

Understanding the adoption of sustainable process technologies in the manufacturing industry

Yao Fu

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technologies in the manufacturing industry

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1.

Introduction

1.1 SUSTAINABLE DEVELOPMENT – A KEY TO SOLVING CONFLICTS BETWEEN ECONOMY AND ENVIRONMENT

In the Global Risk Report 2018, three of the top five risks relate to environmental problems, which are extreme weather events, natural disasters, and failure of climate-change mitigation and adaptation (World Economic Forum, 2018). In an attempt to reach a balance between economic development, social development and environmental protection, sustainable development is embraced by governments, society and firm managers. However, how to realize sustainable development objectives is still an important challenge facing firms and governments.

Sustainable development was first defined as development that “meets the needs of current generations without compromising the ability of future generation to meet their own needs” (WCED 1987, p43). For firms, sustainable development means meeting needs of the organization and its stakeholders while protecting, sustaining and enhancing human and natural resources for the future (Deloitte & Touche & World Business Council for Sustainable Development, 1992). Corporate sustainable development is a multidimensional concept, which includes environmental integrity, economic prosperity and social equity (Bansal, 2005). It consists of a wide range of activities, from changes in inputs (e.g., investment in sustainable equipment), internal behaviors or processes (e.g., the nature of products produced) to changes in output (e.g., community relations and philanthropic programs) (Waddock & Graves, 1997). In this project, we focus on the environmental aspects of sustainable development in firms, particularly on the organizational adoption of sustainable process technologies. Since the aim of adoption, the stakeholders involved, and whether R&D is involved are different for product compared with process technologies (Del Río González, 2009; Ettlie, Bridges, & O’Keefe, 1984), focusing exclusively on process technologies enables us to have more reliable results regarding organizational sustainable technology adoption. Furthermore, comparing between adoption and development, adoption takes the view of the customer or user who implements process technology (as a production process innovation) on the one hand, whereas development takes the view of the supplier that develops process technology as a product innovation on the other hand. Whereas adoption is generally about the decision and implementation of technologies bought off the shelf (e.g., end-of-pipe technologies) or purchased made-to-order (e.g., clean technologies) from suppliers, when it concerns sustainable/environmental process technologies, it may also involve development when the process technology is designed, manufactured and implemented by the user firm, or when that is done in co-operation with the supplier. While the adoption of sustainable production process technologies is part of the innovation and development process, the development of sustainable process technologies 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, Olsthoorn, Oosterhuis, & Verbruggen, 1992).

Therefore, we particularly focus in this project on the implementation aspects of adoption from a user perspective.

Sustainable technologies, defined as technologies that can reduce negative effects on the environment by reducing or preventing pollution, reducing resource consumption, or using less polluting or energy-intensive materials, are crucial to achieve sustainable development. Although corporate responsible behavior is appreciated by society, the transition to using sustainable technologies will not be achieved automatically. Even when owners/managers have high levels of environmental awareness, this may not directly be translated into proactive behavior (Gadenne, Kennedy, & McKeiver, 2009). Barriers, such as a lack of skills, finance and knowledge may lead to under-performance and ineffective embedment of sustainable development in organizations (Birkin, Cashman, Koh, & Liu, 2009). Rennings (2000) summarized three peculiarities of sustainable technologies compared with other technologies, which are (1) positive spillover in both the innovation and the diffusion phase, requiring (2) regulatory push/pull effects and (3) increasing importance of social and institutional innovation. Sustainable development is not only a question of corporate behavior, but it also requires a social learning process with the full involvement of stakeholders and planners and should be grounded in formal legislation as well as ethical principles (Ali & Peder, 2007). Moreover, sustainable technology in itself is a broad concept, including various types of technology that differ in terms of their impact on firms. Therefore, promoting measures for sustainable technology adoption by organizations may be more complicated than measures for regular technologies. New questions, such as whether the traditional promotion of regular technologies is still effective, how extensive the range of stakeholders is promoting firms to be sustainable and how they are related, how to build an environment that could maximize the impact of promotion measures for each type of sustainable technology, are still a challenge facing most governments and firm managers.

1.2 Sustainable organizational behavior: A look into the past and a view of the future

Theories explaining firms' adoption behavior complement and overlap each other. Regarding regular technology adoption, the Technology Acceptance Model (Davis, Bagozzi, & Warshaw, 1989) and the diffusion of innovation theory of Rogers (2003) are used specifically for adoption and diffusion behavior. Organizational theory, such as stakeholder theory (Freeman, 2010) and evolutionary theory (Nelson, 1995) are used to explain why technology needs to be changed in the organization. Institutional theory (DiMaggio & Powell, 1983; Meyer & Rowan, 1977) explains how external pressures, such as rules, social norms, or traditions affect organizational behavior. Specific theories, such as natural-resource-based views (Hart, 1995) and Corporate Social Responsibility (CSR) explain how sustainable behaviors occur in organizations.

These theories emphasize different aspects in explaining organizational sustainable behavior. The Technology Acceptance Model suggests that adopters' perception of the technology characteristics, usefulness and ease of use are important to determine the actual

use (Davis et al., 1989). Rogers (2003) further summarizes five characteristics of innovations that have an impact on the rate of adoption, which are relative advantage, compatibility, complexity, triability, and observability.

Stakeholder theory and evolutionary views do not highlight any set of factors, which means any factor that may have an impact matters. A stakeholder is “any group or individual who can affect or is affected by the achievement of the organization’s objectives” Freeman (2010, p46). With respect to firms’ sustainable technology adoption behavior, three types of stakeholders have been identified in prior studies, which are regulatory stakeholders, internal stakeholders and market stakeholders (Darnall, Henriques, & Sadorsky, 2010; Huang, Ding, & Kao, 2009). Stakeholder theory explains firms’ behavior from the managers’ decision-making process, identifying interests of all parts, while environmental elements are seldom discussed. Del Río González (2005) and Kemp and Soete (1992) adopted an evolutionary perspective to explain firms’ adoption behavior. Del Río González (2005) regards the evolutionary perspective as an eclectic approach, which takes account of economic incentives, competencies of the firms and the institutional structure. Kemp and Soete (1992) argue that the evolutionary perspective regards technological change as a complex, non-linear, path-dependent process, which is driven by short-term benefits. Even though the evolutionary perspective considers other factors, such as firm characteristics, technology, and institutions, it assumes that adoption behavior is primarily driven by economic incentives.

Institutional theory suggests that firms make choices according to norms, rules, regulations, and laws prevailing in the surrounding society (Oliver, 1997). Institutional rules lead firms to behave similarly because of coercive, mimetic and normative processes (DiMaggio & Powell, 1983; Meyer & Rowan, 1977). Due to the externalities of environment-related behaviors, external pressures are needed to regulate firms’ behavior. Regarding organizational environmental behavior, government, professionalization, societal bodies and peer organizations are possible forces that exert institutional pressures.

The natural-resource-based view suggests that firms should develop a natural environmental view because of the environmental constraints (Hart, 1995). Specifically, three strategies – pollution prevention, product stewardship, and sustainable development – have been recommended (Hart, 1995). Social responsibility includes economic, legal, ethical and discretionary expectations that society has regarding organizations (Carroll, 1979). The benefits of CSR include reducing cost and risks, strengthening legitimacy and reputation, building competitive advantages, and creating win-win relationships with stakeholders (Carroll & Shabana, 2010). However, having the aim of being a responsible business by the firm is not sufficient for sustainable development, because there may exist firms that are less concerned about their reputation, do not take a long-term view of business success or may not realize the strategy due to conflicting interests (Moon, 2007). Or in other cases, governments may fail to implement limits to emissions or fail to inhibit harming the environment (Moon, 2007).

In summary, the Diffusion of Innovation Theory and the Technology Acceptance Model emphasize the role of technology and adopter characteristics in adoption decisions. Stakeholder theory and evolutionary theory do not emphasize any specific group of factors, but may include any factor relating to relevant stakeholder identification or selection criteria and organizational adaptation ability. Institutional theories focus on external mandatory, cognitive and normative pressures. The natural-resource-based view and corporate social responsibility emphasize the responsibility of organizations and ways how to be sustainable. Based on these theories, researchers have investigated various factors that may have an impact on organizational adoption of sustainable process technologies. Environmental regulation, anticipated future regulation, improvement in corporate image, environmental product demand, social and environmental responsibility, and higher cost of production are found to be relatively more important than the other factors (Arvanitis & Ley, 2013; Del Río González, 2005; Luken & Van Rompaey, 2008; Zhang, Bi, & Liu, 2009). Many researchers focus on environmental regulations and market demand (Demirel & Kesidou, 2011; Kesidou & Demirel, 2012; Triguero, Moreno-Mondejar, & Davia, 2013; Veugels, 2012).

In view of these theories and prior studies, three research areas have been identified that require further study. First, since factors from different theories are sometimes overlapping or contradicting with each other, there is no theory explaining organizational sustainable behavior specifically. Questions, such as which factors are the main driving forces for sustainable process technology adoption and, since various factors co-exist, how these factors are interrelated remain to be answered. Factors that have an impact on firms' behaviors do not necessarily imply an effective measure to promote sustainable technology adoption. For example, many studies suggest a positive effect of environmental management systems (EMS) on firms' sustainable technology adoption (Demirel & Kesidou, 2011; Luken, Van Rompaey, & Zigova, 2008; Prajogo, Tang, & Lai, 2014; Wagner, 2007), while Ziegler and Nogareda (2009) challenge this relationship and suggested that EMS can be reversely affected by firms' adoption of environmental innovations. If so, adoption of EMS would not need governments' separate support. Wagner (2009) suggests that the impact of the use of EMS on firms' sustainable technology adoption varies between countries, which means that only under some specific circumstances the EMS is significantly associated with sustainable technology adoption. Factors that correlated with firms' sustainable process technology adoption do not automatically result in effective measures to promote sustainable technology adoption and such measures could also vary across countries. Therefore, drivers, which are the reasons that motivate firms to make the adoption decision, need to be distinguished from other correlated factors. Better understanding the drivers of sustainable technology adoption could assist researchers to predict firms' adoption behavior and also allow researchers and policy makers to determine the efficiency of promotional measures (Bansal & Roth, 2000). Furthermore, if various factors have an impact on firms' sustainable technology adoption, whether they act independently or synergistically remains unknown.

Second, since sustainable technology is a broad concept, it is unknown if the underlying adoption mechanism differs for different types of sustainable technology. Sustainable technology could be a product, a (production) process technology, a service, or business model, and is usually used interchangeably with eco, environmental, green, or ecological technologies (Schiederig, Tietze, & Herstatt, 2012). Prior studies use terms such as corporate social responsibility and environmental behavior to investigate sustainable technology adoption behavior, in which case various sustainable technologies have been regarded as one or the same. Besides, sustainable product technology and process technology are often mixed up in measures of the dependent variable. Even regarding sustainable process technologies, various types have been identified, such as end-of-pipe technology and cleaner technology, recycling technology and efficiency technologies. Neglecting the differences between sustainable technologies could result in misunderstanding firms' adoption behavior. Moreover, managerial (organizational) changes and technical changes also need to be differentiated. Only in this way, more specific means to promote sustainable process technology adoption can be provided.

