Drivers and Barriers in the Diffusion of Eco-innovations

Gijs de Leede; 6012124

Supervisor: Marko Hekkert

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Summary

Sustainable development has become an important concept in the last decades. Sustainable development tries to reconcile the relationship between economic growth and environmental damage. In the last decades, ecological problems became more severe. Decoupling economic growth and environmental harm seems to be crucial in order to avert a lot of environmental damage. One major role to tackle this conflict is reserved for environmental innovation. Environmental innovations or eco-innovations are new products and processes that reduce the environmental impact. Eco-innovations can bring sustainable benefits, but only when widely used or implemented. Thus, eco-innovations have to diffuse across society. This paper aims to increase the understanding of the most important factors that slow down or accelerate the diffusion of eco-innovations. It will thus answer the question: *which factors slow down and which factors accelerate the diffusion of eco-innovations?*

To answer this question, a systematic literature review has been carried out. 39 articles about the diffusion and adoption of eco-innovations among firms have been analysed. In the analyses, various factors that influence the diffusion came up. Based on recurring patterns in the articles, five categories were identified in which the factors were placed. These categories form the new classification this paper proposes. The five categories are cost relating factors, benefit relating factors, regulatory factors, informational factors and dummy factors. The factors in the last category are often used as control variables in the literature. The most reported factors (15 times or more) are resources, investment costs, type of regulation (cost relating factors), market demand for sustainable products/services, profitability (benefit relating factors), availability of regulations, type of regulation (regulatory factors), resources, information flows, attitude of managers/owners, organizational environmental practices (informational factors) and size (dummy factors). The new classification is more logical and useful in the current literature.

A limitation is that comparison of factors in different articles can be difficult, because of all the differences in eco-innovation types, industries and adopters. Another limitation is that developing countries are neglected in literature.

Future policies should take the importance of the five categories and corresponding factors into account.

Introduction

Sustainable development has become increasingly important. Sustainable development tries to reconcile the relationship between economic growth and environmental damage. In the last decades, ecological problems became more severe. For example, the rate of biodiversity loss is historically high (Rockström et al., 2009). The burdens placed on the planet are alarming. Decoupling economic growth and environmental harm seems to be crucial in order to avert a lot of environmental damage. Moreover, environmental damage and its consequences can have a negative impact on economic growth. One major role to tackle this conflict is reserved for environmental innovation. *Environmental innovations* or *eco-innovations* are new products and processes that reduce the environmental impact. The concept of eco-innovations is only in recent years more commonly used (Karakaya, Hidalgo & Nuur, 2014, p. 393-394), since in this period the environment is increasingly taken into account. Eco-innovations can decrease the damage inflicted upon the environment while still secure economic growth. Eco-innovations are often argued to be beneficial for companies. They can reduce process costs, via for example efficiency gains, and can increase the product value (Porter & Van der Linde, 1995). However, even if eco-innovations with such benefits exist, they still have to be adopted by other relevant actors to really make a difference. The process in which an innovation is adopted by members of a society is called *diffusion* (Valente & Rogers, 1995, p. 249). The diffusion of innovations is not only dependent on the characteristics of the innovation. Other aspects matter as well. This article will research which factors influence the diffusion. It will focus on diffusion of eco-innovations among firms specifically.

This paper aims to increase the understanding of the most important factors that slow down or accelerate the diffusion of eco-innovations. A lot has been written about the drivers and barriers of the development of eco-innovations, but the literature on the drivers and barriers in the diffusion phase is still lagging behind (see Hojnik & Ruzzier, 2016a for a good overview). This is remarkable, since diffusion is essential to gain significant environmental improvements. The diffusion of eco-innovations is very relevant for sustainable development and large-scale change. Therefore, this paper aims to contribute to the current knowledge of eco-innovation diffusion and to be relevant for future policy-making. The question this paper will try to answer is thus: *which factors slow down and which factors accelerate the diffusion of eco-innovations?*

A literature review is carried out, reviewing both theoretical and empirical studies, in order to find the most important factors. Such a study has, by my knowledge, only been conducted by Hojnik & Ruzzier (2016a) and Bossle, de Barcellos, Vieira & Sauvée (2016). Both articles carried out a literature review to reveal which drivers of eco-innovation are researched and considered important in both development and diffusion phase. Hojnik & Ruzzier (2016a) also provide an inclusive list of drivers and their corresponding articles. Even though both articles have a quite similar research topic as this paper, this paper is still considered relevant to the scientific literature for four reasons; first, this article focuses solely on the diffusion phase, not on the development phase, and intends to go into more detail. That is, naming the factors that affect the diffusion, but also explore the reasons behind them. Second, this article will go into more detail about the connections between different drivers and barriers. They do not only influence the diffusion of eco-innovations, but also each other. How different drivers and barriers relate to each other is often still unclear, but some articles present some interesting insights. Third, this paper proposes a

new classification that places the drivers and barriers in their bigger context. It argues that current classifications do not fit to the current literature on eco-innovation diffusion. The proposed classification creates clarity and indicates the most important categories that play a role in the diffusion. Fourth, a lot of new, relevant, literature has emerged since the articles of Hojnik & Ruzzier and Bossle, de Barcellos, Vieira & Sauvée in 2016. This paper will include some relevant new research, done in the last three years.

The rest of this paper consists of four parts. First, the theory section will discuss the most important concepts. The section starts with a closer look at the concept of eco-innovation. Also, this part will explore why eco-innovations differ from other innovations and thus why they need a different research approach. It follows with an overview of the concept of diffusion. In the last part of this section, different classifications described in the literature are discussed. Secondly, the method section will explain and justify the used method. Using a systematic literature review, factors in both theoretical and empirical papers are researched. The theory and method sections form the basis for the third section, the results. Here, the factors that influence the diffusion are presented. Lastly, the conclusion and discussion section gives some concluding remarks and goes over some of the limitations and some of the implications and recommendations for future research and policy.

Theory

To find out which factors influence the diffusion-rate of eco-innovations, this section will first discuss the main concepts relating to eco-innovation and diffusion. Moreover, this section will present different classifications described in the literature in which factors could fall.

Eco-innovation

While *eco-innovation* or *environmental innovation* are often used in a broad sense, including policy and organizational innovation as well (see Rennings, 2000, p. 322; Oecd Publishing, 2010, p. 40; Kemp & Pearson, 2007, p. 7), in this paper it only refers to product and process improvements (regarding impact on the environment). The diffusion of environmental policy and organizational structures is beyond the scope of this paper. Examples of product and process eco-innovations are '*renewable energy technologies, pollution prevention schemes, waste management equipments, green financial products and biological agriculture*' (Karakaya et al., 2014, p. 393). These kinds of green innovations contribute to a better sustainable performing society and help industries face environmental constraints, such as regulations (Xavier, Naveiro, Aoussat & Reyes, 2017, p. 1280-1281). On top of that, eco-innovations are often argued to have significant positive financial effects for firms. Eco-innovations can reduce process costs or increase product value (Porter & Van der Linde, 1995). Besides the financial benefits eco-innovations might provide, they decrease the environmental impacts of firms. Sustainability itself is often one of the objectives of firms (Siebenhüner & Arnold, 2007, p. 340). Even when this is not the case, when innovations have a positive effect on the environment, be it a side effect or unintentional effect, they are still seen as eco-innovations (Horbach, Rammer & Rennings, 2012, p. 119).

Eco-innovations differ from other innovations in multiple ways. First of all, when eco-innovations are adopted by multiple firms and compete with conventional or 'old' products, positive spillovers appear, because the external costs (from environmental harm) are lower for eco-innovations. On top of that, there are conventional knowledge spillovers. This leads to a *double externality problem*, which reduces the incentives for firms to invest in eco-innovations, because they endure all the costs and not all the benefits (Rennings, 2000, p. 325-326). Secondly, Rennings (2000) continues that due to this double externality problem, regulation is important in pushing for eco-innovation, both in the development and the diffusion (p. 326). This is supported by multiple authors. Most famously, Porter & Van der Linde (1995) stress the influence of environmental regulation on the development of eco-innovations. Karakaya et al. (2014) also see the role of governing and politics in eco-innovations, since sustainability is often a political issue. They state that eco-innovations "*need political support and have a global market potential based on global concerns and discourses that there is an imminent global warming*" (p. 393). So the political aspects and global concerns regarding ecological problems differentiate them from other innovations. Thirdly, the shift to sustainability is considered a radical societal change. For example, the shift to cleaner energy production, including renewables, is a large societal shift (Rennings, 2000, p. 327-329). Far from all eco-innovations are inducing radical change. A lot of eco-innovations are incremental improvements, such as efficiency improvements. Nevertheless, eco-innovations have to be adopted widely across society to make a sustainable change.

