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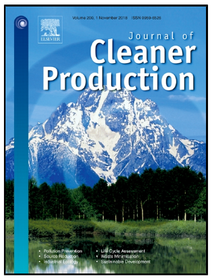

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Factors affecting sustainable process technology adoption: A systematic literature review

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Factors affecting the adoption of sustainable process technologies: A systematic literature review

Abstract

An important challenge facing firms and governments is the realization of sustainable development objectives. Sustainable technology, as an effective means to achieve sustainable development, has recently gained much interest from both society and academia. Prior research has investigated the effects of several factors on the adoption of sustainable technologies and provides a basic understanding of firms' sustainable technology adoption behaviours. However, the results of this research are scattered across different disciplines, making that knowledge on sustainable technology adoption fragmented. In this systematic literature review, Elsevier and Web of Science were used as databases to search articles in the field of sustainable process technology adoption. Based on criteria, i.e., document type, languages, definition of adoption and sustainable technology and analysis level, 34 out of 964 articles were selected in the review. A qualitative synthesis method was chosen because the aim of this study is to understand and explain the effect of a specific factor as well as to explain the often-contradictory evidence in different contexts, focusing on not only the convergence but also the divergence in prior studies. Based on the typology from United Nations Environmental Program of sustainable technologies, a classification of sustainable process technologies is provided: CO_2/emission reduction, material/fuel substitution, energy/material efficiency and recycling technologies. Environmental regulations and firm characteristics are most widely studied factors influencing sustainable process technology adoption. Coercive pressure, market pressure, technology capability, internal support, adoption experience, certified systems, and cooperation are important for sustainable process technology adoption. Firm characteristics (e.g. firm size, ownership) and technology types (e.g. end-of-pipe technology vs. cleaner technology) are mostly discussed as reasons for different effects of factors in prior studies. Lastly, directions for future research are provided.

Keywords

Sustainable technology; Adoption; Production process technology; Systematic review; Determinants

1. Introduction

Failure in climate change mitigation and adaptation is perceived as the most important risk for the future (World Economic Forum, 2016). Governments worldwide are increasingly stimulating sustainable economic development and are urging firms to reduce waste and energy consumption. Sustainable technologies, which can be incorporated in products, processes, services and business models (Schiederig et al., 2012), are considered effective means to achieve sustainable development and have gained much interest from governments and firms. Sustainable technologies reduce negative effects on the environment by reducing or preventing pollution, reducing resource consumption (e.g., raw materials, energy), or using less polluting or energy intensive materials (Babl et al., 2014; Belis-Bergouignan et al., 2004; Dewick and Miozzo, 2002; Kemp et al., 1992; Luken et al., 2008; Shrivastava, 1995). Sustainable technology not only plays an important role for countries in the transition to sustainable development but also simultaneously provides firms with legitimacy and competitiveness (Bansal and Roth, 2000).

Over the past few decades, the number of publications about the sustainability performance of firms has increased dramatically (Linnenluecke and Griffiths, 2013; Schiederig et al., 2012). Extensive studies have been conducted to examine the effects of governmental policies, firm characteristics, and market and societal factors on the adoption of sustainable technologies (e.g., Arvanitis and Ley, 2013; Frondel et al., 2007; Luken and Van Rompaey, 2008; Luken et al., 2008). The research results, however, are mixed across different fields. For example, environmental regulation, considered an important means to promote sustainable technology adoption, has been found to have positive, negative or non-significant effects on sustainable technology adoption by firms. The causes of these varying results, such as the different policy instruments, time at different diffusion stages, and sample heterogeneity, are not clear. This makes the knowledge on sustainable technology adoption not only fragmented but also less valuable, making it difficult for policy-makers and firm managers to draw conclusions and act. Therefore, a literature review analysing the findings from different research settings is needed to integrate these fragments and provide policymakers and practitioners with rigorous and transparent evidence to promote sustainable technology adoption.

Various literature reviews have been published in the past decade. Some were conducted on the broad issue of corporate sustainability (e.g., Adams et al., 2016; Linnenluecke and Griffiths, 2013; Salzmann et al., 2005). The corporate sustainability reviews focus on performance effects (See Linnenluecke and Griffiths, 2013; Salzmann et al., 2005) and broad organizational characteristics (See Adams et al., 2016). In regard to adoption, the focus is largely limited to managerial attitudes (See Salzmann et al., 2005). Only five literature reviews were conducted in the field of sustainable technology adoption (i.e., Del Río González, 2009; Kemp and Volpi, 2008; Montalvo, 2008; Sarkar, 2008; Shi and Lai, 2013). Shi and Lai (2013) conducted a literature review on green and low carbon technology research and found 38 articles in the field of technology innovation adoption and diffusion with no specific discussion about the determinants of sustainable technology adoption. Three literature reviews discuss determinants of sustainable technology adoption: Del Río González (2009), Montalvo (2008), Sarkar (2008). These studies did not distinguish between different types of sustainable technology, such as product, process, practices or systems. Since the determinants of sustainable technology adoption may vary between product and process types (Del Río González, 2009), a more specific literature review is needed. Kemp and Volpi (2008) focused on sustainable process technologies, but they only provide ten stylized facts about the endogenous and exogenous mechanisms of clean process technology adoption and diffusion, without discussing the determinants of adoption.

These descriptive reviews provide a basic understanding of research in this field and the factors affecting sustainable technology adoption. However, since these reviews were published, much more studies have been conducted. The variety of sustainable technologies investigated has increased; more factors have been investigated, and differences in the effects of the factors among studies have become salient. A more rigorous literature review that not only summarizes influential factors but also explains the differences in the effects of factors across studies is needed for policy-makers and managers. Therefore, the aim of our study is to conduct such a systematic review, focusing on sustainable process technologies. By synthesizing the data from prior literature, it provides thoroughness and rigor in the analysis. We focus not only on the convergence of prior studies but also on the divergence, which could provide us with a better understanding of the mixed evidence and the effect of factors in different contexts.

In this literature review, we focus on sustainable process technologies for the following reasons. First, theoretically, determinants for the adoption of process technologies likely differ from the determinants for product technologies (Del Río González, 2009; Ettlie et al., 1984). Designing new products, for example, may have a stronger involvement of and focus on customers, whereas (re)designing new manufacturing processes is largely focused on internal objectives. Besides, while the adoption of sustainable production technology is part of the innovation and development process, the development of sustainable process technology is often done by suppliers, thus separated from the adoption by (customer) firms; only large firms have the capacity to develop sustainable process technologies themselves (Kemp et al., 1992). Therefore, different types of stakeholders are involved for product technology and process technology. Second, practically, according to energy efficiency and CO_2 emission reports, nearly one third of the world's energy consumption and CO_2 emissions can be attributed to manufacturing industries (International Energy Agency, 2007). The use of best practice commercial technologies in manufacturing industries has the potential to reduce industrial energy use by 18-26% and industrial CO_2 emissions by 19-32% (International Energy Agency, 2007). Since best practices in commercial technologies are mostly process technologies, the adoption of sustainable process technologies has the potential to greatly reduce energy consumption and pollution emissions. Third, methodologically, distinguishing between different technology types and focusing on one type ensures a high level of comparability between studies and therefore a greater reliability of the results when summarizing and comparing the effects of various factors on sustainable process technology adoption compared to a review that does not differentiate between technologies.

This literature review aims to systematically analyse and compare the effects of these factors from various studies rather than to provide a summary of factors. Specifically, the overarching review research question is: what factors influence the adoption of sustainable process technologies by firms, and how do the factors differ in their effects? To answer this question, we studied the following elements:

- How was sustainable process technology adoption measured?
- Are the effects of the factors different across various research settings?
- What causes the differences in the effects of factors found across studies?

This paper is structured as follows. First, we describe the method used to select and analyse the studies. Subsequently, general characteristics of the included studies, such as publication trends, and investigated regions and journals, are presented. Then, we synthesize and compare the evidence found in the studies that investigated the factors affecting sustainable process technology adoption by firms. In the final section, we discuss the contribution identify research opportunities in the field of sustainable process technology adoption and draw conclusions.

2. Methodology

Compared with descriptive literature reviews, a systematic review minimizes the bias and random error through a replicable, scientific and transparent process (Cook et al., 1997; Tranfield et al., 2003). A systematic review not only summarizes the results from prior literature but also explains the differences among studies (Cook et al., 1997). By ensuring "context sensitivity" in a methodologically rigorous way, systematic reviews help policy-makers and firm managers build a reliable knowledge base for decision-making (Tranfield et al., 2003).

Conducting a systematic review includes the identification of the research, selection of studies, study quality assessment, data extraction and monitoring progress, and data synthesis (Tranfield et al., 2003). We controlled the quality of the studies through the literature databases employed and by including only peer-reviewed papers. Thus, we did not conduct a separate quality assessment. However, in the data analysis stage, we took the Journal Impact Factor, generalization (sample size, industry coverage), and analytical methods (whether regression is included) into account to help us better interpret the results from the prior studies. In the following sections, we describe the data selection, extraction and synthesis methods.

2.1 Data collection

We used two literature databases, the Social Science Citation Index, based in the Web of Science™ Core Collection of Thomson Reuters, and Science Direct of Elsevier, to search for scholarly peer-reviewed journal articles. The Web of Science Core Collection is commonly used as a source of bibliometric data because it has a comprehensive coverage of over 3000 journals across 55 disciplines since 1956, and ensures the quality of the literature by using the commonly accepted citation indexing. For Science Direct, the section, 'Business, management and accounting', covers over a hundred periodicals and lists potentially important new journals that are not yet included in the citation indexes. These two databases cover most of the studies in this field.

'Sustainable', 'technology' and 'adoption' were chosen as keywords in this literature review. During the search process, similar terms were identified and used for each keyword. Seven synonyms of "sustainable" were identified: 'green', 'eco', 'ecological', 'environmental', 'clean', 'energy-saving/efficiency', and 'material-saving'. 'Adoption' and 'implementation' were chosen as keyword for the firms' technology choice behaviour. The combination of 'sustainable technology' and 'adoption' and their synonyms were used as keywords.

A keyword search was conducted in Web of Science Core Collection for the topic field (Title, abstract and keywords) from 1945 until April 2016. Then, articles were selected according to their field, document type and language. Articles in the field of 'environmental studies', 'environmental sciences', 'management', and 'business' were included. Because the articles normally belong to more than one field, and most articles belong to the fields of 'environmental studies' and 'environmental sciences', most of the studies were included. The document type was restricted to 'articles'. Thus, other document types (proceeding papers, review, book review, etc.) were not considered. Finally, the language was restricted to English.

As for articles collected from Elsevier, a keyword search was conducted in the abstract, title and keyword fields, for all available years (from 1823). The search was refined to journal articles in the field of business, management and accounting. One article was excluded because it was not written in English (there is no language filter in the Elsevier database). Finally, 87 articles were obtained from Science Direct.

The specific search terms and the numbers of the articles from each combination of keywords are listed in Table A.1 in the Appendix. The data was collected in April 2016. After the keyword search was conducted, 218 duplications were excluded from the database. Finally, 447 potential articles remained.

2.2 Inclusion criteria for content screening

Following the keyword search, the potential articles were subjected to a manual content screening process, using the following inclusion criteria (see Figure 1 for the decision tree).

[Please insert Figure 1 about here]

Emphasis on implementation aspects of adoption. During the content screening process, we chose articles that test or explain the effect of specific factors on sustainable technology adoption. Articles focused on the consequences of the adoption, evaluation of sustainable technology and articles that merely studied the development of sustainable technology were excluded from the literature review. By using these criteria, we excluded 192 articles.

We emphasized the implementation aspects of adoption instead of the development of technology. Once organizations realize a need or become aware of a technology, they can develop it themselves or purchase it from technology suppliers. In either case, if the goal is the self-implementation of the technology, it can be considered adoption behaviour. Therefore, in this study, we follow Rogers (2003) to define adoption as the activities that occur from the first awareness of a need to implement a technology to the final routinizing of the technology, and all the activities in-between. Organizations could purchase the technology directly from suppliers, but they could also co-develop it with other organizations or develop the technology themselves. Therefore, this literature review focuses on the adoption literature, instead of on the general innovation literature.

Sustainable production process technology classification. We selected articles about sustainable production process technologies, including end-of-pipe technologies, cleaner technologies, or both. By using this criterion, we excluded 60 articles that did not include sustainable production process technologies and 15 articles that combined sustainable production process technologies with other types of sustainable technologies in a way that the process technologies could not be analysed separately. If an article included not only sustainable production process technology but also product technology, for example, we analysed the results only with respect to sustainable production process technology.

Sustainable process technologies are commonly divided into end-of-pipe technologies and clean technologies according to the way they are integrated in the production process (see Figure 2). End-of-pipe technologies add extra equipment, such as scrubbers and filters to the production process, and address pollutants after they have been generated (Frondel et al., 2007). Cleaner technologies can also result in the reduction of pollutants, but they reduce the pollutants from the generation of pollutions. Cleaner technologies involve substituting or modifying (parts of) the existing production process, which generally leads to both the reduction of pollution and the reduction of energy and resource usage (Frondel et al., 2007).

[Please insert Figure 2 about here]

More specifically, the United Nations Environment Programme (UNEP) defines clean production as "the continuous application of an integrated preventative environmental strategy to processes, products and services to increase efficiency and reduce risks to humans and the environment" (United Nations Industrial Development Organization, accessed on 12 October 2017). UNEP classifies cleaner production implementation into eight categories, which are 'good housekeeping', 'change of input material', 'better process control', 'equipment modification', 'technology change', 'on-site recovery/reuse', 'production of useful by-products', and 'product modification'. Since we focus on sustainable production process technology, we excluded 'good housekeeping' (sustainable management) and 'product modification' (sustainable products).