Third, while barriers to the adoption of sustainable technologies have been extensively identified by researchers, considerable criticism is voiced regarding the existing measures to promote sustainable technology adoption. More research should be conducted on how to enhance the effectiveness of the promoting measures. For example, environmental policies may stifle technologies that are not supported, and subsidies may not provide incentives to reduce polluting technologies and require large public expenditures for technologies that have already penetrated in the market (Jaffe, Newell, & Stavins, 2005). Conflicting and overlapping policies may cause confusion, complexity and higher costs to firms (Borghesi, Crespi, D'Amato, Mazzanti, & Silvestri, 2015b; Chappin, Vermeulen, Meeus, & Hekkert, 2009). Barriers, such as the absence of economic incentives, lax environmental enforcement, high initial capital cost, and a lack of alternative process technologies and lack of tradition/skill are still prominent (Luken & Van Rompaey, 2008; Shi, Peng, Liu, & Zhong, 2008). To provide more practical means to promote sustainable process technology adoption, research should be conducted not only on which factors are relevant but also on what influences the effectiveness of these factors.

1.3 Research questions and contribution

The aim of this dissertation is to better understand organizational sustainable process technology adoption and to provide useful information for firm managers and policy makers in promoting sustainable process technology adoption. Therefore, the research question of this dissertation is:

Which factors influence organizational sustainable process technology adoption and how are they interrelated?

To answer this question, we conducted three studies, first exploring general factors and then more specific ones. A systematic literature review was conducted to get an overview of factors influencing sustainable process technology adoption by firms (Chapter 2). Two strands of factors are identified as important based on prior studies and theories, which are economic drivers and institutional drivers. A more detailed analysis regarding the relative importance of these two strands of factors and their interrelationships is conducted in Chapter 3. Since environmental regulation is still the main driving force for sustainable process technology adoption, a more focused investigation regarding the effectiveness of environmental regulations was conducted, exploring how regulatory context factors affect the relationship between environmental regulations and organizational sustainable behaviors (Chapter 4). The next subsections present an overview of each chapter.

1.3.1 Chapter 2: Factors affecting the adoption of sustainable process technologies:

A systematic literature review

Even though the idiosyncrasies of sustainable technology have been recognized, the different driving mechanisms regarding various types of sustainable technologies are rarely addressed. Furthermore, with the increase of research in the field of sustainability performance, the results are scattered across different disciplines, fragmenting the knowledge on sustainable technology adoption. Therefore, in Chapter 2, focusing only on sustainable process technologies, we summarize the results from prior studies investigating how sustainable *process* technology adoption is measured and what causes the different effects of various factors of influence across studies.

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 several criteria, i.e., document type, language, definition of adoption, definition of sustainable technology, and analysis level, 34 out of 964 articles were selected for 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 the United Nations Environmental Program of sustainable technologies, a classification of sustainable process technologies was developed: CO₂/emission reduction, material/fuel substitution, energy/material efficiency and recycling technologies.

This chapter contributes to sustainable technology adoption studies by providing a more coherent investigation of factors related to the adoption of sustainable process technologies only. Furthermore, this chapter contributes to prior review studies by offering explanations for the inconsistent effects of factors across studies, which results in a more context-related understanding of sustainable *process* technology adoption in organizations.

1.3.2 Chapter 3: What influences manufacturing firms to adopt sustainable process technologies? The relative importance of economic and institutional drivers

There are many theories and even more factors in prior studies that have been found to explain and influence sustainable process technology adoption, resulting in the question which class of factors is more important than the others and how they are interrelated. In this chapter, we identify economic and institutional drivers as the most important driving forces based on prior theories and investigate their relative importance for the adoption of different sustainable process technologies and the interrelationships between these drivers.

Specifically, in Chapter 3, first economic explanations are distinguished from institutional explanations of firms' adoption behavior and second, sustainable process technologies are categorized according to their cost-saving potentials. Hypotheses about the relative importance of economic drivers and institutional drivers for different types of sustainable process technologies were developed. Additionally, synergy effects between economic and institutional drivers were investigated. Hypotheses were tested using survey data of energy-intensive manufacturing firms from various industries in China and The Netherlands.

This chapter contributes to adoption theory by combining economic and institutional theoretical perspectives explaining sustainable process technology adoption behavior by organizations. The relative importance and synergy effects of factors from these two strands of theories have been tested. By doing this, we developed a better integrated model of organizational sustainable process technology adoption.

1.3.3 Chapter 4: The effects of environmental regulations on managerial and technical sustainable responses of firms: The role of regulatory uncertainty and information transparency

Environmental regulations are still the main driving force for sustainable process technology adoption by organizations. However, even though governments worldwide have made great efforts to promote sustainable technology adoption, the adoption rate of sustainable process technologies is still low. Moreover, criticism regarding the effectiveness of environmental regulations is pervasive. Therefore, in this chapter, we focus on the impact of environmental regulation and how this impact is subject to different regulatory contexts.

The impact of environmental regulations could result in various types of organizational behavior. We distinguished technical (the adoption of process technologies) from managerial responses of firms to perceived environmental regulations. The impact of environmental regulations on technical and managerial sustainable practices is analyzed separately. Moreover, the impact of regulatory uncertainty is distinguished from the impact of information transparency in order to incorporate differences in regulatory contexts and their effects.

This chapter contributes to the literature on sustainable organizational behavior by distinguishing managerial from technical responses. Managerial and technical practices

are related and yet distinct within organizations. This not only captures a broader range of organizational behaviors but also allows developing a more specific understanding of the impact of environmental regulations on technical practices, comparing it with the impact on managerial practices. Furthermore, this chapter contributes to environmental regulation literature by investigating the moderating effect of regulatory context factors. Even though environmental regulation is deemed effective in general, how effective it could be is controversial. This chapter further shows that its effectiveness is influenced by the uncertainty and transparency of the regulation.

1.4 Dissertation outline

Table 1-1 provides an overview of the chapters, illustrating the objectives, theoretical focus, research design, and the methods used in each chapter.

Table 1-1: Overview of the chapters

Chapter	Study	Objective	Theoretical focus	Research design & Method
Introduction				
2	Factors affecting sustainable process technology adoption: A systematic literature review	Analyze and compare the effects of factors affecting sustainable process technology in prior studies systematically	<ul style="list-style-type: none"> • The measurement of sustainable process technology adoption • The effects of the factors across different research settings • Reasons for the differences in the effects of factors across studies 	Systematic literature review <ul style="list-style-type: none"> • Inductive approach of content analysis • Multiple-theory-based approach • Qualitative synthesis method
3	What influences manufacturing firms to adopt sustainable process technologies? The relative importance of economic and institutional drivers	Examine the effect of institutional drivers and economic drivers	<ul style="list-style-type: none"> • Institutional theory • The relative importance of institutional drivers and economic drivers • The synergy effects between institutional drivers and economic drivers 	<ul style="list-style-type: none"> • Quantitative • Survey • Hypotheses test • Hierarchical regression analysis test
4	The effect of environmental regulations on managerial and technical sustainable responses of firms: The role of regulatory uncertainty and information transparency	Examine the effects of environmental regulations on organizational sustainable behavior	<ul style="list-style-type: none"> • Managerial and technical sustainable behavior • The effect of environmental regulations • The impact of regulatory uncertainty and information transparency on the effectiveness of environmental regulations 	<ul style="list-style-type: none"> • Quantitative • Survey • Hypotheses test • Structural equation modeling
Conclusion				

2.

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

This chapter is based on: Fu, Y., Kok, R. A. W., Dankbaar, B., Ligthart, P. E. M., & van Riel, A. C. R. 2018. Factors affecting sustainable process technology adoption: A systematic literature review. *Journal of Cleaner Production*, 205: 226-251.

2.1. 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, Schiereck, & von Flotow, 2014; Belis-Bergouignan, Oltra, & Saint Jean, 2004; Dewick & 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 & Roth, 2000).

Over the past few decades, the number of publications about the sustainability performance of firms has increased dramatically (Linnenluecke & 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 & Ley, 2013; Frondel, Horbach, & Rennings, 2007; Luken & 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, Jeanrenaud, Bessant, Denyer, & Overy, 2016; Linnenluecke & Griffiths, 2013; Salzmänn, Ionescu-somers, & Steger, 2005). The corporate sustainability reviews focus on performance effects (See Linnenluecke & Griffiths, 2013; Salzmänn 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 Salzmänn et al., 2005). Only five literature reviews were conducted in the field of sustainable technology adoption (i.e., Del Río González, 2009; Kemp & Volpi, 2008; Montalvo, 2008; Sarkar, 2008; Shi & 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 CO₂ emission reports, nearly one third of the world's energy consumption and CO₂ 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 CO₂ 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.

2.2. Methodology

Compared with descriptive literature reviews, a systematic review minimizes the bias and random error through a replicable, scientific and transparent process (Cook, Mulrow, & Haynes, 1997; Tranfield, Denyer, & Smart, 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.

2.2.1 Data collection

We used two literature databases, the Social Science Citation Index, based in the Web of ScienceTM 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 Appendix A. 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.

2.2.2 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 2-1 for the decision tree).

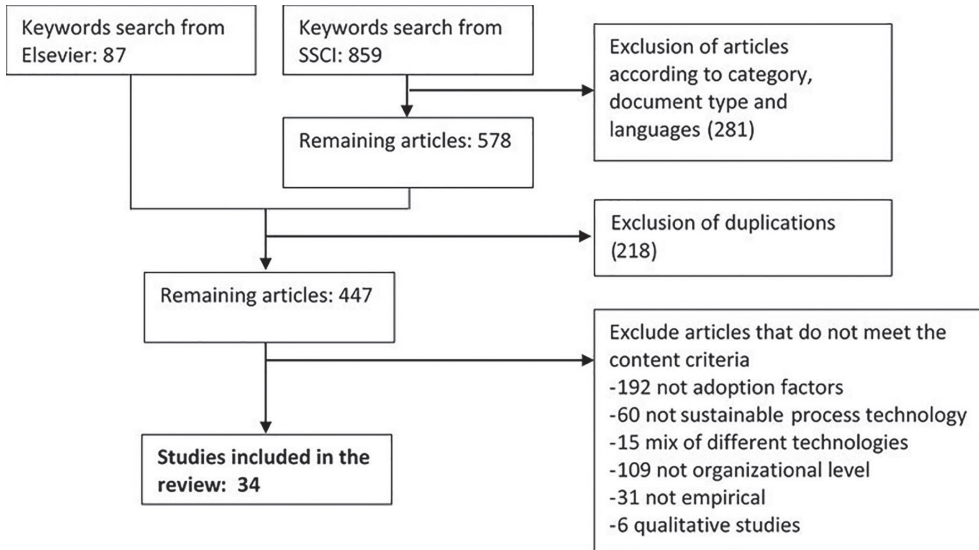


Figure 2-1 Decision tree of data selection

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 2-2). 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).