Various types of eco-innovations can be distinguished. Most commonly and already clear in a definition widely used in literature, is the distinction between product, service, process and organizational innovations (Xavier et al., 2017, p. 1281). As said, this paper will not focus on the diffusion of organizational eco-innovation, although its importance for eco-technology diffusion will be discussed. Kemp & Pearson (2007) make a similar distinction. They differentiate between product and service innovations, environmental technologies (mostly process innovations), organizational innovations and green system innovations (p. 10-11). The latter is about large societal production and consumption systems and is not included in this paper as well. Another distinction can be made between end-of-pipe (EOP) technologies and clean technologies (del Rio González, 2009, p. 862). EOP technologies treat emissions and waste after it has been produced, while clean technologies reduce the emissions and waste that is produced. Often, these reductions provide (apart from environmental) economic benefits (for example, higher energy-efficiency). A third common division is based on how far-reaching the innovation is. In general, radical eco-innovations change systems of production strongly, while incremental eco-innovations improve some parts of the product or production process (Peng, Lui & Zhao, 2014). Radical eco-innovations have stronger positive impacts on the environment.

Diffusion

Once an eco-innovation exists, it can diffuse across society. Diffusion is a widely used concept in the innovation field. It is the process of an innovation being spread among a society. More specifically, in his highly influential book 'Diffusion of Innovations', Rogers (2003) describes *diffusion* as '*the process by which an innovation is communicated through certain channels over time among the members of a social system*' (p. 19-47). This highlights the importance of information channels in diffusion. Valente & Rogers (1995) note that beside information channels, there is an individual adoption decision that has to be made by the members of a social system (p. 249). This means that diffusion is also about individual

adoption. Many authors have conducted multiple case studies to reveal the process of diffusion. One of the first, starting the diffusion of innovations paradigm, were Ryan and Gross (1943) studying the diffusion of hybrid seed corn in rural communities of Iowa. Since then diffusion became more and more interesting for a growing number of disciplines in a growing number of countries (Valente & Rogers, 1995). It became more important in disciplines such as economics, geography, political science and communication science (Valente & Rogers, 1995, p. 264-265). Also in the sustainability field diffusion research is relevant. When innovations have an impact on the environment (for better or for worse) the study of diffusion and reasons behind the diffusion can increase the understanding and thus help in shaping policy. For sustainability in general, such studies could help increase environmental performance.

This paper will focus on the diffusion of eco-innovations among firms. An important aspect of this is the individual firm decision to adopt an eco-innovation. Furthermore, since eco-innovations have some special characteristics, it makes sense to research the diffusion of eco-innovations specifically. This paper will focus on the drivers and barriers of the diffusion of eco-innovations.

Classification

Classification helps to clarify drivers and barriers of diffusion of eco-innovations. As Xavier et al. (2017) argue: "*Classification is an essential tool to facilitate the diffusion of this field of knowledge and to achieve a higher maturity level on the concept of eco-innovation*" (p. 1279). Thus by classifying the drivers and barriers this paper hopes to contribute to the concept of eco-innovation.

Several classifications have been made in literature. One of the most prominent is described by Rennings (2000, p. 324-329). He explains the three categories in which factors play a role in driving eco-innovations. The first two, technological push and market pull, are based on normal innovation theory. Technological push relies on factors such as product quality or energy efficiency to boost (environmental) innovation. Market pull factors include customer demand or competition. Eco-innovations, however, are also determined by regulatory push factors, because of their distinct double externality problem. Especially for eco-innovations, factors as environmental law and expected regulation are important. By adding the regulatory push to existing innovation theories, Rennings (2000) pointed out the importance of regulation for eco-innovations specifically.

Another frequently used classification is the distinction between factors internal and external to the firm (for example del Rio González, 2009, p. 862-864). It is mostly supplemented by characteristics of the environmental technologies. Factors internal to the firm exists within the firm itself and play a facilitating or stimulating role. Attitudes of the managers, resources and firm size are all examples of factors that can influence a firm's environmental performance. Factors external to the firm influence a firm's decision from outside the firm. Governments, competitors, suppliers, consumers and NGOs are a few examples of actors that can stimulate or hinder the involvement of a firm in eco-innovation. Characteristics of the eco-innovations consist of particular features relating to the technology itself, such as the costs and benefits in brings to the firm, but also complexity and compatibility with existing technologies are important.

The classification of Horbach, Rammer & Rennings (2012) is somewhat different to that of del Rio González. It recognizes firm strategies, technology, market and regulation as the four categories in which the factors of eco-innovation involvement belong. Firm strategies and

technology show a lot of similarities with factors internal to the firm and characteristics of environmental technology respectively. Market and regulation, on the other hand, seem to belong to the factors external to the firm. The distinction between market factors and regulation factors highlights the different channels in which they influence the involvement in eco-innovation of firms.

Díaz-García, González-Moreno & Sáez-Martínez (2015) take another approach. They identify three different levels that can drive eco-innovation. The micro-level includes reputation, the value of managers, cost savings and resources. The meso-level focuses on the role of market dynamics, pressure groups and demand, while the macro-level is about regulation and technological change in industries and sectors.

This paper will propose an alternative classification based on the literature review it will carry out. It will argue that the classification makes more sense in the current literature on eco-innovation diffusion.

For all classifications however, the interplay between the categories is important to keep in mind. This is what drives the rate and direction of technological change (del Rio González, 2009, 863). Different categories do not stand on their own. For example, Agan, Acar & Borodin (2013), find that expected benefits and reputation as well as environmental management together are an important driver for the adoption of eco-innovations. These factors can belong to different categories. Similarly, Nesta, Vona & Nicolli (2014) research the effects of environmental policy on innovation under different levels of competition. The interaction effects have to be considered when analysing the drivers of eco-innovation diffusion.

Method

To identify the most important drivers and barriers of the diffusion of eco-innovations, a systematic literature review is applied. Both theoretical and empirical studies will be reviewed. The literature that is used is found on the search engines scopus, google scholar and WorldCat catalogus. Articles that are included in this research were often found via citations in other articles as well. The most commonly used search terms were ‘diffusion of eco-innovations’, ‘adoption of eco-innovations’, ‘diffusion of environmental innovations’, ‘adoption of environmental innovations’ and ‘drivers and barriers in eco-innovation diffusion’.

135 potential articles were found. Of these, abstracts were read or, if that was not clear enough, the articles were read completely. Only literature that discusses at least one driver or barrier of the diffusion of eco-innovations was included. While a lot of literature is about the drivers of eco-innovation development, these are not considered relevant for this research. Some articles were not entirely clear whether the drivers related to the development phase or diffusion phase or both. These articles were not included either. Furthermore, some articles focussed on the diffusion of eco-innovations among households. These articles were excluded from the analysis as well. In total, 39 articles are analysed. 18 were found via citations in other articles, 14 were found on scopus, 6 on google scholar and 1 article was found on WorldCat catalogus. Figure 1 below displays the years in which the articles were published. Over half of the articles used in the analysis is published after 2015,

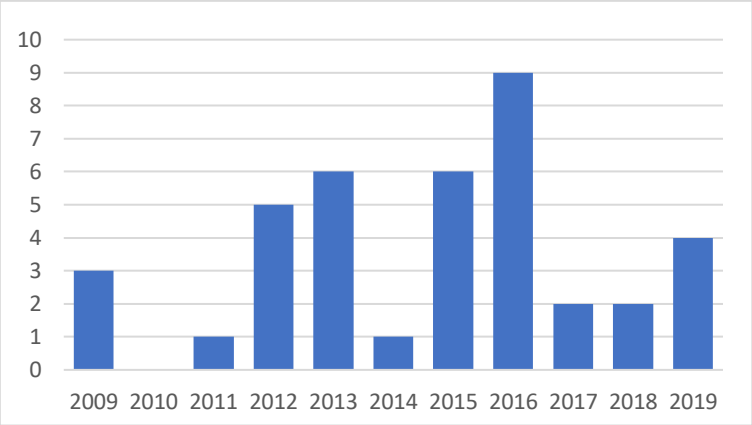
indicating the rapid increase of interest in the field of eco-innovations and the diffusion and adoption of eco-innovations. Both empirical and theoretical studies were included. 25 of the articles empirically investigated the drivers and barriers of eco-innovation diffusion, while 14 articles took a theoretical approach. Data analysis based on surveys was the most commonly used method. The appendix gives the full overview of all the articles, placed right from the factor discussed. One article can belong to multiple factors.

The literature is reviewed and the qualitative as well as quantitative data are used to identify the main drivers and barriers. The combination of qualitative and quantitative data can bring relevant insights in this topic. As del Rio González (2009) states: "*Although quantitative analyses are usually considered more rigorous and objective, they are less able to capture the relevance of the local institutional and socioeconomic context. They often establish general relationships and omit crucial aspects (and variables) of the determinants for innovation/adoption of specific technologies*." (p. 863). Thus, both methods are important for this paper.

