finally, we show that there is a diversity of profiles of eco-innovators. In fact, firms cluster into five main profiles and exhibit different eco-innovation drivers. We highlight that the different types of eco-innovators do not face the same difficulties in accessing funds. These findings have important implications for the implementation of public policy designed to promote eco-innovative activity, and they highlight the need to design policies that take into account the distinctive character of each profile.

1. Introduction

In a context of natural resource scarcity, environmental degradation, and wasteful consumption, urgent solutions are required, and to this end governments and society have recognized the crucial role of sustainability. Achieving the objectives of sustainable development involves the participation of all economic actors: companies are thus also involved in these environmental and societal changes, and are responding to social demand by developing processes and solutions capable of offering greener goods and services. These changes are an important strategic concern for manufacturers in terms of positioning their products in highly competitive markets. Some companies are looking to take advantage of the niche opportunities created by the transition towards sustainable development: indeed, an OECD (2010) survey revealed that environmental challenges are seen in many countries as a new opportunity for competitiveness. In addition, the increasing scarcity of fossil fuels, as well as a potential increase in the tax on carbon, could lead to an increase in the prices of primary resources, which might weaken the competitiveness of actors and territories not prepared for transition (Deboutière and Georgeault, 2015).

We observe, therefore, the emergence of new, more resilient and future-oriented economic models, among which we can cite the circular economy, the collaborative economy, or the functionality economy (ADEME, 2004). The production system has begun to adopt greener and renewable energy sources, and green entrepreneurs have become established as important actors in this process of transition. In this context, there is an important role for new products, processes, and practices that reduce or limit environmental impacts (Geels, 2010). Thus, start-ups ought to be a major concern of public policy and for innovation policy, given that they allow the development of solutions which induce a positive impact on at least one of the fundamental pillars of sustainable development—i.e., the economy (by increasing energy efficiency, for example), society, and the environment. Start-ups have features that make the development of eco-innovations easier: they have the flexibility to adapt to changes in their activity (Aragón-Correa et al., 2008; Keskin et al., 2013), they display a spirit of risk-taking, and they also have a key role in bringing radical innovations to the market and in developing breakthrough eco-technologies (Demirel et al., 2019). But,

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as yet, we know very little about the distinctive innovation strategies adopted by this type of firm.

At the European level, several incentives have been set up to encourage the creation of green SMEs. These initiatives include the Small Business Act and the Green Action Plan, which support SMEs that seek to turn environmental problems into opportunities.

Since 2010, as part of the Programme d'Investissement d'Avenir (PIA), the French environment and energy management agency (ADEME) has provided a total of 93 million euros in grants to SMEs that are carrying out projects designed to benefit the environment (ADEME, 2018). In order to face up to its environmental challenges, France is engaged in a structural transformation of its economy. The legislative framework that regulates this transformation is the law on energy transition for green growth. According to a report by the Ministry for Ecological Transition, this is an opportunity for companies to create new activities and jobs, and hence generate wealth, while also playing a crucial role in achieving sustainable development objectives (MTES, 2020).

The French economy is based heavily on small and medium-sized enterprises (SMEs). In 2017 there were 3.8 million SMEs in France (i.e., 97 % of the total number of enterprises); the majority of these (97 %) were microenterprises (MIC), which generated 43 % of the added value and employed 6.3 million people (Insee, 2019). The empirical literature has highlighted the importance of these companies for the economy, whether in terms of job creation (Birley, 1986) or innovation (Drucker, 1985), and their impact on the environment is significant. Given that SMEs have been identified as contributing to environmental degradation (Jenkins, 2009), so they may also represent a promising arena for environmental solutions (Kiefer et al., 2019). The study of eco-innovative start-ups is therefore relevant in order to better guide the development of appropriate public policies. Although the individual impact of each company is low compared to the role that a large company could play in reducing pollution, the cumulative impact of all SMEs promises to be considerable (EC, 2020). Yet although the number of green start-ups has increased worldwide in recent years, their number as a proportion of total start-ups remains low. In fact, at the start of 2020, Frenchtech identified 14,189 microenterprise start-ups in France, of which 482 were cleantech start-ups, representing a share of just 3.4 %.

With respect to the academic literature, the study of eco-innovative firms has attracted the attention of researchers who have studied the determinants of eco-innovation in depth (see Del Río et al., 2015 for a review). The study of the typologies of firms, principally SMEs, has focused on the eco-innovative nature of the firm without taking into account the entrepreneurial nature of the activity. Moreover, these studies do not distinguish between established firms and newly created firms ("born to be green" firms).[1] The typology has been elaborated on the basis of three main factors related to the determinants of environmental innovation: technology push, market pull, and regulation. Some of them go further in their analysis by taking into account the factor of cooperation and the diffusion of knowledge (Castellacci and Lie, 2017; Doloreux and Kraft, 2019). Another area of the literature is concerned with studying the typologies of sustainable entrepreneurship. The main factors considered in this literature are the motivation of the entrepreneur (economic or environmental values) as well as the main orientation of the entrepreneur (Linnanen, 2002; Schaltegger, 2002; Schaltegger and Wagner, 2011); however, the eco-innovation aspect is marginal.

This paper seeks to address the two following questions: (a) what are the drivers of eco-innovation among the French start-ups? (b) What are the profiles of eco-innovative start-ups? To address the first question, this paper studies what is distinctive about eco-innovative start-ups compared to non-eco-innovative start-ups based on two themes: socio-demographic characteristics, and environmental policy. To do so, we apply a decision-making model, namely a discriminant analysis (DA), which is a modeling method that is particularly well suited for decision-making and scoring (Tuffery, 2007; Saporta, 2011).

To address the second question, this paper provides a typology of eco-innovative start-ups developed using a hierarchical ascendant clustering (HAC) approach based on five main themes: financial resources, external knowledge, eco-innovation type, motivation, and environmental orientation. The approach adopted rests on a combined use of multidimensional data analyses (Tuffery, 2007; Hosmer and Lemeshow, 2000; Lebart et al., 2000) that take into account several components of entrepreneurial characteristics. The aim is to examine whether a variety of profiles emerges among the sample of eco-innovative start-ups. Moreover, the typology makes it possible to identify the different incentives that apply to each category (Nikolaou et al., 2018). The taxonomic study is an appropriate method for this case because it constitutes an intermediate approach between analyses based on various individual cases and the generality of macroeconomic studies (sector or country level) (Marin et al., 2015). Furthermore, the study of the specific characteristics of eco-innovators and the understanding of their diverse patterns, in a context of environmental challenges, is of high relevance for developing public policies. The main information needed to carry out this study in the context of start-ups is not available in the existing datasets; for this reason, the analysis is based on a survey of 120 eco-innovative and non-eco-innovative French start-ups that we conducted in 2019.

The theoretical framework is based on literature that combines the resource-based view and the evolutionary perspective to categorize the drivers of eco-innovation into internal and external factors (del Río González, 2009; del Río et al., 2016; Demirel and Kesidou, 2011; Sáez-Martínez et al., 2014). In our case factors internal to the firm refer, for instance, to financial resources and environmental orientation (for more details, see Section 4). Meanwhile, external factors refer to cooperation. We complete this framework with some aspects of the entrepreneurship literature (Casson, 2005).

The results of the DA reveal that the founders of eco-innovative start-ups possess differentiating characteristics related to their environmental education and professional experience. Furthermore, the eco-innovative start-ups are differentiated from non-eco-innovative start-ups by the presence of voluntary environmental practices, such as adherence to a code of corporate social responsibility. The results of the HAC reveal the diversity of profiles of eco-innovators, with firms clustering into five main profiles. And we show empirically that the different types of eco-innovators do not all face the same kinds of difficulties in accessing funds.

The empirical literature on the determinants of eco-innovation is based mainly on patent databases and Community Innovation Surveys (CIS) (Belin et al., 2011; Costantini et al., 2017; Horbach, 2016). The diversity of these databases has made it possible to study the development of eco-innovations in the case of large firms and SMEs (Parrilli et al., 2023; Sáez-Martínez et al., 2016). However, few studies have investigated eco-innovation in the entrepreneurial context, and fewer still in the specific context of start-ups. Some researchers have indeed attempted to shed light on environmental practices in the specific context of new businesses, and many of them have focused on the environmental practices of the sustainable entrepreneurs (Linnanen, 2002; Muñoz and Dimov, 2015; Schaltegger and Wagner, 2011); yet despite these contributions, research on eco-innovation in the specific entrepreneurial context of green start-ups remains scarce. Several authors have pointed out the scarcity of investigations related to eco-innovation within green start-ups and have pointed to the need to study the eco-innovative start-ups in more depth (Colombelli and Quatraro, 2018; Corradini, 2019; Fichter et al., 2022; Horbach, 2020). This study aims to address this gap by providing four key contributions to the literature.

First, the literature has investigated the determinants of eco-innovation from the perspective of the context (e.g., environmental

[1] This concept is used by Demirel et al. (2019) to qualify new businesses created with a sustainable approach to entrepreneurship.

policy (Guo et al., 2022)), the firm (e.g., internal resources (Demirel and Kesidou, 2019)), or the products/services (e.g., eco-innovations as market drivers (Ghisetti, 2017)); yet despite the existence of some integrative research (Castellacci and Lie, 2017; Doloreux and Kraft, 2019; Kammerer, 2009), there are no empirical studies on eco-innovation in start-ups that bring together all these dimensions combined with the entrepreneurs' characteristics (e.g., motivation and individual features). In doing so, we extend the previous literature on the determinants of eco-innovation to the specific context of eco-innovative start-ups.

Second, the existing typologies of sustainable entrepreneurship and green start-ups have been derived from theory and are conceptual or based on qualitative analysis; with the exception of Olteanu and Fichter (2022), who focused on the degree of environmental orientation and the degree of economic orientation of green start-ups, they have not been tested on empirical data. Based on empirical data gathered from 64 eco-innovative start-ups, this paper provides a more refined typology, taking into account the eco-innovation determinants related to four dimensions (context, firm, market and entrepreneur). In so doing, this article extends the previous conceptual typologies of sustainable entrepreneurship and green start-ups. We also investigate whether distinct groups of start-ups are associated with different driving factors.

Third, by focusing on eco-innovative start-ups and including an individual dimension inherent to the entrepreneurs themselves (e.g., motivation), this paper responds to a recent call for more integrative research on eco-innovation (Corradini, 2019; Fichter et al., 2022; Horbach, 2020). In fact, this article proposes to combine together in a single empirical study three research streams that have otherwise been little mobilized together in a single empirical study: literatures on firms' eco-innovation (Porter and Van der Linde, 1995; Rennings, 2000), sustainable entrepreneurship (Kuckertz and Wagner, 2010; Shepherd and Patzelt, 2011), and start-ups (Birley, 1986; Carter et al., 1996).