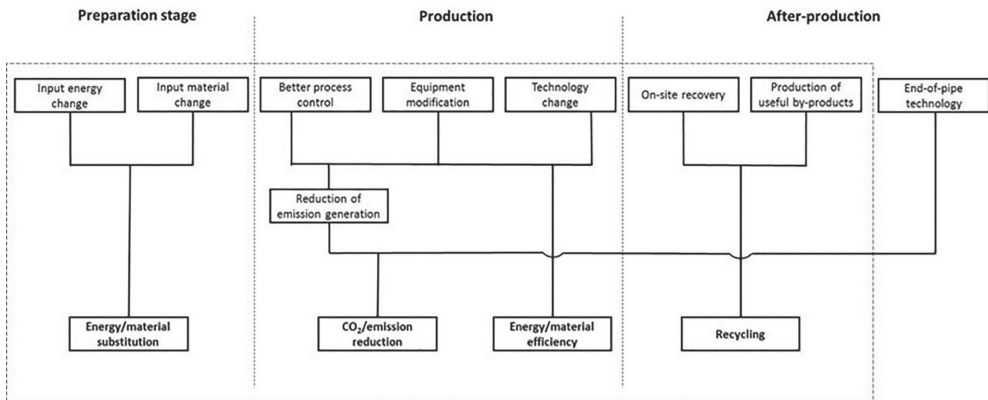


Figure 2-2 Categories of sustainable process technologies

Adapted from UNIDO'S definition of Cleaner Production (CP) (UNEP, 1999); Del Río González (2005); Frondel et al. (2007)

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” (UNEP, 1999). 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 2-2). 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.

2.2.3 Analysis

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.

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.

2.3. 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 2-3 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.

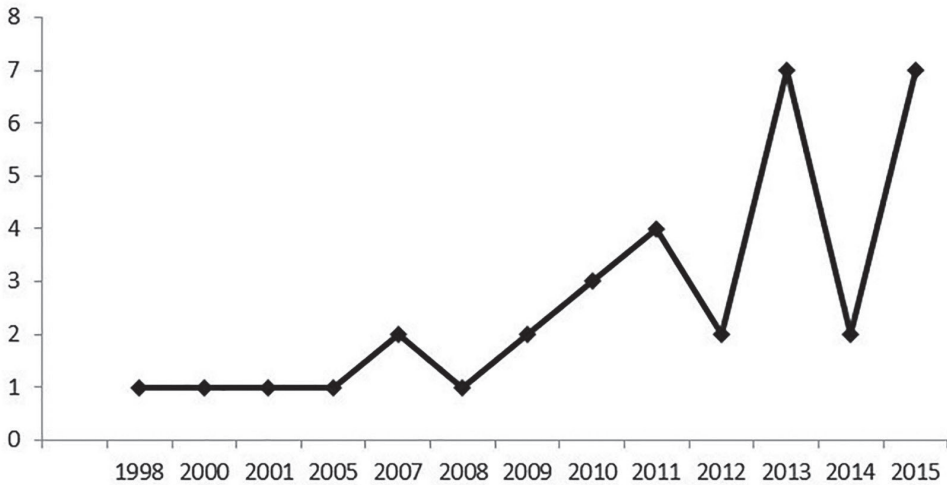


Figure 2-3 Publication trend

Sustainable process technology adoption has been studied mostly in Europe, followed by the US (See Table 2-1). 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.

Table 2-1: 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%

The distribution of publication journals (see Table 2-2) 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.

Table 2-2 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%

2.4. 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 2-3). In addition to the five types of sustainable process technologies (See Figure 2-2), 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 ‘CO₂/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. ‘CO₂/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 Appendix B. 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 & Kesidou, 2011; Hammar & Lofgren, 2010; Lofgren, Wrake, Hagberg, & Roth, 2014). Only one study investigates information gathering during the adoption process (i.e., Kounetas, Skuras, & Tsekouras, 2011). Two studies investigate the adoption time (i.e., Bellas & Nentl, 2007; Maynard & Shortle, 2001) and the same for the willingness of entrepreneurs (i.e., Zhang, Fei, Zhang, & Liu, 2015; Zhang, Yang, & Bi, 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 CO₂/emission reduction technology is the reduction of emissions to the solid, water, air etc. Because of the specificity of CO₂, the reduction of CO₂ emission is often used as an independent variable distinguished from other types of emissions like NO_x or water (See Antonioli, Mancinelli, & Mazzanti, 2013; Borghesi, Cainelli, & Mazzanti, 2015a; Cainelli, Mazzanti, & Montresor, 2012; Lofgren et al., 2014; Veugelers, 2012). End-of-pipe technology is used directly in some cases (e.g., Camison, 2010; Demirel & Kesidou, 2011; Hammar & Lofgren, 2010), while others used specific examples, such as fabric filter (e.g., Bellas & Nentl, 2007) or post-combustion technology (e.g., Bonilla, Coria, Mohlin, & Sterner, 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 & Chandra, 2013; Maynard & Shortle, 2001; Theyel, 2000; Yusup, Mahmood, Salleh, & Ab Rahman, 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 & Lin, 2011). Fuel substitution technology is studied only in one case, using a specific example of propane in the brickmaking industry (i.e., Blackman & 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, D'Amato, & Mazzanti, 2015; Leenders & Chandra, 2013; Triguero, Moreno-Mondejar, & Davia, 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.

Table 2-3 Measurement scales of sustainable process technology adoption

Item	Scale	Initiation		Implementation		
		Information gathering	Adoption willingness	Expenditure	Put into use	Adoption degree
General sustainable technology						
Clean technology			(Zhang et al., 2013);	(Demirel & Kesidou, 2011); (Hammar & 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 & Sangle, 2015); (Huang et al., 2009); (Jimenez, 2005); (Prajogo et al., 2014); (Weng & Lin, 2011); (Wu, 2013);
CO2/Emission reduction technology						
General	Result in emission reduction				(Antoniolli et al., 2013); (Cainelli et al., 2012)	
	Result in lower total CO2 production		(Lofgren et al., 2014)		(Antoniolli et al., 2013); (Borghesi et al., 2015a); (Cainelli et al., 2012); (Veugelers, 2012);	
End-of-pipe	Generic		(Demirel & Kesidou, 2011); (Hammar & Lofgren, 2010)		(Bellas & Nenti, 2007);	(Bellas & Nenti, 2007)
	Fabric filter				(Bonilla et al., 2015); (Popp, 2010);	
	NOx abatement technology (post-combustion technology)				(Bonilla et al., 2015); (Popp, 2010);	
Reduction of emission generation	NOx abatement technology (combustion modification technology)					

Material/fuel substitution		
Material substitution	Use organic products or processes	(Leenders & Chandra, 2013);
	Use non-hazardous or less hazardous materials	(Theyel, 2000); (Yusup et al., 2015)
	Elemental chlorine-free bleaching	(Maynard & Shortle, 2001); (Maynard & Shortle, 2001)
substitution	Propane	(Blackman & 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	(Borghesi et al., 2015a); (Trianni, Cagno, & Worrell, 2013); (Veugelers, 2012); (Yusup et al., 2015)
	Flue gas condensation technology	(Bonilla et al., 2015);
	List of energy saving technologies	(Arvanitis & Ley, 2013); (Arvanitis & 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 & Shortle, 2001); (Maynard & 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 & Chandra, 2013);

2.5. 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 2.5.1) and the interrelationships between these factors (section 2.5.2). 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.

2.5.1 The direct effect of determinants

Table 2-4 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 2-4, 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.

Table 2-4: 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				CO2/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 & Lin, 2011) (1); (Triguero et al., 2013) (1)								(Triguero et al., 2015) (2)				(Arvanitis & Ley, 2013) (6)			(Leenders & Chandra, 2013) (1)	(Triguero et al., 2015) (2)		(Leenders & Chandra, 2013) (1)	
Market competition									(Arvanitis & Ley, 2013) (1)				(Arvanitis & Ley, 2013) (11)			(Leenders & Chandra, 2013) (1)			(Leenders & Chandra, 2013) (1)	
Resource price	(Lukon et al., 2008) (1); (Triguero et al., 2013) (1)							(Lofgren et al., 2014) (2)					(Arvanitis & Ley, 2013) (2)							
Legitimacy																				
Coercive pressures																				
Regulation stakeholder	(Huang et al., 2009) (1);																			
Regulation	(Lukon et al., 2008) (1); (Sangle, 2011) (1); (Veugelaers, 2012) (2); (Weng & Lin, 2011) (1)				(Triguero et al., 2013) (1)				(Bellas & Nentl, 2007) (1); (Borghesi et al., 2015a) (1)	(Veugelaers, 2012) (2); (Borghesi et al., 2015a) (1); (Triguero et al., 2015) (1)			(Arvanitis & Ley, 2013) (2); (Bonnilla et al., 2015) (5); (Triguero et al., 2015) (1)			(Blackman & Bannister, 1998) (1); (Leenders & Chandra, 2013) (1)		(Leenders & Chandra, 2013) (1); (Triguero et al., 2015) (2)		
Voluntary standard	(Jimenez, 2005) (2)																			
Governmental support	(Weng & Lin, 2011) (1)																			

Economic support	(Demirel & Kesidou, 2011)(2);	(Triguero et al., 2013)(1); (Veugeliers, 2012)(1)	(Veugeliers, 2012)(1);	(Borghesi et al., 2015a)(2)	(Borghesi et al., 2012)(1); (Triguero et al., 2015)(1); (Borghesi et al., 2015a)(1)	(Leenders & Chandra, 2013)(1)	(Triguero et al., 2015)(2)
Technical support		(Lukén et al., 2008)(1)					
Industry initiative							
Mimetic pressure							
Diffusion rate							
Normative pressures	(Zhang et al., 2013)(1); (Zhang et al., 2015)(1)	(Sangle, 2011)(1)	(Lukén et al., 2008)(2)	(Bonilla et al., 2015)* (1); (Popp, 2010)* (1)	(Popp, 2010)* (1)	(Arvanitis & Ley, 2013)(1); (Borghesi et al., 2015)* (1); (Arvanitis & Ley, 2013)(2)	
Information							
Information uncertainty		(Weng & Lin, 2011)(1)					
Information sources	(Triguero et al., 2013)(1)		(Borghesi et al., 2015a)(3)	(Borghesi et al., 2015a)(1)	(Borghesi et al., 2015a)(16)	(Arvanitis & Ley, 2013)(2)	(Cainelli et al., 2015)(3)
Firm characteristics							
Firm size	(Lukén et al., 2008)(1); (Hammar & Loigren, 2010)(1); (Wagner, 2009)(1);	(Bonilla et al., 2015)* (1); (Popp, 2010)* (2); (Bellas & Nentli, 2007)* (1); (Hammar & Loigren, 2010)(1); (Loigren et al., 2014)(1)	(Bellas & Nentli, 2007)(2)	(Bonilla et al., 2015)* (29); (Popp, 2010)* (2); (Bellas & Nentli, 2007)* (1); (Borghesi et al., 2015a)(2); (Loigren et al., 2014)(1)	(Arvanitis & Ley, 2013)(6); (Borghesi et al., 2015)* (1);	(Maynard & Shortle, 2001)* (1)	(Blackman & Bannister, 1998)(1);
Ownership							