All the articles are critically examined to identify the most important factors influencing the diffusion of eco-innovations. This led to the factors listed in the appendix. This method allows for an inclusive and structured overview of the current scientific knowledge and reveals patterns in the literature. Special attention is given to the combination in which factors occur in literature. It can be argued that comparison of factors in different articles is difficult or even impossible, because of all the differences in eco-innovation types, industries and adopters. However, analysing recurring factors in literature is considered relevant, especially when factors recur often, even for different eco-innovations, industries and adopters. This paper only wants to highlight general findings and is not claiming to explain all factors in all the different settings.

In the next section, all the identified drivers and barriers are discussed, also if articles present conflicting results or if sufficient literature is lacking. Furthermore, this paper will pay special attention to the relations between the different drivers and barriers and the combinations in which they appear in the articles. This will form the basis of the proposed classification presented in the next section.

figure 1. number of articles per publication year.



Results

All the factors influencing the diffusion of eco-innovations as found in the literature are presented in table 1. The factors are categorized based on a classification that is made when analysing the articles. The factors are ranked based on the number of times they are identified as a relevant factor in the literature. So resources are found to be an important factor in 22 articles.

Below, all the factors are discussed per category. Some of the most recurring relations between different factors are discussed as well. Four main categories can be identified, based on recurring patterns in the literature. These are cost relating factors, benefit relating factors, regulatory factors and informational factors. On top of that, there are factors that influence the diffusion in all the clusters. These are often used as dummy variables in literature and include firm size, ownership, age and sector-specific characteristics.

Cost relating factors

Cost relating factors consist of the factors that deal with the costs involved in eco-innovations. This includes resources, investment costs, type of regulation (subsidies, taxes), competition, cost savings, access to credit, technological lock-in, commodity prices, applicability and expected future improvement of the innovation.

Lack of *resources* (human capital, time, knowledge, financial resources) is one of the most important barriers for eco-innovation adoption. The financial barriers perceived by firms are especially important for cost-relating barriers, although the costs of human capital and knowledge gathering are also mentioned. Antonioli, Borghesi & Mazzanti (2016), de Jesus Pacheco, Caten, Jung, Navas & Cruz-Machado (2018), Fleiter, Hirzel & Worrell (2012), Klewitz, Zeyen & Hansen (2012), Long, Blok & Coninx (2016), Marin, Marzucchi & Zoboli (2015), Pansera (2013), Pereira & Vence (2012), Trianni, Cagno, Worrell & Pugliese (2013) and Trianni, Cagno, Thollander & Backlund (2013) all stress the importance of financial resources for the adoption of eco-innovations. Lack of financial resources is very often associated with firm size (de Jesus Pacheco et al., 2018; Horbach & Rammer, 2018; Hasler, Olfs, Omta & Bröring, 2017; Hojnik & Ruzzier, 2016a; Veugelers, 2012). Smaller firms do not have the knowledge and finances to get involved in eco-innovations. Larger firms are more likely to adopt eco-innovations, because they face less financial barriers and have more knowledge within the firm. Smaller firms also perceive barriers stronger (Trianni, Cagno, Thollander & Backlund, 2013).

Frequently reported as major barrier are the high *investment costs* (Fleiter et al., 2012; Hojnik & Ruzzier, 2016b; Marin et al., 2015; Smith, 2016; Trianni, Cagno & Worrell, 2013; Trianni, Cagno, Worrell & Pugliese, 2013). Adoption of eco-innovations requires financial investments. High upfront costs can be a reason not to adopt an innovation. Again, the size of the company (and related financial resources) is an important factor. Smaller companies perceive high investment costs as a larger barrier than larger companies (Hasler et al., 2017; Klewitz et al., 2012; Pereira & Vence, 2012). Others also found investment costs to be an important barrier. De Jesus Pacheco et al. (2018) state that especially in competitive industries with low profit margins high investment costs are not always feasible and thus hindering the adoption. Horbach & Rammer (2018), as well as Long et al., (2016), Cantona &

Silverberg (2009) and Fleiter et al., (2012), found that some firms delay the adoption of eco-innovations because they expect the investment costs to decline in the future. Horbach (2016) reported that the investment costs are higher when the technology does not fit well on current infrastructure. The costs of disruption of the production when adopting new technologies (Trianni, Cagno, Thollander & Backlund, 2013) and the higher costs when capital is relatively new (Khanna, Deltas & Harrington, 2009) also relate to the barrier of high investment costs.

The most reported barriers are thus resources and investment costs. Not coincidentally, *subsidies* is one of the policy measures that is described as the most effective in stimulating the diffusion (Borghesi, Cainelli & Mazzanti, 2015; Cantono & Silverberg, 2009; Hojnik & Ruzzier, 2016a; Hojnik & Ruzzier, 2016b; Horbach, 2014; Horbach, 2016; Long et al., 2016; Pereira & Vence, 2012; Veugelers, 2012; Woerter, Stucki, Arvanitis, Rammer & Peneder, 2017; Zhang, Xue & Zhou, 2019). Furthermore, Horbach (2014, 2016) reported that subsidies were more effective in the low-income countries of the EU. *Taxes* on the other hand (also a market-based instrument) is only found effective in some articles (Borghesi et al., 2015; Bossle, de Barcellos & Vieira, 2015; Hojnik & Ruzzier, 2016a; Veugelers, 2012; Woerter et al., 2017). Pereira & Vence (2012) found subsidies to be more effective than taxes and Cainelli, D'Amato & Mazzanti (2015) did not found taxes to be relevant at all.

Competition is also quite often reported as a relevant factor. Mostly, it is mentioned that competition pressure drives the adoption of eco-innovations (Bossle, de Barcellos & Vieira, 2016; Bossle, de Barcellos, Vieira & Sauvée, 2016; Hojnik & Ruzzier, 2016a; Hojnik & Ruzzier, 2016b; Horbach, 2016; Horbach & Rammer, 2018). Under strong competition, cost savings and keeping or increasing competitive advantage is very important. On the other hand, however, Díaz-García, González-Moreno & Sáez-Martínez (2015) noticed that labour costs are more important than the benefits of resource-efficiency, de Jesus Pacheco et al. (2018) found that low margins do not allow the adoption of eco-innovations and Long et al. (2016) state that competition of new environmental products against established products can act as a barrier. Trianni, Cagno, Worrell & Pugliese (2013) also argue that under strong competition the stakes are higher, so when costs are higher than thought or benefits lower, the impact for the company is stronger.

Cost savings or expected cost savings are a relevant factor a well. It is considered an important driver of eco-innovations by many authors (Díaz-García et al., 2015; Hojnik & Ruzzier, 2016a; Horbach, 2016; Klewitz et al., 2012; Pereira & Vence, 2012; Veugelers, 2012). Bossle, de Barcellos & Vieira (2016) even call it one of the most important factors. Borghesi et al. (2015) state that cost savings are even more important when energy prices are high. Arsil, Sahirman & Hidayat (2019) found in their case study that the cost savings were often too low or even negative, thus forming a barrier for adoption. Müller, Kaufmann-Hayoz, Schwaninger & Ulli-beer (2013) argue that especially for relatively new innovations, the cost savings can be rather disappointing, because these innovations are still in an early stage of the learning curve.

Access to credit is also mentioned multiple times as a factor that drives or facilitates the adoption (Borghesi et al., 2015; Díaz-García et al., 2015; D'Orazio & Valente, 2019; Hasler et al., 2017; Pansera, 2013; Trianni, Cagno, Worrell & Pugliese, 2013). Public as well as private funds are important. The role of international development funds is reported two times; one time positively influencing adoption (Pansera, 2013) and one time negatively, because it was too bureaucratic and complex (de Jesus Pacheco et al., 2018). Trianni, Cagno, Worrell & Pugliese (2013) report that access to credit is more important for small enterprises

and Borghesi et al. (2015) found that it was not relevant for large firms. Lack of access to credit is found to be a barrier as well (Fleiter et al., 2012; Long et al., 2016; Marin et al., 2015; Pacheco et al., 2018; Trianni, Cagno, Worrell & Pugliese, 2013).

Technological lock-in is among the least mentioned factors. It is reported as a barrier (mostly on the industry level), since changing the production system becomes more difficult and costly (Borghesi et al., 2015; Crespi, Ghisetti & Quatraro, 2015; Horbach, 2016; Marin et al., 2016; Wagner & Llerena, 2011). Fichter & Clausen (2016) state that it is a barrier particularly for radical innovations, since these require large changes in the system.