Sustainable technologies could be used in the preparation stage, production stage, and after-production stage. In the preparation stage, besides 'input materials change', 'input energy change' (cogeneration or fuel substitution) is also a type of cleaner technology (See Del Río González, 2005), which is not included in UNEP's definition. They could be referred to together as 'Energy/material substitution' sustainable technology. In the production stage, by modifying working procedures, production equipment or replacement of technology, etc., the effects of 'better process control', 'equipment modification' and 'technology change' are either more efficient use of energy or materials, lower generation of emissions, or both. Therefore, 'better process control', 'equipment modification' and 'technology change' could further be classified as 'reduction of emission generation technology' or 'energy/material efficiency technology'. Because an increase in energy/material efficiency would result in the reduction of emissions simultaneously, the 'reduction of emission generation technology' is referred to only when the effect of 'better process control', 'equipment modification', or 'technology change' was merely the reduction of emissions generation. Lastly, the after-production stage includes 'on-site recovery', 'production of useful by-products', and 'end-of-pipe technology'. 'On-site recovery' and 'production of useful by-products' are both 'recycling technology', because such technologies recycle the waste either within or outside the firm. The main difference between 'material efficiency' and 'recycling' technologies is that material efficiency technologies reduce the generation of waste and recycling technologies reuse the waste after it has been generated.

Therefore, by adding "end-of-pipe technology" and 'input energy change' to UNEP's definition of clean production, we get a more comprehensive categorization of sustainable technologies (Figure 2). Using this categorization, we selected articles investigating the adoption of sustainable process technologies.

Organizational level of analysis. The aim of this study is to analyse organizational sustainable technology adoption. Therefore, articles that were at the individual, family, regional, industry or state level of analysis are excluded. By this criterion, we excluded 109 articles.

Only quantitative empirical studies. In this study, we include only quantitative empirical studies. By this criterion, we excluded four literature reviews, 27 theoretical or conceptual articles, and six qualitative studies. Finally, 34 articles met all criteria and were included in the review.

2.3 Analysis

2.3.1 Theoretical background of factor classification

The aim of the literature review is to have a full description of factors that have an impact on sustainable process technology adoption. The classification of factors aims to be theoretically meaningful, robust and testable for future theory development. Factors within one category should be consistent, and the distinction between categories should be clear. Single-theory-based classification inevitably focuses on particular types of factors while neglecting others, making it difficult to capture the whole range of factors of sustainable technology adoption, whereas multiple-theory-based classification usually overlaps in labelling factors. For example, environmental regulation is deemed as coercive pressure in institutional theory, while in stakeholder theory, the government is deemed as one stakeholder. Therefore, we adopted a two-stage approach; in the first stage, an inductive approach of content analysis for factors used in prior studies based on the measurements and labels is used. In the second stage, we used a multiple-theory-based approach to further condense the classification of factors and make it more theoretically testable.

First, measurements and labels of factors were coded. In the first round, we use categories that are more descriptive than analytical. Simple categories, such as internal, external and technology characteristics were derived by analysing the measurement scales and labels of factors. This process is conducted in several rounds; similar measurements of factors are grouped in a generic classification. Second, within each category, factors were grouped according to their theoretical background in prior studies. For example, technology factors were grouped under the label of relative advantages and compatibility according to Rogers (2003)'s diffusion of innovation model. External factors from the governments, peer organization and society were grouped as legitimacy according to institutional theory. Number of employee, production capacity, and revenues were grouped as firm size. Environmental management tools include cost management, environmental management system (EMS), ISO certification, life-cycle analysis etc. In general, the classification merged from an iterative content analysis of measurement model and theories, involving coding, developing and refining, and investigating theories.

2.3.2 Data synthesis and comparison

A two-stage analysis is used, as suggested by Tranfield et al. (2003). The first stage provides a descriptive analysis by summarizing the general characteristics of the included studies. The second stage is an in-depth synthesis of the results from the studies.

In the second part of the analysis, we chose a qualitative synthesis method instead of a quantitative method. The aim of a quantitative synthesis is to evaluate the effect of a specific intervention quantitatively by combining evidence from various studies together in a meta-analysis using multivariate statistics. A qualitative synthesis, on the other hand, can consider the context of former studies. Since the aim of this literature review is not only to understand the effect of a specific factor but also to explain the effect and understand the often-contradictory evidence in different contexts, a qualitative synthesis appears to be appropriate for this purpose. Moreover, because of the wide variety of sustainable technologies under investigation and the variation in the measurement of adoption in the literature compared with the limited number of studies included, a quantitative synthesis would not be appropriate. Lastly, a qualitative synthesis can also identify contributions in a field, whereas a statistical procedure only synthesizes findings and does not distinguish individual contributions (Tranfield et al., 2003).

Following the description of qualitative synthesis by Petticrew and Roberts (2008), the results were summarized in three steps: (i) organizing the studies into logical categories; (ii) analysing the findings within each category; and (iii) synthesizing the findings across all studies. In the analysing phase, information about the measurement of the independent and dependent variables, sample, control variables, positive, negative or non-significant effects of the factors under investigation was extracted from each study in a standard format. Categories of dependent and independent variables are firstly recognized. The category of dependent variables is based on the definition of sustainable process technologies that is discussed in Section 2.2. For each type of sustainable process technology and each factor, the number of positive, negative, non-significant results was counted. In the analysing process, we firstly described the measurement scale of each factor, then examined whether there is consensus of positive, negative or non-significant impact in prior studies. In the case of different findings regarding the impact of factors, we continued by comparing technology difference, factor measurement difference and sampling difference. Finally, we summarized the findings of the prior literature, considering the variations of samples, measurement models, interventions, and research settings.

3. General characteristics of included studies

First, a descriptive summary of the characteristics of the included studies is presented, including publication dates, the investigated regions, and journals.

Figure 3 presents the distribution of publications per year. The first publication was in 1998. Until 2005, only one paper on sustainable process technology adoption per year was published, with no publications in 1999, 2002, 2003 and 2004. Since 2008, the number of publications has increased gradually, peaking at seven publications in 2013 and 2015. When Kemp and Volpi (2008) and Montalvo (2008) published their literature reviews in 2008, few studies in the field of sustainable process technology adoption had been published. The limited number of publications may be the result of inadequate access to the data concerning sustainable process technology adoption.

[Please insert Figure 3 about here]

Sustainable process technology adoption has been studied mostly in Europe, followed by the US (See Table 1). Among the five international studies, three studies collected data within European countries. Among the 10 studies investigating other regions, six occurred in European countries, i.e., Spain, Belgium, Greece, Switzerland, Germany or the UK. With respect to Asia, most studies were conducted in mainland China, India and Taiwan.

[Please insert Table 1 about here]

The distribution of publication journals (see Table 2) indicates that the studies in this field are scattered over various journals. Two journals were found to be slightly more important in this field: Ecological Economics and Research Policy. Sixteen journals published only one article about sustainable process technology adoption. Most of these 16 journals are in the fields of business & management, environmental studies, and economics.

[Please insert Table 2 about here]

4. Measurement of sustainable process technology adoption

We discuss the characteristics of the dependent variables from two perspectives: the technology type and the adoption stage (See Table 3). In addition to the five types of sustainable process technologies (See Figure 2), we added another category, named 'general sustainable technology', to include studies that measure sustainable technology as a mixed combination of more than one type of sustainable technology. Moreover, we combined 'end-of-pipe technology' and 'reduction of emission generation technology' into one category 'CO_2/Emission reduction', since in some studies it is unclear whether it is end-of-pipe technology or clean technology. Most studies are classified in the general sustainable process technology category.

‘CO_2/emission reduction technology’ and ‘energy/material efficiency technology’ are also widely investigated compared with others. ‘Material/fuel substitution’ and ‘recycling’ are seldom studied independently.

Regarding the adoption stage, initiation is distinguished from the implementation of sustainable process technology. In the initiation stage, information gathering and adoption willingness are studied. In the implementation stage, four indicators are used to measure adoption, which are investment in sustainable process technology, a dichotomous variable for having implemented the technology, adoption time and adoption degree of sustainable process technologies. The detailed measurements of sustainable process technology adoption in each study are listed in Table A.2. With respect to adoption indicators, most studies used either a dichotomous variable or an ordinal variable to measure sustainable technology adoption. Three studies use expenditure on sustainable process technology as the dependent variable (i.e., Demirel and Kesidou, 2011; Hammar and Lofgren, 2010; Lofgren et al., 2014). Only one study investigates information gathering during the adoption process (i.e., Kounetas et al., 2011). Two studies investigate the adoption time (i.e., Bellas and Nentl, 2007; Maynard and Shortle, 2001) and the same for the willingness of entrepreneurs (i.e., Zhang et al., 2015; Zhang et al., 2013).

End-of-pipe technology and clean technology are a common classification of sustainable process technology. The term ‘clean technology’ was used directly in some cases (e.g., Wagner, 2007, 2009; Zhang et al., 2013). Otherwise, researchers adapted the definition of clean technology from similar terms. Demirel and Kesidou (2011) adopted OECD’s definition of clean technology, referring it to “new or modified production facilities, which are more efficient than previous technologies, and contribute to pollution reduction by cutting down the amount of inputs used for production and/or by substituting the inputs with more environmentally friendly alternatives”. Sangle (2011) described four integrating method of clean technology, which are input material change, better process control, equipment modification, and on-site recovery and reuse. These two studies put emphasis on three aspects of clean technology, which are efficiency increase, environmentally friendly input use, and pollution reduction. However, other studies only emphasized parts of these aspects. For example, Triguero et al. (2013) used the term 'eco-innovative production process or method', adapted from the definition of eco-innovation - "reduces the use of nature resources (including materials, energy, water and land) and decreases the release of harmful substances" - , neglecting the environmentally friendly input use. Hammar and Lofgren (2010) used investment in clean technology as indicator, so they adapted the definition from Environmental Protection Investment, - the "prevention, reduction and elimination of pollution or any other degradation of the environment" - only emphasizing the pollution aspect. Most often, 'general sustainable technology' contains a list of various sustainable technologies.

The main effect of CO_2/emission reduction technology is the reduction of emissions to the solid, water, air etc. Because of the specificity of CO_2, the reduction of CO_2 emission is often used as an independent variable distinguished from other types of emissions like NO_X or water (See Antonioli et al., 2013; Borghesi et al., 2015; Cainelli et al., 2012; Lofgren et al., 2014; Veugelers, 2012). End-of-pipe technology is used directly in some cases (e.g., Camison, 2010; Demirel and Kesidou, 2011; Hammar and Lofgren, 2010), while others used specific examples, such as fabric filter (e.g., Bellas and Nentl, 2007) or post-combustion technology (e.g., Bonilla et al., 2015; Popp, 2010). Another emission reduction technology is combustion technology that inhibits the formation of NO_x in the combustion stage, so it is regarded as a clean technology (See Bonilla et al., 2015; Popp, 2010).

Material/fuel substitution technology is studied as a separate dependent variable only in five studies (i.e., Leenders and Chandra, 2013; Maynard and Shortle, 2001; Theyel, 2000; Yusup et al., 2015). In other studies, it is incorporated as part of the category 'general sustainable technology' that is measured by a list of various sustainable technologies (See

Camison, 2010; Jimenez, 2005; Veugelers, 2012; Weng and Lin, 2011). Fuel substitution technology is studied only in one case, using a specific example of propane in the brickmaking industry (i.e., Blackman and Bannister, 1998).

Energy/material efficiency technology is widely studied. It aims to reduce the material and/or energy use per unit of output. One example of energy efficiency technology is flue gas condensation technology, which is studied by Bonilla et al. (2015). Another specific example of material efficiency technology is extended delignification, oxygen delignification, studied by Maynard and Shortle (2001). Arvanitis and Ley (2013) listed various energy-saving technologies according to application fields, such as in electromechanical and electronic applications, and power-generating processes.

Recycling technology is used as a separate variable in four studies (i.e., Cainelli et al., 2015; Leenders and Chandra, 2013; Triguero et al., 2015; Yusup et al., 2015). Recycling sometimes is combined with material efficiency technology as one variable, even though from the definition material efficiency technology results in lower rates of waste generation while recycling technology utilizes wastes after they are generated.

[Please insert Table 3 about here]

5. Determinants of sustainable technology adoption

In this section, we synthesize the results of studies on the effect of the factors on sustainable process technology adoption (section 5.1) and the interrelationships between these factors (section 5.2). Every determinant (or independent variable) in the prior studies is coded, classified, and compared across studies. We classified the determinants into the following categories: market pressure, legitimacy pressure, and characteristics of the information, firm, technology, and network. The difference regarding the impact of factors across studies is analysed from the perspective of measurements of independent variable and dependent variable and sample difference. Control variables used in the studies were not included in our analysis since our focus is on the determinants that researchers recognize as important. When more than one regression model is used in a study, we extracted the results only from the full model that includes all the factors.

5.1 The direct effect of determinants

Table 4 lists the studies and the number of positive, negative and non-significant relationships tested in each study for each determinant. When analysing the positive, negative and non-significant relationships, we adopted the 5% level of significance for two-tailed tests and the 10% level of significance for one-tailed tests. Factors that have been included in only one study are excluded because there is not enough information available to draw valid conclusions.