Foreign owned	(Luken et al., 2008) (1)	(Cainelli et al., 2012) (1)	(Cainelli et al., 2012) (2)	(Arvanitis & Ley, 2013) (3)	(Arvanitis & Ley, 2013) (3)	(Blackman & Bannister, 1998) (1)	
Public owned			(Bellas & Nentl, 2007) (2); (Popp, 2010) (2)				
Private owned		(Luken et al., 2008) (1)	(Popp, 2010) (1)				
Export activity		(Luken et al., 2008) (1); (Cainelli et al., 2012) (1)	(Cainelli et al., 2012) (2)	(Arvanitis & Ley, 2013) (6)			
Responsibility							
Corporate social responsibility		(Demirel & Kesidou, 2011) (2)					
Internal support	(Huang et al., 2009) (1); (Weng & Lin, 2011) (1)						
Human capital intensity							
Quality	(Weng & Lin, 2011) (1);		(Lofgren et al., 2014) (1)	(Arvanitis & Ley, 2013) (2)	(Arvanitis & Ley, 2013) (1)	(Blackman & Bannister, 1998) (2); (Maynard & Shortle, 2001) (1)	(Cainelli et al., 2015) (1)
Complementary	(Antonioli et al., 2013) (3)	(Antonioli et al., 2013) (21)	(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); (Hammar & Lofgren, 2010) (1)	(Triguero et al., 2013) (1)	(Triguero et al., 2015) (1)	(Triguero et al., 2015) (1)	(Triguero et al., 2015) (1)
R&D or expert	(Hammar & Lofgren, 2010) (1)	(Hammar & Lofgren, 2010) (1)	(Arvanitis & Ley, 2013) (2);	(Arvanitis & Ley, 2013) (4); (Theyel, 2000) (1);	(Theyel, 2000) (1)
Innovative capability	(Bhupendra & Sangle, 2015) (3)				
Financial capability	(Luken et al., 2008) (1);		(Maynard & Shortle, 2001) (1)	(Maynard & Shortle, 2001) (2)	
Resources intensity					
Resource cost	(Hammar & Lofgren, 2010) (1);	(Hammar & Lofgren, 2010) (1);	(Arvanitis & Ley, 2013) (3)		
Resource used	(Lofgren et al., 2014) (3)	(Lofgren et al., 2015) (12); (Popp, 2010) (2); (Lofgren et al., 2014) (1)	(Bonilla et al., 2015) (3);		
Knowledge stock					
Technology substitutes	(Hammar & Lofgren, 2010) (1)	(Bonilla et al., 2015) (3); (Popp, 2010) (1);	(Popp, 2010) (1)	(Bonilla et al., 2015) (4);	
Adoption experience		(Hammar & Lofgren, 2010) (1)	(Bonilla et al., 2015) (1); (Hammar & Lofgren, 2010) (2); (Lofgren et al., 2014) (2)	(Bonilla et al., 2015) (6);	
				(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 & Chandra, 2013) (2); (Theyel, 2000) (3)	(Leenders & Chandra, 2013) (1); (Leenders & Chandra, 2013) (3)
Certified systems	(Luken et al., 2008) (1); (Prasanna et al., 2014) (1); (Wagner, 2007) (1)	(Demirel & Kesidou, 2011) (2); (Prasanna et al., 2014) (1); (Wagner, 2009) (1);			
Others	(Wu, 2013) (1);	(Lofgren et al., 2014) (2)	(Arvanitis & Ley, 2013) (5)	(Arvanitis & Ley, 2013) (1)	
Technology characteristics					
Relative advantage	(Zhang et al., 2013) (1); (Zhang et al., 2015) (1); (Sangle, 2011) (2); (Weng & Lin, 2011) (1)	(Demirel & Kesidou, 2011) (2)			(Blackman & Bannister, 1998) (1);
Financial cost	(Sangle, 2011) (1)				
Compatibility	(Weng & Lin, 2011) (1)		(Arvanitis & Ley, 2013) (2)	(Arvanitis & Ley, 2013) (4)	

Network characteristics					
Member-ship		(Borghesi et al., 2015a) (2)	(Borghesi et al., 2015a) (2);	(Maynard & 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)

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.

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 CO₂/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 & Lin, 2011). However, no significant effect from customer demand was found on the adoption of energy-saving technologies (Arvanitis & Ley, 2013), material/fuel substitution or recycling technologies (Leenders & 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 & 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 CO₂. 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 CO₂ price (See Lofgren et al., 2014), used in the European Emission Trading System, and the energy price (See Arvanitis & Ley, 2013) do not have a significant effect on CO₂/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 & Lin, 2011), and regulatory stakeholder pressure (e.g., Huang et al., 2009), have a positive effect on sustainable process technology adoption. With respect to CO₂/emission reduction technology adoption, more studies found a positive effect of environmental policies (e.g., Bonilla et al., 2015; Borghesi et al., 2015a; Demirel & 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., 2015a; Popp, 2010). Borghesi et al. (2015a) 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 CO₂/emission reduction technology and energy-saving technologies, Borghesi et al. (2015a) 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 CO₂ 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 & Ley, 2013; Bellas & Nentl, 2007; Blackman & Bannister, 1998; Leenders & Chandra, 2013; Lofgren et al., 2014; Triguero et al., 2013). Most of these studies either focus on one specific industry (i.e., Blackman & Bannister, 1998; Leenders & Chandra, 2013), a specific regulation scheme (i.e., Lofgren et al., 2014), or a specific sustainable technology (i.e., Bellas & 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., 2015a), 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 CO₂/emission reduction technology according to Borghesi et al. (2015a), whereas Veugelers (2012) suggests that

positive policy instruments have a positive effect on CO₂ 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 & 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 CO₂/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. (2015a) 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 CO₂ 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 & Ley, 2013; Bonilla et al., 2015; Hammar & Lofgren, 2010; Lofgren et al., 2014; Popp, 2010), negative (See Bellas & Nentl, 2007; Maynard & Shortle, 2001) and no significant effect (See Blackman & 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 & 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-shaped 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 CO₂/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 & Ley, 2013). The adoption of energy/material efficiency technology and CO₂ 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 & Nentl, 2007; Blackman & 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 & 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 & 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 & 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 & Bannister, 1998; Cainelli et al., 2015; Weng & Lin, 2011). With respect to investments in CO₂ 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 & 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 & Ley, 2013; Maynard & Shortle, 2001). The complementarity of human resource management with other organizational innovations is present only in the case of CO₂ 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 & Ley, 2013; Cainelli et al., 2015; Hammar & Lofgren, 2010; Lofgren et al., 2014; Maynard & 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 & 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 & Shortle, 2001), with the exception of profit on the adoption of elemental chlorine-free bleaching (See Maynard & 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 & Lofgren, 2010) and energy-saving technologies in power-generating (Arvanitis & 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 CO₂/emission reduction technologies, the use of bio-fuel has a significant positive effect on large investors in CO₂-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 & Lofgren, 2010). These effects hold only for small investors in CO₂ 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 & 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 & 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 & Kesidou, 2011) but not on clean technology adoption (Demirel & 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 & Ley, 2013), are more likely to adopt sustainable technologies. However, investments in CO₂ 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 CO₂/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 substitution, 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 & 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 & Ley, 2013) and on the adoption degree of various sustainable technologies (See Weng & 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., 2015a) and recycling technologies (See Cainelli et al., 2015). However, membership in an environmental group (See Maynard & Shortle, 2001) or institutional revolutionary party (e.g., Federation of Mexican Workers, Brickmakers' Union) (See Blackman & 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 CO₂/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 CO₂/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).

2.5.2 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 CO₂ 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 CO₂/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).

2.6. DISCUSSION

2.6.1 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 & 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 CO₂ 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.

2.6.2 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, Frambach, and Bijmolt (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 & 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.

2.7. 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., CO₂/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. 'CO₂/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 CO₂/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 CO₂/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 CO₂/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.

3.

**What influences manufacturing firms to adopt
sustainable process technologies?
The relative importance of economic and institutional drivers.**

Fu, Y., Ligthart, P. E. M., Kok, R. A. W., van Riel, A. C. R., & Dankbaar, B., “What influences manufacturing firms to adopt sustainable process technologies? The relative importance of economic and institutional drivers”, paper under review at Research Policy since July 2018.

3.1 INTRODUCTION

Governments worldwide are promoting sustainable development, stimulating firms to save energy and materials and reduce environmental pollution. In China, for example, several environmental measures have been implemented, such as the new Environmental Protection Law, the National Carbon Emission Trading System and Environmental Taxes (Bao, 2014; Wang, 2017; Zeng, 2018). In addition, local communities, NGOs and mass media are increasingly active in environmental issues (Yang & Calhoun, 2007). Several firms, including multinational firms such as Toyota and BP, have seized the opportunity to gain competitive advantages by being more sustainable (Esty & Winston, 2006, p10-13). Nevertheless, many firms are still lagging behind. Adoption rates of sustainable technologies are low, leaving great potential to save energy and to reduce pollutants (Birkin et al., 2009; Palcic, Pons, Bikfalvi, Llach, & Buchmeister, 2013; Short, Lee-Mortimer, Luttrupp, & Johansson, 2012).

Research has progressed in understanding and explaining firms' sustainable technology adoption. From an economic perspective, if a market requires sustainable behavior or allows firms to gain a competitive advantage using sustainable technologies, firms have reasons to adopt sustainable technologies. Some studies claim that it pays to be green, because environmental performance is positively related to economic performance (e.g., Molina-Azorín, Claver-Cortés, López-Gamero, & Tarí, 2009; Orlitzky, Schmidt, & Rynes, 2003; Russo & Fouts, 1997). Other studies were inconclusive regarding the relationship between environmental and economic performance (e.g., Keele & DeHart, 2011; Kevin, Beate, Tony, & G., 2004; Link & Naveh, 2006; Pons, Bikfalvi, Llach, & Palcic, 2013). This suggests that economic benefits are not always strong enough to induce the diffusion of sustainable technologies. When the benefits cannot be captured or do not compensate for the cost of investing in sustainable technologies, institutional pressure is needed. Institutional pressure is essential to explaining technology diffusion through its role in creating legitimacy (Bansal & Roth, 2000; Tolbert & Zucker, 1983), which is needed for firms to survive (Meyer & Rowan, 1977). For example, environmental regulations can raise firms' awareness, motivate them to innovate, ensure environmental investment is rewarding, or signal the inefficient use of resources and potential technology improvement (Porter & Van der Linde, 1995). However, environmental regulations also have their limitations. For example, they do not provide incentives to go beyond the required standards and will gradually become obsolete or even counterproductive (Montalvo, 2008). Similarly, other institutional pressures, such as mimetic pressures from peer organizations and normative pressure from mass media, local communities, and professionalization exposing nonenvironmentally friendly behavior and spreading environmental knowledge may also affect sustainable development. For example, in the paper and pulp industry, Greenpeace reported the environmental impact of dioxin on consumer products that raised public awareness and induced the adoption of chlorine-free bleaching technology, and regulations were later formulated to reduce the use of chlorine (Popp, Hafner, & Johnstone, 2011).