Finally, the previous typologies, being predominantly conceptual, do not offer substantive suggestions for policies to promote and support eco-innovation in the specific context of start-ups. The policy implications arising from this study are important for policies aiming at fostering eco-innovation, and can serve as a foundation for programs to develop eco-innovative start-ups. By outlining the different forms that eco-innovative start-ups can take, this allows structures supportive of national entrepreneurship, including incubators, to adapt their support strategies according to the diversity of profiles of eco-innovative start-ups.

Our paper is structured as follows: Section 2 explains some concepts and gives a literature review. Section 3 presents the questionnaire and data collection. The methods and the results of the analysis are provided and discussed in Section 4. Section 5 concludes and gives policy recommendations.

2. Literature review

In what follows, we first define eco-innovation and set out its theoretical foundations; we then present the determinants of eco-innovation from different perspectives; finally, we give an overview of previous typologies of eco-innovative start-ups.

2.1. Eco-innovation: definition and theoretical foundations

2.1.1. The concept of eco-innovation

Eco-innovation is a complex concept that takes several forms (Ekins, 2010), and it is important to delineate its boundaries. According to the definition given by Kemp and Pearson (2007, p.7) provided in the European commission report, "Eco-innovation is 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 resource use (including energy use) compared to relevant alternatives". Garcia and Calantone (2002) distinguish between two forms of eco-innovation: radical eco-innovation (i.e., a completely new product and process that causes a change in production, consumption or organization patterns), and incremental eco-innovation (i.e., a simple improvement, characterized by a low degree of innovation and a moderate change in the market or customer value. Other researchers, including Bocken et al. (2014), distinguish between frontstage eco-innovation (also called front-end), which is the initial phase of idea generation, and backstage eco-innovation (also known as back-end eco-innovation), which is the product development phase. Whatever its forms (radical, incremental, frontstage, or backstage), researchers agree that what characterizes eco-innovation is the positive impact of the innovation provided on the environment (Carrillo-Hermosilla et al., 2009; Rennings, 2000). This has led many researchers to address the following question: why are some firms more eco-innovative than others?

2.1.2. Theoretical foundations

The determinants of eco-innovation at the firm level have been approached from different theoretical perspectives—among others, the resource-based view (Barney, 1991) and evolutionary theory (Nelson and Winter, 1982).[2] The studies based on these theories distinguished between external and internal determinants of eco-innovation. Earlier literature had focused on the external factors; however, some authors had pointed out shortcomings in these studies linked to their inability to explain the firms' internal stimuli. External factors are not sufficient to explain eco-innovation decisions at the firm level (Demirel and Kesidou, 2011; Kesidou and Demirel, 2012; Triguero et al., 2014); they must be supplemented by factors internal to the firm. In order to address these shortcomings, there has been increasing interest in the resource-based view (Barney, 1991), which emphasizes the importance of the internal resources of firms. These resources can be classified into three categories: physical capital (physical technology, equipment, location), human capital (managers' and workers' skills) and organizational capital (Aragón-Correa et al., 2008; Triguero et al., 2016). By contrast, the evolutionary theory states that innovation is a complex and dynamic system influenced by both internal and external factors. Recent studies have taken into account both internal and external factors (Galliano and Nadel, 2013; Triguero et al., 2014).

Over the past decade, several studies have highlighted the particular nature of eco-innovation within SMEs, and this question has started to arouse increasing interest among researchers (for more details, see Pacheco et al., 2018, 2017). SMEs have the particular feature of innovating differently (Bos-Brouwers, 2009; Klewitz and Hansen, 2014), and play a central role in the transition towards a sustainable economy (Hall et al., 2013). The study of the internal drivers of the environmental practices of SMEs also draws on entrepreneurship theory. According to the theory of entrepreneurship, a firm's strategic direction is closely related to the decision making of the entrepreneur, who is responsible for the gathering and analyzing of available information to make important business decisions. The theory thus states that the entrepreneurial capabilities are a firm's main human resource (Casson, 2005).

In addition to evolutionary theory, the resource-based view, and entrepreneurship theory, as just mentioned, eco-innovation has also been approached from the perspective of the general theory of innovation (Di Stefano et al., 2012). Applied to the investigation of the determinants of eco-innovation, this theory distinguishes two important factors that stimulate innovation: technology push, and market pull (Di

[2] Other researchers have analysed the determinants of eco-innovation by using other theories, such as stakeholder theory, theory of planned behaviour or institutional theory. These theories are not the subject of this study (for more details, see Hazarika and Zhang, 2019; Munodawafa and Johl, 2019; Boutry and Nadel, 2021).

Stefano et al., 2012). In addition to these two factors, Horbach (2008) and Porter and Van der Linde (1995) outline the determining role of environmental policies (both in the form of command and control and market-based instruments).

2.2. The key determinants of eco-innovation

Relying on the theories mentioned above, the determinants of eco-innovation can be divided into four categories. Based on the evolutionary theory (Nelson and Winter, 1982), the first category emphasizes the determinant role of contextual factors surrounding the firm (Guo et al., 2022). Based on resource-based view (Barney, 1991), the second one outlines the importance of the firms' resources and characteristics (Demirel and Kesidou, 2019). Founded on entrepreneurship theory, the third one underlines the importance of the entrepreneur, or more precisely the interaction between the entrepreneur and his/her firm (Muñoz and Dimov, 2015). Based on the general theory of innovation (Di Stefano et al., 2012), the last one focuses on the products and services as well as the target market (Ghisetti, 2017).

2.2.1. Context related determinants

Interaction with the environment is a key factor for eco-innovation (Galliano and Nadel, 2013). The environmental policy factor (regulatory push/pull effect)[3] comprises all public measures to reduce the environmental impact. According to Rennings (2000), regulation is important in addressing the double externality problem associated with eco-innovation. Previous studies have found that different regulation instruments have an influence on the decision to undertake eco-innovation (Belin et al., 2011; Rehfeld et al., 2007). Stringent regulations can stimulate investment in eco-innovation (Kammerer, 2009).

The literature has also emphasized the importance of the "external knowledge" factor. Eco-innovations are characterized by a higher level of risk, uncertainty, and novelty (Belin et al., 2011), and they are also more complex (De Marchi, 2012). Because of this, they are highly dependent on knowledge and information which cannot be satisfied only internally. The existing literature points out that eco-innovation is more cooperation-intensive than other innovations. Thus, it is crucial for eco-innovation that there is cooperation between heterogeneous partners such as firms (De Marchi, 2012; Horbach, 2008), clients, distributors, suppliers (Buttol et al., 2012; Cainelli et al., 2012; Cainelli and Mazzanti, 2013), universities (Cainelli et al., 2012; Triguero et al., 2013), and governmental partners (Doblinger et al., 2019).

2.2.2. Firm-related determinants

Several studies have highlighted the influence of the internal characteristics of firms on eco-innovation (Castellacci and Lie, 2017; Doloreux and Kraft, 2019; Triguero et al., 2016). Among those drivers internal to the firm, the availability of resources (people, technology, and know-how) stands out as a critical determinant (Pacheco et al., 2018). The technology push factor is associated with technological capabilities which mainly combine human capital and physical capital (Horbach, 2008; Triguero et al., 2013). High technological capacities can lead to new eco-innovations (Belin et al., 2011; Horbach, 2008). To acquire these capabilities, investment in R&D and the training of employees is of high importance (Cainelli et al., 2015; Horbach et al., 2012). A firm's decision to introduce eco-innovations is also influenced by the access to financial resources (Scarpellini et al., 2018), especially in the case of SMEs, which struggle more from financial constraints compared to large firms (Triguero et al., 2013). The importance of introducing environmental practices such as Environmental Management Systems (EMS) for eco-innovation has been illustrated by several authors (Khanna et al., 2009; Wagner, 2008). For instance, Horbach et al. (2012) have shown that EMS has a significant impact on eco-innovation as well as on organizational changes such as new forms of work organization.

2.2.3. Entrepreneur-related determinants

Entrepreneurship theory outlines the important role of the entrepreneur. Sustainable entrepreneurship refers to "entrepreneurial activities that contribute positively to sustainable development and the objectives derived from it" (Kuckertz and Wagner, 2010). Several other concepts are used to designate the relationship between entrepreneurship and sustainable development, such as ecopreneurship, social entrepreneurship, or green entrepreneurship (for more details, see Gast et al., 2017). A crucial role is played here by the entrepreneur's specific values and culture (Anderson, 1998). Sustainable entrepreneurs have specific business and organizational motivators and skills (Bocken, 2015). Thus, the main factors discussed under this heading are related to the individual entrepreneur. The importance of the sustainability intention and orientation of the entrepreneur is highlighted in many articles (Linnanen, 2002; Schaltegger, 2002; Schaltegger and Wagner, 2011). Linnanen (2002) shows that green entrepreneurs have several characteristics in common with traditional entrepreneurs; the main difference is the important role of ethical values. Hoogendoorn et al. (2020) show that environmental value creation has a positive effect on the innovativeness of the start-ups. Moreover, the entrepreneur's prior knowledge is also relevant (Patzelt and Shepherd, 2011).

2.2.4. Products, services and markets related drivers

Empirical findings differ concerning the importance of market pull factors for stimulating eco-innovation. Some studies suggest that demand factors have a positive effect on the firm's decision to undertake eco-innovations (Fernández et al., 2021; Kesidou and Demirel, 2012; Triguero et al., 2013). Others argue that market pull factors play a limited role in spurring eco-innovation because eco-friendly products are still expensive (Rehfeld et al., 2007). Moreover, the effect of the market pull is limited in countries with low environmental awareness and willingness to pay (del Río et al., 2016). Regarding the structure of eco-innovation, previous literature has shown that the determinants of eco-innovation differ when considering the distinct sub-types of green innovation (energy-reducing innovations, carbon dioxide–reducing innovations, etc.) (Veugelers, 2012).

The empirical literature on the determinants of eco-innovation is based mainly on patent databases and the Community Innovation Surveys (CIS). The diversity of these databases has made it possible to study the development of eco-innovations in the case of large firms and SMEs. However, they do not allow the study of the entrepreneurs themselves, despite their importance as a source of innovation (Colombelli and Quatraro, 2019; Corradini, 2019). This represents an important gap in the research literature, especially since start-ups have more flexibility in their innovation policy compared to established firms (Keskin et al., 2013) and can be a major source of radical innovations (Colombelli and Quatraro, 2019). We fill this gap in the literature by studying the distinctiveness of eco-innovative start-ups compared to non-eco-innovative start-ups. And in addition to the scarcity of studies on the determinants of eco-innovation at start-up level, the previous literature has also overlooked the diversity of eco-innovative start-ups.