Since adoption willingness, expenditure, put into use and adoption degree largely represent firms' adoption behaviours, we treated them as adoption behaviours and listed them in Table 4. However, although the studies with the dependent variables of information gathering and adoption time were discussed when relevant, they were excluded from Table 4, because the former is only one stage in the adoption process and the latter distinguishes between early adopters and later adopters but does not measure behaviour. Furthermore, because Camison (2010), Trianni et al. (2013) and Yusup et al. (2015) do not use regression analyses, they are not included in the list but are discussed when relevant. If more relationships are tested in one study due to multiple samples or multiple dependent variables, we use the figure between brackets to indicate the number of relationships tested in each study.

[Please insert Table 4 about here]

Market pressure. The market exerts pressure on sustainable technology adoption through customer demand, market competition and the price of resources, but there is little evidence, and it is largely mixed, especially regarding CO_2/emission reduction, energy/material efficiency and material/fuel substitution technology adoption.

Perceived pressure from market stakeholders, measured without distinguishing customers, suppliers and competitors, shows a positive effect on the sustainable technology adoption degree (Huang et al., 2009). Studies show that *customer demand* for green products has a positive effect on sustainable technology adoption, measured by whether the company introduced clean technology or recycling technology (e.g., Triguero et al., 2015; Triguero et al., 2013), and a 7-point Likert scale that measured the extent of green innovation adoption (e.g., Weng and Lin, 2011). However, no significant effect from customer demand was found on the adoption of energy-saving technologies (Arvanitis and Ley, 2013), material/fuel substitution or recycling technologies (Leenders and Chandra, 2013).

Regarding *market competition*, the intensity of price competition is found to have a positive effect on the adoption of energy-saving technologies in electromechanical and electronic applications only (Arvanitis and Ley, 2013). Additionally, Leenders and Chandra (2013) did not find a significant effect of competitive pressure on the adoption degree of material/fuel substitution or recycling technologies.

Resource prices include the prices of energy, materials and CO_2. General sustainable technology adoption is positively affected by the energy price but not by the material price (Luken et al., 2008; Triguero et al., 2013). Unexpectedly, the CO_2 price (See Lofgren et al., 2014), used in the European Emission Trading System, and the energy price (See Arvanitis and Ley, 2013) do not have a significant effect on CO_2/emission reduction technology or energy-saving technology respectively.

Legitimacy. Most studies found that governmental regulations, measured by regulatory implementation strategy (e.g., Luken et al., 2008), regulatory pressure (e.g., Sangle, 2011; Weng and Lin, 2011), and regulatory stakeholder pressure (e.g., Huang et al., 2009), have a positive effect on sustainable process technology adoption. With respect to CO_2/emission reduction technology adoption, more studies found a positive effect of environmental policies (e.g., Bonilla et al., 2015; Borghesi et al., 2015; Demirel and Kesidou, 2011; Popp, 2010; Veugelers, 2012).

However, the effect of environmental policies is mixed, and seems to depend on the type of sustainable technology and firm size. While Veugelers (2012) found a positive effect of both current regulations and expected regulations on various types of sustainable technology, Bonilla et al. (2015) and Demirel and Kesidou (2011) found that environmental regulations have a positive effect on end-of-pipe technologies only, not on clean technologies. Additionally, environmental regulations have a significant positive effect on the adoption of material-saving technology for medium-sized firms but do not for small-sized firms (Triguero et al., 2015).

Two specific environmental regulations are found to have a negative effect on sustainable technology adoption (See Borghesi et al., 2015; Popp, 2010). Borghesi et al. (2015) studied the effect of European Emission Trading Schemes, and Popp (2010) investigated the presence of federal, state and local level regulations and the allowable levels of emissions. When a strict regulation is launched or fewer emissions are allowed, firms are more likely to adopt more advanced technologies (Popp, 2010). Adoption of the technology that has the highest emission reduction potential caused a negative environmental regulation effect on the less advanced technologies. This also proved the effectiveness of environmental regulations on sustainable technology adoption. Even though firms in the European Emission Trading Schemes are more likely to adopt both CO_2/emission reduction technology and energy-saving technologies, Borghesi et al. (2015) found a negative effect of the stringency of European Emission Trading Scheme and explain it as a “wait and see” policy in the first phase of regulation. This result is consistent with Lofgren et al. (2014), who found no significant effect of CO_2 price on sustainable technology adoption by firms. Both results questioned the effectiveness of the European Emission Trading System. Despite of the strong connections between environmental regulation and sustainable technology adoption by firms, there are several studies that did not find a significant relationship (e.g., Arvanitis and Ley, 2013; Bellas and Nentl, 2007; Blackman and Bannister, 1998; Leenders and Chandra, 2013; Lofgren et al., 2014; Triguero et al., 2013). Most of these studies either focus on one specific industry (i.e., Blackman and Bannister, 1998; Leenders and Chandra, 2013), a specific regulation scheme (i.e., Lofgren et al., 2014), or a specific sustainable technology (i.e., Bellas and Nentl, 2007). Therefore, environmental regulation generally has a positive effect on sustainable technology adoption. However, regarding specific environmental laws and specific sustainable technologies, its effect varies.

Voluntary standards, such as cleaner production agreements (CPA) launched by the Chilean government, to carry out well-defined environmental action plans, are found to have a significant positive effect on incremental innovation and process change (Jimenez, 2005).

The effects of governmental *economic and technical support* are mixed. Whereas Weng and Lin (2011) found that positive governmental policy instruments, such as financial support, technical assistance and training manpower have a positive effect on the adoption of green innovations by firms, Triguero et al. (2013) and Veugelers (2012) have not found a significant relationship between positive policy instruments and sustainable technology in general (measured as whether firms adopt sustainable technology). Additionally, positive policy instruments are also measured as whether firms adopt sustainable technologies in reaction to subsidies or other financial incentives (See Veugelers, 2012), public funding for innovation (See Borghesi et al., 2015), access to subsidies and fiscal incentives (See Triguero et al., 2015; Triguero et al., 2013), and technical support (See Luken et al., 2008). However, the effect of public funding is not significant for the adoption of CO_2/emission reduction technology according to Borghesi et al. (2015), whereas Veugelers (2012) suggests that positive policy instruments have a positive effect on CO_2 emission reduction technologies but no significant effect on energy-saving technologies. In addition, subsidies or other financial incentives are found to have a positive effect on clean technology adoption for small firms only (Triguero et al., 2015).

Therefore, coercive pressures could promote sustainable technology adoption by firms, although its effect also depends on the type of coercive pressure, the type of sustainable process technology (See Camison, 2010; Demirel and Kesidou, 2011; Triguero et al., 2015) and the firm size (See Triguero et al., 2015).

Mimetic pressure has been studied less frequently than coercive pressure. Arvanitis and Ley (2013) found that whether firms in the same industry have introduced energy-saving technology has a significant positive effect on firms' adoption, whereas the adoption intensity of other firms within the same industry does not have a significant effect. Bonilla et al. (2015) found that the number of firms that adopted the technology in a previous year has a significant positive effect on the adoption of clean technologies (combustion technology and flue gas condensation technology) but not on end-of-pipe technologies (post-combustion technology). Contrary to Bonilla et al. (2015), Popp (2010) found that industry experience with combustion modification technology had a negative effect on its adoption, but the effect is minimal, and industry experience with post-combustion technology has a positive effect on the adoption of post-combustion technology by firms.

Normative pressures also received little attention. Zhang et al. (2013) and Zhang et al. (2015) confirmed the positive effect of normative pressures on entrepreneurs' willingness to adopt sustainable technology, even though this may be because both studies combined regulatory pressure with social pressures. On the other hand, Sangle (2011) found that adopters perceive lower stakeholder pressure (pressures from business partners, financial institutes, investors, owners, parent company, customers, NGOs, local community) than non-adopters. Both Arvanitis and Ley (2013) and Luken et al. (2008) found no significant effect of normative pressure on general sustainable technology and energy-saving technology in either a developed country (Swiss) or developing countries. Therefore, the effect of the pressure from the public on the adoption behaviour of firms is still uncertain.

In conclusion, regulation is an important determinant for sustainable technology adoption, especially for CO_2/emission reduction technology and energy/material efficiency technology. The effect of economic support on sustainable technology adoption is still uncertain. Most studies found non-significant effects for general sustainable technology, which may indicate that economic support is particularly important for a specific type of sustainable technology instead of sustainable technology as a whole. Mimetic pressure seems to have significant effect on sustainable technology adoption by firms, even though its effect varies with the type of sustainable technology that others have adopted. Normative pressure has been seldom investigated for specific types of sustainable process technology. Whether it has positive, negative, or non-significant effects is still unclear.

Information characteristics. Information characteristics are studied from the perspective of uncertainty and source diversity. Weng and Lin (2011) found that perceived environmental *uncertainty*, relating to competitor and customer behaviours, and technology development, has no significant effect on sustainable technology adoption by firms. Moreover, Arvanitis and Ley (2013) found that non-adopters of energy-saving technology regard information less as a problem than adopters, which may be because they assess the problems to be less severe before adoption.

Information from various *sources*, such as internal sources, suppliers, private research institutes, conferences and business associations, has a positive effect on sustainable technology adoption, measured as whether sustainable technology is adopted (Cainelli et al., 2015; Triguero et al., 2013). Borghesi et al. (2015) found that information from other firms, clients, and conferences is positively related to energy efficiency technology adoption, whereas information from conferences and industrial association services are positively related to CO_2 reduction technology adoption.

Firm characteristics. *Firm size* is measured by the number of employees, capacity, revenue or sales. The conclusions of the studies differ in regard to the effect of firm size across the four sustainable technology adoption categories, whereas no study was found in the recycling category. Positive (See Arvanitis and Ley, 2013; Bonilla et al., 2015; Hammar and Lofgren, 2010; Lofgren et al., 2014; Popp, 2010), negative (See Bellas and Nentl, 2007; Maynard and Shortle, 2001) and no significant effect (See Blackman and Bannister, 1998; Luken et al., 2008; Popp, 2010; Wagner, 2009) were all found. These different conclusions may relate to more than the difference in measures.

A negative effect of firm size is explained from a diffusion perspective; smaller firms are more likely to be the earliest adopters of innovative technology, and larger plants are more likely to adopt innovation when installing new equipment (Bellas and Nentl, 2007). A positive effect likely relates to the financial resources that firms possess and access to knowledge (Lofgren et al., 2014). The contrasting effects may also suggest an inverse U-shared relationship. Yusup et al. (2015) found that firms with less than 75 employees and with 201-400 employees adopted more renewable resources than firms with 75-200 employees. Overall, firm size is more often found to have a positive effect on the adoption of CO_2/emission reduction technologies than the other types of technologies.

The few studies that investigate *ownership* effects have different conclusions across sustainable technology categories. No study was found in the recycling technology category. Foreign ownership of firms in developing countries has a positive effect on general sustainable technology adoption (Luken et al., 2008) because the partners bring new technologies. However, the role of foreign ownership depends on the type of sustainable technology and the type of ownership. Firms are less willing to adopt energy-saving technology related to power-generation, because they do not own the energy-generation processes (Arvanitis and Ley, 2013). The adoption of energy/material efficiency technology and CO_2 abatement technology does not appear to be affected by multinational ownership (Cainelli et al., 2012). State-owned firms are more willing to adopt sustainable technologies due to privileged access to finance (Luken et al., 2008), whereas privately owned firms are less likely to adopt post-combustion treatment technologies, because of the cost concerns (Popp, 2010). The adoption of propane and fabric filter technology is not found to be significantly related to public or private ownership (Bellas and Nentl, 2007; Blackman and Bannister, 1998).

Export activity effects have rarely been investigated. No significant effect of has been found on the adoption of various sustainable process technologies (See Arvanitis and Ley, 2013; Cainelli et al., 2012; Luken et al., 2008). Kounetas et al. (2011) found that firms that have access to foreign markets are more likely to be informed of sustainable technology. However, technology cost considerations and environmental regulations of the importing countries may be barriers.

Regarding firms' sense of *responsibility*, the limited number of available studies show that internal support from top managers (See Weng and Lin, 2011) and internal stakeholders (See Huang et al., 2009) have a positive effect on the sustainable technology adoption by firms, though investments in environmental protection following a corporate social sustainability strategy have no significant effect (See Demirel and Kesidou, 2011).

Human capital intensity is studied from the perspective of human resource quality and the complementarity of human resource management with other organizational innovations. Human resource quality is measured by the investment per employee, employees' education, experience and wages. Human resource quality positively affects the adoption of general sustainable technology, fuel substitution technology (propane), and recycling technology (See Blackman and Bannister, 1998; Cainelli et al., 2015; Weng and Lin, 2011). With respect to investments in CO_2 reduction technologies, a negative effect of human resource quality (measured as wages) on small investments is seen, but no significant effect on large investments is found (Lofgren et al., 2014). However, the adoption of energy-saving technology (dummy) is significantly positively related to investment per employee (Arvanitis and Ley, 2013), whereas the adoption of energy-saving technologies in power-generating and of material substitution technologies (elemental chlorine-free bleaching) is negatively related to the share of employees with tertiary-level education (Arvanitis and Ley, 2013; Maynard and Shortle, 2001). The complementarity of human resource management with other organizational innovations is present only in the case of CO_2 reduction technology adoption (Antonioli et al., 2013). In general, firms with high levels of human resource quality are more likely to adopt sustainable technologies, but it depends on the type of technology and the size of the investments in human resources.