Institutional and economic drivers coexist and have been the subject of investigations, but academic research concerning their relative importance for the adoption of different generic sustainable process technologies is lacking. Therefore, our research investigates under what conditions institutional drivers are more important than economic drivers for sustainable process technology adoption or vice versa, and whether these drivers act independently or create synergies. Answers to these questions provide useful information for both policy-makers and firm managers in terms of how to promote sustainable process technology adoption. This study contributes to the adoption theory by investigating more comprehensively the impact of institutional pressures, suggesting that an adoption process could be first legitimated. In addition, this study contributes to sustainable technology adoption literature by exploring the different underlying mechanisms for the adoption of two types of sustainable process technologies – cost-increasing and cost-decreasing sustainable technologies – from the perspective of the relative importance of different driving forces and synergy effects between drivers.

The article is structured as follows. Section 2 reviews theories of sustainable technology adoption and develops the hypotheses to be tested. Section 3 describes the targeted sample and reports the scales we use and the results of measurement model tests. Section 4 presents the results. Lastly, Section 5 discusses the main conclusions and contributions.

3.2 THEORETICAL FRAMEWORK

3.2.1 Sustainable process technologies

Whereas sustainable technologies can also be incorporated in products, services and business models (Schiederig et al., 2012), we focus on process technologies. A process technology is process equipment, material inputs, work or information flow etc. that is used to create a product or service (Utterback & Abernathy, 1975). We define sustainable process technologies as production technologies that can 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 (Belis-Bergouignan et al., 2004; Kemp et al., 1992; Schiederig et al., 2012).

A new framework of sustainable technologies was developed to distinguish between cost-increasing and cost-decreasing sustainable technologies based mainly on the United Nations Environment Programme (UNEP) classification (See Figure 3-1). The UNEP identifies eight categories of clean production: ‘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’ (UNEP, 1999). Since we focus on sustainable process technology, we excluded ‘good housekeeping’ and ‘product modification’ technologies, but we added ‘end-of-pipe technology’ and ‘input energy change’. Cleaner technology involves substituting or modifying (parts of) existing

production process technology (Frondel et al., 2007), whereas end-of-pipe, such as filters, scrubbers or coolers and condensers, is defined as extra equipment that reduces air, water, or soil pollutants after they are generated (Frondel et al., 2007; Hammar & Lofgren, 2010). Both end-of-pipe technology and cleaner technology lead to either reduction of pollution, or a reduction of energy and resource usage, or both (Frondel et al., 2007).

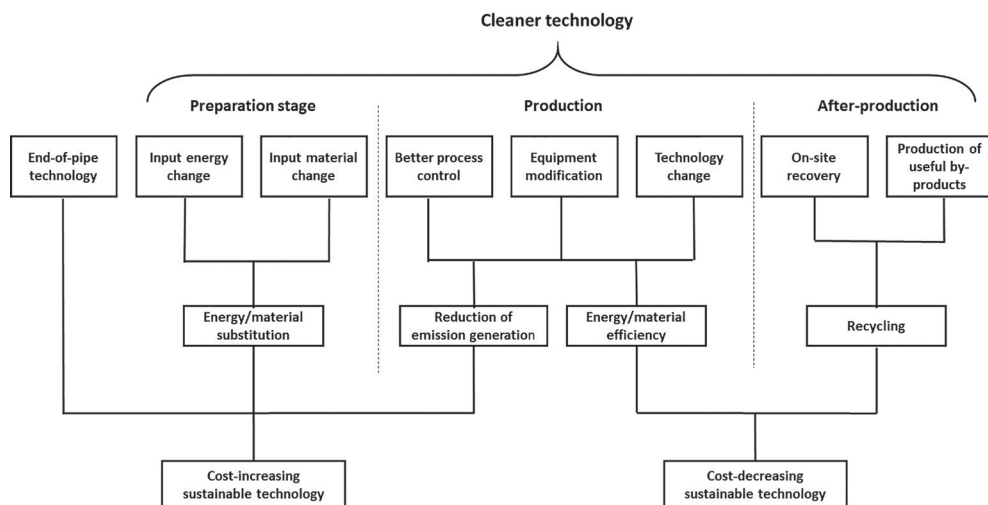


Figure 3-1 Classification of sustainable technologies

Because of different cost consequences, drivers to adopt each type of sustainable technology will be different. For example, environmental regulations are more important for end-of-pipe technologies, while cost savings are an important motivation for reducing energy and material use (Frondel et al., 2007; Horbach, Rammer, & Rennings, 2012). Therefore, we further classify sustainable technologies according to their potential impact on the firm's cost structure, which we think is pivotal for firms' adoption decision. 'Input material change' and 'input energy change' indicate a substitution by more sustainable fuel or materials, such as biomass or biodegradable materials that are usually more expensive (Chu & Majumdar, 2012; Goldemberg, 2007; Philibert, 2017) and thus are classified as cost-increasing 'energy/material substitution' technologies. Implementing 'better process control', 'equipment modification', and 'technology change' will increase operation efficiency, generate less waste, lower emission rates, or reduce pollutants emission. However, whereas some clean technologies in these categories have a cost-saving potential by increasing the efficiency of energy or material use, others only have the potential to reduce emissions at higher costs and are thus classified as cost-increasing 'reduction of emission generation' technologies. An example is combustion technology, which is designed to inhibit the generation of NO_x, as illustrated by Bonilla et al. (2015) and Popp (2010). 'On-site recovery' and 'production of useful by-products' are classified as cost-decreasing 'recycling technologies' because according to

the definition they have the potential to save material consumption or create new output. Investments in end-of-pipe technologies are often perceived as costly by firms with limited environmental benefits (Ashford, 1994; OECD, 2009) and thus are classified as cost-increasing sustainable technologies. This classification is consistent with McKinsey's Global greenhouse gas (GHG) abatement cost curve, in which energy/material efficiency technology, such as efficiency improvements, motor systems efficiency, and recycling technology, such as waste recycling have negative abatement cost compared with the abatement cost of per ton CO₂ at the business-as-usual situation (Enkvist, Denkil, & Lin, 2010).

3.2.2 Organizational adoption of process technologies

Previous research has investigated adoption at different levels. At the individual level, adoption entails the acceptance and usage of a technology by an individual (Davis et al., 1989). At the organizational level, researchers focus more on the adoption process in organizations or organizational units. Rogers (2003) uses the term innovation rather than technology and identifies five subprocesses of adoption: agenda-setting, matching, redefining/restructuring, clarifying, and routinizing. Similarly, Damanpour and Gopalakrishnan (1998) claim that the adopting organization goes through the process of awareness of innovation, attitude formation, evaluation, decision to adopt, trial implementation and sustained implementation.

Some studies approach adoption as part of organizational innovation that may also include the development of the technology. In Rogers (2003) diffusion of innovation model, the adoption process is part of the broader innovation development process that includes all activities: from recognizing a problem or need, basic and applied research, development, commercialization, diffusion and adoption, and consequences. This model reflects the assumption that technology may not only be bought but can also be developed by the organization that adopts it. Damanpour and Gopalakrishnan (1998) distinguish here between innovation generation and innovation adoption; generation results in an outcome (e.g., a new product or service), while adoption results in the assimilation of that outcome.

In this paper, following Damanpour and Gopalakrishnan (1998), we emphasize the implementation aspects of adoption. Instead of innovation, we use technology as a narrower term that more accurately reflects changes or improvements in production or manufacturing systems. Moreover, we are more interested in the actual implementation of the technology than in its generation, especially since sustainable process technologies are often developed by specialized firms rather than by the adopting firm (Kemp & Soete, 1992). We speak of organizational choice, because even if individuals make the choice, they are generally embedded in the organization or organizational unit purchasing the technology.

3.2.3 Theories explaining adoption behavior

A combination of diffusion theory, competitive advantage theory, and institutional theory is used to explain adoption behavior. According to Rogers (2003) diffusion theory, the

adoption process is triggered by a performance gap, which is the discrepancy between an organization's expectations and actual performance. Perceived attributes of the technology, such as the relative advantage of the technology, are important predictors for the adoption rate (Rogers, 2003). Competitive advantage theory points to the importance of market power and resources to achieve production efficiency or product differentiation (Rindova & Fombrun, 1999). Technology could be a means of increasing efficiency and thus market share. From a market perspective, meeting customers' demand enhances competitive advantage. Therefore, from an economic perspective, both the relative advantages of the technology and customer demand could result in improved competitive performance, which will drive adoption behavior.

However, traditional adoption models have a pro-innovation bias, assuming innovation is beneficial and efficient (Abrahamson, 1991). In reality, economic considerations may not fully explain adoption, because institutional pressure also plays a role. Institutional theory suggests that organizations adopt technology because of external legitimacy, i.e., the political, inter-organizational and societal acceptance of their behavior (Kennedy & Fiss, 2009; Tolbert & Zucker, 1983). Abrahamson (1991) uses an institutional perspective to explain why inefficient innovations are adopted, in which the forced-selected, fad and fashion choices are in accordance with coercive, normative, and mimetic pressures, respectively. Kennedy and Fiss (2009) also argue that adopters not only have economic considerations (such as improved productivity) but also social considerations (such as the influence of accreditation commissions). They find that legitimacy and economic expectations coexist as adoption drivers. In the study of the ecological responsiveness of firms, Bansal and Roth (2000) also suggest that technology adoption can be explained from the perspective of organizational interests and legitimacy.

Institutional theory suggests that in an elaborated institutional environment, organizations need legitimacy to survive by conforming to prevailing norms, rules, traditions, and social pressures (Meyer & Rowan, 1977; Oliver, 1997). Legitimacy defines what activities are desirable, proper, or appropriate in an institutionalized context (Suchman, 1995), which is created by the interconnectedness of societal relations, the collective organization of society, and the leadership of organizational elites (Meyer & Rowan, 1977).