2.3. Eco-innovative firms: an overview of previous typologies

Table 1 represents an overview of previous typologies of eco-innovative firms according to the eco-innovation drivers, and typologies of sustainable entrepreneurs according to their main characteristics. There are a few studies that have proposed typologies of SMEs by

[3] The literature distinguishes two categories of public policy instruments (command and control, and economic instruments). Command and control are regulatory instruments such as bans, emission volume limits, and technical requirements. Economic instruments consist of retaining a price on negative externalities. They are more flexible because they leave the choice of the least-cost strategy to the agents.

Table 1
Typologies for eco-innovative firms and sustainable entrepreneurship.

Authors	Theoretical foundations	Typologies	Samples	Methodologies			Classification criteria									
							Context-related characteristics		Firm-related characteristics				Entrepreneur-related characteristics		Product/service-related characteristics	
				Quantitative	Qualitative	Conceptual	Environmental policy	Knowledge	Resources	Organizational Strategies	Environmental practices	Firms' features	Entrepreneus' motivation	Individuals' characteristics	Eco-innovation structure	Markets
Aragón-Correa et al. (2008)	Resource-based view	1. Reactive regulatory compliance 2. Proactive pollution prevention 3. Environmental leadership	108 automotive repair sector SMEs in Spain	×						×						
Bergset and Fichter (2015)	Entrepreneurship theory	1. The alternative start-up 2. The visionary start-up 3. The ecopreneurial start-up 4. The inventive start-up 5. The unintentionally green start-up	Start-ups			×			×	×			×			×
Triguero et al. (2016)	Resource-based view	1. Laggards eco-innovators 2. Lounger eco-innovators 3. Followers eco-innovators 4. Leaders eco-innovators	3852 European SMEs	×			×	×			×	×				×
Doloreux and Kraft (2019)	Resource-based view	1. Eco-innovation laggers 2. Product-oriented eco-innovators 3. Process-oriented eco-innovators 4. Fully integrated eco-innovators	151 Canadian wine SMEs	×				×				×			×	
Castellacci and Lie (2017)	Unspecified	1. Carbon dioxide reducing green innovators 2. Waste reducing 3. Recycling Innovator 4. Pollution-reducing	1719 South Korean manufacturing firms	×			×	×		×		×			×	×

(*continued on next page*)

Table 1 (*continued*)

Authors	Theoretical foundations	Typologies	Samples	Methodologies			Classification criteria									
							Context-related characteristics		Firm-related characteristics				Entrepreneur-related characteristics		Product/service-related characteristics	
				Quantitative	Qualitative	Conceptual	Environmental policy	Knowledge	Resources	Organizational Strategies	Environmental practices	Firms' features	Entrepreneus' motivation	Individuals' characteristics	Eco-innovation structure	Markets
Sáez-Martínez et al. (2016)	Evolutionary economic theory	1. Technology-driven innovators 2. Traditional firms 3. Market-driven innovators 4. Sporadic innovators	212 SMEs in Spain	×				×							×	×
Olteanu and Fichter (2022)	Entrepreneurship theory	1. Sustainability transformer 2. Biopreneur 3. Sustainability sensitive venture 4. Growth-only venture 5. Market-focused venture 6. Non-growth venture	1674 German start-ups	×									×			×
Muñoz and Dimov (2015)	Entrepreneurship theory	1. Conformist 2. Insurgent	45 sustainability-oriented new firms		×								×	×		×
Taylor and Walley (2004)	Entrepreneurship theory	1. Innovative opportunist 2. Visionary champion 3. Ethical maverick 4. Ad hoc enviropreneur	Green entrepreneurs			×	×	×					×			×
Linnanen (2002)	Entrepreneurship theory	1. Self-employer 2. Non-profit business 3. Opportunist 4. Successful idealist	5 start-ups		×								×			×
Schaltegger and Wagner (2011)	Entrepreneurship theory	1. Administration of social or/and environmental requirements 2. Management of social/ environmental challenges/ opportunities 3. Traditional social	Sustainable entrepreneurs			×							×			×

(*continued on next page*)

Table 1 (*continued*)

Authors	Theoretical foundations	Typologies	Samples	Methodologies			Classification criteria									
							Context-related characteristics		Firm-related characteristics				Entrepreneur-related characteristics		Product/service-related characteristics	
				Quantitative	Qualitative	Conceptual	Environmental policy	Knowledge	Resources	Organizational Strategies	Environmental practices	Firms' features	Entrepreneus' motivation	Individuals' characteristics	Eco-innovation structure	Markets
Schaltegger (2002)	Entrepreneurship theory	entrepreneurship 4. Sustainability innovation in a niche (Bioneers) 5. Institutional entrepreneurship 6. Ecopreneurship 7. Sustainable entrepreneurship 1. Environmental administrator 2. Environmental manager 3. Alternative actors 4. Bioneers 5. Ecopreneurs	7 firms (Ecopreneurs)		×								×			×

studying eco-innovation. Triguero et al. (2016) study the diversity of eco-innovators based on eco-innovation intensity. Their study is based on the triangle model of Van Dijken et al. (1999), which considers three factors: business skills, environmental orientation, and network involvement. They distinguish between leaders, followers, loungers, and laggards. Leaders are highly eco-innovative, while laggards have a low level of eco-innovation and reduced environmental impact. Doloreux and Kraft (2019) and Castellacci and Lie (2017) study the main determinants of different types of eco-innovations. Doloreux and Kraft (2019) measure the intensity of eco-innovation by the diversity of eco-innovations developed (products and processes). They identify eco-innovation laggers, product-oriented eco-innovators, process-oriented eco-innovators, and fully integrated eco-innovators. Castellacci and Lie (2017) identify the different determinants according to the types of eco-innovations. They distinguish between CO_2-reducing, waste reducing, recycling, and pollution-reducing innovators. Sáez-Martínez et al. (2016) distinguish between technology-driven innovators, traditional firms, market-driven innovators, and sporadic innovators.

While studies investigating the diverse patterns of eco-innovative start-ups are relatively scarce, the different categories of sustainable entrepreneurs have received greater attention in the literature. Muñoz and Dimov (2015) used individual factors related to the entrepreneur (knowledge, orientation, intention) and external factors related to perceived social support and business support, in order to identify two paths for entrepreneurs: conformist "sustainability conveyors" operate in a social context characterized by the abundance of environmental values and convictions, and their motivation is to comply with existing standards and values; "insurgents," on the other hand, emerge in a context characterized by a lack of environmental convictions, and are entrepreneurs who find inspiration in personal values and must operate against defined standards. Aragón-Correa et al. (2008) established a classification of SMEs based on internal organizational capabilities. Being mainly interested in the level of proactivity[4] in the implementation of environmental practices, they distinguish three categories: reactive, pollution prevention, and leadership. However, most of these studies make only a succinct reference to eco-innovation, and focus, rather, on corporate environmental practices. Bergset and Fichter (2015) have established a conceptual typology of green start-ups based on a literature review. They focus on the factors that play an important role in the financing decisions of investors, including sustainability motivations and business qualifications. They distinguish five categories of green start-ups: the alternative start-up, the visionary start-up, the inventive start-up, the "ecopreneurial" start-up, and the unintentionally green start-up. The latter is characterized by highly innovative entrepreneurs, is exposed to high risks, and requires high levels of capital. Taylor and Walley (2004) have presented a theoretical typology of eco-entrepreneurs based on their individual orientation and the intensity of external influence. They distinguish between innovative opportunist, visionary champion, ethical maverick, and ad hoc "enviropreneur". The innovative opportunist has a purely economic objective and is greatly influenced by external pressures.

As shown in Table 1, the few empirical studies on the typologies of eco-innovative start-ups are exclusively related to the case of SMEs, and do not distinguish established firms from newly created start-ups. They therefore do not take into account the distinctiveness of start-ups, which constitute a special case because of the ease with which they are able to adapt their business plan to environmental issues. They are also not interested in the role that the entrepreneur might play. On the other side, empirical research on sustainable entrepreneurship is mostly focused on the characteristics of the entrepreneur (motivation, intentions, values, etc.) (Linnanen, 2002; Schaltegger and Wagner, 2011).

[4] Strategic proactivity is defined as a firms ability to initiate changes in its strategic policies regarding its entrepreneurial, engineering, and administrative activities, rather than reacting to events (Aragón-Correa, 1998).

This article is aimed at filling the gap in the literature by linking the analysis of the eco-innovation drivers to the wide body of literature that investigates sustainable entrepreneurship.

Moreover, Table 1 shows that the existing typologies of sustainable entrepreneurship and green start-ups have been derived from theory and are therefore conceptual, or are based on qualitative analysis and have not been tested by empirical data (with the exception of Olteanu and Fichter, 2022). The latter provide an empirically founded taxonomy of the transformative orientation of German start-ups expressed by degree of planned market impact and degree of priority of environmental and societal impact. They show that environmental and economic objectives are not always in mutual opposition (Bocken, 2015; Olteanu and Fichter, 2022), and point out that there exist firms which place a high priority on economic objectives, others that prioritize environmental objectives, and another category of firms named "sustainability transformers" that are characterized by both high transformation orientation and high market impact. In line with the empirical work by Olteanu and Fichter (2022), we address the gap in the literature related to the lack of empirical evidence. We provide a more refined typology of eco-innovative start-ups based on a quantitative approach, and we combine several eco-innovation drivers of a socio-demographic character, including prior knowledge of the entrepreneur (measured by environment-related education and experience), financial resources, environmental practices of the firm, the type of the eco-innovation developed (incremental, radical, frontstage, and backstage), external knowledge and environmental policy. In fact, the orientation of entrepreneurial initiatives towards the consideration of the environmental aspect cannot be understood by focusing exclusively on the actions taken by entrepreneurs, or by limiting the analysis to the organizational structures of firms and the context in which they operate (Taylor and Walley, 2004). Environmental initiatives should be considered in terms of the mutual interrelationships between the individual characteristics (the entrepreneur), the company, and the context in which the company operates. It is therefore appropriate to develop a typology with a broader perspective that takes into account all of these aspects. We fill this gap in the literature by showing that distinct groups of start-ups are associated with different driving factors.

3. Data: development of a survey

3.1. Questionnaire design and development

Unfortunately, the European and French censuses of start-ups do not provide details of their innovation strategies, financing, or growth. Data on this type of businesses is therefore not very accessible. Indeed, all start-ups are SMEs, but not all SMEs are start-ups, differing in particular in terms of their growth and their vision (Steigertahl and Mauer, 2018). The main information needed to carry out this study in the context of start-ups is not available in the existing datasets; for this reason we elaborated and conducted our own survey.

Drawing on the entrepreneurship literature, we used three criteria to select the innovative start-ups:

(a) Independence (Bruyat and Julien, 2001): not being dependent on an established structure.