Technological capability is measured as a compound construct, R&D activities, internal expertise and innovation capabilities. When technology capability is measured as a compound construct, positive effects are found for the adoption of sustainable process technologies (See Luken et al., 2008; Sangle, 2011; Triguero et al., 2015; Zhang et al., 2015; Zhang et al., 2013). Compared with medium-sized firms, technology capability is more important for small firms to adopt both recycling technologies and material/energy efficient technologies (Triguero et al., 2015). The only case where a non-significant effect is found is the study by Triguero et al. (2013). When measured by R&D activity, it has a significant positive effect only on whether a firm adopts energy-saving technologies and invests in clean technology, not on the adoption degree of clean or end-of-pipe technologies or investment in various types of sustainable technologies (See Arvanitis and Ley, 2013; Cainelli et al., 2015; Hammar and Lofgren, 2010; Lofgren et al., 2014; Maynard and Shortle, 2001; Theyel, 2000). More specifically, Bhupendra and Sangle (2015) found that clean technology adoption requires a broad innovative capability, while pollution prevention technology adoption requires only a partial innovation capability, including business process innovativeness and behavioural innovativeness (Bhupendra and Sangle, 2015).

Financial capability is measured by the profitability, per capital income, and market share, which are not found to have a significant effect (See Luken et al., 2008; Maynard and Shortle, 2001), with the exception of profit on the adoption of elemental chlorine-free bleaching (See Maynard and Shortle, 2001). Therefore, the effect of financial capability is inconclusive.

Resource intensity is studied from the perspective of resource cost (measured by the cost of raw materials, material assets or energy, divided by the turnover, revenue or sales) or resource use in the firms. The results are mixed. Energy expenditure positively affects whether the firm adopts end-of-pipe technologies (Hammar and Lofgren, 2010) and energy-saving technologies in power-generating (Arvanitis and Ley, 2013). With respect to the resources used in the firm, bio-fuel use positively affects whether the firm adopts flue gas condensation technology (energy efficiency technology) instead of post-combustion technology and combustion technology, since it is profitable for earlier adopters (Bonilla et al., 2015). However, with respect to CO_2/emission reduction technologies, the use of bio-fuel has a significant positive effect on large investors in CO_2-reducing technologies only and not on small investors, whereas fossil fuel use is positively significant for both small and large investors in the European Emission Trading Systems sectors (Lofgren et al., 2014). No significant effect has been found regarding the use of coals with different sulphur contents on the firms' adoption of emission reduction technologies (Popp, 2010). Therefore, whether firms use bio-fuel or fossil fuel seems to be important, since they could largely determine the investment returns and the type of sustainable technology needed.

The *knowledge stock* is studied from the perspective of sustainable technology substitution, adoption experience, and patents. With respect to *technology substitution*, Bonilla et al. (2015)

studied three types of specific NO_x emission reduction technologies, and found that post-combustion and flue gas condensation technologies are complementary, while post-combustion and combustion technologies are substitutes, which is in accordance with the results from Popp (2010). *Adoption experience* is measured by earlier investments in other sustainable technologies or former adoption behaviour. The adoption of end-of-pipe technology is positively affected by both earlier investments in sustainable technologies and investments in other technologies, whereas clean technology adoption is significantly positively affected only by investments in other technologies (Hammar and Lofgren, 2010). These effects hold only for small investors in CO_2 reduction technology but not for larger investors (Lofgren et al., 2014). Even though Bonilla et al. (2015) found one significant positive effect of adoption experience, in most cases, it does not have a significant effect on the adoption of NO_x reduction technologies. The firms' adoption experiences could help them to reduce adoption costs, which is especially important for complicated technologies and small firms. However, firms that have adopted sustainable technologies earlier may also be less likely to adopt more sustainable technologies if they are able to meet the environmental standards. Similar to the situation in information gathering, firms that have introduced innovative procedures before are less likely to be informed of energy-saving technologies (Kounetas et al., 2011). With respect to the *patent stock*, the patent growth in sustainable technology has a negative effect on the adoption of less advanced sustainable technologies (combustion modification technology), while it could promote the adoption of the advanced technologies, such as post-combustion (Popp, 2010).

The *environmental management tools* are categorized in environmental practices, certified systems and others managerial activities. *Environmental practices* include cost and quality management. Whether to adopt technology that reduces waste generation is significantly positively affected by waste audits and total cost accounting (Theyel, 2000). Material substitution technology (e.g., non or less hazardous material) is related to quality management and environmental management (Leenders and Chandra, 2013), as well as total cost accounting and pollution prevention for suppliers (Theyel, 2000). For recycling technologies, only environmental management practices have significant positive effects (Leenders and Chandra, 2013). *Certified systems* include environmental management systems (EMS) and ISO certifications. Adopting an EMS has a significant positive effect on general sustainable technology adoption (Luken et al., 2008; Prajogo et al., 2014; Wagner, 2007). However, the EMS and the ISO certificate have significant positive effects on investments in end-of-pipe technology adoption (Demirel and Kesidou, 2011) but not on clean technology adoption (Demirel and Kesidou, 2011; Wagner, 2009). *Others managerial activities* include internal integration of environmental issues and investment in environmental administration. Organizations that have a higher degree of environmental issue integration in their management work, such as cross-functional cooperation for environmental improvements (See Wu, 2013), and environmental criteria for purchasing (See Arvanitis and Ley, 2013), are more likely to adopt sustainable technologies. However, investments in CO_2 reduction technologies is not significantly related with investments in environmental administration (Lofgren et al., 2014).

In conclusion, firm size has a significant positive effect on the adoption of CO_2/emission reduction technology by firms, in particular. Other firm characteristics that are important for all types of sustainable technology adoption include resource costs, adoption experience and environmental tool-certified systems. Technology capability is important for sustainable technology adoption by firms, especially for energy/material efficiency and recycling technology. Environmental practices are more important for material/fuel substation, energy/material efficiency and recycling technology than general sustainable technologies. Human capital quality has both positive and negative effects on sustainable technology adoption by firms. Export activity does not have significant effects on sustainable technology adoption by firms. Regarding the other firm characteristics, because of the limited number of studies and the variations in the results across studies, their effects are still not clear.

Technology characteristics. Perceived relative advantage, measured as a compound construct (See Sangle, 2011; Weng and Lin, 2011; Zhang et al., 2015; Zhang et al., 2013), and perceived economic benefits (See Sangle, 2011) are found to have a positive effect on general sustainable technology adoption. When focusing on one particular aspect of relative advantage, Blackman and Bannister (1998) found that healthy benefits are positively related to the adoption of propane only at the significance level of 10% (2-tailed test), and Demirel and Kesidou (2011) found that cost-saving is not a significant determinant for firms to invest in either end-of-pipe or clean technologies.

The *financial cost*, including the up-front cost, running cost, training cost and return on investment, has a negative effect on sustainable technology adoption (Sangle, 2011). Moreover, taking fabric filters as an example, Bellas and Nentl (2007) found the cost for early adopters are significantly less than for late adopters, likely because the early fabric filters were installed on older units.

When the new technology is *compatible* with existing operations, existing systems, company values or product programme, it has a positive effect on whether the firm adopts energy-saving technology (See Arvanitis and Ley, 2013) and on the adoption degree of various sustainable technologies (See Weng and Lin, 2011). The relative advantage and compatibility are important factors for sustainable technology adoption by firms. However, their effects have not been widely investigated for the adoption of specific types of sustainable technologies. Similarly, the impacts of the financial cost of sustainable technology and other technology characteristics have not been studied enough to draw firm conclusions.

Network characteristics. Network relates to the membership and cooperation of firms with external organizations. With respect to the effect of *membership* of business groups, positive relationships are found for whether the firm adopts energy efficiency technologies (See Borghesi et al., 2015) and recycling technologies (See Cainelli et al., 2015). However, membership in an environmental group (See Maynard and Shortle, 2001) or institutional revolutionary party (e.g., Federation of Mexican Workers, Brickmakers' Union) (See Blackman and Bannister, 1998) that are supposed to promote sustainable technology adoption, does not have a significant effect on sustainable technology adoption by firms. Membership seems to be more important for energy/material efficiency and recycling technologies than CO_2/emission reduction technologies and material/fuel substitution.

Cooperation with different types of stakeholders, which are predominantly environmentally concerned stakeholders (e.g., waste disposal firms, recycling firms), partly environmentally concerned stakeholders (e.g., scientific institutions, competitors), and environmentally neutral stakeholders (e.g., users of products, suppliers of raw material), have different effects on the firms' sustainable technology adoption behaviours (Wagner, 2007). However, eventually, cooperation with various types of stakeholder has positive effects on the sustainable technology adoption by firms. For example, cooperation with both public and private organizations has a positive effect on whether firms adopted sustainable technology, and CO_2/emission reduction technologies in particular (Cainelli et al., 2012). More specifically, cooperation with research institutions, universities or business partners has a positive effect on sustainable technology adoption (Triguero et al., 2013), especially for small firms and recycling technology (See Triguero et al., 2015). Additionally, supplier integration and customer integration also have a positive effect on sustainable technology adoption (Wu, 2013). With respect to sustainable technology information acquisition, cooperation with external experts also promotes information gathering by firms (Kounetas et al., 2011).

5.2 Interrelationships between independent variables

Only six studies have investigated the moderating or mediating relationships of sustainable technology adoption. Information uncertainty (demand uncertainty and technology uncertainty) was hypothesized to moderate the relationship between internal integration, supplier integration, customer integration and sustainable technology adoption, where only demand uncertainty has a significant moderating effect (Wu, 2013).

Additionally, the moderating effects of firm size (See Triguero et al., 2015), and ownership (See Huang et al., 2009) have been investigated. Bigger firms and non-family firms perceive coercive pressure (mainly from environmental regulations) and market pressure to have a greater influence than small firms and family firms on sustainable technology adoption (See Huang et al., 2009; Triguero et al., 2015). Additionally, the influence of subsidies is more important for the adoption of clean technology in small firms than in medium-sized firms (Triguero et al., 2015). However, firm size did not significantly moderate the relationship between technology capability and sustainable technology adoption (Triguero et al., 2015). Huang et al. (2009) found that the relationship between internal support and green innovation adoption is stronger in non-family firms.

Regarding network characteristics, network involvement is more important for small firms to adopt sustainable technology than medium-sized firms (Triguero et al., 2015). In addition, the moderating effects of the spatial relationship (belonging to an industrial district or mechanical district) and cooperation with universities and suppliers have been investigated. The industrial district and mechanical district (more specialized manufacturing region) moderate the relationship between multinational ownership and CO_2 reduction technology adoption (Cainelli et al., 2012). Moreover, supplier cooperation reinforces the relationship between export propensity and various types of sustainable technology adoption, including material efficiency technology and CO_2/emission reduction technology (Cainelli et al., 2012).

Wagner (2009) investigated the moderating effect of country location and country characteristics on the relationships between Environmental Management Systems and cleaner technology implementation. With respect to country location, positive moderating effects are found for the Netherlands, Germany, Sweden, the United Kingdom and Norway (Wagner, 2009). With respect to the country characteristics, such as masculinity and uncertainty avoidance, only stringency of enforcement and institutions had significant negative moderating effects.

The mediating effects of firms' attitudes towards reducing pollution and social pressure have been investigated (Zhang et al., 2015). Regulatory uncertainty negatively affects firms' perceived attitudes towards relative advantage and social pressure, which will prohibit sustainable technology adoption by firms, subsequently (Zhang et al., 2015).

6. Discussion

6.1 Contribution

This study contributes to the literature in two ways. First, it contributes to the sustainable technology adoption review studies by focusing only on sustainable *process* technology, but distinguishing the main types. Prior sustainable technology adoption literature reviews do not make a clear distinction between the various sustainable technology types (cf. Del Río González, 2009; Montalvo, 2008; Sarkar, 2008; Shi and Lai, 2013). Sustainable technology is a broad concept, which can represent products, processes, practices, systems or business models. Because of different consequences, integrating methods and required resources, the determinants for the adoption of each type of sustainable technology may be different (Del Río González, 2009). Based on the typology from the United Nations Environmental Programme, a classification of sustainable process technologies according to the integration method and environmental performance is provided. Our literature review provides therefore a more coherent investigation of the factors related to sustainable process technology adoption, and compares the effects of influential factors for the adoption of each type of sustainable process technology.

Secondly, this literature review contributes to the sustainable technology adoption literature by explaining the different or inconsistent effects of factors across studies. Compared with prior literature reviews that emphasize consensus among results (cf. Del Río González, 2009; Montalvo, 2008; Sarkar, 2008), our literature review described and explained different results in different contexts by distinguishing different sustainable process technologies and measurements, and interrelationships between factors. For example, economic support is more important for CO_2 reduction technology than for the other types of sustainable technologies. Technology capability is less related to sustainable technology adoption when measured by R&D activities than measured by a generic construct. Except for firm characteristic, technology type and measurement difference that could cause the different impacts of factors across studies, another reason is the interrelationships between factors. While most studies in this field focus only on the direct effects of factors, the interrelationships between various influential factors have not been given much attention. Only six articles studied the moderating and/or mediating effects between factors: Cainelli et al. (2012), Huang et al. (2009), Triguero et al. (2015), Wagner (2009), Wu (2013), Zhang et al. (2015), Therefore, this literature review contributes by investigating the differences in impact of factors across studies, and for calling on more studies of the interrelationships between factors.

6.2 Limitation and future research agenda

There are some limitations of this literature review. First, while we collected studies from peer-reviewed academic journals, we did not assess the methodological rigor of the studies reviewed. Further research is needed to include these assessments analysing the results of the studies, for example based on journal citation scores.