Basically, three types of institutional pressures are recognized in the literature: coercive, normative and mimetic pressure. Coercive pressure (DiMaggio & Powell, 1983) comes from regulative institutions that constrain and regularize behavior and define legally sanctioned legitimacy by rules, laws and sanctions (Scott, 2013). Normative pressure derives from normative institutions defining moral legitimacy, focusing on social obligation (Scott, 2013), which includes both the professionalization perspective – the formal education and legitimacy produced by university specialists (DiMaggio & Powell, 1983), and the social perspective – legitimacy built by media, local communities or NGOs (Delmas & Toffel, 2004; Hoffman, 2001; Muthuri & Gilbert, 2011). Mimetic pressure is caused by uncertainty speaks of cultural-cognitive institutions (DiMaggio & Powell, 1983; Scott, 2013). Organizations

respond to uncertainty by imitating other organizations' behavior to reduce the ambiguity of innovation and to avoid sanctions for noncompliance (Bansal & Roth, 2000; DiMaggio & Powell, 1983; Rogers, 2003).

We conclude that economic and institutional rationales are both important in explaining firms' adoption behaviors.

3.2.4 Economic drivers of sustainable process technology adoption

Based on a literature review from a competitive advantage and diffusion perspective, we propose that perceived customer green demand and relative advantage are the two main economic drivers of sustainable process technology adoption.

Customer green demand

Customer green demand refers to consumers or industrial firms asking for products that are produced in a sustainable way. Firms generally respond to customer demands and aim to meet them more efficiently and effectively than competitors do to achieve a competitive advantage (Berger, 2008; Chikán, 2008). If firms perceive that customers require proof of sustainable production through labels or procedures that indicate that environmental requirements are met, they respond to the demand by adopting sustainable technologies. Many studies have shown that increased demand for green products significantly influences firms' sustainable process technology adoption (e.g., Arvanitis & Ley, 2013; Triguero et al., 2015; Triguero et al., 2013; Weng & Lin, 2011). Customer demand is especially relevant in the case of inter-firm deliveries. Organizations require sustainable behavior from their suppliers in order to improve their own sustainable performance. Moreover, when environmental regulations are strict, customers want to ensure that their suppliers will not be shut down because of environmental issues.

Relative advantage

The relative advantage is defined as the degree to which a technology is better than the previous one, as perceived by firms (Rogers, 2003, p229). The perceived relative advantage of a sustainable technology may include both direct and indirect economic benefits. First, managers may believe suppliers' test reports about the potential of sustainable technologies to save energy or materials, which provides direct economic benefits. Indirect economic relative advantages, such as improvement of environmental performance, social prestige, product quality and safety, may also be realized by sustainable technologies. Contrary to early assumptions that sustainable behavior results in loss of competitiveness, firms that are proactive in sustainable development appear to perform well both financially and environmentally (Claver, López, Molina, & Tarí, 2007; Judge & Douglas, 1998; Nakao, Amano, Matsumura, Genba, & Nakano, 2007). Managers of firms may know the results of these studies and realize they could achieve those potential benefits by adopting appropriate sustainable technologies.

Overall, from an economic perspective, we identified two drivers for firms' sustainable technology adoption: customer green demands and relative advantages of the sustainable technology. We hypothesize the following:

H1: Economic drivers (customer green demand, relative advantage) are positively related to sustainable process technology adoption.

3.2.5 Institutional drivers of sustainable process technology adoption

Government is one of the salient and powerful authorities exerting coercive pressure through environmental regulations. Environmental regulation is among the most effective measures to promote sustainable technology adoption (Del Rio, Moran, & Albinana, 2011; Demirel & Kesidou, 2011; Luken et al., 2008; Sangle, 2011; Veugelers, 2012; Weng & Lin, 2011). Specific regulatory instruments, such as legally enforced requirements, subsidies or taxes, could either punish firms' violation or benefit compliance. Complying with environmental regulations provides firms with legal legitimacy. Therefore, both the awareness of environmental regulations and regulation enforcement of various policy instruments have a positive impact on firms' sustainable process technology adoption.

Normative pressure comes from professional and societal bodies of influence. Professionalization establishes a cognitive basis for legitimacy (Abrahamson, 1991; DiMaggio & Powell, 1983). Members of professional associations inside and outside the firm shape the cognitive definition of the conditions and methods of the work (DiMaggio & Powell, 1983). Professional associations, such as standard-setting bodies, could affect organizational behavior by accreditations or certifications (Casile & Davis-Blake, 2002; Ruef & Scott, 1998). Other professional associations, such as in-house expertise, consultants, universities, industry trade shows, etc., can also influence firms' adoption decision by providing advice or technology information, or through cooperation. Therefore, if the professional sources favor sustainable behavior, firms are more likely to adopt sustainable process technologies.

Stakeholder theory could be used to explain the influence of society pressure from local communities, NGOs and media. Public stakeholders such as local communities and NGOs can either exert pressure directly on firms or indirectly through regulatory or media channels (Luken et al., 2008; Montalvo, 2008). On the one hand, public stakeholders are involved directly in defining what moral legitimacy is. On the other hand, mass media provide the communication channels that are prerequisites for the involvement of local citizens, NGOs and politicians (Yang & Calhoun, 2007). These public stakeholders also have the potential to monitor legal legitimacy, because they increasingly obtain access to the judicial systems. Therefore, pressure from society toward sustainable behavior will have a positive impact on sustainable process technology adoption.

The behavior of peer organizations influences cognitive legitimacy. Organizations tend to imitate other organizations in the same or related industries that they perceive to be more legitimate or successful (DiMaggio & Powell, 1983). Theories of organizational ecology (Carroll, 1985; Hannan & Freeman, 1987) emphasize that firms tend to imitate the behavior

of organizations within a population, because their behavior is more closely monitored and is viewed as more salient than outside organizations (Haveman, 1993). Other authors use learning effects and epidemic theories to explain why the diffusion rate has a positive impact on sustainable technology adoption (e.g., Arvanitis & Ley, 2013; Bonilla et al., 2015). From a supply chain perspective, the sustainability of final products is affected by the sustainable performance of each firm in the supply chain (Kumar & Rahman, 2015). Therefore, peer influences coming from related industries, such as suppliers and customers, affect firms' adoption behavior. Another source of peer influence is from firms that produce substitute or similar products, because they are reviewed as competitors and are thus closely monitored. Furthermore, since firms with high visibility and prestige are more likely to influence others (Burns & Wholey, 1993), leading and successful firms are always viewed as models that attract other firms to imitate. Overall, if peer organizations have adopted sustainable process technologies, firms are more likely to adopt these technologies as well maintain their legitimacy. Therefore, we hypothesize the following:

H2: Institutional drivers (environmental regulation, professionalization pressure, society pressure and peer organizations' adoption) are positively related to sustainable process technology adoption.

3.2.6 The relative importance of economic drivers and institutional drivers

Organizational efficiency and institutional legitimacy are both needed for firms' survival (Meyer & Rowan, 1977). This raises the question of whether the two drivers of sustainable technology adoption are equally important or if they substitute for each other, wherein one may be more important than the other in some cases. The distinction between cost-increasing and cost-decreasing technologies appears to be useful here.

Several researchers have found that environmental regulations are more important for end-of-pipe technologies than clean technologies (Bonilla et al., 2015; Demirel & Kesidou, 2011; Frondel et al., 2007; Horbach et al., 2012), while the adoption of energy-saving technology is mainly motivated by economic drivers (Horbach et al., 2012). Because end-of-pipe and energy/material substitution technologies (cost-increasing) can simply be added to the production process without changing the existing routines (Kemp & Soete, 1992), it is easier to meet the requirements of legitimacy compared with cost-decreasing sustainable technologies. In the long run, however, cost-decreasing sustainable technologies have greater potential for firms to achieve competitive advantage. This is supported by the argument that early adopters adopt innovation because of internal organizational considerations, while later adopters adopt innovation because of institutional legitimacy (Tolbert & Zucker, 1983). Early birds represent the firms that want to exploit the economic advantages of cost-decreasing technologies. Similarly, whereas small firms are more focused on cost-efficiency than larger firms, Triguero et al. (2015) found that institutional drivers such as environmental regulation are more important for medium-sized than for small firms' cleaner technology adoption. In general, cost-decreasing sustainable technologies provide firms with more opportunities to

increase their competitiveness, whereas cost-increasing sustainable technologies provide easier ways to achieve legitimacy. Therefore, we hypothesize the following:

H3: Economic drivers (customer green demand and relative advantage) have a larger effect than institutional drivers (environmental regulation, professionalization pressure, society pressure and peer organizations' adoption) on cost-decreasing sustainable process technology adoption.

H4: Institutional drivers have a larger effect than economic drivers on cost-increasing sustainable process technology adoption.

3.2.7 Synergy effects between economic drivers and institutional drivers

Another question that arises is whether economic drivers and institutional drivers may reinforce each other's impact. Institutional pressures are external forces that lead to convergent firm behavior within an institutional sector (Greenwood & Hinings, 1996). Nevertheless, under the same institutional pressure, firms may react differently depending on the cause, constituents, contents, control, and context of the institutional pressure (Oliver, 1991). If the institutional pressures are compatible with their economic organizational goals, firms are more likely to react positively to the pressures (Oliver, 1991). On the other hand, when aiming to pursue the economic benefits of sustainable technologies, if firms perceive this could provide them with legitimacy as well, they may adopt more sustainable technologies. Environmental regulations have been criticized for their ineffectiveness when standards and limits are set below the capabilities of existing technologies (Jaffe & Stavins, 1995) or because firms are satisfied with meeting the standards and reluctant to go beyond that. However, if firms perceive greater economic benefits, they are more likely to react positively to institutional pressures (Oliver, 1991). If firms perceive higher relative advantage or customer demand for cost-increasing sustainable technology, they are more likely to go beyond what is required by the environmental regulation. Therefore, we hypothesize the following:

H5: Economic drivers (relative advantage, customer green demand) strengthens the positive effect of environmental regulations on the adoption of cost-increasing sustainable process technologies.

Regarding cost-decreasing sustainable technologies, even though firms could perceive the relative advantages and customer green demand, several reasons may prevent them from adopting, such as technology 'lock-in' (current technology is interdependent with other technologies) (Del Río González, 2005) or investment 'lock-in' (current technology needs to be depreciated) (Demirel & Kesidou, 2011). In addition, cultural inertia, represented by existing values and past experience, could prevent adoption to occur as well, especially for process innovation rather than product and market innovation (Trianni et al., 2013). Therefore, economic drivers alone may not always suffice for the adoption of sustainable technologies. Environmental regulations could compensate for the failure of economic drivers. First, environmental regulations could reinforce the impact of the relative advantages of cost-

decreasing technologies. For example, in the Netherlands, feed-in tariffs make one of the energy-saving technologies, i.e., cogeneration of heat and power, profitable for firms (Chappin et al., 2009). In this case, the instruments of environmental policy increase the relative advantage of the technology. Moreover, if the environmental regulation requirements are high, customers' demand for green behaviors will also be stronger. Thus, we hypothesize the following:

H6: Environmental regulation strengthens the positive effect of economic drivers (relative advantage and customer green demand) on the adoption of cost-decreasing sustainable process technologies by firms.