(b) Newness (Bruyat and Julien, 2001): the firm was not created as an extension of an existing activity, and the firm has been in existence for fewer than 12 years.

(c) Innovativeness (Lumpkin and Dess, 1996): the firm brings new or improved products or processes to the market. According to these criteria we define innovative start-ups as "a new independent innovative firm." Despite the diversity of terms used to describe eco-innovative firms, including green tech-based firms (Coll-Martínez et al., 2022), cleantech firms (Giudici et al., 2019), and green start-ups (Bergset and Fichter, 2015), there is a consensus among researchers that these firms contribute innovative solutions to environmental challenges (Tiba et al., 2021). Therefore, we define an eco-innovative start-up as "a new

independent innovative firm providing innovation with a positive impact on the environment".[5]

Our questionnaire is structured in four parts: the first part gathers a set of general information on the company (year of creation, turnover, etc.); the second part is devoted to the socio-demographic characteristics of the firm; the third part relates to non-environmental innovation activity; and the fourth part covers the questions related to the eco-innovation activity. We chose to separate non-environmental innovation activities from eco-innovation activities for two reasons. First, to be able to identify the companies that develop the two types of innovation (environmental and non-environmental); second, to identify the specific drivers of eco-innovative and non-eco-innovative start-ups. A start-up is considered to be eco-innovative if the answer to the question, "During the last five years, has your company introduced or developed one or more environmental innovation(s)?" is "Yes"; it is considered non-eco-innovative if the answer is "No".[6] This decision to question the founders was also based on the fact that the founders have a better knowledge of the start-up and the motivations behind its creation. The survey was conducted face-to-face and by email to start-ups in France, from March 2019 to February 2020.

The face-to-face survey was carried out at the "Change Now" summit and the "International cleantech week meeting". Twenty-five questionnaires were collected through the face-to-face survey. The sample was completed by sending the questionnaire by email to the firms listed as winners of the innovation contests such as "I-Nov", "I-lab" and "Prix pépite pour l'entreprenariat étudiant". In order to contact the entrepreneurs we used the open access diffusion reports of the innovation contests. These contain a set of information about the start-ups (e.g. description of the project, location, name and surname of the founder and his email). Given the diversity of contests, we were able to build a dataset of almost 700 contacts of start-ups operating in various sectors in France. During these contests, the evaluation criteria are mainly: the ambition and relevance of the innovation, the economic viability of the project, the potential for development and creation of national and international value, the quality of the team and the adequacy of the contests objectives. Usually, the selection of applicants is done first on the basis of the written application and then the selected applicants are invited for an audition. Most of these contests are supported by the Ministry of Higher Education and Research as part of the "Programme d'Investissements d'Avenir (PIA)" and implemented by Bpifrance. Their objective is to support the winners by financing part of the project, through grants and/or repayable advances. More information on the contests and meetings used is presented in Table 8 in appendix.[7]

Using this contacts dataset, more than 700 companies were contacted and 124 questionnaires were returned by email. A total of 149 responses were collected, representing a response rate of 21 %. Among them, 29 responses were invalid, either because they did not meet the selection criteria (the age of the firm exceeded 12 years and/or the start-up was not concerned with innovation activity), or because they were non-profit associations or the responses were incomplete. There remained a total of 120 valid responses, which were used for this study. The response rate is considered satisfactory, especially given that it was company founders who were requested to participate in the survey. Similar response rates have been recorded in the literature for the use of non-mandatory surveys (Doloreux and Kraft, 2019). The personal characteristics of the respondent were used to characterize the entrepreneur in the case of multiple-founder firms.

[5] In this article, we refer to non-eco-innovative start-ups as those whose innovation does not reduce environmental impacts.

[6] The detailed questions included in the questionnaire are available under request. Note that the questionnaire is in French.

[7] Further details on these contests are available at Bpifrance website. https://www.bpifrance.fr.

3.2. Sample characteristics

Table 2 provides detailed information on the final sample of 120 start-ups. It is representative of the population of French start-ups according to the sectors of activity. This was checked by a chi-square adequacy test: the null hypothesis of adequacy is not rejected for a risk of error of 5 % (see Table 9 in appendix). Since this sample was targeted at nascent entrepreneurs, most firms were established fewer than five years ago (79 %), 87 % have fewer than 10 employees, and 24 % have not yet started to market their products. It is worth noting that 21 start-ups are both eco- and non-eco-innovative. First, we determine what differentiates eco-innovative firms (64 start-ups) from non-eco-innovative firms (56 start-ups) according to different themes. Second, we establish a typology of eco-innovative firms according to their entrepreneurial characteristics.

4. Methodology and empirical results

Our study is based on the implementation of multidimensional data analysis methods. The analysis is built in two stages. First, we used a decision-making model, namely discriminant analysis (DA) (Celeux and Nakache, 1994; Huberty, 1994), with the aim of discriminating between the drivers of eco-innovative firms and those of non-eco-innovative firms. Then, we used hierarchical ascendant clustering (HAC) (Lebart et al., 2000; Saporta, 2011) to establish a typology of the 64 eco-innovative start-ups. Fig. 1 gives a conceptual framework overview of the empirical approach.

4.1. Differentiating the drivers of eco-innovative and non-eco-innovative start-ups

We consider two sets of explanatory variables associated with socio-demographic and environmental themes. The aim is to study their effect on eco-innovation in the specific case of start-ups. To this end, we can use different predictive techniques: a discriminant analysis model (Tuffery, 2007; Nakache, 1981), or logistic or probit regression models (Hosmer and Lemeshow, 2000). Although the models differ in their assumptions, they are actually quite close and the scores obtained in

Table 2
Descriptive statistics.

Start-ups characteristics	Number of firms	Frequency (%)
Age		
≤ 5 years	95	79
> 5 years	25	21
Total	120	100
Turnover		
≤100,000	50	42
]100,000–500,000]	25	21
]500,000–1,000,000]	11	9
> 1 M€	5	4
The firm has not yet started to commercialize its products	29	24
Total	120	100
Employees		
≤ 5 employees	83	69
]5–10]	21	18
> 10 employees	16	13
Total	120	100
Innovation type		
Eco-innovative	64	53
Non Eco-innovative	56	47
Total	120	100

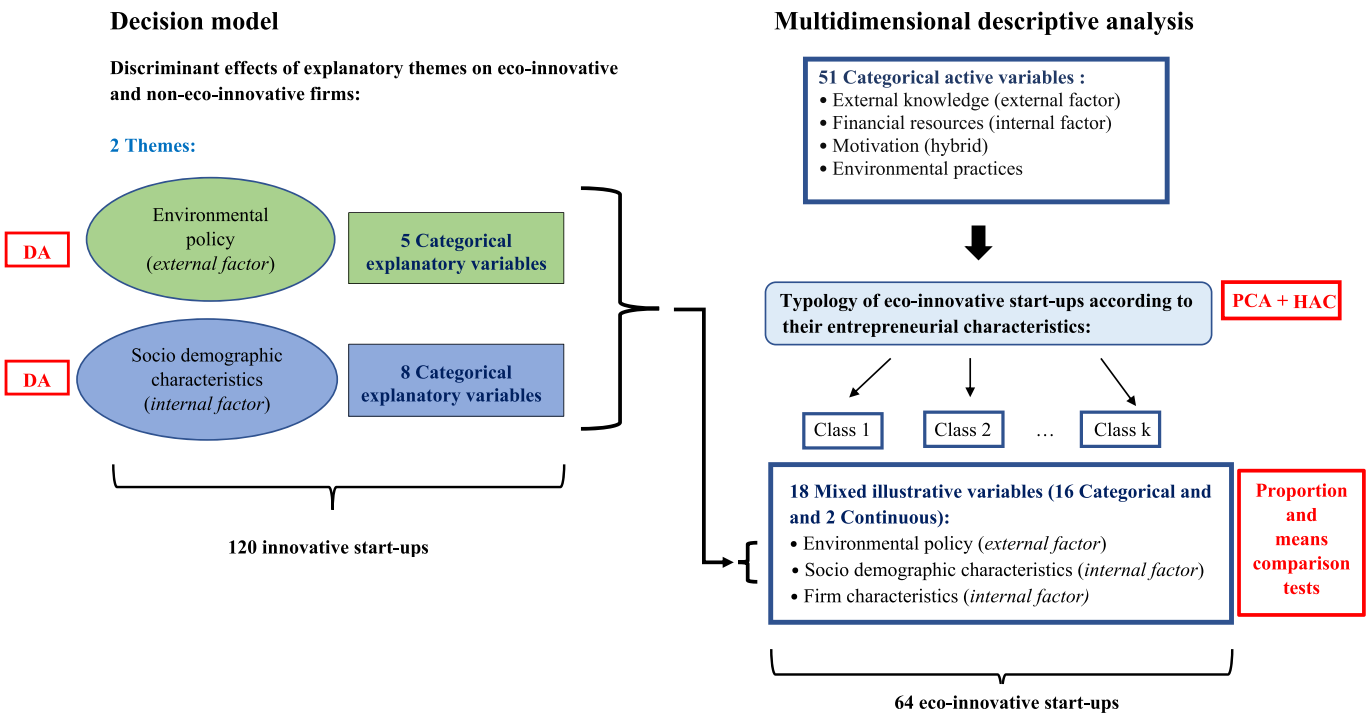

Fig. 1. Methodology overview.

practice are similar. We chose to implement discriminant analysis (DA) for a number of reasons (Tuffery, 2007; Saporta, 2011). Logistic regression directly models a probability in order to provide an approximation, while DA provides a direct solution. The accuracy of logistic regression is lower than that of DA when the latter's assumptions are satisfied,[8] since it is optimal. Logistic regression does not always converge towards an optimal solution: in particular, it is inoperative in the case of complete separation of classes. Finally, logistic regression does not deal with missing values and is sensitive to non-standard values of continuous explanatory variables. Moreover, in our case, where the target variable consists of two classes (eco-innovative/non-eco-innovative), the results of the linear discriminant analysis are much more precise and provide for better discrimination than those of binary logistic regression.

Discriminant analysis is a multivariate model which makes it possible to study the effect of a set of explanatory variables of a homogeneous theme on a target variable, in our case, eco-innovation. The DA approach is close to that of regression. In each case, we try to explain or predict a dependent variable by a linear combination of explanatory continuous variables. In DA, the explained or dependent variable is qualitative, thus 'DA' specifically means DA on continuous explanatory variables. When the explanatory variables are qualitative, a Multiple Correspondence Analysis (MCA) is first applied, then a DA is carried out on the principal components of the MCA as continuous explanatory variables. This methodological chain of data analysis methods is known as DA on qualitative variables.