Commodity prices act as a barrier in case of low prices and as a driver in case of high prices. de Jesus Pacheco et al. (2018) (commodities), Smith (2016) (oil) and Trianni, Cagno & Worrell (2013) (energy) report that low prices lead to less pressure to invest in resource-efficient innovations. Borghesi et al. (2015), Horbach & Rammer (2018) and Woerter et al. (2017) all found that high energy prices drive the adoption of eco-innovations.

Applicability is about how well new technology fits the production process. Clausen & Fichter (2019) and Fichter & Clausen (2016) report that an innovation is more likely to be implemented if there is low need for behavioural modifications. Cainelli et al. (2015) state that innovations that fit the production process are more frequently adopted and Long et al. (2016) state that not all technologies diffuse, because they do not always match with the demand.

The *expected future improvement of an innovation* is already discussed under investment costs and cost savings, where firms delay the adoption because they expect declines in costs.

Benefit relating factors

The cluster 'factors relating to benefits' is also strongly embedded in a firm's finances. Market demand, profitability, reputation and cultural views all influence the benefits a firm may have from adopting eco-innovations.

A lot reported as relevant factor is the *market demand for sustainable products/services*. It can act as a driver, when the demand is high, or as a barrier, when the demand is low. Antolioni et al. (2016), Borghesi et al. (2015), Bossle, de Barcellos & Vieira (2016), Bossle, de Barcellos, Vieira & Sauvée (2016), del Rio González (2009), Díaz-García et al. (2015), D'Orazio & Valente (2019), Hojnik & Ruzzier (2016a), Hojnik & Ruzzier (2016b), Horbach (2016), Veugelers (2012), Wagner & Llerena (2011) and Woerter et al. (2017) all report that demand for sustainable products or services drives the diffusion of eoc-innovation. From a firm's perspective, the chance to secure or increase market shares drives the adoption (Bossle, de Barcellos, Vieira & Sauvée, 2016; Díaz-García et al., 2015; Hojnik & Ruzzier, 2016a; Veugelers, 2012). de Jesus Pacheco et al. (2018) observe that the low market demand in Brazil is a barrier and Klewitz et al. (2012) found that the low demand for sustainable technologies in the metal and engineering sector acts as a barrier. Moreover, Trianni, Cagno & Worrell (2013) and Trianni, Cagno, Worrell & Pugliese (2013) observe that little changes in demand when switching to more sustainable production withhold firms from adopting eco-innovations.

The role of *profitability* of innovations is also widely discussed in the literature. When eco-innovations are expected to be profitable, it drives the diffusion (Arsil et al., 2019; Clausen & Fichter, 2019; de Jesus Pacheco et al., 2018; Fichter & Clausen, 2016; Hasler et al., 2017; Hojnik & Ruzzier, 2016a; Ozusaglam, 2012). However, often the eco-innovation are not

perceived as profitable enough (Arsil et al., 2019; Klewitz et al., 2012; Trianni, Cagno & Worrell, 2013; Trianni, Cagno, Worrell & Pugliese, 2013). Furthermore, the long pay-back periods are repeatedly mentioned as a barrier (Fleiter et al., 2012; Long et al., 2016; Pereira & Vence, 2012) and uncertainty regarding profitability is seen as barrier multiple times as well (Hojnik & Ruzzier, 2016a; Marin et al., 2015; Long et al., 2016; Ozusaglam, 2012).

Reputation is closely related to market demand and cultural views, since better reputations can increase market shares for firms. Several authors acknowledge the importance of reputation as a driver of eco-innovation adoption (Clausen & Fichter, 2019; de Jesus Pacheco et al., 2018; Fichter & Clausen, 2016; Hojnik & Ruzzier, 2016a; Hojnik & Ruzzier, 2016b; Horbach, 2016; Klewitz et al., 2012; Veugelers, 2012). Horbach & Rammer (2018) add that a good reputation can attract skilled workers who bring knowledge relating to eco-innovations to the firm. Bossle, de Barcellos, Vieira & Sauvée (2016) found that reputation was important to keep good relations with stakeholders.

Cultural views on sustainability is also seen as a driver (Borghesi et al., 2015; Bossle, de Barcellos & Vieira, 2016; Hojnik & Ruzzier, 2016a; Pansera, 2013) and is strongly correlated to market demand for sustainable products (Bossle, de Barcellos, Vieira & Sauvée; de Jesus Pacheco et al., 2018; Díaz-García et al., 2013; Horbach, 2016; Horbach & Rammer, 2018).

Regulatory factors

Regulatory factors highlight the importance of regulation in eco-innovation. Seven regulatory factors are involved in this cluster; regulation, type of regulation, stringency, expected future regulation, complementarity of regulations, its neutrality and its stability.

As Rennings (2000) indicated, regulation is for eco-innovations in particular an important aspect. Also in the literature it is evident that regulation plays an important role in the diffusion of eco-innovations. *Regulations* in general is reported 24 times as a relevant factor for the diffusion of eco-innovations. According to the literature, regulations drive the diffusion (Borghesi et al., 2015; Bossle, de Barcellos, Vieira & Sauvée, 2016; Cainelli et al., 2015; Fichter & Clausen, 2016; Hojnik & Ruzzier, 2016a; Hojnik & Ruzzier, 2016b; Horbach, 2014; Horbach & Rammer, 2018; Müller et al., 2013; Wagner & Llerena, 2011; Woerter et al., 2017; Zhang et al., 2019). For example, firms have to comply to environmental standards (Antonioli et al., 2016; Klewitz et al., 2012; Veugelers, 2012). Lack of a regulatory framework is repeatedly described as a barrier (Díaz-García et al., 2015; Long et al., 2016; Marin et al., 2015), for example in Brazil (Bossle, de Barcellos & Vieira, 2016; de Jesus Pacheco et al., 2018), Bolivia (Pansera, 2013) and Eastern Europe (Horbach, 2016). Antonioli, Mancinelli & Mazzanti (2013), Horbach (2016) and Khanna et al. (2009) state that regulation is especially important for the most polluting sectors. According to them, polluting sectors are more prone to regulations. Veugelers (2012) found that to be true for bigger firms. Crespi et al. (2015) found that regulations indeed drive the diffusion, but only of innovations with incremental improvements. Clausen & Fichter (2019) were the only ones that did not observe regulations to be important.

A lot of articles reviewed different *types of regulation*. Reappearing regulations were command and control, subsidies, taxes, voluntary agreements, labels, supporting activities and promoting awareness (the last two only mentioned once). It is often said that the policy mix matters for its effectiveness in diffusing eco-innovations, but little is known about that topic (see for example Veugelers, 2012). Different articles present different outcomes about which policies are most effective. Subsidies (discussed under cost relating factors) was identified in most articles as one of the most effective measures to speed up the diffusion.

Voluntary agreements were also seen as effective (Borghesi et al., 2015; Hojnik & Ruzzier, 2016a; Pereira & Vence, 2015; Veugelers, 2012; Woerter et al., 2012), while taxes were considered relevant by some authors (Borghesi et al., 2015; Bossle, de Barcellos & Vieira, 2016; Hojnik & Ruzzier, 2016a; Veugelers, 2012; Woerter et al., 2012) and not very much by others (Cainelli et al., 2015; Pereira & Vence, 2015). Command and control is a driver (Borghesi et al., 2015; Hojnik & Ruzzier, 2016b; Pereira & Vence, 2015), although it is not analysed a lot. The same holds for supporting activities and promoting awareness (Bossle, de Barcellos & Vieira, 2016; Bossle, de Barcellos, Vieira & Sauvée, 2016). The role of labels is minor (Bossle, de Barcellos, Vieira & Sauvée, 2016; Ozusaglam, 2012; Pereira & Vence, 2015) or even irrelevant for diffusion (Hojnik & Ruzzier, 2016a).

Stringency of regulations is considered a driver for eco-innovation diffusion (Bossle, de Barcellos, Vieira & Sauvée, 2016; Cainelli et al., 2015; Crespi et al., 2015; Díaz-García et al., 2015; Hojnik & Ruzzier, 2016a) and lack of stringency a barrier (Borghesi et al., 2015; Bossle, de Barcellos & Vieira, 2016; Pereira & Vence, 2015).

Expected future regulations is an important driver as well (Borghesi et al., 2015; Hojnik & Ruzzier, 2016; Horbach, 2016; Horbach & Rammer, 2018). According to a few even one of the most important drivers behind the diffusion (Khanna et al., 2009; Veugelers, 2012). Firms anticipate on expected regulations to avoid costs and risks. Bossle, de Barcellos & Vieira (2016) also see the importance of expected regulation in the food sector in Brazil, but the lack of stringency in that country partly represses the effect.