Regarding mimetic pressure, institutional theory suggests that it has a direct effect on adoption behavior, since firms are afraid to lose their competitiveness and legitimacy if they do not imitate others' behaviors (Abrahamson, 1991; Kostova & Roth, 2002). Haunschild and Miner (1997), however, found that organizations only imitate certain organizations or practices. They distinguished between frequency imitation, trait imitation and outcome imitation and found that salient beneficial outcomes enhance outcome imitations. The relative advantages of sustainable technology that firms perceive will reinforce firms' tendency to mimic other firms' adoption behavior. Therefore, we hypothesize the following:

H7: Peer organizations' adoption combined with relative advantages has a positive synergy effect on both cost-increasing and cost-decreasing sustainable process technology adoption.

Regarding sustainable process technology adoption, environmental experts and sustainable technology suppliers often act as change agents, who provide information and influence adoption decisions in a desired direction (Rogers, 2003). The work of a change agent, such as consulting firm, is risky, because consultants attempt to change the current situation of a firm (Yair, 2004). However, if firms perceive more relative advantages of sustainable process technologies, they are more likely to accept the recommendations from experts. Therefore, we hypothesize the following:

H8: Professionalization pressure combined with relative advantages has a positive synergy effect on both cost-increasing and cost-decreasing sustainable process technology adoption.

Society pressure is a type of voluntary normative pressure that influences firms' moral legitimacy, exerted by various public stakeholders, such as the local citizens, NGOs, or mass media. From the perspective of stakeholder theory, organizations generally do not respond to each stakeholder individually, but to the entire stakeholder network (Rowley, 1997), so the effect of a combined demand from various stakeholders is more salient (Neville & Menguc, 2006). If public and market stakeholders have the same goals towards firms' sustainable behaviors, the impact will be more salient. Therefore, we hypothesize the following:

H9: Society pressure combined with customer green demand has a positive synergy effect on both cost-increasing and cost-decreasing sustainable process technology adoption.

3.3. METHODOLOGY

3.3.1 Sample

The sample consists of 768 cases representing manufacturing firms in China and the Netherlands. We selected manufacturing firms for two reasons. Practically, nearly one-third of the world's energy consumption and CO₂ emissions are attributed to manufacturing industries (International Energy Agency, 2007). Sustainable technology adoption in manufacturing firms is greatly beneficial for the environment. Methodologically, because firms in different sectors face distinct differences regarding the availability of sustainable technology, visibility to society, and environmental regulations, they may have different adoption behaviors and motivations. Focusing on the manufacturing industry could lead to a more robust result concerning firms' adoption behavior.

A self-reporting questionnaire is used to collect data. Firm managers were asked to fill in the questionnaire because they are most knowledgeable about perceptions of different driving forces and organizational practices. Managers in the following positions/departments were selected: production, environmental protection, procurement, CEO or owner, or technology center. This ensured that respondents had enough knowledge about the firm's production process. A trap question was designed to control data quality, that is, "I can understand all the questions in the questionnaire very well," on a Likert scale from not agree at all (1) to strongly agree (7), in which 3 to 7 are regarded as valid answers.

The Chinese sample consists of 610 valid responses, collected by approaching IE expo China 2017 visitors and by using a Chinese survey platform, KurunData. The mixed-mode survey is increasingly preferred because it can compensate for the weaknesses of each individual data collection mode, reduce the total survey error, control cost, increase the response rate, and address different coverages (Couper, 2011; Lavrakas, 2008). IE expo China is a leading Asian trade fair for environmental technology solutions (in Shanghai with 55,000 visitors, on 4-6 May 2017). KurunData is a popular online survey platform (and member of ESOMAR) in China with more than 2.7 million members. We sent 3388 invitations out to middle- or higher-level managers in manufacturing industries. In the end, we received 207 valid responses out of 351 filled-in questionnaires from IE expo and 403 valid responses out of 648 returned questionnaires from KurunData after assessing valid responses and data cleaning.

The Dutch sample comprised 158 valid responses after assessing valid responses and data cleaning, collected through an online questionnaire in Qualtrics. Invitations were mailed to all manufacturing firms (nearly 9000) in the Netherlands and 380 returned their

answers. Different from the Chinese sample, we included firms with less than 20 employees in the Netherlands as a control variable.

Table 3-1 summarizes sample characteristics. Due to missing variables, cumulative percentage does not equal to 1 in every category. We compared the industry distribution of our sample with the population of Chinese and Dutch manufacturing firms. The data is based on China's Third Economic Census Data (National Bureau of Statistics of China, 2013) and an electronic databank of the Netherlands (Statistics Netherlands, 2010), respectively. Because of the different industry classifications, the population percentage is estimated at the Classes level in the Netherlands (four levels are included: Section, Division, Group, and Classes) and at the Division level in China. Regarding firm size, data is only available for the number of large- (more than 1000 employees) and medium-sized (300-1000 employees) manufacturing firms in China. There are 59500 large- and medium-sized manufacturing firms in China, accounting for 2.6% of all manufacturing firms (National Bureau of Statistics of China, 2013).

Table 3-1: Sample characteristics (N=768)

	Percentage (%)	China Sample (%)	China Population (%)	Netherlands Sample (%)	Netherlands Population (%)
Country					
Netherlands	20.6	-	-	-	-
China	79.4	-	-	-	-
Export					
Yes	64.7	61		79.1	
No	34.2	38.4		18.4	
Leading Firm					
Yes	50.3	46.6		64.6	
No	49.5	53.4		34.2	
Industry					
Iron and steel	8.5	5.6	1.7	19.6	0.3
Pulp, paper and print	5.3	6.4	5.3	1.3	9.2
Chemical and pharmaceutical	7.9	9.0	5.6	3	2.0
Machinery	28.4	32.3	35.1	13.3	30.2
Food and beverage	8.2	7.5	8.4	15.8	9.5
Non-metallic minerals	6.0	7.0	9.5	1.9	3.8
Petroleum refineries	3.6	4.4	0.3	0.6	0.1
Non-ferrous metal	4.0	5.1	1.2	0	0.4
Other manufacturing	27.0	22.6	32.9	43.7	44.6
Firm size					
0-19	3.1	0		15.2	87.2
20-49	13.2	9.7		26.6	7.2

50-99	18.4	16.9	24.1	2.8
100-249	23.2	24.8	17.1	
250-499	13.9	15.1	9.5	2.9
500-999	10.0	12.1	1.9	
1000 or more	18.2	21.5	5.7	
Turnover				
0-0.5	3.9	4.6	1.3	
0.5-2	18.2	19.7	12.7	
02-Oct	27.1	25.6	32.9	
Oct-50	23.8	22.8	27.8	
50 or more	25.8	26.4	23.4	
Ownership				
State-owned or holding	19.4	24.4	0	
Foreign-invested	16.3	15.7	18.4	
Private	60.3	55.1	80.4	
Collective	2.9	3.3	1.3	
Others	1.0	1.3	0	
Working department				
Production department	31.9	37.4	10.8	
Environmental protection	8.3	9.3	4.4	
Purchasing	8.9	10.7	1.9	
CEO or owner	15.0	5.4	51.9	
Technology/maintenance	28.9	36.2	0.6	
Others	6.8	7	30.4	

3.3.2 Scale development and measurement model test

Items for each concept were generated from theory, prior literature and five preinterviews in China and the Netherlands. Constructs and items used in the study were examined by researchers in both countries to achieve construct and item equivalence between different cultures (van Herk, Poortinga, & Verhallen, 2005).

Table 3-2: Measurement items for sustainable technology adoption

Technology type			Items	Percentage		
				Not Adopted	Adopted	Not applicable
Cost-increasing sustainable technologies			31.64%	47.08%	21.28%	
Energy/ material substitution	D_6:	Fuel substitution from coal or oil to natural gas or biomass	29.17%	37.37%	33.46%	
	D_7:	Transition from producing gray electricity to green electricity based on solar, wind or water	44.01%	36.46%	19.53%	
	D_8:	Replacement of hazardous or non-renewable inputs by less hazardous or renewable materials (e.g. biodegradable)	33.59%	46.74%	19.66%	
	D_9:	Replacement of materials by recycled materials	28.13%	58.72%	13.15%	
CO2/emission reduction	D_1:	End-of-pipe technology to remove CO2 emission or air pollutants at the last stage of production	34.11%	41.28%	24.61%	
	D_2:	End-of-pipe technology to remove water or soil pollutants at the last stage of production	25.78%	50.00%	24.22%	
	D_5:	Modification of the production equipment, working procedures, machine instructions etc. to reduce only emission generation	26.69%	58.98%	14.32%	
Cost-decreasing sustainable technologies			26.20%	61.46%	12.31%	
Energy/ material	D_3:	Modification of the production equipment, working procedures, machine instructions etc. to increase the efficiency of material use	23.05%	68.75%	8.2%	
		(e.g. less material, minimize waste)	24.61%	68.49%	6.9%	
	D_4:	Modification of the production equipment, working procedures, machine instructions etc. to increase the efficiency of energy use				
Recycling	D_10:	Reuse of the waste materials in the same process or for another useful application within the firm;	28.13%	55.60%	16.28%	
	D_11:	Transformation of previously discarded waste into materials that can be reused or recycled for another application outside the firm;	30.21%	55.73%	14.06%	
	D_12:	Use of recycled water or use water-saving technology	25.00%	58.72%	16.28%	

Measures of dependent variables. In total, 12 sustainable process technologies were recognized, including energy/material substitution, CO₂/emission reduction, energy/material efficiency and recycling technologies (see Table 3-2), based on the descriptions of sustainable process technologies (Frondel et al., 2007; Hammar & Lofgren, 2010; UNEP, 1999). Five scales were developed to measure the adoption stage, expressed as follows: no plan; we are preparing for decision-making; we are in the process of implementation; we are utilizing it; not applicable. Next, the scales of each sustainable process technology were transformed into a dummy variable, reflecting whether or not it was adopted. Specifically, adopted equals 1, indicating firms are in the process of implementing or utilizing it, while not adopted equals 0, indicating firms have no plan or are preparing for decision-making. Table 3-2 illustrates the percentages of not adopted, adopted and not applicable for each type of sustainable technology. Among the cost-increasing sustainable technologies, D_2, D_5 and D_9 are more popular than the others, with more than 50% adoption rate. The adoption rate of each cost-decreasing sustainable technology is higher than 50%. Compared with cost-increasing sustainable technologies, cost-decreasing sustainable technologies have a higher level of adoption (61.46%) and a lower level of nonapplicability (12.31%).

The adoption of cost-increasing and cost-decreasing sustainable technologies is measured by a scale score indicating the percentage of adopted sustainable technologies divided by the number of technologies applicable for each firm.