Second, we used renowned reports from UNEP and ICT to help us classify the types of sustainable technologies, however, environmental problems have attracted attention from more international organizations. For example, the OECD launched a project on sustainable manufacturing and eco-innovation in 2008. The United Nations Industrial Development Organizations and United Nations Environment Programme have jointly founded the National Cleaner Production Centres. The World Bank developed the Clean Production and Energy Efficiency Project. All these project reports could provide valuable knowledge on sustainable technologies, including process technologies adopted in firms. Future review researchers could also include results from these governmental reports, amongst others.

Third, because of the limited number of studies, it is difficult to explain the differences in the results of some influential factors precisely. We aimed for integrating the different results from the perspective of the sustainable technology under investigation across different samples, and measurements of the independent and dependent variables. More importantly, the diverse results may occur because of the interrelationships between influential factors. A meta-analytic procedure to test the moderating effects of factors could be conducted, as in the study by Damanpour (1991) on the impact of firm characteristics on innovation or in the study by Arts et al. (2011) on green innovation adoption by consumers. Future review researchers could consider more interrelationships between influential factors, such as demographics (i.e., age, size) and behavioural factors (i.e., inter-organizational cooperation) that moderate the impact of the factors on the sustainable technology adoption by firms.

Based on the results of our systematic review, a research agenda can be set out for future studies. First, regarding the limited number of papers and the peculiarities of sustainable process technologies, more factors should be investigated. Even though compared with regular innovations, external pressures, such as environmental regulations are deemed as more important, the investigation of technology characteristics, such as relative advantage, compatibility, and financial cost is useful for policy-makers and technology suppliers to decide what sustainable technology is appropriate to promote. Moreover, compared with regular innovation, sustainable technologies have the double externality problem and more interactions with the ecological, social and institutional systems, require more regulatory push/pull effects and a full involvement of stakeholders (Ali and Peder, 2007; Rennings, 2000), factors, such as the coordination between environmental policy and innovation policy, societal and institutional pressures, effects from capital markets and banking systems should be investigated.

Second, a more integrated conceptual model for sustainable technology adoption should be constructed. Where traditional innovation adoption studies focus on firm characteristics and technology characteristics, sustainable technology adoption is affected more by external pressures and the interrelationships between factors. A conceptual model that includes different theoretical perspectives and the interrelationships between factors is needed. According to innovation diffusion theory, innovation benefits and communication channels are important for the diffusion process (Rogers, 2003). More comparisons between sustainable technology and regular technology is needed, based on which a fundamental theory of sustainable technology adoption should be built. Questions, such as whether the diffusion mechanism of sustainable technology is the same as regular innovation should be discussed, especially whether the benefits of sustainable technology is sufficient to self-sustained its diffusion process. Furthermore, since sustainable technology adoption is stimulated by not only the economic system, but also the institutional and social systems, interactions between various factors may be more complicated than regular innovation adoption. Studies investigating the interrelationships between influential factors, such as between economic factors and institutional factors, reinforcement or conflicting effects between various policy instruments should be taken into account to explain sustainable process technology adoption.

Finally, the adoption variations of different types of sustainable technology, different stages of adoption and in different countries should be paid more attention to explain the inconsistent results across studies. Since influential factors for the adoption of each type of sustainable technology may be different, focusing on one particular type of sustainable technology could provide managers and policy-makers with more concrete advice. For example, more research is needed to determine how to promote firms adopt more material/fuel substitution technologies and recycling technologies. Moreover, each stage of sustainable technology adoption needs to be studied separately. According to Rogers, the organizational adoption contains five stages: agenda-setting, matching, redefining, clarifying and routinizing (Rogers, 2003, p420). Most prior research focuses on whether the firms adopt sustainable technologies or the adoption degree. Studies for the other stages of adoption, such as information gathering and evaluation criteria are valuable to provide explicit suggestions for promoting sustainable process technology adoption. In addition, since most studies regarding sustainable process technology adoption conducted within Europe, more comparative research between countries should be carried out. If the social and institutional systems are influential for sustainable process technology adoption, the impact of different institutions, cultures and social norms may vary across countries. Therefore, more comparison studies between countries should be conducted.

7. Conclusion

While the number of articles in the field of sustainable process technology adoption have increased recently, it is still limited. The difficulty in accessing firms with sustainable process technology adoption practices is one of the most likely reasons for the limited number of studies. After 2007, more papers in this field were published using survey data, such as the Community Innovation Survey and Flash Eurobarometer. Most research was conducted within Europe.

We recognised four types of sustainable process technologies, i.e., CO_2/emission reduction technology, energy/material efficiency technology, material/fuel substitution technology and recycling technology. Since most researchers investigated sustainable technology adoption as a composite construct, we incorporated an additional category, 'general sustainable technology' to represent the combination of various types of sustainable process technologies. 'CO_2/emission reduction technology' and 'energy/material efficiency technology' are more widely investigated than 'material/fuel substitution' and 'recycling' technologies. Most research studied the 'general sustainable technology', neglecting the differences between types of sustainable process technologies. However, because of their different performances, firms' attitudes and behaviours as well as effective governmental policies may be different for specific types of sustainable process technologies. For example, a positive policy instrument maybe more important for CO_2/emission reduction technology than for energy efficiency technology. The adoption of energy/material efficiency technologies may require more market demand, technology capability and cooperation than CO_2/emission reduction technologies.

The multitude of influential factors indicates that the adoption of sustainable process technologies can be affected in many ways, requiring the involvement of various stakeholders to align their activities and facilitate the adoption process. Several factors have been identified as important, such as coercive pressure, market pressure, technology capability, internal support, adoption experience, certified systems, and cooperation. Technology characteristics are rarely investigated. Most researchers focus on coercive pressures and firm characteristics. Compared to coercive pressure from governments, firms feel less pressure from industry, business groups and society. Regarding the different effects of factors between studies, most researchers try to explain them by different firm characteristics (e.g., firm size, ownership) and technology types, such as end-of-pipe technology and clean technology. However, other reasons for the different results, such as the interrelationship between factors and the time difference during the diffusion process still lack exploration. Meanwhile, some factors have not received enough attention yet, such as the regional infrastructural factors and the cultural and regulatory regimes of countries, as in the studies by Cainelli et al. (2015) and Wagner (2009).

This study helps policy-makers, technology suppliers and firm managers better promote and adopt sustainable technologies. For policy-makers, the implementation of environmental policies is essential to promote firms' adoption of sustainable technologies, especially for CO_2/emission reduction technologies and energy/material efficiency technologies. However, the specific instruments may vary for different firms and technologies. Furthermore, emphasizing firms' adoption behaviours may not be enough: building an environment that promotes the sustainable behaviour of various stakeholders, such as customers, suppliers, research institutes, could effectively influence firms' behaviours. Additionally, regulatory uncertainty could negatively influence firms' perceptions of relative advantages of sustainable technologies and external pressures. The signal of the environmental regulations of future sustainable development direction is requisite. For technology suppliers, the integration with firms' technology adoption processes is an effective way to promote sustainable technology adoption, such as getting involved in the technology development process with firms and setting environmental goals together. Moreover, since firms acquire sustainable technology information from conferences, business associations, and private research institutes etc., promoting sustainable technology information in various occasions is necessary. For firm managers, general technology capabilities and high human resource quality are essential for sustainable technology adoption. Cooperation with other organizations, such as business partners, suppliers and research institutes could also benefit firms' sustainable technology adoption.

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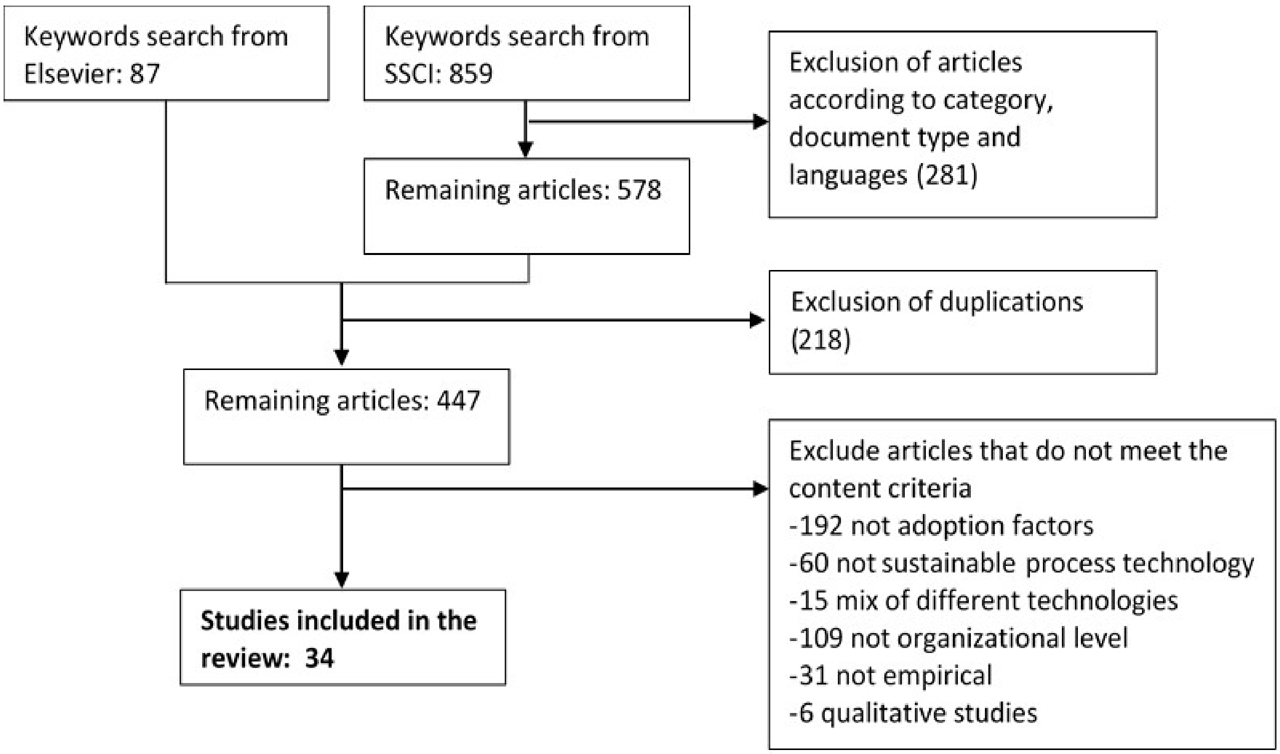

Figure 1. Decision tree of data selection

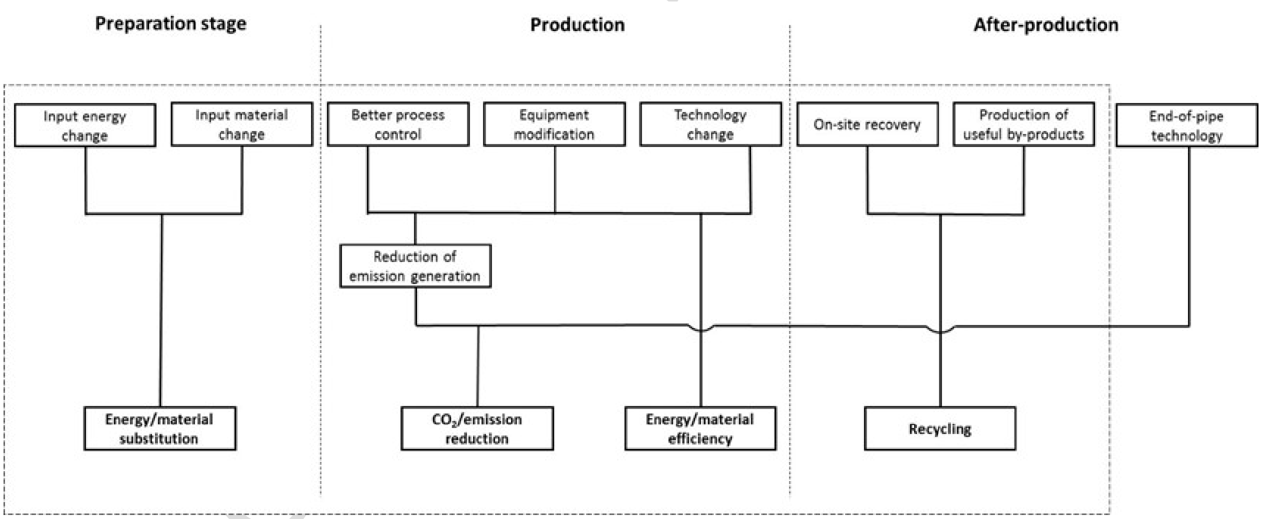

Figure 2 Categories of sustainable process technologies

Adapted from UNIDO'S (United Nations Industrial Development Organization) definition of Cleaner Production (CP); Del Río González (2005); Frondel et al. (2007)

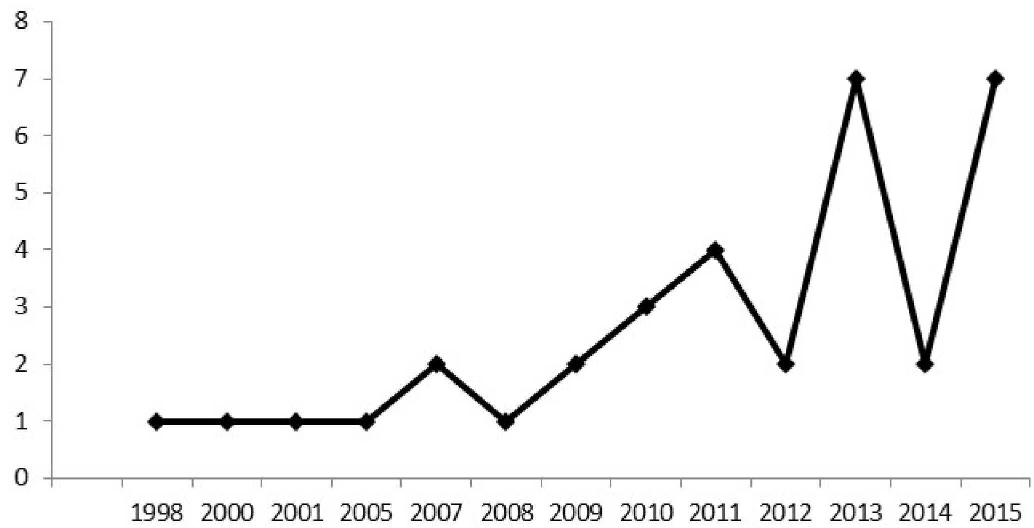

Fig. 3. Publication trend

Del Río González, P., 2005. Analysing the factors influencing clean technology adoption: a study of the Spanish pulp and paper industry. Business strategy and the environment 14(1), 20-37.
Frondel, M., Horbach, J., Rennings, K., 2007. End-of-pipe or cleaner production? An empirical comparison of environmental innovation decisions across OECD countries. Business Strategy and the Environment 16(8), 571-584.
United Nations Industrial Development Organization, Cleaner Production (CP). http://www.unido.org/cp/o5152.html. 2017).