Complementarity of regulations is about how well policies fit in their wider context. Veugelers (2012) indicates that little is known about complementarity of regulations, but she found that subsidies and taxes is an effective policy mix. Crespi et al. (2015) argue that if the complementarity between policies is not good, it can have negative effects for the diffusion. Long et al. (2016) observed that inconsistent policies between different countries or regions in the EU hinders the diffusion.

Not much reported either is the *neutrality of regulations*. de Jesus Pacheco et al. (2018) state that regulation in Brazil is in favour of larger firms and hiders adoption among SMEs. Long et al. (2016) report that it can be difficult to compete with other products that have subsidies.

Stability of regulations is reported only once, but it can help making expected regulations more clear and credible (Veugelers, 2012).

Informational factors

Informational factors are about knowledge, knowledge gathering and networking. Important factors in this are resources, information flows, attitude of managers/owners, organizational environmental practices, the ease of use of an innovation, regional characteristics, attitude of internal stakeholders, NGOs, trade/foreign direct investment and stakeholder pressure.

While financial *resources* and time constraints were more important for the cost related factors, human capital related to knowledge is more important for informational factors. Human capital brings relevant knowledge to the firms that is required to adopt eco-innovations. Human capital or qualified personnel thus drives the adoption of eco-innovations (Díaz-García et al., 2015; Long et al., 2016; Pereira & Vence, 2012). Training staff to increase human capital is also reported to drive the adoption within firms (Antonioli et al., 2016; Bossle, de Barcellos & Vieira, 2016; Cainelli et al., 2015; Hojnik & Ruzzier, 2016a). On the other hand, lack of human capital and essential knowledge to adopt eco-innovations can act as a major barrier (Fleiter et al., 2012; Long et al., 2016; Pansera, 2013), especially among

SMEs (de Jesus Pacheco et al., 2018; Klewitz et al., 2012; Marin et al., 2015). Eco-innovations can be complex and require sufficient knowledge. Another aspect that is also important for knowledge gathering is to engage in information flows. Setting up networks or internal platforms drives the adoption (Bossle, de Barcellos & Vieira, 2016; Bossle, de Barcellos, Vieira & Sauvée, 2016; del Rio González, 2009).

Information flows is also among the most frequently mentioned factors. Networks, collaboration and information sharing especially with other firms in the industry are essential for the diffusion of eco-innovations (Antonioli et al., 2013; Borghesi et al., 2015; Bossle, de Barcellos & Vieira, 2016; Bossle, de Barcellos, Vieira & Sauvée, 2016; Díaz-García et al., 2015; Hasler et al., 2017; Klewitz et al., 2012; Pansera, 2013; Pereira & Vence, 2012; Trianni, Cagno & Worrell, 2013). Being aware of the existence of innovations and related benefits and costs is a precondition for adoption (Horbach & Rammer, 2018). Rogers (2003) already pointed out the importance of communication for the diffusion of innovations 57 years ago. Some studies found that lack of information sharing was one of the main barriers of eco-innovation diffusion (de Jesus Pacheco et al., 2018; Long et al., 2016; Marin et al., 2015; Trianni, Cagno & Worrell, 2013). Trianni, Cagno & Worrell (2013) and Trianni, Cagno, Worrell & Pugliese (2013) also found difficulty to find external competencies with knowledge to be a barrier. Communication and cooperation with suppliers and consumers is also important (Borghesi et al., 2015; Bossle, de Barcellos & Vieira, 2016; Trianni, Cagno & Worrell), as well as attending conferences (Borghesi et al., 2015).

The *attitude of the managers or owners* of a firm towards sustainability is strongly highlighted in literature. Strong environmental concerns drive the adoption of eco-innovation (Díaz-García et al., 2015; Hojnik & Ruzzier, 2016a; Hojnik & Ruzzier, 2016b; Horbach & Rammer, 2018; Long et al., 2016; Woerter et al.,2017). Attention given to sustainability by managers is important for a firm's involvement in sustainability and its sustainable organizational practices (Bossle, de Barcellos, Vieira & Sauvée; Klewitz et al., 2012; Marin et al., 2015). Risk-taking is another aspect of this factor and encourages the adoption of radical innovations in particular (Bossle, de Barcellos & Vieira, 2016; de Jesus Pacheco et al., 2018; Hasler et al., 2012; Smith, 2016). A barrier is formed by lack of interest of managers in sustainability (Arsil et al., 2019; Long et al., 2016; Trianni, Cagno & Worrell, 2013; Trianni, Cagno, Worrell & Pugliese, 2013). Lack of awareness or knowledge about eco-innovations is described as a barrier as well (de Jesus Pacheco et al., 2018; Díaz-García et al., 2015; Long et al., 2016). Resistance to change (Arsil et al., 2019; de Jesus Pacheco et al., 2018), perceived risks involved in the adoption of an eco-innovation (Fleiter et al., 2012; Long et al., 2016) and a short term focus (de Jesus Pacheco et al., 2018) are other barriers related to the attitude of managers.

O*rganizational environmental practices* represent the way in which firms are organized and their activities so that sustainability is incorporated into the firm's activities. A well-known example is environmental management systems (EMS). The presence of organizational environmental practices is seen as a driver for the adoption, or at least as a facilitator (Antonioli et al., 2013; Borghesi et al., 2015; Díaz-García et al., 2015; Hojnik & Ruzzier, 2016a; Horbach, 2016; Horbach & Rammer, 2018; Khanna et al., 2009; Long et al., 2016; Pereira & Vence, 2015; Wagner & Llerena, 2011; Woerter et al., 2017). Bossle, de Barcellos, Vieira & Sauvée (2016) even call it one of the most important factors of eco-innovation adoption. Pereira & Vence (2012) indicate that organizational environmental practices help to gather information, help in the learning process (when adopting an innovation) and allows for detection of cost savings. De Jesus Pacheco et al. (2018) state that

the absence of organizational environmental practices is a barrier and Trianni, Cagno, Thollander & Backlund (2013) state that smaller firms might experience organizational issues.

The *ease of using* or implementing the eco-innovation is another factor that is sometimes mentioned. Easy to implement and use innovations are more likely adopted (Clausen & Fichter, 2019; Hasler et al., 2017). If eco-innovations are very complex, it might withhold the adoption, because they come more often with information problems and higher costs (Arsil et al., 2019; Fichter & Clausen, 2016; Fleiter et al., 2012; Long et al., 2016; Trianni, Cagno & Worrell, 2013). Díaz-García et al. (2015) also indicate that novelty of innovations can be a barrier.

Regional characteristics were found important for the diffusion five times. Antonioli et al. (2016), Díaz-García et al. (2015) and Horbach & Rammer (2018) indicate that diffusion happens faster when firms are located near each other and when the adoption of eco-innovation is high in that region. Cainelli et al. (2015) and Khanna et al. (2009) both found regional policies for waste reducing technologies to be important.

Attitude of internal stakeholders is mostly about the pressure of employees towards the firm. It pushes a firm to get more involved in sustainability and eco-innovations (Bossle, de Barcellos & Vieira, 2016; Bossle, de Barcellos, Vieira & Sauvée, 2016; Hojnik & Ruzzier, 2016a; Long et al., 2016).

NGOs can help in providing information and building networks according to Klewitz et al. (2012) and Pansera (2013). Bossle, de Barcellos & Vieira (2016) and Bossle, de Barcellos, Vieira & Sauvée (2016) indicate that NGOs can drive the demand for sustainable products.

Trade or foreign direct investment can diffuse clean technologies from developed to developing countries (del Rio González, 2009; Díaz-García et al., 2015) or from West to Eastern Europe (Horbach, 2014).

Pressure from stakeholders such as suppliers is mentioned twice as a relevant driver for eco-innovation adoption (Bossle, de Barcellos & Vieira, 2016; Hojnik & Ruzzier, 2016a).

Dummy factors

The dummy factors are factors that are often used as control variables in literature. They are already discussed throughout the other categories. Size and sector-specific characteristics are by far the most reported factors. Ownership and age are only mentioned twice and once respectively.

larger firms are almost always reported to adopt more eco-innovations and to perceive less barriers than smaller firms (for example, Antonioli et al., 2013; Fichter & Clausen, 2016; Veugeler, 2012). S*ector-specific characteristics* are almost always about the polluting level of an industry. Larger polluters are more involved in eco-innovation adoption (see for example, Horbach, 2016; Pereira & Vence, 2012; Veugelers, 2012).