The analysis is carried out on two groups of start-ups: eco-innovative and non-eco-innovative. The first group contains 64 start-ups and the second group contains 56 start-ups. The dependent variable is the qualitative variable "eco-innovation" with two modalities-groups: eco-innovative start-ups and non-eco-innovative start-ups. We use explanatory variables from two homogeneous themes, socio-demographic characteristics and environmental policy. The former includes the variables related to gender, age, educational level, obtaining a degree related to environmental studies, situation before creation, professional experience related to the environment, number of years of this experience, and the existence of other co-founders. The latter consists of the following variables: environmental regulations (standards, permissions, and prohibitions), taxes on inputs (energy), taxes on polluting emissions, lack of environmental policy instruments, and Corporate Social Responsibility (CSR) policies (for more details on the explanatory variables, see Table 10 in appendix A). The purpose is to highlight the conditions—for each of the socio-demographic characteristics and environmental policy themes—which best differentiate eco-innovative firms from non-eco-innovative firms.

4.1.1. *Socio-demographic characteristics*

Table 3 summarizes the percentage of correctly classified and misclassified start-ups in each group. The percentage of correctly classified start-ups (69.17 %) measures the quality of the discriminant model. The error rate is 30.83 %: the model is satisfactory.

The main results of the DA are summarized in Table 4, which presents the coefficients of the discriminant function, and the modalities of the eight variables that discriminate between eco-innovative firms and non-eco-innovative firms. The model as a whole is significantly discriminating. In fact, the probability (p-value = 0.001) is less than the classical error risk α = 5 %. Therefore, socio-demographic

Table 3
Classification table – DA of the socio-demographic explanatory theme.

	Classification counts and (Percentages)		
Original groups	Correctly classified	Misclassified	Total
Eco-innovative start-up	43.00 (67.19)	21.00 (32.81)	64.00 (100.00)
Non-eco-innovative start-up	40.00 (71.43)	16.00 (28.57)	56.00 (100.00)
Total	83.00 (69.17)	37.00 (30.83)	120.00 (100.00)

[8] The DA is based on the normality of populations. The discriminant functions are linear if the matrices of variances and co-variances of these populations are equal: otherwise, they are quadratic. All these conditions of application have been checked.

Table 4
Discriminant analysis results of socio-demographic explanatory theme.

Linear discriminant analysis model: "Socio-demographic" theme					
Variable	Modality	Parameter estimates		Standard error	Student *t*-test
		Disc. Function	Regression		
Eco-innovative start-up					
GENDER	Male	0.1382	0.0577	0.1345	0.43
AGE	18–25 years	3.1930	1.3334	1.0821	1.23
AGE	26–35 years	0.4807	0.2007	0.3192	0.63
AGE	45–54 years	3.4304	1.4325	0.7977	1.80
ELEVEL	BEP-CAP, no diploma	6.8198	2.8479	1.9808	1.44
ELEVEL	Bachelor	1.0140	0.4234	1.1261	0.38
ELEVEL	Master-Engineer	2.2247	0.9290	0.2642	3.52**
EDIPLO	Yes-Env-Diploma	6.4182	2.6802	1.0482	2.56**
SBCREA	Others	0.2449	0.1023	1.0907	0.09
SBCREA	Company manager experience	1.5593	0.6511	0.6726	0.97
SBCREA	Student	2.3594	0.9852	0.5953	1.65
EPEXPE	Yes-Env-Prof-Experience	4.2474	1.7736	0.7526	2.36**
NYEPEX	1–5 years	1.2187	0.5089	1.2149	0.42
NYEPEX	5–10 years	0.1152	0.0481	1.6194	0.03
NYEPEX	Over 10 years	10.9668	4.5796	1.5008	3.05**
CFOUND	No co-founder	4.0698	1.6995	0.8325	2.04*
Non-eco-innovative start-up					
GENDER	Female	−0.5528	−0.2308	0.5379	−0.43
AGE	36–44 years	−3.3919	−1.4164	0.4749	−2.98**
AGE	Over 55 years	−0.2531	−0.1057	0.5996	−0.18
ELEVEL	PhD	−5.1100	−2.1338	0.5072	−4.21**
EDIPLO	No-Env-Diploma	−0.5204	−0.2173	0.0850	−2.56**
SBCREA	Job seeker	−3.7378	−1.5609	0.7147	−2.18*
SBCREA	Salaried employee	−0.5754	−0.2403	0.3348	−0.72
EPEXPE	No-Env-Prof-Experience	−0.6597	−0.2755	0.1074	−2.57**
NYEPX	No professional experience	−0.6068	−0.2534	0.1075	−2.36**
CFOUND	Yes co-founder	−1.0710	−0.4472	0.2191	−2.04*
	INTERCEPT	0.226456	0.00000		
D2 = 0.84921, T2 = 25.36314, p-value = 0.001, The overall rate of misclassification: 30.83 %					

Significance level α: **α ≤ 1 %; *α∈[1 %, 5 %].
Note: the description of the variables is provided in Table 10 in appendix.

characteristics have a significant effect on the creation of eco-innovative start-ups. The modalities which discriminate between the two groups of start-ups are those with a probability lower than the error risk chosen (p-value ≤5 %). Among the eight explanatory variables introduced into the model, only the variable gender is not discriminating. All the other variables effectively differentiate the two groups of start-ups.

Thus, we can characterize eco-innovative start-ups as firms created by single people, without co-founders, who have a diploma at engineer or master level and have more than 10 years of professional experience in an environmental field. As to non-eco-innovative start-ups, these are companies created with co-founders. The manager tends to be aged between 36 and 44 years, and was a jobseeker before creating the company; they are highly educated people without any professional experience related to the environment.

4.1.2. Environmental policy

Table 5 summarizes the percentage of correctly classified and misclassified start-ups in each group according to the environmental policy theme. 68.33 % of companies are correctly classified by the model, the error rate is 31.67 %, and so the model is satisfactory. Table 6 presents the results of the linear Fisher's function of the DA environmental policy theme. The model as a whole is significant (p-value = 0.001 < 5 %).

Table 5
Classification table – DA of the environmental policy explanatory theme.

	Classification counts and (percentages)		
Original groups	Correctly classified	Misclassified	Total
Eco-innovative start-up	38.00 (59.38)	26.00 (40.63)	64.00 (100.00)
Non-eco-innovative start-up	44.00 (78.57)	12.00 (21.43)	56.00 (100.00)
Total	82.00 (68.33)	38.00 (31.67)	120.00 (100.00)

Among the five variables introduced into the model, only two explanatory variables—taxes on inputs (energy) and taxes on polluting emissions—are not significantly discriminating. All the other variables distinguish the two groups of start-ups effectively. Indeed, the existence of environmental regulations and a CSR policy (whether formalized or not) differentiate the two groups of start-ups. Non-eco-innovative start-ups are characterized by the absence of environmental regulations and a CSR policy. Eco-innovative start-ups are subject to incentives provided by environmental policy instruments and they are characterized by the existence of voluntary environmental practices such as CSR.

Environmental instruments commonly known as "command and control," such as emissions or product standards, or prohibitions and authorizations issued by administrative authorities, differentiate between eco-innovative and non-eco-innovative start-ups. Non-eco-innovative start-ups are distinguished by the absence of command-and-control instruments. The environmental instruments commonly named "economic instruments," such as taxes on polluting emissions and inputs, have not proven to be elements that separate the two groups.

Table 6
Discriminant analysis results of environmental policy explanatory theme.

Linear discriminant analysis model: "Environmental policy" theme					
Variable modality		Parameter estimates		Standard Error	Student T-Test
		Disc. Function	Regression		
Eco-innovative start-up					
REG	REG-Yes selected	1.9324	0.8185	0.2960	2.77**
TI	TI- Yes selected	10.0794	4.2694	4.7391	0.90
TPE	TPE-Yes selected	12.7902	5.4176	4.6184	1.17
EPINON	NONE-Not selected	1.7184	0.7279	0.2839	2.56**
CSR	NA	13.8058	5.8478	4.6846	1.25
CSR	YES-CSR	2.6015	1.1019	0.490	2.25*
Non-eco-innovative start-up					
REG	REG-Not selected	−1.2012	−0.5088	0.1840	−2.77**
TI	TI-Not selected	−0.0847	−0.0359	0.0398	−0.90
TPE	TPE-Not selected	−0.1075	−0.0455	0.0388	−1.17
EPINON	NONE-Yes selected	−1.3593	−0.5758	0.2246	−2.56**
CSR	NO-CSR	−2.5316	−1.0723	0.4339	−2.47**
	CONSTANT	0.130223	0.000000		
D2 = 0.69044, T2 = 21.34278, p-value = 0.001, The overall rate of misclassification: 31.67 %					

Significance level α: **α ≤ 1 %; *α∈[1 %, 5 %].
Note: the description of the variables is provided in in Table 10 in appendix.

The creation of eco-innovative start-ups can be stimulated by the need to comply with existing or anticipated environmental standards and authorizations. It can also be spurred by a desire to conform to the principles of sustainable development, in particular by implementing a CSR policy.

4.2. Typology of eco-innovative start-ups according to their entrepreneurial characteristics

Secondly, a methodological sequence of two data analysis methods (Tuffery, 2007; Hosmer and Lemeshow, 2000; Lebart et al., 2000) was used to group the 64 eco-innovative start-ups into homogeneous classes according to their entrepreneurial characteristics related to access to finance, access to external knowledge (cooperation, exchange of ideas), the type of eco-innovation developed (radical, frontstage, etc.), motivation and environmental orientation (implementation of an environmental management system, analysis of the environmental impacts of products, etc.). The two main clustering methods most used are the K-means - non-hierarchical method used when the number of objects-start-ups is large and with a number of classes of objects fixed a priori - and the HAC - hierarchical Ascendant Clustering method used when the number of objects is small and which makes it possible to choose the level of the cut of the hierarchical tree, and thus the number of classes of the clustering. Hence we opted for a hierarchical clustering method. More precisely, hierarchical ascendant clustering (HAC) was used on the significant factors of the Multiple Correspondence Analysis (MCA). This methodological linking of a factorial analysis and clustering method constitutes an instrument that is particularly well suited to the statistical observation and structural analysis of multidimensional data. This analysis allows to identify different homogeneous classes of start-ups according to their entrepreneurial characteristics. The methodological framework of the HAC is given in Note 1 in Appendix.

In the analysis, the active variables are used to build the typology and to characterize the most homogeneous and distinct eco-innovative start-up classes possible. Using an HAC with the Ward criterion,[9] we establish a typology of five homogeneous classes of eco-innovative start-ups. Table 7 summarizes the main results and profiles of the eco-innovative start-ups selected from the cut of the hierarchical tree given in Fig. 2 in appendix.

All the other variables of the questionnaire can be introduced as illustrative variables in the HAC. These supplementary variables do not participate in the characterization of the typology; they are used a posteriori to attempt to describe the eco-innovative start-up classes previously characterized by the active variables. All the variables are described in Table 10 in appendix.