Table 1. Investigated regions

Regions	Number of articles	Percentage
International	5	14.7%
Italy	5	14.7%
U.S.	4	11.8%
China	3	8.8%
Sweden	3	8.8%
India	2	5.9%
Taiwan	2	5.9%
Other	10	29.4%
Total	34	100%

Table 2. Article distribution over journals

Journal Title	Number of articles	Percentage
Ecological Economics	4	11.8%
Research policy	4	11.8%
Journal of Cleaner Production	2	5.9%
Business Strategy and the Environment	2	5.9%
Energy Policy	2	5.9%
Environmental & Resource Economics	2	5.9%
International Journal of Operations & Production Management	2	5.9%
Others	16	47.1%
Total	34	100%

Table 3. Measurement scales of sustainable process technology adoption

Item	Scale	Initiation		Implementation			
		Information gathering	**Adoption willingness**	**Expenditure**	**Put into use**	**Adoption degree**	**Adoption time**
General sustainable technology							
Clean technology			(Zhang et al., 2013);	(Demirel and Kesidou, 2011); (Hammar and Lofgren, 2010)	(Sangle, 2011); (Triguero et al., 2013); (Wagner, 2007); (Wagner, 2009);		
Combination of different sustainable technologies	Energy/material efficiency technology and recycling technology				(Cainelli et al., 2012);		
	End-of-pipe technology and clean technology					(Luken et al., 2008);	
	List of various sustainable technologies		(Zhang et al., 2015)		(Camison, 2010); (Veugelers, 2012);	(Bhupendra and Sangle, 2015); (Huang et al., 2009); (Jimenez, 2005); (Prajogo et al., 2014); (Weng and Lin, 2011); (Wu, 2013);	
CO_2/Emission reduction technology							
General	Result in emission reduction				(Antonioli et al., 2013); (Cainelli et al., 2012)		
	Result in lower total CO_2 production			(Lofgren et al., 2014)	(Antonioli et al., 2013); (Borghesi et al., 2015); (Cainelli et al., 2012); (Veugelers, 2012);		
End-of-pipe	Generic			(Demirel and Kesidou, 2011); (Hammar and Lofgren, 2010)	(Camison, 2010);		
	Fabric filter				(Bellas and Nentl, 2007);		(Bellas and Nentl, 2007)
	NO_x abatement technology (post-combustion technology)				(Bonilla et al., 2015); (Popp, 2010);		
Reduction of emission generation	NO_x abatement technology (combustion modification technology)				(Bonilla et al., 2015); (Popp, 2010);		
Material/fuel substitution							
Material substitution	Use organic products or processes					(Leenders and Chandra, 2013);	
	Use non-hazardous or less hazardous materials				(Theyel, 2000);	(Yusup et al., 2015)	

	Elemental chlorine-free bleaching				(Maynard and Shortle, 2001);		(Maynard and Shortle, 2001)
Fuel substitution	Propane				(Blackman and Bannister, 1998)		
Energy/material efficiency technology							
Energy/material efficiency technology	Reduce material and/or energy use per unit of output				(Antonioli et al., 2013);		
Energy efficiency technology	Reduce energy use per unit of output	(Kounetas et al., 2011)			(Borghesi et al., 2015); (Trianni et al., 2013); (Veugelers, 2012);	(Yusup et al., 2015)	
	Flue gas condensation technology				(Bonilla et al., 2015);		
	List of energy saving technologies				(Arvanitis and Ley, 2013);	(Arvanitis and Ley, 2013);	
Material efficiency technology	Reduce waste generated and more efficient to material cost				(Theyel, 2000); (Triguero et al., 2015);	(Yusup et al., 2015)	
	Extended delignification (ED), oxygen delignification (OD)				(Maynard and Shortle, 2001);		(Maynard and Shortle, 2001)
Recycling							
Recycle waste, water or materials					(Cainelli et al., 2015); (Triguero et al., 2015);	(Yusup et al., 2015)	
List of recycling technologies						(Leenders and Chandra, 2013);	

Table 4: Studies and numbers of relationships between determinants and sustainable technology adoption variables (Except for Article (Camison, 2010; Kounetas et al., 2011; Trianni et al., 2013; Yusup et al., 2015)

	General sustainable technology			**CO_2/emission reduction**			**Energy/material efficiency**			**Material/fuel substitution**			**Recycling**		
	P	N	NS	P	N	NS	P	N	NS	P	N	NS	P	N	NS
Market pressures															
Market stakeholder	(Huang et al., 2009)(1)														
Customer demand	(Weng and Lin, 2011)(1); (Triguero et al., 2013)(1)						(Triguero et al., 2015)(2)		(Arvanitis and Ley, 2013)(6)			(Leenders and Chandra, 2013)(1)	(Triguero et al., 2015)(2)		(Leenders and Chandra, 2013)(1)
Market competition							(Arvanitis and Ley, 2013)(1)		(Arvanitis and Ley, 2013)(11)			(Leenders and Chandra, 2013)(1)			(Leenders and Chandra, 2013)(1)
Resource price	(Luken et al., 2008)(1); (Triguero et al., 2013)(1)		(Triguero et al., 2013)(1)			(Lofgren et al., 2014)(2)			(Arvanitis and Ley, 2013)(2)						
Legitimacy															
Coercive pressures															
Regulation stakeholder	(Huang et al., 2009)(1);														
Regulation	(Luken et al., 2008)(1); (Sangle, 2011)(1); (Veugelers, 2012)(2); (Weng and Lin, 2011)(1)		(Triguero et al., 2013)(1); (Demirel and Kesidou, 2011)(1)	(Bonilla et al., 2015)*(5); (Demirel and Kesidou, 2011)(1); (Veugelers, 2012)(2); (Borghesi et al., 2015)(1); (Popp, 2010)*(9)	(Popp, 2010)*(2); (Borghesi et al., 2015)(1)	(Bellas and Nentl, 2007)(1); (Bonilla et al., 2015)*(5); (Lofgren et al., 2014)(2)	(Veugelers, 2012)(2); (Borghesi et al., 2015)(1); (Triguero et al., 2015)(1)	(Borghesi et al., 2015)(1)	(Arvanitis and Ley, 2013)(2); (Bonilla et al., 2015)*(5); (Triguero et al., 2015)(1)			(Blackman and Bannister, 1998)(1); (Leenders and Chandra, 2013)(1)			(Leenders and Chandra, 2013)(1); (Triguero et al., 2015)(2)
Voluntary standard	(Jimenez, 2005)(2)		(Jimenez, 2005)(2)												
Governmental support	(Weng and Lin, 2011)(1)														
Economic support	(Demirel and Kesidou, 2011)(2);		(Triguero et al., 2013)(1); (Veugelers, 2012)(1)	(Veugelers, 2012)(1);		(Borghesi et al., 2015)(2)	(Veugelers, 2012)(1); (Triguero et al., 2015)(1); (Borghesi et al., 2015)(1)		(Borghesi et al., 2015)(1); (Triguero et al., 2015)(1)						(Triguero et al., 2015)(2)
Technical support			(Luken et al., 2008)(1)												
Industry initiative												(Leenders and Chandra, 2013)(1)			(Leenders and Chandra, 2013)(1)

	General sustainable technology			CO_2/emission reduction			Energy/material efficiency			Material/fuel substitution			Recycling		
	P	N	NS	P	N	NS	P	N	NS	P	N	NS	P	N	NS
Mimetic pressure															
Diffusion rate				(Bonilla et al., 2015)*(1); (Popp, 2010)*(1)	(Popp, 2010)*(1)	(Bonilla et al., 2015)*(5)	(Arvanitis and Ley, 2013)(4); (Bonilla et al., 2015)*(2);	(Arvanitis and Ley, 2013)(1)	(Arvanitis and Ley, 2013)(7); (Bonilla et al., 2015)*(1);						
Normative pressures	(Zhang et al., 2013)(1); (Zhang et al., 2015)(1)	(Sangle, 2011)(1)	(Luken et al., 2008)(2)						(Arvanitis and Ley, 2013)(2)						
Information															
Information uncertainty			(Weng and Lin, 2011)(1)				(Arvanitis and Ley, 2013)(4)		(Arvanitis and Ley, 2013)(2)						
Information sources	(Triguero et al., 2013)(1)			(Borghesi et al., 2015)(3)	(Borghesi et al., 2015)(1)	(Borghesi et al., 2015)(16)	(Borghesi et al., 2015)(3)		(Borghesi et al., 2015)(17)				(Cainelli et al., 2015)(5)		
Firm characteristics															
Firm size			(Luken et al., 2008)(1); (Hammar and Lofgren, 2010)(1); (Wagner, 2009)(1);	(Bonilla et al., 2015)*(1); (Popp, 2010)*(2); (Bellas and Nentl, 2007)*(1); (Hammar and Lofgren, 2010)(1); (Lofgren et al., 2014)(1)	(Bellas and Nentl, 2007)*(2)	(Bonilla et al., 2015)*(29); (Popp, 2010)*(2); (Bellas and Nentl, 2007)*(1); (Borghesi et al., 2015)(2); (Lofgren et al., 2014)(1)	(Arvanitis and Ley, 2013)(6); (Bonilla et al., 2015)*(1);	(Maynard and Shortle, 2001)*(1)	(Borghesi et al., 2015)(2); (Bonilla et al., 2015)*(14);	(Maynard and Shortle, 2001)*(1)		(Blackman and Bannister, 1998)*(1);			
Ownership															
Foreign owned	(Luken et al., 2008)(1)		(Cainelli et al., 2012)(1)			(Cainelli et al., 2012)(2)		(Arvanitis and Ley, 2013)(3)	(Arvanitis and Ley, 2013)(3)						
Public owned						(Bellas and Nentl, 2007)*(2); (Popp, 2010)*(2)									
Private owned		(Luken et al., 2008)(1)			(Popp, 2010)*(1)	(Popp, 2010)*(1)						(Blackman and Bannister, 1998)*(1)			
Export activity			(Luken et al., 2008)(1); (Cainelli			(Cainelli et al., 2012)(2)			(Arvanitis and Ley, 2013)(6)						

	General sustainable technology			CO_2/emission reduction			Energy/material efficiency			Material/fuel substitution			Recycling		
	P	N	NS	P	N	NS	P	N	NS	P	N	NS	P	N	NS
			et al., 2012)(1)												
Responsibility															
Corporate social responsibility			(Demirel and Kesidou, 2011) (2)												
Internal support	(Huang et al., 2009)(1); (Weng and Lin, 2011)(1)														
Human capital intensity															
Quality	(Weng and Lin, 2011)(1);				(Lofgren et al., 2014)(1)	(Lofgren et al., 2014)(1)	(Arvanitis and Ley, 2013)(2)	(Arvanitis and Ley, 2013)(1)	(Arvanitis and Ley, 2013)(9); (Maynard and Shortle, 2001)(1)	(Blackman and Bannister, 1998)*(2);	(Maynard and Shortle, 2001)(1)		(Cainelli et al., 2015)(1)		
Complementary				(Antonioli et al., 2013)(3)		(Antonioli et al., 2013)(21)	(Antonioli et al., 2013)(1)		(Antonioli et al., 2013)(11)						
Technological capability															
Technological capability construct	(Zhang et al., 2013)(1); (Zhang et al., 2015)(1); (Luken et al., 2008)(1); (Sangle, 2011)(1);		(Triguero et al., 2013)(1)				(Triguero et al., 2015)(1)		(Triguero et al., 2015)(1)				(Triguero et al., 2015)(1)		(Triguero et al., 2015)(1)
R&D or expert	(Hammar and Lofgren, 2010)(1)		(Hammar and Lofgren, 2010)(1)			(Lofgren et al., 2014)(2)	(Arvanitis and Ley, 2013)(2);		(Arvanitis and Ley, 2013)(4); (Theyel, 2000)(1);			(Theyel, 2000)(1)			(Cainelli et al., 2015)(1)
Innovative capability	(Bhupendra and Sangle, 2015)(3)														
Financial capability			(Luken et al., 2008)(1);				(Maynard and Shortle, 2001)*(1)		(Maynard and Shortle, 2001)*(2)			(Maynard and Shortle, 2001)*(2)			
Resources intensity															
Resource cost			(Hammar and Lofgren, 2010)(1);	(Hammar and Lofgren, 2010)(1);			(Arvanitis and Ley, 2013)(3)		(Arvanitis and Ley, 2013)(3)						
Resource used				(Lofgren et al., 2014)(3)		(Bonilla et al., 2015)*(12); (Popp,	(Bonilla et al., 2015)*(3);								