Self- or family-owned firms were more likely to adopt (Hasler et al., 2018; Horbach & Rammer, 2018) and for *age* it is unclear (Pereira & Vence, 2012).

table 1. factors influencing the diffusion of eco-innovations ranked by category and times reported as influencing factor by the literature.

category	**factor**	**times reported**

Cost relating factors	resources investment costs type of regulation competition cost savings access to credit technological lock-in commodity prices applicability expected future improvement of innovation	22 17 17 12 11 11 7 6 4 3
Benefit relating factors	market demand for sustainable products/services profitability reputation cultural views	19 15 10 9
Regulatory factors	regulations type of regulation stringency expected future regulations complementarity of regulations neutrality of regulations stability of regulations	24 17 8 7 3 2 1
Informational factors	resources information flows attitude of managers/owners organizational environmental practices ease of use of innovation regional characteristics attitude of internal stakeholders NGOs trade/foreign direct investment stakeholder pressure	22 20 17 15 10 5 4 4 3 2
Dummy factors	size sector-specific characteristics ownership age	16 14 2 1

Conclusion and discussion

In this paper, the drivers and barriers of the diffusion of eco-innovations as they appear in the literature are researched and an alternative classification is proposed based on recurring

patterns in the literature. A systematic literature review was applied, in which 39 articles were analysed. In total, 33 factors were identified. Some were reported by many articles, others only once or twice. All the factors together form the answer to the research question 'which factors slow down and which factors accelerate the diffusion of eco-innovations?' Based on the literature, a new classification was proposed. Five categories were distinguished; cost relating factors, benefit relating factors, regulatory factors, informational factors and dummy factors. The categories of costs/benefits and regulation are often acknowledged in literature regarding eco-innovation, but informational factors as a category is almost never used, even though information related factors keep appearing in the articles. This new classification is thus more useful for categorizing factors that drive or slow down the diffusion of eco-innovation and for analysing articles.

Though comparison gives great insights in the most important findings in literature, it is also one of the largest limitations of this paper. All articles researched drivers and barriers in different contexts. Some articles studied energy-efficient technologies, while others looked into products innovations. The factors that are important for the diffusion might differ for various eco-innovation types. The same is true for different kind of industries and different countries. Due to time and word constraints this was included very limited in this paper. Future research should look into the differences between eco-innovation types, between industries and between countries. More research about complementarities between various factors themselves would also be useful.

A second limitation is the focus on western countries in literature. Research in middle and low income countries is scarce. In this paper, almost all place-bound studies were performed in western countries, mostly within the EU. Especially in emerging economies research about the diffusion of eco-innovations would be very relevant.

Future policy should acknowledge the important role of information and information flows in the diffusion of eco-innovations. Providing information and knowledge, helping setting up networks or creating platforms are policies that could drive the diffusion of eco-innovations. Especially for SMEs it is important to help them find external knowledge sources that could get them involved in eco-innovations. SMEs are also most likely to see financial costs as a barrier. Helping firms overcome costs relating barriers, for example via subsidies, could drive the diffusion and improve the innovations. For the larger and more polluting sectors in particular, regulation is a very important aspect. It stimulates the adoption in the most polluting industries and thus can bring large environmental improvements. That is after all the ultimate goal. Eco-innovations can bring sustainable benefits, but only when widely used or implemented. Factors driving and hindering the diffusion are thus crucial to investigate.

References

Agan, Y., Acar, M. F., & Borodin, A. (2013). Drivers of environmental processes and their impact on performance: a study of Turkish SMEs. *Journal of cleaner production*, *51*, 23-33.

Antonioli, D., Borghesi, S., & Mazzanti, M. (2016). Are regional systems greening the economy? Local spillovers, green innovations and firms' economic performances. *Economics of Innovation and New Technology*, *25*(7), 692-713.

Antonioli, D., Mancinelli, S., & Mazzanti, M. (2013). Is environmental innovation embedded within high-performance organisational changes? The role of human resource management and complementarity in green business strategies. *Research Policy*, *42*(4), 975-988.

Arsil, P., Sahirman, S., & Hidayat, H. H. (2019, March). The reasons for farmers not to adopt System of Rice Intensification (SRI) as a sustainable agricultural practice: an explorative study. In *IOP Conference Series: Earth and Environmental Science* (Vol. 250, No. 1, p. 012063). IOP Publishing.

Borghesi, S., Cainelli, G., & Mazzanti, M. (2015). Linking emission trading to environmental innovation: evidence from the Italian manufacturing industry. *Research Policy*, *44*(3), 669-683.

Bossle, M. B., De Barcellos, M. D., & Vieira, L. M. (2016). Why food companies go green? The determinant factors to adopt eco-innovations. *British Food Journal*, *118*(6), 1317-1333.

Bossle, M. B., de Barcellos, M. D., Vieira, L. M., & Sauvée, L. (2016). The drivers for adoption of eco-innovation. *Journal of Cleaner production*, *113*, 861-872.

Cainelli, G., D'Amato, A., & Mazzanti, M. (2015). Adoption of waste-reducing technology in manufacturing: Regional factors and policy issues. *Resource and Energy Economics*, *39*, 53-67.

Cantono, S., & Silverberg, G. (2009). A percolation model of eco-innovation diffusion: the relationship between diffusion, learning economies and subsidies. *Technological forecasting and social change*, *76*(4), 487-496.

Clausen, J., & Fichter, K. (2019). The diffusion of environmental product and service innovations: Driving and inhibiting factors. *Environmental Innovation and Societal Transitions*.

Crespi, F., Ghisetti, C., & Quatraro, F. (2015). Environmental and innovation policies for the evolution of green technologies: A survey and a test. *Eurasian Business Review*, *5*(2), 343-370.

de Jesus Pacheco, D. A., ten Caten, C. S., Jung, C. F., Navas, H. V. G., & Cruz-Machado, V. A. (2018). Eco-innovation determinants in manufacturing SMEs from emerging markets:

Systematic literature review and challenges. *Journal of Engineering and Technology Management*, *48*, 44-63.

del Río González, P. (2009). The empirical analysis of the determinants for environmental technological change: A research agenda. *Ecological Economics*, *68*(3), 861-878.

Díaz-García, C., González-Moreno, Á., & Sáez-Martínez, F. J. (2015). Eco-innovation: insights from a literature review. *Innovation*, *17*(1), 6-23.

D'Orazio, P., & Valente, M. (2019). The role of finance in environmental innovation diffusion: an evolutionary modeling approach. *Journal of Economic Behavior & Organization*, *162*, 417-439.

Fichter, K., & Clausen, J. (2016). Diffusion dynamics of sustainable innovation-insights on diffusion patterns based on the analysis of 100 sustainable product and service innovations. *Journal of Innovation Management*, *4*(2), 30-67.

Fleiter, T., Hirzel, S., & Worrell, E. (2012). The characteristics of energy-efficiency measures–a neglected dimension. *Energy policy*, *51*, 502-513.

Hasler, K., Olfs, H. W., Omta, O., & Bröring, S. (2017). Drivers for the Adoption of Different Eco-Innovation Types in the Fertilizer Sector: A Review. *Sustainability*, *9*(12), 2216.

Hojnik, J., & Ruzzier, M. (2016a). What drives eco-innovation? A review of an emerging literature. *Environmental Innovation and Societal Transitions*, *19*, 31-41.

Hojnik, J., & Ruzzier, M. (2016b). The driving forces of process eco-innovation and its impact on performance: Insights from Slovenia. *Journal of cleaner production*, *133*, 812-825.

Horbach, J. (2014). Determinants of Eco-innovation from a European-wide Perspective–an Analysis based on the Community Innovation Survey (CIS). *SEEDS Working Paper*, *7*, 2014.

Horbach, J. (2016). Empirical determinants of eco-innovation in European countries using the community innovation survey. *Environmental Innovation and Societal Transitions*, *19*, 1-14.

Horbach, J., & Rammer, C. (2018). Energy transition in Germany and regional spill-overs: The diffusion of renewable energy in firms. *Energy policy*, *121*, 404-414.

Horbach, J., Rammer, C., & Rennings, K. (2012). Determinants of eco-innovations by type of environmental impact—The role of regulatory push/pull, technology push and market pull. *Ecological economics*, *78*, 112-122.

Karakaya, E., Hidalgo, A., & Nuur, C. (2014). Diffusion of eco-innovations: A review. *Renewable and Sustainable Energy Reviews*, *33*, 392-399.

Kemp, R., & Pearson, P. (2007). Final report MEI project about measuring eco-innovation. *UM Merit, Maastricht*, *10*.

Khanna, M., Deltas, G., & Harrington, D. R. (2009). Adoption of pollution prevention techniques: the role of management systems and regulatory pressures. *Environmental and Resource Economics*, *44*(1), 85-106.

Klewitz, J., Zeyen, A., & Hansen, E. G. (2012). Intermediaries driving eco-innovation in SMEs: a qualitative investigation. *European Journal of Innovation Management*, *15*(4), 442-467.