4.2.1. Class 1: senior entrepreneurs with environmental concerns

The class of senior entrepreneurs with environmental concerns represents 17.19 % of the sample. These start-ups are developing radical eco-innovations. The project has been developed from the idea stage so that the environmental aspect is considered throughout the innovation. These innovations are initially designed in such a way that they reduce environmental impact, in particular through analysis of the environmental impacts of products. The project is credible and attractive, which enables these start-ups to access grants, in particular those from national organizations. They are also characterized by the important role played by the personal financial contribution of the founder. Interest in the environmental aspect is high, which can be observed in particular through the importance given to training employees on subjects related to environmental issues. Their purpose is not to reduce the costs but rather to provide a radical solution to an environmental problem. The start-ups of this class tend to have three and more co-founders and the leader is aged 55 or over.

Start-ups that develop radical innovations are characterized by the presence of several founders. This could be the source of a diversity of skills (management, technical, accounting, financial, legal, commercial). Several studies have highlighted the positive effect of the founder's involvement in other functions (CEO, president, manager, etc.) (Adams et al., 2009; Li and Srinivasan, 2011). Fahlenbrach (2009) examines the investment decisions of founder CEOs and finds that they invest more in research and development. Chen et al. (2012) find that multi-founder firms are more valuable than all other types of firms (including family firms and single-founder firms).

4.2.2. Class 2: necessity entrepreneurs without environmental concerns

This class represents the smallest part of the sample (6.25 %). The environmental aspect is not a major concern in this category of start-up, which is evident in the fact that they do not set environmental objectives for their products. They integrate the environmental aspect into their activity in a haphazard manner. The start-ups of this class tend to have no co-founders and the entrepreneur was often a job-seeker before creating the company. In the literature on entrepreneurship they are known as push entrepreneurs (Amit and Muller, 1995); they engage in an entrepreneurial activity because of lower opportunity costs (the individual is in a bad position in the labor market) (Oxenfeldt, 1943). Their goal is to earn enough money to make a living and they do not live to grow wealth (Choi and Gray, 2008). By contrast, “pull” entrepreneurs are those who start a business to exploit an attractive idea.

These start-ups have difficulties accessing funding and grants. They have very little access to external knowledge due to the lack of cooperation and exchange of ideas through meetings. This class shows great similarities with the ad hoc “enviropreneur” (Taylor and Walley, 2004) and with the unintentionally green start-up (Bergset and Fichter, 2015).

4.2.3. Class 3: entrepreneurs with ecological awareness

This class represents 26.56 % of the companies in the sample. These start-ups do not raise funds. This can be explained by the low interest of investors in this type of start-up or by the desire to keep full power over the decision-making process and avoid the risk of deviating from environmental objectives. They also do not have access to grants. The entrepreneurs create these start-ups because they are convinced of the need to provide solutions to environmental problems, and persuaded that the challenges could be met through the efforts of all. Thus, they are making their contribution by developing an eco-innovative project. Their main objective is not profit; indeed the turnover is lower than 100,000 €. Their eco-innovation is an improvement of existing products (incremental eco-innovation). The environmental aspect is introduced in the product or service in the development phase; in fact, these companies have no R&D activity either internally or externally, and they do not benefit from external knowledge because their networks and partners are limited.

The environmental orientation is stimulated by an internal factor based on the will of the founder and his team. The variable[10] “funded by sustainable investors”[11] is not significant. However, this can be explained by the small share (1.6 %) of companies financed by sustainable investors in our sample. These start-ups have not selected “no incentive to environmental policy” and their managers tend to have a bachelor's degree. This class has features that are close to the ethical maverick (Taylor and Walley, 2004) and the alternative start-up (Bergset and Fichter, 2015).

[9] Generalized Ward's Criteria, i.e. aggregation based on the criterion of the loss of minimal inertia.

[10] Table 7 reports only the significant results, the detailed results are available upon request.

[11] Sustainable investors are investors who direct their investment capital towards firms that have an environmental and social impact.

Table 7
Significant results of the Hierarchical Ascendant Clustering.

	Theme	Cluster 1: Senior entrepreneurs with environmental concerns	Cluster 2: Necessity entrepreneurs without environmental concerns	Cluster 3: Entrepreneurs with ecological awareness	Cluster 4: Market-driven opportunist entrepreneurs without environmental concerns	Cluster 5: Opportunist leaders
		11 Start-ups (17.19 %)	4 Start-ups (6.25 %)	17 Start-ups (26.56 %)	16 Start-ups (25.00 %)	16 Start-ups (25.00 %)
Active variables	Financial resources	+ Fundraising + Funding through personal contribution + Grants for eco-innovation + National grants	- Fundraising	- Fundraising - Grants for environmental innovation - National organizations grants - Grants from local authorities	- Grant from the European Union	+ Fundraising + Private investors or venture capital funds + Regional grant
	Eco-innovation Type	+ Radical eco-innovations - Backstage eco-innovation	-Technologies aimed at reducing polluting emissions	+ Incremental eco-innovation + Backstage eco-innovation - R&D activity		+ Technologies aimed at reducing polluting emissions (CO_2, NO_2, etc.) + Adoption of a new innovation by the start-up + Frontstage eco-innovation + Internal R&D
	Environmental orientation	+ Environmental benchmarking (sometimes) + Environmental impact assessment + Employees environment-related training	+ Eco-brainstorming (rarely) + Frontstage-environmental impact assessment (Rarely) - Setting environmental goals		+ Not concerned by environmental management + Eco-conception (never) - Frontstage: Setting environmental goals	+ Environmental benchmarking (often) + Eco-brainstorming (often) + Frontstage-environmental impact assessment (often) + Eco-conception (often) + Environmental management and audit system + Setting environmental goals
	Motivation	- Cost savings	- Increasing demand for green products	+ Ecological awareness - Cost savings	+ Increasing demand for green products	+ Cost savings - Ecological awareness
	Access to external knowledge			- Cooperation with universities	- Cooperation - Exchange of ideas related to the environment through meetings	+ Cooperation with universities or higher education + Cooperation with suppliers + Cooperation with consultants, commercial or private laboratories + Cooperation with other companies of the same group or the retail network
Illustrative variables		+Three or more co-founders + Founder's age: 55 and over	+ No co-founder + Job-seeker founder	+ Turnover <100,000 € + Bachelor diploma + None-Not selected		+ Environment related professional experience of the founder (5–10 years) + Average number of employees[a]: 11,688

Note: The modalities of the variables presented in the table are significant at the 0.05 level. The sign '+' (respectively '-') indicates a significantly higher level (respectively lower) of the proportion of the modality in the class considered compared to the proportion of the modality in all the 64 start-ups in the sample. The modalities of the active variables and possibly illustrative modalities of qualitative variables are projected onto the PCA factorial planes, the active modalities to characterize the classes of the typology and the illustrative modalities to (possibly) describe these classes. To do this, each modality was subjected to a comparison test of two proportions. The proportion of the modality in the class is compared to that of the modality in the whole sample. The active (resp. illustrative) modality characterizes (resp. describes) the class if the test is significantly positive "Profile (+)". The modality is an "Anti-profile (−)" of the class if the test is significantly negative, with a risk of error less than or equal to 5 %.

[a] Corresponds to the year 2018 expressed in Full-Time Equivalent (FTE).

4.2.4. Class 4: market-driven opportunist entrepreneurs without environmental concerns

This class represents 25 % of the start-ups in the sample. These start-ups were created following the discovery of market niches related to an increasingly high demand for environmentally friendly products or services. Competition is less pronounced in these niches, which are weakly occupied by large groups. The environmental aspect is introduced because it allows the company to exist and to make profits; they rarely carry out an environmental assessment of their products. They have weak access to funds and grants, as is the case for the class 2 start-ups (necessity entrepreneurs without environmental concerns). Investors have little interest in this category of start-up. They do not benefit from external knowledge due to the small number of their partners and their non-participation in the exchange of ideas on environmental aspects through meetings. This class is comparable to the innovative opportunist (Taylor and Walley, 2004) and to the "ecopreneurial" start-up (Bergset and Fichter, 2015).

4.2.5. Class 5: opportunist leaders[12]

This class represents 25 % of the sample. The start-up is created following the emergence of an idea which is conceived from the start in order to reduce or limit environmental impacts (frontstage eco-innovation). A research and development activity is carried out internally in order to implement the idea. These start-ups develop eco-innovative solutions for their activity and for industries that apply for eco-innovations, allowing them to achieve cost savings. These are the most advanced start-ups in terms of integrating the environment into their activity. Their activity is organized through an environmental management system, and they are therefore concerned with the image they project. The analysis of environmental impacts is a priority for their projects, with a desire to offer completely eco-designed products.

They are strongly committed to partnership and have an extended network made up of other companies in their sector of activity, suppliers, consultants, and private laboratories. They are generally created by entrepreneurs with professional experience related to the environment who have therefore been able to develop their network and know-how. These are projects that have also been supported by applied academic research. The main field of their intervention is the reduction of greenhouse gas emissions.

These start-ups have strong development potential and a promising future. They manage to attract funding from private investors, especially during the development phase. They also manage to obtain subsidies, in particular from local authorities. Start-up companies that make up this class tend to have a medium to large salaried workforce, and the founder usually has 5 to 10 years of corporate experience related to the environment. This class shows similarities with the visionary champion (Taylor and Walley, 2004) and the visionary start-up (Bergset and Fichter, 2015).

5. Discussion and policy implications

We have identified five categories of eco-innovative start-ups. Some of these categories have been mentioned in previous theoretical studies by Taylor and Walley (2004) and Bergset and Fichter (2015). The results highlight that two profiles of start-ups (senior entrepreneurs with environmental concerns and opportunist leaders) contribute strongly to the development of radical and/or frontstage eco-innovation and display a strong environmental orientation. These profiles are more likely to meet the conditions promoting the success of their project, notably the availability of financial resources and access to external knowledge (through cooperation). Another important feature of these profiles is their ability to generate radical or frontstage eco-innovations. Conversely, the market-driven opportunist without environmental concerns and the necessity entrepreneurs without environmental concerns are characterized by low environmental orientation and low access to finance and external knowledge. Entrepreneurs with ecological awareness, for their parts, are characterized by strong environmental values but low access to finance and external knowledge, and develop incremental eco-innovations.