	General sustainable technology			CO_2/emission reduction			Energy/material efficiency			Material/fuel substitution			Recycling		
	P	N	NS	P	N	NS	P	N	NS	P	N	NS	P	N	NS
						2010)*(2); (Lofgren et al., 2014)(1)									
Knowledge stock															
Technology substitutes				(Bonilla et al., 2015)*(3); (Popp, 2010)*(1);	(Popp, 2010)*(1)	(Bonilla et al., 2015)*(17); (Popp, 2010)*(2);	(Bonilla et al., 2015)*(4);		(Bonilla et al., 2015)*(6);						
Adoption experience	(Hammar and Lofgren, 2010)(1)		(Hammar and Lofgren, 2010)(1)	(Bonilla et al., 2015)*(1); (Hammar and Lofgren, 2010)(2); (Lofgren et al., 2014)(2)		(Bonilla et al., 2015)*(19); (Lofgren et al., 2014)(2)			(Bonilla et al., 2015)*(10);						
Patent				(Popp, 2010)*(1)	(Popp, 2010)*(2)	(Popp, 2010)*(5)									
Environmental tools															
Environmental practice			(Wagner, 2007)(1); (Wagner, 2009)(1)				(Theyel, 2000)(2)		(Theyel, 2000)(6);	(Leenders and Chandra, 2013)(2); (Theyel, 2000)(3)		(Leenders and Chandra, 2013)(2); (Theyel, 2000)(6)	(Leenders and Chandra, 2013)(1)		(Leenders and Chandra, 2013)(3)
Certified systems	(Luken et al., 2008)(1); (Prajogo et al., 2014)(1); (Wagner, 2007)(1)		(Demirel and Kesidou, 2011)(2); (Prajogo et al., 2014)(1); (Wagner, 2009)(1);	(Demirel and Kesidou, 2011)(2);											
Others	(Wu, 2013)(1);					(Lofgren et al., 2014)(2)	(Arvanitis and Ley, 2013)(5)		(Arvanitis and Ley, 2013)(1)						
Technology characteristics															
Relative advantage	(Zhang et al., 2013)(1); (Zhang et al., 2015)(1); (Sangle, 2011)(2); (Weng and Lin, 2011)(1)		(Demirel and Kesidou, 2011)(2)									(Blackman and Bannister, 1998)*(1);			
Financial cost		(Sangle, 2011)(1)													

	General sustainable technology			CO_2/emission reduction			Energy/material efficiency			Material/fuel substitution			Recycling		
	P	N	NS	P	N	NS	P	N	NS	P	N	NS	P	N	NS
Compatibility	(Weng and Lin, 2011)(1)						(Arvanitis and Ley, 2013)(2)		(Arvanitis and Ley, 2013)(4)						
Network characteristics															
Membership						(Borghesi et al., 2015)(2)	(Borghesi et al., 2015)(2);		(Maynard and Shortle, 2001)*(1)			(Blackman and Bannister, 1998)*(1); (Maynard and Shortle, 2001)*(1);	(Cainelli et al., 2015)(1)		
Cooperation	(Wu, 2013)(2); (Cainelli et al., 2012)(2); (Triguero et al., 2013)(1)		(Wagner, 2007)(3)	(Cainelli et al., 2012)(4)					(Triguero et al., 2015)(2)				(Triguero et al., 2015)(1)		(Triguero et al., 2015)(1)

Note: P = Positive, N = Negative and NS = Non-significant. (1-tailed test: 10% level of significance; 2-tailed test: 5% level of significance) Prajogo et al. (2014), Weng and Lin (2011), Zhang et al. (2015) and Zhang et al. (2013) adopted a one-tailed test at a 5% significance level, and Bhupendra and Sangle (2015) adopted two-tailed tests at the 1% significance level.

The number between the brackets indicates the number of relationships tested in each study.

General means dependent variable that contains more than one type of sustainable process technologies.

The star marks indicate that the dependent variable is a specific technology, such as combustion modification treatment, or elemental chlorine-free bleaching.

Appendix

Table A.1 The number of articles from each combination of keywords search

Keywords	SSCI		Science Direct
	Number	Filter	Number
"sustainable technolog*" AND adopt*	26	13	5
"sustainable innovation*" AND adopt*	20	15	3
"sustainable technolog*" AND implement*	32	15	4
"sustainable innovation*" AND implement*	17	8	2
"green* technolog*" AND adopt*	37	24	3
"green* innovation*" AND adopt*	23	17	3
"green* technolog*" AND implement*	39	23	4
"green* innovation*" AND implement*	18	14	3
"eco-innovation*" AND adopt*	43	33	5
"eco-innovation*" AND implement*	28	20	6
"ecological technolog*" AND adopt*	1	0	0
"ecological innovation*" AND adopt*	2	1	1
"ecological technolog*" AND implement*	2	1	0
"ecological innovation*" AND implement*	1	0	0
"environmental* technolog*" AND adopt*	52	38	6
"environmental* innovation*" AND adopt*	69	52	14
"environmental* technolog*" AND implement*	40	30	5
"environmental* innovation*" AND implement*	38	28	4
"environmental* friendly technolog*" AND adopt*	15	8	1
"environmental* friendly innovation*" AND adopt*	4	2	0
"environmental* friendly technolog*" AND implement*	9	3	1
"environmental* friendly innovation*" AND implement*	0	0	0
"environmental* sound technolog*" AND adopt*	9	7	0
"environmental* sound innovation*" AND adopt*	1	0	0
"environmental* sound technolog*" AND implement*	4	4	0
"environmental* sound innovation*" AND implement*	0	0	0
"clean* technolog*" AND adopt*	85	56	5
"clean* innovation*" AND adopt*	1	1	1
"clean* technolog*" AND implement*	49	30	6
"clean* innovation*" AND implement*	0	0	0
"clean* production*" AND adopt*	56	45	2

“clean* production*” AND implement*	89	66	1
“energy-saving technolog*” AND adopt*	34	15	2
“energy-saving innovation*” AND adopt*	1	1	0
“energy-saving technolog” AND implement*	0	0	0
“energy-saving innovation*” AND implement*	1	1	0
“energy efficiency technolog*” AND adopt*	10	4	1
“energy efficiency innovation*” AND adopt*	2	2	0
“energy efficiency technolog” AND implement*	0	0	0
“energy efficiency innovation*” AND implement*	0	0	0
“material-saving technolog*” AND adopt*	1	1	0
“material-saving innovation*” AND adopt*	0	0	0
“material-saving technolog” AND implement*	0	0	0
“material-saving innovation*” AND implement*	0	0	0
Total	859	578	88
Language check for Science Direct			87
Duplication removal		447	

Note: Articles from SSCI are filtered by category (environmental studies; environmental sciences; management; business), document type (articles) and language (English).

Table A.2 Overview of articles on sustainable process technology adoption

Authors	Title	Dependent variable label and measurement	Sample size	Quality assessment	Journal Impact Factor 2016
(Antonioli et al., 2013)	Is environmental innovation embedded within high-performance organisational changes? The role of human resource management and complementarity in green business strategies	Did the firms adopt "environmental" products and/or process technological innovations that induced the following benefits? **Environmental Innovation - ENERGY** =1 If reduction in the use of material and/or energy by output unit (included recycling) as Yes; =0 otherwise **Environmental innovation - CO_2** =1 If CO_2 emission reduction marked as Yes; =0 otherwise **Environmental innovation- EMISSIONS** =1 If Emission reductions that improve the quality of soil, water and air; =0 otherwise	555 Italian industrial firms	1.Probit regression (2-tailed test: 5% level of significance)	4,495
(Arvanitis and Ley, 2013)	Factors Determining the Adoption of Energy-Saving Technologies in Swiss Firms: An Analysis Based on Micro Data	**Inter-firm Adoption-Energy-saving technologies in electromechanical and electronic applications** =1 if adoption of at least one out five technology applications: in electrical machines and drive systems; in formation and communication technologies; in consumer electronics; in components of process engineering; in process engineering =0 otherwise **Inter-firm Adoption-Energy-saving technologies in power-generating processes** =1 if adoption of at least one out of four technology applications: combined heat and power generation based on biomass; combined heat and power generation based on oil/gas/carbon; heat pumps; heat recuperation systems =0 otherwise **Intra-firm Adoption-Energy-saving technologies in electromechanical and electronic application** =2 if adoption of 3, 4, or 5 of the technology application =1 if adoption of 1 or 2 of the technology application =0 otherwise **Intra-firm Adoption-Energy-saving technology in power-generating processes** =2 if adoption of 2, 3, 4 of the technology application =1 if adoption of 1 of the technology application	2324 Swiss firms	1.Probit regression & multinomial logit estimates (2-tailed test: 5% level of significance)	1,582

		=0 otherwise			
(Bellas and Nentl, 2007)	Adoption of environmental innovations at US power plants	**Adoption of environmental innovations - An innovation pollution control device (fabric filter)** =1 If FGP (Flue Gas Particulates) unit was a fabric filter =0 otherwise	61 power plants in USA	1.Logistic regression (2-tailed test: 5% level of significance) 2.Small sample 3.One industry-power plants	1,371
(Bhupendra and Sangle, 2015)	What drives successful implementation of pollution prevention and cleaner technology strategy? The role of innovative capability	**Implementing pollution prevention strategy** (Seven-point Likert scale for the following items) 1. In my organization, there is wide spread understanding on pollution prevention policy 2. My organization has implemented best housekeeping practices to reduce in-house pollution …… **Implementing clean technology strategy** (Seven-point Likert scale for the following items) =1 If firm adopted cleaner technology 1. My organization is planning to develop/adopt clean technology 2. My organization is planning to adopt cleaner production processes …..	689 India firms	1. Logistic regression (2-tailed test: 1% level of significance) 2.No control variable information, such as firm size and industry	4.01
(Blackman and Bannister, 1998)	Community pressure and clean technology in the informal sector: An econometric analysis of the adoption of propane by traditional Mexican brickmakers	**Adoption of clean technology (propane)** =1 If brickmakers adopted propane =0 otherwise	76 informal (or even small-scale) traditional brick kilns in Mexico	1.Probit adoption function estimation (2-tailed test: 5% level of significance) 2.Small sample 3.One industry-brickmaker	2.305
(Bonilla et al., 2015)	Refunded emission payments and diffusion of NOx abatement technologies in Sweden	**NO_x abatement technology adoption – Post-combustion technology** =1 if the boiler has post-combustion technology installed =0 otherwise **NO_x abatement technology adoption – Combustion technology** =1 if the boiler has combustion technology installed =0 otherwise **NO_x abatement technology adoption – Flue gas condensation technology**	524 boilers under the Swedish NO_x charge system	1.Cox proportional hazard model (2-tailed test: 5% level of significance)	2,965

		=1 if the boiler has flue gas condensation technology installed =0 otherwise			
(Borghesi et al., 2015)	Linking emission trading to environmental innovation: Evidence from the Italian manufacturing industry	During the three years 2006-2008, did your enterprise introduce a product (good or service), process, organizational or marketing innovation with any of the following environmental benefits? **Environmental innovation-ECOEN** =1 If reduced energy use per unit of output marked as Yes; =0 otherwise **Environmental innovation-ECOCO** =1 if reduced CO_2 "footprint" (total CO_2 production) by your enterprise marked as Yes; =0 otherwise	6483 Italian firms	1.Probit regression (2-tailed test: 5% level of significance)	4,495
(Cainelli et al., 2015)	Adoption of waste-reducing technology in manufacturing: Regional factors and policy issues	During the three years 2006-2008, did you enterprise introduce a product (good or service), process, organizational or marketing innovation with any of the following environmental benefits? **Adoption of waste-reducing technology – ECOWA** =1 if recycled waste, water or materials marked as Yes; =0 otherwise	6483 Italian firms	1.Probit regression (1-tailed test: 10% level of significant)	1,701
(Cainelli et al., 2012)	Environmental Innovations, Local Networks and Internationalization	During the three years 2006-2008, did your enterprise introduce a product (good or service), process, organizational or marketing innovation with any of the following environmental benefits? **Material/Resource reduction technology** =1 If reduction in the use of material/energy sources per unit of output (including recovery, recycling, closed loops) is marked as Yes; =0 otherwise **CO_2 abatement technology** =1 If CO_2 abatement is marked as Yes; =0 otherwise **Emissions abatement technology** =1 If emission reductions gene rating effects on soil, water, air is marked as Yes; =0 otherwise	555 firms in the Emilia-Romagna (ER) region (North-East Italy)	1.Probit models (1-tailed test: 10% level of significance) 2.Low Journal Effect factor	0,791
(Camison, 2010)	Effects of coercive regulation versus voluntary and cooperative auto-regulation on environmental adaptation and performance:	**Reactive environmental productive practices (end-of-pipe) comparison between 2002 & 2005** **Preventive environmental production practices comparison between 2002 & 2005**	1151 Spanish firms	1.No regression (variance analysis: 5% level of significance)	2,481