Long, T. B., Blok, V., & Coninx, I. (2016). Barriers to the adoption and diffusion of technological innovations for climate-smart agriculture in Europe: evidence from the Netherlands, France, Switzerland and Italy. *Journal of Cleaner Production*, *112*, 9-21.

Marin, G., Marzucchi, A., & Zoboli, R. (2015). SMEs and barriers to Eco-innovation in the EU: exploring different firm profiles. *Journal of Evolutionary Economics*, *25*(3), 671-705.

Müller, M. O., Kaufmann-Hayoz, R., Schwaninger, M., & Ulli-Beer, S. (2013). The Diffusion of Eco-Technologies: A Model-Based Theory. In *Energy Policy Modeling in the 21st Century* (pp. 49-67). Springer, New York, NY.

Nesta, L., Vona, F., & Nicolli, F. (2014). Environmental policies, competition and innovation in renewable energy. *Journal of Environmental Economics and Management*, *67*(3), 396-411.

Oecd Publishing. (2010). *Eco-innovation in industry: Enabling green growth*. OECD.

Ozusaglam, S. (2012). Environmental innovation: a concise review of the literature. *Vie sciences de l'entreprise*, (2), 15-38.

Pansera, M. (2013). Innovation system for sustainability in developing countries: the renewable energy sector in Bolivia.

Peng, X., Liu, Y., & Zhao, L. (2014). A literature review of corporate eco-innovation: theoretical veins, concept clarification and measurement. *Acta Ecologica Sinica*, *34*, 6440-6449.

Pereira, Á., & Vence, X. (2012). Key business factors for eco-innovation: an overview of recent firm-level empirical studies.

Pereira, Á., & Vence, X. (2015). Environmental policy instruments and eco-innovation: an overview of recent studies. *Innovar*, *25*(58), 65-80.

Porter, M. E., & Van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *Journal of economic perspectives*, *9*(4), 97-118.

Rennings, K. (2000). Redefining innovation—eco-innovation research and the contribution from ecological economics. *Ecological economics*, *32*(2), 319-332.

Rockström, J., Steffen W. L., Noone, K., Persson, A., Chapin, III, F. S., Lambin, E., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H., Nykvist, B., De Wit, C. A., Hughes, T., van der

Leeuw, S., Rodhe, H., Sorlin, S., Snyder, P. K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R. W., Fabry, V. J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P. & Foley, J. (2009). Planetary boundaries:exploring the safe operating space for humanity. *Ecology and Society 14(2): 32*.

Rogers, E. (2003). *Diffusion of innovations* (5th ed.). New York: Free Press.

Ryan, B., & Gross, N. C. (1943). The diffusion of hybrid seed corn in two Iowa communities. *Rural sociology*, *8*(1), 15.

Siebenhüner, B., & Arnold, M. (2007). Organizational learning to manage sustainable development. *Business Strategy and the Environment, 16*(5), 339-353.

Smith, D. J. (2016). The sustainable and green engine (SAGE)–Aircraft engine of the future?. *The International Journal of Entrepreneurship and Innovation*, *17*(4), 256-262.

Trianni, A., Cagno, E., Thollander, P., & Backlund, S. (2013). Barriers to industrial energy efficiency in foundries: a European comparison. *Journal of Cleaner Production*, *40*, 161-176.

Trianni, A., Cagno, E., & Worrell, E. (2013). Innovation and adoption of energy efficient technologies: An exploratory analysis of Italian primary metal manufacturing SMEs. *Energy Policy*, *61*, 430-440.

Trianni, A., Cagno, E., Worrell, E., & Pugliese, G. (2013). Empirical investigation of energy efficiency barriers in Italian manufacturing SMEs. *Energy*, *49*, 444-458.

Valente, T. W., & Rogers, E. M. (1995). The origins and development of the diffusion of innovations paradigm as an example of scientific growth. *Science communication*, *16*(3), 242-273.

Veugelers, R. (2012). Which policy instruments to induce clean innovating?. *Research Policy*, *41*(10), 1770-1778.

Wagner, M., & Llerena, P. (2011). Eco-innovation through integration, regulation and cooperation: comparative insights from case studies in three manufacturing sectors. *Industry and Innovation*, *18*(8), 747-764.

Woerter, M., Stucki, T., Arvanitis, S., Rammer, C., & Peneder, M. (2017). The adoption of green energy technologies: The role of policies in Austria, Germany, and Switzerland. *International journal of green energy*, *14*(14), 1192-1208.

Xavier, A. F., Naveiro, R. M., Aoussat, A., & Reyes, T. (2017). Systematic literature review of eco-innovation models: Opportunities and recommendations for future research. *Journal of Cleaner Production*, *149*, 1278-1302.

Zhang, L., Xue, L., & Zhou, Y. (2019). How do low-carbon policies promote green diffusion among alliance-based firms in China? An evolutionary-game model of complex networks. *Journal of Cleaner Production*, *210*, 518-529.

Appendix

Factor	Theoretical/empirical	Authors
regulations	Theoretical	Bossle, de Barcellos, Vieira & Sauvée (2016) de Jesus Pacheco et al. (2018) Díaz-García et al. (2015) Hojnik & Ruzzier (2016a) Müller et al. (2013) Zhang et al. (2019)
	Empirical	Antonioli et al. (2016) Borghesi et al. (2015) Bossle, de Barcellos & Vieira (2016) Cainelli et al. (2015) Crespi et al. (2015) Fichter & Clausen (2016) Hojnik & Ruzzier (2016b) Horbach (2014) Horbach (2016) Horbach & Rammer (2018) Khanna et al. (2009) Klewitz et al. (2012) Long et al. (2016) Marin et al. (2015) Pansera (2013) Veugelers (2012) Wagner & Llerena (2011) Woerter et al. (2017)
resources	Theoretical	Bossle, de Barcellos, Vieira & Sauvée (2016) de Jesus Pacheco et al. (2018) del Rio González (2009) Díaz-García et al. (2015) Fleiter et al. (2012) Hasler et al. (2017) Hojnik & Ruzzier (2016a) Pereira & Vence (2012)
	Empirical	Antonioli et al. (2016) Borghesi et al. (2015) Bossle, de Barcellos & Vieira (2016) Cainelli et al. (2015) Horbach (2014) Horbach & Rammer (2018) Khanna et al. (2009)

		Klewitz et al. (2012) Long et al. (2016) Marin et al. (2015) Pansera (2013) Trianni, Cagno, Thollander & Backlund (2013) Trianni, Cagno & Worrell (2013) Trianni, Cagno, Worrell & Pugliese (2013)
information flows	Theoretical	Bossle, de Barcellos, Vieira & Sauvée (2016) de Jesus Pacheco et al. (2018) del Rio González (2009) Díaz-García et al. (2015) Fleiter et al. (2012) Ozusaglam (2012) Pereira & Vence (2012)
	Empirical	Antonioli et al. (2016) Antonioli et al. (2013) Borghesi et al. (2015) Bossle, de Barcellos & Vieira (2016) Cainelli et al. (2015) Clausen & Fichter (2019) Horbach (2014) Horbach & Rammer (2018) Klewitz et al. (2012) Long et al. (2016) Marin et al. (2015) Pansera (2013) Trianni, Cagno & Worrell (2013) Trianni, Cagno, Worrell & Pugliese (2013)
market demand for sustainable products/services	Theoretical	Bossle, de Barcellos, Vieira & Sauvée (2016) de Jesus Pacheco et al. (2018) del Rio González (2009) Díaz-García et al. (2015) D'Orazio & Valente (2019) Hojnik & Ruzzier (2016a)
	Empirical	Antonioli et al. (2016) Borghesi et al. (2015) Bossle, de Barcellos & Vieira (2016) Hojnik & Ruzzier (2016b) Horbach (2016) Klewitz et al. (2012) Long et al. (2016) Marin et al. (2015) Trianni, Cagno & Worrell (2013)

		Trianni, Cagno, Worrell & Pugliese (2013) Veugelers (2012) Wagner & Llerena (2011) Woerter et al. (2017)
type of regulation	Theoretical	Bossle, de Barcellos, Vieira & Sauvée (2016) Cantono & Silverberg (2009) Díaz-García et al. (2015) Hojnik & Ruzzier (2016a) Ozusaglam (2012) Pereira & Vence (2015) Zhang et al. (2019)
	Empirical	Borghesi et al. (2015) Bossle, de Barcellos & Vieira (2016) Cainelli et al. (2015) Crespi et al. (2015) Hojnik & Ruzzier (2016b) Horbach (2014) Horbach (2016) Long et al. (2016) Pansera (2013) Veugelers (2012) Woerter et al. (2017)
attitude of managers/owners	Theoretical	Bossle, de Barcellos, Vieira & Sauvée (2016) de Jesus Pacheco et al. (2018) Díaz-García et al. (2015) Fleiter et al. (2012) Hasler et al. (2017) Hojnik & Ruzzier (2016a)
	Empirical	Arsil et al. (2019) Bossle, de Barcellos & Vieira (2016) Hojnik & Ruzzier (2016b) Horbach & Rammer (2018) Klewitz et al. (2012) Long et al. (2016) Marin et al. (2015) Smith (2016) Trianni, Cagno & Worrell (2013) Trianni, Cagno, Worrell & Pugliese (2013)