We have shown empirically that the different types of eco-innovative start-ups do not have the same difficulties in accessing funds, as has been assumed by Bergset and Fichter (2015). According to the literature, radical sustainable innovation is a long-term investment (Bocken, 2015; Freimann et al., 2012) and constitutes a high risk, whereas investors expect to obtain their profits after a short period of time, which makes access to funds challenging (Bergset and Fichter, 2015). Our findings indicate that despite the radical and front-stage nature of their innovations, the category of start-ups that manages to attract investors is the opportunist leaders, and this may be due to three main reasons. The innovations are radical; they are therefore attractive prospects for the investors who agree to fund them. Moreover, these companies are founded by older entrepreneurs with professional experience, which has allowed them to develop their professional network. In addition, these start-ups have an economic motivation; they are therefore funded by conventional investors. On the other hand, entrepreneurs with ecological awareness do not raise funds and have not obtained grants. This can be explained by three factors. They are selective in the choice of investors because they worry about the firm's objectives potentially being redirected, and they are therefore seeking investors that share the same sustainable values (Bocken, 2015; Choi and Gray, 2008). A second possible reason is that these firms may not strive to grow; their only desire is to meet their needs by exercising a profession consistent with their values. A third reason is the incremental nature of their innovations. Necessity entrepreneurs without environmental concerns do not have access to funds. This may be due to their lack of experience and lack of prior knowledge related to the environment. This leads to the exploitation of less profitable opportunities (Block and Wagner, 2010).

In regards to the difference between the profiles according to the access to knowledge, we have shown that the category of start-ups with the most successful cooperation network (cooperation with other companies, suppliers, universities, etc.) is the opportunist leaders. These start-ups display the highest environmental orientation; in fact, they set environmental objectives for their products and integrate the environmental aspect from the initial phase of the innovation process (frontstage eco-innovation). For this reason, external knowledge plays a crucial role for these firms. The establishment of this network is enabled, among other factors, by the professional experience related to the environment acquired by the entrepreneur. These results are consistent with those obtained by Doloreux and Kraft (2019) which confirm that companies with a high eco-innovation intensity—namely fully integrated eco-innovators—differ in the exploitation of external knowledge; in fact, they have a larger network. By contrast, cooperation plays a limited role in the case of the other classes.

Environmental policy instruments seem to have a limited role in the differentiation between the categories of eco-innovators, except for the grants, which are significant for the classes of opportunist leaders and senior entrepreneurs with environmental concerns. These results are consistent with those of Triguero et al. (2016), who find that environmental policy has no effect on the intensity of eco-innovation.

At European and French level, environmental policies are proposed to encourage companies' environmental practices. In this respect, it is crucial to understand the distinctiveness of eco-innovators versus non-eco-innovators, and to examine the different typologies of eco-innovators. Hence, this study has important implications for policy-makers.

Environmental policy in European countries is based on national objectives and only a few measures concern specific sectors or companies (Marin et al., 2015). Moreover, the environmental policy is mainly based on the traditional instruments of “command and control” and “economic instruments”; but these instruments are insufficient.

In fact, the discriminant analysis on the socio-demographic theme shows that environment-related education as well as environment-related professional experience differentiate eco-innovators from non-eco-innovators. Therefore, public policy should not focus solely on regulatory instruments but must also rely on other levers, including education. We are already seeing initiatives emerging to train young people for tomorrow's professions—for example, the “campus transition” universities and “ecological transition schools”. These schools have the ambition to think of new economic models, and new ways of producing, consuming, and managing resources. Therefore, it is necessary to strengthen and support these emerging initiatives. One of the aims of the programme “Plan d'investissement dans les compétences” of the period 2018–2022 is to contribute to ensuring the workforce is qualified to respond to the changing skills demanded by the ecological transition. At present, however, this activity is only marginal, and we believe it

[12] This class shows similarities with that of Taylor and Walley (2004), but with the major difference that in our case these entrepreneurs do not have a personal environmental conviction.

should be scaled up.

It has become clear from the taxonomic analysis that eco-innovators do not have a homogeneous profile. Indeed, there is a diversity of profiles among eco-innovators. Therefore, the main implication is that the implementation of public policy must take into account the diversity of eco-innovators' profiles. Given the pressing environmental issues, it is essential to rely on all profiles in order to trigger eco-innovation.

In that respect, we propose the following public policy measures. We note that senior entrepreneurs with environmental concerns will have carried out an activity which has enabled them to build up the funds to start a business. They also have extensive professional experience and have been able to build up a professional network. This allows society to benefit from their experience. In addition, senior entrepreneurs with environmental concerns create their business with co-founders. This suggests a complementarity between the experience and availability of resources on the part of seniors, and the technical skills in new technologies on the part of the young (Isele and Rogoff, 2014; Schott et al., 2017). When this configuration does not appear spontaneously, efforts to bring these two parties together could be considered. In fact, it would seem appropriate to encourage intergenerational co-entrepreneurship, in particular by setting up associations and private and public support structures that will be able to match up these two parties, or by creating networking platforms. This could improve the functioning of companies, and therefore expand the labor market, while reducing the environmental impact.

Entrepreneurs with ecological awareness can play an important role in sustainable development. It is necessary to support them through funding. Sustainable investors share the same environmental values as entrepreneurs with ecological awareness. However, the variable "funded by sustainable investors" introduced in the taxonomic analysis is not significant. In our case, this may be due to the small number of companies funded through this mode of finance. Sustainable investment is still emerging: the number of sustainable investors is increasing but remains very low. Nevertheless, we consider it a suitable financing method for firms with an ecological awareness based on their common values. For sustainable investors and start-ups with an ecological awareness to find their way into the market, the network needs to be developed and organized in a formal way and the start-ups and investors need to show a clear signal of their "sustainable" character (Demirel et al., 2019). Because of this information asymmetry, it is necessary to facilitate the right match between sustainable investors and entrepreneurs with an ecological awareness by setting up an environmental measurement impact such as an "impact factor" recognized by the state to rate and evaluate the "sustainability" efforts of firms, and it is also necessary to promote "green" investment platforms.

6. Conclusion

This paper makes a contribution to the literature on sustainable entrepreneurship by focusing on the factors that stimulate start-ups to undertake eco-innovation. Firstly, we made a comparison between eco-innovators and non-eco-innovators according to two themes: socio-demographic and environmental policy. The results show that eco-innovative start-ups differ in the skills acquired by the entrepreneur, in particular through environment-related studies and environment-related professional experience. The existence of "command and control" environmental instruments such as standards and prohibitions distinguish eco-innovators from non-eco-innovators. However, "economic instruments" such as environmental taxes do not separate the two groups of start-ups. Furthermore, the presence of a CSR policy (whether formalized or not) is an important differentiating factor.

Secondly, we propose a typology of eco-innovative start-ups based on internal factors and external factors related to the environment in which the start-up operates (such as external knowledge). Due to the diversity of start-ups, we include internal factors that can play a key role, in this case such as access to funding, the entrepreneur's socio-demographic profile, and the environmental orientation. In studies on SMEs, start-ups are often combined with existing firms; however, these firms have specific features which make them adopt a different attitude towards eco-innovation. In this paper, we try to address the shortcomings observed in the literature by focusing on nascent start-ups. The typology is used to examine the distinctive characteristics of eco-innovators. It also allows us to distinguish between eco-innovators by considering economic and environmental motivation.

This study has some limitations, which nevertheless offer interesting directions for future research. First, the resulting typology is static and is based on cross-sectional data. The availability of longitudinal data would allow us to study the long-term evolution of eco-innovative start-ups by highlighting the possible trajectories associated with each profile. Second, our study focuses on the case of France. Because of the possible differences in environmental policies between countries, more evidence from various countries, and especially a multi-country analysis, would be interesting. Third, in our sample we observed a low rate of eco-innovative start-ups that have been funded by eco-investors. However, the latter may be guided by environmental values in the choice of the companies they agree to finance. Given the scarcity of studies on the funding of eco-innovative start-ups, a deeper investigation of the role of eco-investors and the interaction between eco-investors and eco-innovative start-ups would be of high importance.

CRediT authorship contribution statement

Rafik Abdesselam: Methodology, Data curation, Formal analysis, Writing - Review & Editing.

Malia Kedjar: Conceptualization, Writing- Original draft preparation, Investigation, Writing - Review & Editing.

Patricia Renou-Maissant: Methodology, editing, Writing - Review & Editing.

Data availability

Data will be made available on request.

Appendix A

Table 8
Overview of the meetings and contests used for the survey.

Event	Description
pépite tremplin contest	It promotes projects led by students who have the status of student-entrepreneurs by rewarding the winners of the competition with financial aid.
I lab contest	It is accessible to French firms that have been established for less than two years. Anyone with an innovative project, whatever their nationality or situation (student, public or private employee or job seeker) can participate in this competition. The grant paid to the winners can go up to 60 % of the project's funding.
I Nov contest	This contest is designed to reward innovative projects carried out in France by start-ups and SMEs. It aims to support the rapid emergence of firm with the potential to become leaders. Winners receive funding of 35 % to 45 % of the project amount

(*continued on next page*)

Table 8 (*continued*)

Event	Description
Digital Innovation Contest	It is accessible to existing firms (startups, SMEs or ETIs) or those in the process of being created, based in France, which propose an innovative project in the digital field. Winners receive funding of up to 50 % of the project amount.
Researcher-entrepreneur challenges	It includes two contests: Doctors-Entrepreneurs and Start-Up Connexion. Doctors-Entrepreneurs rewards the best entrepreneurial initiatives of PhDs who graduated <3 years ago or PhD students, who aim to create a start-up from an innovative research project. Start-up Connexion is dedicated to confirmed researchers who have already created their own company, with the objective of putting them in touch with investors or large groups that can help them develop their structure.
Go entrepreneurs meeting	It is organized each year and it is open to all firms that are interested in participating. Firms pay a participation fee to book online or by email a stand and/or other services (marketing, coaching....) within the limit of available places.
International Cleantech week	The event aims to present, test and promote environmental technologies. It is organized by a non-profit organization "Le cinquième element". The objective is to bring together the actors of the territory around the environmental challenges. Companies can register via the website of the trade fair or by email and pay a fee to book their stand.
Change now summit	It is organized by the start-up change now. Firms at the international level that are interested in exhibiting their products or services apply to a call for solutions and pay a participation fee. Start-ups are selected according to the proposed solution which must meet some criteria such as having a positive impact (address one or more of the sustainable development goals), being innovative, and having a viable business model.

Table 9
The representativeness of the sample according to the activity sector and Chi-square test of fit or adequacy.

Sector of activity	Population French start-ups INSEE[a]	Sample observed frequency
Industry	11.27 %	19
Construction	1.30 %	1
Trade, transport, accommodation	8.90 %	7
Financial and insurance activities	2.93 %	1
Specialized activities, scientific, technical, IT & communication	74.30 %	91
Public administration, education, health	1.30 %	1
Total	100 %	120
Calculated Chi-Square: 5.73	Degrees of freedom: 5	p-value = Prob (χ^2_5 >5.73): 0.3339

[a] INSEE: French National Institute of Statistical and Economic Studies.