	Empirical evidence in Spain				
(Demirel and Kesidou, 2011)	Stimulating different types of eco-innovation in the UK: Government policies and firm motivations	**End-of-pipeline Pollution Control Technologies** Firms' investment in End-of-pipe pollution control technologies (EOP) **Integrated Cleaner Production Technologies** Firms' investment in integrated cleaner production technologies (International Energy Agency)	289 UK firms	1.Tobit model (2-tailed test: 5% level of significance)	2,965
(Hammar and Lofgren, 2010)	Explaining adoption of end of pipe solutions and clean technologies-Determinants of firms' investments for reducing emissions to air in four sectors in Sweden	**Investment in end-of-pipe technology** =1 if investment in end of pipe technology during a year =0 otherwise **Investment in clean technology** =1 if investment in clean technology during a year =0 otherwise	477 Swedish firms (pulp and paper; chemical; basic metal; energy and heating)	1.Logit regression (2-tailed test: 5% level of significance)	4,14
(Huang et al., 2009)	Salient stakeholder voices: Family business and green innovation adoption	**Adoption of Green Technical Innovation** (Five-point Likert scale for the following items) 1. My company adopts the technologies of energy conservation 2. My company adopts the technologies of resource regeneration 3. My company adopts the technologies of recycling industrial waste 4. My company adopts the technologies of pollution prevention process 5. My company adopts the design for natural environment to R&D the green product	235 manufacturing firms in Taiwan (chemical; electronic and information technology)	10Hierarchical linear regression (1-tailed test: 10% level of significance) 2.Low Journal Effect Factor 3.No sector control	0,539
(Jimenez, 2005)	Innovation-oriented environmental regulations: direct versus indirect regulations; an empirical analysis of small and medium-sized enterprises in Chile	Environmental projects or activities carried out in the last five years (Five-point Likert scale: totally; to a certain extent; considering; no; not applicable) **Radical Multimedia Innovations** The combination of items for Incremental Innovations and Process change **Radical Innovations on waste management** 1. Process and product redesign to prevent environmental problems; 2. Reduction, recycling, or reuse of wastes; and 3. Substitution of toxic raw materials by less harmful ones **Incremental Innovations**	322 SMEs in Chile (Chemical; Foundry; Sawmill; Swine)	1.No regression (propensity-scores analysis: 5% level of significance)	1,389

		1. Systematic monitoring of compliance with environmental legislation 2. Environmental management system with written procedures that set clear and quantifiable targets as well as an explicit timetable to act in accordance with regulations 3. Pollution control through filters and/or effluent-treatment plants 4. Environmental audit 5. Proper disposal of industrial solid waste 6. Improvements in internal working conditions **Process change** 1. Maintenance of equipment and processes to correct minor environmental problems 2. Process and product redesign to prevent environmental problems 3. Change in fuel to reduce atmospheric emissions 4. Reduction of water consumption in the production process and/or reuse of effluent 5. Reduction, recycling, or reuse of waste 6. Substitution of toxic raw materials by less harmful ones			
(Kounetas et al., 2011)	Promoting energy efficiency policies over the information barrier	**INF** =1 If the firm is informed about energy saving technologies =0 otherwise **Emerging information (EMRINF)** =0 if not informed =1 if merely or partial informed =2 if full informed **Epidemic information (EPINDINF)** =0 if not informed =1 if merely or partial informed =2 if full informed	161 manufacturing firms that actually accomplished the adoption of energy-efficiency technology (EET) in Greece	1.Two-ordered probit models (2-tailed: 5% level of significance) 2.Dependent variable focus on information acquire instead of adoption behavior 3.Low journal Effect Factor 4.No industry control	0.739
(Leenders and Chandra, 2013)	Antecedents and consequences of green innovation in the wine industry: the role of channel structure	5-point scales that measure the prominence of specific green innovation activities in the firm **Use of organic products and processes** 1. Seek organic certification 2. Produce bio-dynamic wine 3. Use green and innovative chemicals **Recycling activities in the winery** 1. Package products in recyclable materials	123 wineries in Australia, New Zealand, South Africa, USA and Canada	1.Regression model (2-tailed test: 5% level of significance) 2.One industry - winery	1,273

		2. Recycle materials for bottling 3. Recycle waste materials from wine making			
(Lofgren et al., 2014)	Why the EU ETS needs reforming: an empirical analysis of the effect on company investments	**Large investment in carbon abatement measures** =1 if the firm has made an investment equal to or above €1 million =0 otherwise **Small investment in carbon abatement measures** =1 if the firm has made an investment below €1 million =0 otherwise	706 Swedish firms	1.No regression (difference-in-difference estimator: 10% level of significance) 2.Controlled for European Union's Emissions Trading Scheme (EU ETS) sector	2,735
(Luken et al., 2008)	The determinants of EST adoption by manufacturing plants in developing countries	**Environmentally Sound Technology Adoption** =0 if no pollution abatement technologies (PATs) and no pollution prevention/cleaner technologies (CTs) =1 if PATs only =2 if PATs plus lower order of complexity CTs (input material change; better process control) =3 if PATs plus medium order of complexity CTs (equipment modification; on-site reuse; useful by-products) =4 if PATs plus higher order of complexity CTs (major technology change; product modification)	98 plants (pulp and paper; textile; leather) in eight developing countries (Brazil; China; India; Viet Nam; Thailand; Tunisia; Kenya; Zimbabwe)	1.Ordered probit regression (2-tailed test: 5% level of significance) 2.Small sample size	2,965
(Maynard and Shortle, 2001)	Determinants of cleaner technology investments in the US bleached kraft pulp industry	**Adoption of ED/OD** =1 if extended delignification (ED), oxygen delignification (OD) is adopted =0 otherwise **Adoption of ECF** =1 if elemental chlorine-free bleaching (ECF) is adopted =0 otherwise	75 bleached kraft pulp mills of the U.S. pulp and paper industry	1.Probit model (2-tailed test: 5% level of significance) 2.Small sample size 3.One industry-paper and pulp industry	1,895
(Popp, 2010)	Exploring Links Between Innovation and Diffusion: Adoption of NOX Control Technologies at US	**Adoption of post-combustion techniques** =1 if post-combustion technique is adopted =0 otherwise **Adoption of combustion modification techniques** =1 if combustion modification technique is adopted =0 otherwise	996 US coal-fired power plant boilers	1.Hazard model (2-tailed test: 5% level of significance) 2.One industry-coal-fired power plant	1,582

	Coal-fired Power Plants				
(Prajogo et al., 2014)	The diffusion of environmental management system and its effect on environmental management practices	**Implementation of Green Processes** Please indicate to what extent your organization has implemented the following environmental practices in these operations and supply chain areas? (5-point Likert Scale from "not at all" to "very large extent") 1. Acquisition of clean technology/equipment 2. Installing energy efficiency equipment 3. Installing pollution control technologies 4. Production planning and control focused on reducing waste and optimizing materials	286 companies in Australia which were certified to ISO 14001	1.Multiple regression (1-tailed test: 5% level of significance) 2.Control variable of manufacturing firms and non-manufacturing firms	3,339
(Sangle, 2011)	Adoption of Cleaner Technology for Climate Proactivity: a Technology-Firm-Stakeholder Framework	**Adoption of Cleaner Technology (CT) for climate Proactivity** =1 if they already using CT; or had taken decisive steps to use CT =0 otherwise	106 Indian firms	1.Logistic regression (1-tailed test: 10% level of significance) 2.No industry control	3,076
(Theyel, 2000)	Management practices for environmental innovation and performance	**Environmental Innovation-Material substitution** =1 if a firm modified its production processes by substituting the use of non-hazardous or less hazardous materials during the past three years =0 otherwise **Environmental Innovation-Process change** =1 if a firm develop or modified production processes in order to reduce the amount of waste generated during the past three years =0 otherwise	181 US firms (plastics and resins; ink manufacturing)	1.No regression (Pearson correlation analysis: 5% level of significance)	3,339
(Trianni et al., 2013)	Innovation and adoption of energy efficient technologies: An exploratory analysis of Italian primary metal manufacturing SMEs	**Barriers to the adoption of energy-efficient measures** 4-point Likert Scale from (not important) to 4 (very important)	20 primary metal manufacturing SMEs in North Italy	1.Small sample size 2.No regression (taxonomy)	4,14

(Triguero et al., 2015)	Eco-innovation by small and medium-sized firms in Europe: from end-of-pipe to cleaner technologies	**End-of-pipe Technology** =1 if the company reported recycling practices in the 5 years prior to the interview =0 otherwise **Cleaner Technology** =1 if the company purchased more efficient technologies to material costs in the past 5 years and/or if the company stated the in-house development of more efficient technologies in the past =0 otherwise	5135 SMEs in 27 European countries	1.Bivariate probit regression (2-tailed test: 5% level of significance) 2.Low Journal Effect Factor	0.95
(Triguero et al., 2013)	Drivers of different types of eco-innovation in European SMEs	**Eco-innovation production process method (ecoprocess)** =1 if the company have introduced a new or significantly improved eco-innovative production process or method =0 otherwise	4947 SMEs in the 27 EU members	1.Probit regression (2-tailed test: 5% level of significance)	2,965
(Veugelers, 2012)	Which policy instruments to induce clean inn.ovating?	**Adoption of eco-innovations (ECOOWN)** =1 if the firm introduced a product (good or service), process, organizational or marketing innovation that reduced material use per unit of output, reduced energy use per unit of output, reduced CO_2 'footprint' (total CO_2 production), reduced materials with less polluting or hazardous substitutes, reduced soil, water, noise, or air pollution, or recycled waste, water, or materials =0 otherwise **Adoption of lower CO_2 emission (ECOCO)** =1 if the firm introduced a product (good or service), process, organizational or marketing innovation that reduced CO_2 'footprint' (total CO_2 production) =0 otherwise **Adoption of lower energy use (ECOEN)** =1 if the firm introduced a product (good or service), process, organizational or marketing innovation that reduced energy use per unit of output =0 otherwise	2894 Flemish firms	1.Probit model (2-tailed test: 5% level of significance)	4,495
(Wagner, 2007)	On the relationship between environmental management, environmental innovation and patenting: Evidence from	**Environmentally related process innovations** =1 if the firm implemented cleaner technology during 1998-2000 =0 otherwise	342 Germany firms	1.Multivariate probit model (1-tailed test: 10% level of significance)	4,495

	German manufacturing firms				
(Wagner, 2009)	National Culture, Regulation and Country Interaction Effects on the Association of Environmental Management Systems with Environmentally Beneficial Innovation	**Environmentally beneficial process innovations** =1 if the firm implemented cleaner technology during 1998-2000 =0 otherwise	2039 European firms	1.Multivariate probit model (2-tailed test: 5% level of significance)	3,076
(Weng and Lin, 2011)	Determinants of green innovation adoption for small and medium-size enterprises (SMES)	**Green Innovation** (7-point Likert Scale from “not at all” to “to a great extent”) The decision of a company to use the green innovations to respond to environmental issues (consolidating shipments, disposing waste responsibly, purchasing ecological products, reducing energy consumption, reducing solid/water waste and emissions, using cleaner production methods and using recyclable packaging/containers)	244 SMEs in China	1.Standardized regression (1-tail: 5% level of significance) 2.No control variable information	1,105
(Wu, 2013)	The influence of green supply chain integration and environmental uncertainty on green innovation in Taiwan's IT industry	**Green Process Innovation** (7-point Likert Scale) 1. Using cleaner technology to reduce hazardous substance emissions and/or waste 2. Recycling and reusing waste and/or emissions 3. Reducing the consumption of water, electricity, gas or oil 4. Reducing the use of raw materials	211 Taiwanese Information technology manufacturers	1.Hierarchical moderated regression (1-tailed test: 10% level of significance) 2.One industry - IT manufacturing	4,072
(Yusup et al., 2015)	The implementation of cleaner production practices from Malaysian manufacturers' perspectives	**Cleaner Production Practices (CPP) Implementation** (7-point Likert Scale to assess CPP implementation from “strongly disagree” to “strongly agree”) CCP 3: Implement waste minimization programme CCP 7: Integrate environmental issues in process and innovation CCP 11: Reduce the use of raw materials and resources CCP 15: Efficient use of chemicals in manufacturing processes CCP 18: Reduce the use of natural resources in manufacturing process CCP 19: Evaluate the replacement of materials with non-toxic and non-polluting products	107 Malaysian manufacturers	1.No regression (Kruskal-Wallis H test)	5.715

		CCP 20: Evaluate the possibilities of recyclability in operational activities CCP 21: Increase the use of renewable resources CCP 26: Use energy-saving equipment			
(Zhang et al., 2013)	Enterprises' willingness to adopt/develop cleaner production technologies: an empirical study in Changshu, China	**The willingness to adopt/develop Cleaner Production (CP)** (7-point Likert Scale from "extremely unlikely" to "extremely likely") 1. Our enterprise has plans to develop cleaner options in our product designs 2. Our enterprise has plans to develop cleaner options in our production progress	143 enterprises in Chengdu, China	1. Structural equation model (1-tailed test: 5% level of significance) 2.No control variable information	5.715
(Zhang et al., 2015)	Regulatory uncertainty and corporate pollution control strategies: an empirical study of the 'Pay for Permit' policy in the Tai Lake Basin	**The willingness to promote environmental practices and to reduce pollution** (7-point Likert Scale from "extremely unlikely" to "extremely likely") 1. Our firm has plans to reduce water polluting by changing our product design 2. Our firm has plans to reduce water pollution by adopting cleaner technologies in our product production 3. Our firm has plans to reduce water pollution by strengthening our environmental management system 4. Our firm has plans to reduce water pollution by acquiring new equipment	162 firms in the Tai Lake Basin, China	1.Structural equation model (1-tailed test: 5% level of significance) 2.No control variable information	1,771

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