		Woerter et al. (2017)
investment costs	Theoretical	Cantono & Silverberg (2009) de Jesus Pacheco et al. (2018) Fleiter et al. (2012) Hasler et al. (2017) Pereira & Vence (2012)
	Empirical	Clausen & Fichter (2019) Hojnik & Ruzzier (2016b) Horbach (2016) Horbach & Rammer (2018) Khanna et al. (2009) Klewitz et al. (2012) Long et al. (2016) Marin et al. (2015) Smith (2016) Trianni, Cagno, Thollander & Backlund (2013) Trianni, Cagno & Worrell (2013) Trianni, Cagno, Worrell & Pugliese (2013)
size	Theoretical	Bossle, de Barcellos, Vieira & Sauvée (2016) de Jesus Pacheco et al. (2018) del Rio González (2009) Hasler et al. (2017) Hojnik & Ruzzier (2016a) Pereira & Vence (2012)
	Empirical	Antonioli et al. (2013) Cainelli et al. (2015) Fichter & Clausen (2016) Horbach (2016) Horbach & Rammer (2018) Marin et al. (2015) Trianni, Cagno, Thollander & Backlund (2013) Trianni, Cagno, Worrell & Pugliese (2013) Veugelers (2012) Woerter et al. (2017)
profitability	Theoretical	de Jesus Pacheco et al. (2018) Fleiter et al. (2012) Hasler et al. (2017) Hojnik & Ruzzier (2016a) Ozusaglam (2012) Pereira & Vence (2012)
	Empirical	Arsil et al. (2019) Clausen & Fichter (2019)

		Fichter & Clausen (2016) Klewitz et al. (2012) Long et al. (2016) Marin et al. (2015) Trianni, Cagno & Worrell (2013) Trianni, Cagno, Worrell & Pugliese (2013)
organizational environmental practices	Theoretical	Bossle, de Barcellos, Vieira & Sauvée (2016) de Jesus Pacheco et al. (2018) Díaz-García et al. (2015) Hojnik & Ruzzier (2016a) Pereira & Vence (2012) Pereira & Vence (2015)
	Empirical	Antonioli et al. (2013) Borghesi et al. (2015) Horbach (2016) Horbach & Rammer (2018) Khanna et al. (2009) Long et al. (2016) Trianni, Cagno, Thollander & Backlund (2013) Wagner & Llerena (2011) Woerter et al. (2017)
sector-specific characteristics	Theoretical	Bossle, de Barcellos, Vieira & Sauvée (2016) Díaz-García et al. (2015) Pereira & Vence (2012)
	Empirical	Antonioli et al. (2013) Borghesi et al. (2015) Clausen & Fichter (2019) Fichter & Clausen (2016) Horbach (2016) Khanna et al. (2009) Klewitz et al. (2012) Marin et al. (2015) Trianni, Cagno & Worrell (2013) Veugelers (2012) Wagner & Llerena (2011)
competition	Theoretical	Bossle, de Barcellos, Vieira & Sauvée (2016) de Jesus Pacheco et al. (2018) Díaz-García et al. (2015) Hojnik & Ruzzier (2016a)
	Empirical	Bossle, de Barcellos & Vieira (2016) Clausen & Fichter (2019) Fichter & Clausen (2016)

		Hojnik & Ruzzier (2016b) Horbach (2016) Horbach & Rammer (2018) Long et al. (2016) Trianni, Cagno, Worrell & Pugliese (2013)
cost savings	Theoretical	Bossle, de Barcellos, Vieira & Sauvée (2016) Díaz-García et al. (2015) Hojnik & Ruzzier (2016a) Müller et al. (2013) Pereira & Vence (2012)
	Empirical	Arsil et al. (2019) Borghesi et al. (2015) Hojnik & Ruzzier (2016b) Horbach (2016) Klewitz et al. (2012) Veugelers (2012)
access to credits	Theoretical	de Jesus Pacheco et al. (2018) Díaz-García et al. (2015) D'Orazio & Valente (2019) Fleiter et al. (2012) Hasler et al. (2017)
	Empirical	Borghesi et al. (2015) Long et al. (2016) Marin et al. (2015) Pansera (2013) Trianni, Cagno, Worrell & Pugliese (2013)
reputation	Theoretical	Bossle, de Barcellos, Vieira & Sauvée (2016) de Jesus Pacheco et al. (2018) Hojnik & Ruzzier (2016a)
	Empirical	Clausen & Fichter (2019) Fichter & Clausen (2016) Hojnik & Ruzzier (2016b) Horbach (2016) Horbach & Rammer (2018) Klewitz et al. (2012) Veugelers (2012)
ease of use of innovation	Theoretical	Díaz-García et al. (2015) Fleiter et al. (2012) Hasler et al. (2017)
	Empirical	Arsil et al. (2019)

		Clausen & Fichter (2019) Fichter & Clausen (2016) Horbach & Rammer (2018) Long et al. (2016) Trianni, Cagno & Worrell (2013) Trianni, Cagno, Worrell & Pugliese (2013)
cultural views	Theoretical	Bossle, de Barcellos, Vieira & Sauvée (2016) de Jesus Pacheco et al. (2018) Díaz-García et al. (2015) Hojnik & Ruzzier (2016a)
	Empirical	Borghesi et al. (2015) Bossle, de Barcellos & Vieira (2016) Horbach (2016) Horbach & Rammer (2018)
stringency	Theoretical	Bossle, de Barcellos, Vieira & Sauvée (2016) Díaz-García et al. (2015) Hojnik & Ruzzier (2016a) Pereira & Vence (2015)
	Empirical	Borghesi et al. (2015) Bossle, de Barcellos & Vieira (2016) Cainelli et al. (2015) Crespi et al. (2015)
technological lock-in	Theoretical	
	Empirical	Borghesi et al. (2015) Cainelli et al. (2015) Crespi et al. (2015) Fichter & Clausen (2016) Horbach (2016) Marin et al. (2015) Wagner & Llerena (2011)
expected future regulations	Theoretical	Hojnik & Ruzzier (2016a)
	Empirical	Borghesi et al. (2015) Bossle, de Barcellos & Vieira (2016) Horbach (2016) Horbach & Rammer (2018) Khanna et al. (2009) Veugelers (2012)
commodity prices	Theoretical	de Jesus Pacheco et al. (2018)

	Empirical	Borghesi et al. (2015) Horbach & Rammer (2018) Smith (2016) Trianni, Cagno & Worrell (2013) Woerter et al. (2017)
regional characteristics	Theoretical	Díaz-García et al. (2015)
	Empirical	Antonioli et al. (2016) Cainelli et al. (2015) Horbach & Rammer (2018) Khanna et al. (2009)
applicability	Theoretical	
	Empirical	Cainelli et al. (2015) Clausen & Fichter (2019) Fichter & Clausen (2016) Long et al. (2016)
attitude of internal stakeholders	Theoretical	Bossle, de Barcellos, Vieira & Sauvée (2016) Hojnik & Ruzzier (2016a)
	Empirical	Bossle, de Barcellos & Vieira (2016) Long et al. (2016)
NGOs	Theoretical	Bossle, de Barcellos, Vieira & Sauvée (2016)
	Empirical	Bossle, de Barcellos & Vieira (2016) Klewitz et al. (2012)
expected future improvement of innovation	Theoretical	Cantono & Silverberg (2009) Fleiter et al. (2012)
	Empirical	Horbach & Rammer (2018)
complementarity of regulations	Theoretical	
	Empirical	Crespi et al. (2015) Long et al. (2016) Veugelers (2012)
trade/foreign direct investment	Theoretical	del Rio González (2009) Díaz-García et al. (2015)
	Empirical	Horbach (2014)

neutrality of regulations	Theoretical	de Jesus Pacheco et al. (2018)
	Empirical	Long et al. (2016)
stakeholder pressure	Theoretical	Hojnik & Ruzzier (2016a)
	Empirical	Bossle, de Barcellos & Vieira (2016)
ownership	Theoretical	Hasler et al. (2017)
	Empirical	Horbach & Rammer (2018)
stability of regulations	Theoretical	
	Empirical	Veugelers (2012)
age	Theoretical	Díaz-García et al. (2015)
	Empirical	