Table 10
Description of the variables

Abbreviation - Label	Modalities	Active variable	Illustrative variable
The type of eco-innovation developed			
Energy savings	Yes/No	✖	
Renewable energy technologies	Yes/No	✖	
Recycling and/or reducing waste	Yes/No	✖	
Technologies aimed at reducing polluting emissions	Yes/No	✖	
Entirely new to the market (Radical eco-innovation)	Yes/No	✖	
Product improvement (Incremental eco-innovation)	Yes/No	✖	
Adoption of a new innovation by the start-up	Yes/No	✖	
Eco-conception	Never/Rarely/Sometimes/Often	✖	
Environmental benchmarking	Never/Rarely/Sometimes/Often	✖	
Eco-brainstorming	Never/Rarely/Sometimes/Often	✖	
Front end- environmental impact assessment	Never/Rarely/Sometimes/Often	✖	
Front end- setting environmental goals	Never/Rarely/Sometimes/Often	✖	
Initial stage (Idea generation)	Frontstage-Yes/Frontstage-No	✖	
Product development stage	Backstage-Yes/Backstage-No	✖	
R&D activity	Yes/No	✖	
Internal R&D activities	Yes/No	✖	
External R&D activities	Yes/No	✖	
Patent related to environmental innovation	Yes/No	✖	
Environmental practices			
Certifications (ISO 5001 etc.)	Yes/No	✖	
Environmental management and audit system	Yes/No	✖	
Setting environmental goals	Yes/No	✖	
Find out about new environmental regulatory requirements	Yes/No	✖	
Environmental impact assessment	Yes/No	✖	
Not concerned with environmental management	Yes/No	✖	
Internal or external training related to the environment	Yes/No	✖	
Motivation behind eco-innovation			
Public grants related to the environment	Yes/No	✖	
Reducing the costs	Yes/No	✖	
Increase market share (competitiveness)	Yes/No	✖	
Improve the firm's image	Yes/No	✖	
Increasing demand for environmentally friendly products	Yes/No	✖	
To be in line with the environmental regulation	Yes/No	✖	
Ecological awareness	Yes/No	✖	

(*continued on next page*)

Table 10 (*continued*)

Abbreviation - Label	Modalities	Active variable	Illustrative variable
Financial resources			
The start-up has raised funds	Yes/No	✖	
Founder's personal financial contribution	Yes/No	✖	
Private investors or venture capital funds	Yes/No	✖	
Crowdfunding	Yes/No	✖	
Business Angel	Yes/No	✖	
Private equity funds	Yes/No	✖	
Eco-investors	Yes/No	✖	
Environmental innovation activity grants	Yes/No	✖	
Regional grant	Yes/No	✖	
National grants	Yes/No	✖	
European Union grant	Yes/No	✖	
External knowledge			
Cooperation for environmental innovation activities	Yes/No	✖	
Competitors or other firms in your sector of activity	Yes/No	✖	
Cooperation with consultants, commercial or private laboratories	Yes/No	✖	
Cooperation with suppliers	Yes/No	✖	
Public R&D organizations or private non-profit institutes	Yes/No	✖	
Cooperation with universities or higher education institutions	Yes/No	✖	
Participation in exchanges of ideas about environmental themes (workshops, conferences, or seminars)	Yes/No	✖	
Others	Yes/No	✖	
Socio-demographic explanatory variables			
GENDER (Gender of the entrepreneur)	Female/Male		✖
AGE (Age of the entrepreneur)	18-25 Years/26-35 Years/36-44 Years/45-54 Years /Over 55 years		✖
ELEVEL (Educational level of the entrepreneur)	BEP-CAP/no diploma/Licence/Master-Ingénieur/PhD		✖
EDIPLO (Diploma related to the environment)	Yes-Env-Diploma/No-Env-Diploma		✖
SBCREA (Situation before creation)	Job seeker/Company manager experience/Student/Salaried employee/ Others (retired –liberal profession)		✖
EPEXP (Environmental professional experience)	Yes-Env-Prof-Experience/ No-Env-Prof-Experience		✖
NYEPEX (Number of years of the environmental professional experience)	1-5 years/5-10 years/No professional experience/Over 10 years		✖
CFOUND (Existence of other co-founders)	Yes co-founder/No co-founder		✖
Environmental policy explanatory variables			
REG (Environmental regulation ; standards, permissions, and prohibitions)	REG-Yes selected /REG-Not selected		✖
TI (Taxes on inputs (energy)	TI- Yes selected/TI-Not selected		✖
TPE (Taxes on polluting emissions)	TPE-Not selected/TPE-Yes selected		✖
EPINON (Environmental policy instruments – None)	NONE-Yes selected/NONE-Not selected		✖
CSR (Corporate Social Responsibility)	NO-CSR/YES-CSR /NA (No-Answer)		✖
Organizational features of the firm			
Legal status	limited company (SA)/Limited liability firm/Cooperative and Participative Societies/Simplified Stock firm		✖
Average turnover	Not yet started to commercialize its products/less than 100 000 /]100 000; 500 000]/]500 000; 1000 000]/More than 1 M€		✖
Number of co-founders	One /Two /Three and more co-founders		✖
Average number of employees (FTE)			✖
Number of employees (FTE) 2018			✖

Note 1: The Hierarchical Ascendant Clustering (HAC).

Clustering is one of the most used approaches to explore multidimensional data. The two common unsupervised clustering strategies are hierarchical clustering: HAC used when the number of objects to be clustered is small and non-hierarchical clustering: k-means, when the number of objects to be clustered is large. These two types of strategies are used to identify groups of similar objects in a data set in order to divide it into homogeneous groups.

The HAC, according to Ward's method, consists of gathering clusters or classes for which the loss of inertia between classes ΔI_B is the lowest. In this case, the distance between two classes is measured by the loss of inertia that one undergoes in the gathering, called the cluster index or index level of the clustering. A high loss of inertia means that the two classes k and k_{-1} that have been grouped are quite distant from each other. Then a "good" partition is a partition that precedes a significant loss of inertia. It is this test that is commonly used to select the number of classes for HAC.

The choice of the number of classes is usually accomplished based on the diagram of aggregate indices. This is a crucial aspect of the evaluation of the proposed solutions when analyzing a hierarchical clustering; one is faced with the problem of getting too many or too few classes. However, while there is no single index to determine the optimal number of classes, many criteria can be used to facilitate this decision. First, it is possible to take a decision based on the characterization of classes by the active variables with $\alpha = 0.05$, a classic level of significance. If the profiles and/or anti-profiles of the obtained classes differ significantly on these variables for the clustering, the proposed solution is probably relevant. Second, the ease of interpretation is also a criterion that tells us the required number of classes. It is important to question the relevance of the theoretical profiles and/or anti-profiles obtained. Finally, the size of the sample must also be taken into consideration: the larger the sample, the higher the number of classes.

Statistical criteria can be also used to decide how many classes to choose, such as the Semi-Partial R-Squared (SPR^2) or the R-Squared (R^2) criteria.

- The $SPR^2 = \Delta I_B / I_T$ measures the loss of inertia between classes or cluster indexes ΔI_B as a percentage of total inertia I_T caused by grouping two

classes. The goal is to have a maximum within-classes inertia, and we look for a low SPR^2 followed by a strong SPR^2 at the following aggregation: a hollow for k classes and a peak for k_{-1} classes indicates a good clustering in k_{-1} classes. This means that we must cut the hierarchical tree before heavy loss of inertia: a low value of SPR^2 means the fusion of two homogeneous classes.

- The $R^2 = I_B / I_T$ is the proportion of variance explained by classes; it measures the quality of the clustering. Its value should be as close as possible to one without too many classes; the ideal is to stop after the last big jump. To assess the stability of obtained classes of HAC, we have consolidated all the classes using a non-hierarchical clustering, which is more robust, with mobile centers (k-means). The interpretation of a class is a qualitative description of its profile and/or anti-profile created from the active variables—those on which we wanted to differentiate the classes—but also with other additional (illustrative) variables selected. A generic name has been assigned to each class of HAC.

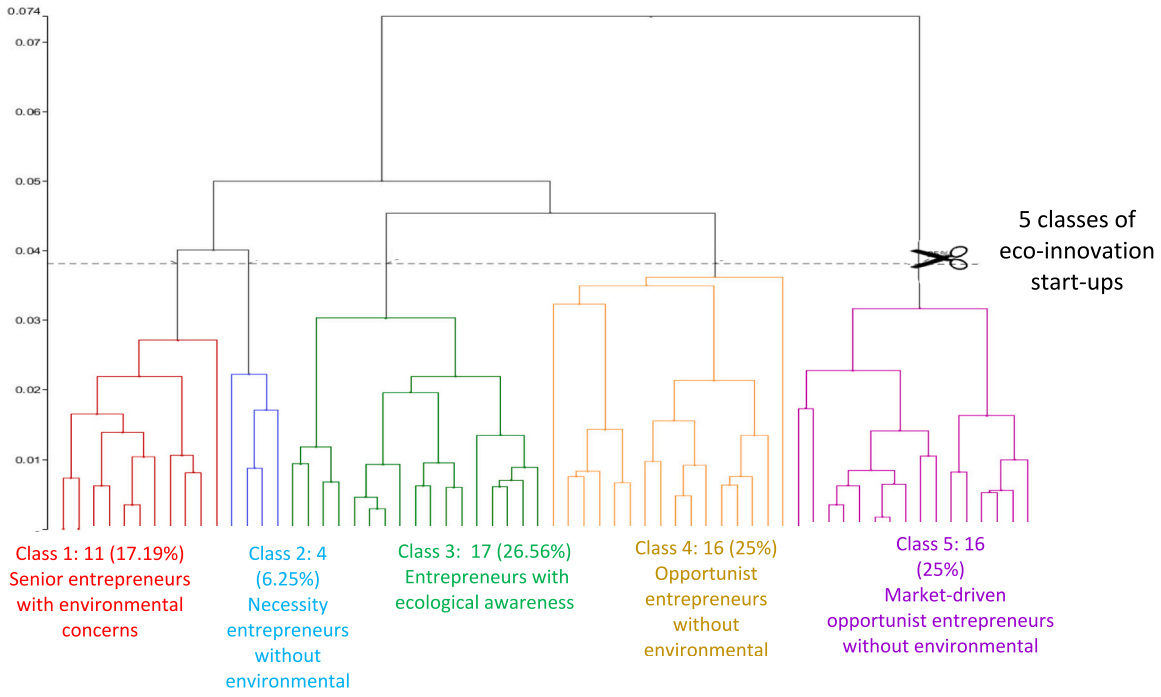

Fig. 2. Dendrogram of eco-innovative start-ups according to their entrepreneurial characteristics.

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