Measures of independent variables. Respondents were asked to answer questions about economic and institutional drivers of sustainable technology adoption. Multiple-item scales were developed for each construct to increase validity and reliability, with a seven-point Likert semantic scale. Items were developed based on the definition of institutional pressures (Abrahamson, 1991; DiMaggio & Powell, 1983) and interviews conducted in China and the Netherlands, and adapted from prior studies (Luken et al., 2008; Sangle, 2011; Triguero et al., 2013; Weng & Lin, 2011; Zhu, Geng, & Sarkis, 2016). Items for each construct are listed in Table 3-3.

Table 3-3: Descriptive statistics of items used

Construct/items	Loading	Mean	SD
Institutional Drivers			
Coercive pressure-Policy awareness			
National environmental regulations	.877	5.15	1.54
National energy conservation and emission reduction regulations	.899	5.01	1.66
Regional (provincial and municipal) resource saving and conservation regulations	.877	5.02	1.66
Coercive pressure-Policy enforcement			
Current subsidy schemes for sustainable technology alleviate the financial burden when investing in these technologies	.652	4.50	1.68
On average the environmental taxation and/or polluting discharge fees are higher than the cost of pollution treatment	.620	4.43	1.62
We got on site environmental inspection or environmental audits by public authorities	.650	4.61	1.70

Mimetic pressure-Peer organizations' adoption

Most firms in our industry have plans to save energy and reduce emission	.883	4.99	1.50
Most firms in related industries (supplier, customers, and industries that produce substitute products or similar product) have plans to save energy and reduce emission	.866	4.93	1.43
The leading firms in our industry have plans to save energy and reduce emission	.805	5.18	1.47

Normative pressure-Professionalization pressure

When external experts or consulting firms give suggestions, they always take environmental issue into account	.856	5.01	1.47
When internal experts give suggestions, they always take environmental issues into account	.861	5.06	1.51
When suppliers introduce their new products, they always take environmental issues into account	.846	4.96	1.50

Normative pressure-Society pressure

Firms in our industry have been exposed to complaints about environmental issues by local citizens or NGOs	.820	3.36	1.98
Our firm has been criticized about environmental issues by local citizens, NGOs, or media	.888	2.99	2.09
Our industry's environmental problems were exposed by news media	.878	3.16	2.03

Economic Drivers**Relative Advantage**

Sustainable technology always improves the economic performance of our firm	.777	4.94	1.60
Sustainable technology always improves the reputation of our firm	.555	5.33	1.44
Sustainable technology always improves our product quality	.849	4.72	1.66
Sustainable technology has reduced safety-related incidences compared to the technologies we used before	.832	4.64	1.70

Customer Green Demand

Our customers demand green products	.836	4.64	1.74
Our major customers require us to achieve environmental certification (e.g. ISO 14001, ISO 5001)	.801	4.70	1.88
Our customers will withdraw the contract if we do not meet their requirements of environmental performance	.813	4.28	1.89
Our customers request detailed information on energy saving and emission reduction to ensure our environmental compliance	.843	4.33	1.91

Country, industry, firm size (the number of employees, turnover), ownership, export activity, working-department were selected as control variables following prior studies (Cainelli et al., 2012; Luken et al., 2008; Triguero et al., 2015). We adopted two measurements for firm size because they reflect different aspects. Specifically, the number of employees reflects firms' labor input (Dang, Li, & Yang, 2018), while turnover reflects firms' capability in the production market (Dang et al., 2018). In particular, we adopted whether the firm is a leader in the industry as a control variable to avoid bias in case leading firms had different perceptions of mimetic pressure, since one item measures influence from leading firms.

Measurement model test. A confirmatory factor analysis was conducted to test the goodness-of-fit of the measurement model, and the convergent and discriminant validity (See Table 3-4 & Table 3-5). Moreover, multigroup confirmative factor analysis was used to test the configural, metric and scalar equivalence for the three data sets (two in China and one in The Netherlands). The results showed that all constructs have reached either full or partial equivalence.

Table 3-4: Model fit for the measurement model

Indicators	Institutional drivers	Economic Drivers
Chi-square	247.729	68.236
Degree of freedom	80	16
Probability level	.000	.000
CMIN/DF	3.097	4.265
CFI	.978	.987
RMSEA	.052	.065
SRMR	.0383	.0235

Table 3-5: Convergent and discriminant validity

Factor	AVE	CR	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
Policy Awareness	0.78	0.92	0.88						
Policy enforcement	0.42	0.68	.48	0.64					
Peer organizations' adoption	0.73	0.89	.54	.49	0.85				
Professionalization Pressure	0.73	0.89	.54	.56	.71	0.85			
Society Pressure	0.75	0.90	.23	.50	.25	.31	0.86		
Relative Advantage	0.58	0.84						0.76	
Customer Green Demand	0.68	0.89						.68	0.82

Square root of AVE on the diagonal

Data analysis. In addition to the control variables described above, we added six and four dummy variables for the adoption of cost-increasing and cost-decreasing sustainable technologies, respectively, as controls, indicating the number of technologies that are applicable. In so doing we avoid the bias of using different criteria to evaluate firms' adoption. Hierarchical regression analysis was conducted to test the hypotheses. Model 1 includes only control variables, and drivers were entered in Model 2. In Model 3, we included all the variables and interaction terms. Polynomial and multicollinearity were tested. VIF for all variables are below five, indicating no multicollinearity problems.

3.4. RESULTS

Table 3-6 provides the descriptive statistics of and correlations between the institutional drivers, economic drivers and dependent variables. Overall, respondents indicate relatively high levels of policy awareness, professionalization pressure, peer organizations' adoption and relative advantage, with relatively low levels of policy enforcement, societal pressure and customer green demand. Professionalization pressure is highly correlated with other variables (above 0.6). As expected, all drivers have positive correlations with the adoption of both cost-increasing and cost-decreasing sustainable process technologies.

Table 3-6: Descriptive statistics and correlation matrix (n=768)

	Mean	SD	1	2	3	4	5	6	7
1 Policy awareness	5.06	1.498							
2 Policy enforcement	4.52	1.298	0.478						
3 Professionalization pressure	5.01	1.351	0.535	0.563					
4 Societal pressure	3.17	1.853	0.230	0.499	0.307				
5 Peer organizations' adoption	5.03	1.325	0.544	0.491	0.705	0.254			
6 Customer green demand	4.48	1.630	0.516	0.694	0.600	0.439	0.470		
7 Relative advantage	4.91	1.342	0.518	0.625	0.688	0.388	0.564	0.682	
8 Cost-increasing sustainable technology adoption	0.61	0.34	0.415	0.271	0.316	0.156	0.367	0.289	0.281
9 Cost-decreasing sustainable technology adoption	0.71	0.32	0.355	0.220	0.239	0.094	0.286	0.244	0.228

Note: All variables are significantly correlated (Pearson correlation)

The hierarchical regression analysis results to test the hypotheses can be found in Table 3-7. Due to space limitation, the results of export, leading firm, ownership, and working department with no significant impact are not presented.

The adjusted R^2 values for Model 1 are 11.2% and 7% respectively for the adoption of cost-increasing and cost-decreasing sustainable technologies. After including drivers of sustainable technology adoption, the adjusted R^2 increased substantially, with significant F change to 25.2% and 17.2% respectively. For the adoption of both cost-increasing sustainable technology and cost-decreasing sustainable technology, Model 2 showed better model fit than Model 1 and Model 3.

We hypothesized in H1 and H2 that economic and institutional drivers have positive impacts on both cost-increasing and cost-decreasing sustainable process technology adoption. Findings (see Model 2) show that policy awareness ($\beta=0.286$, $p=0.000$), society pressure ($\beta=0.104$, $p=0.011$) and peer organizations' adoption ($\beta=0.174$, $p=0.000$) are significantly positive on the adoption of cost-increasing sustainable technologies, while for the adoption of cost-decreasing sustainable technologies, policy awareness ($\beta=0.281$, $p=0.000$), peer organizations' adoption ($\beta=0.091$, $p=0.080$) and customer demand ($\beta=0.142$, $p=0.022$) are significantly positive. Thus, Hypotheses 1 and 2 are both partially supported.

Table 3-7: Standardized coefficients of the hierarchical regression analysis

Variable entered	Cost-increasing (N=746)			Cost-decreasing (N=748)		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Country	.234***	.057	.040	.124*	-.059	-.073
Industry						
Iron and steel	-.013	-.010	-.006	-.033	-.025	-.022
Pulp paper and print	.016	.008	.007	.008	.003	.001
Chemical pharmaceutical	-.014	-.025	-.026	-.002	-.007	-.007
Food and beverage	-.018	-.034	-.039	-.026	-.030	-.031
Non metallic minerals	-.041	-.043	-.047	-.066	-.064+	-.067+
Petroleum refineries	-.047	-.025	-.027	-.106**	-.085*	-.089*
Non ferrous metal	-.052	-.059+	-.058	-.027	-.027	-.028
Machinery	-.064	-.061	-.062	-.089*	-.083+	-.079+
Other manufacturing industries	Ref	Ref	Ref	Ref	Ref	Ref
Number of employees						
0-19	-.050	-.008	-.007	-.008	.031	.034
20-49	-.122*	-.036	-.037	-.040	.039	.038
50-99	-.125*	-.047	-.050	-.041	.022	.017
100-249	-.158**	-.098+	-.104*	-.097+	-.044	-.051
250-499	-.096*	-.080+	-.084+	-.013	.010	.007
500-999	.053	.058	.057	.039	.043	.041
1000 or more	Ref	Ref	Ref	Ref	Ref	Ref
Turnover (million euros)						
0-0.5	-.072+	-.048	-.044	-.097*	-.071+	-.070+
0.5-2	-.035	.001	.006	-.149**	-.112*	-.120*
02-Oct	-.058	-.035	-.029	-.094+	-.069	-.073
Oct-50	.028	.007	.014	.002	-.015	-.013
more than 50	Ref	Ref	Ref	Ref	Ref	Ref
Number of applicable technologies						
1 cost increasing technology	.114**	.114***	.114***			
2 cost increasing technology	.114**	.130***	.128***			
3 cost increasing technology	.182***	.204***	.207***			
4 cost increasing technology	.095*	.099**	.096**			
5 cost increasing technology	.141***	.149***	.152***			
6 cost increasing technology	.067+	.079*	.078*			
7 cost increasing technology	Ref	Ref	Ref			
1 cost decreasing technology				-.019	-.012	-.014
2 cost decreasing technology				.151***	.148***	.144***
3 cost decreasing technology				.086*	.084*	.084*
4 cost decreasing technology				.064+	.079*	.075*
5 cost decreasing technology				Ref	Ref	Ref
Drivers						
Policy Awareness		.286***	.278***		.281***	.279***
Policy Enforcement		-.004	.005		-.023	-.039
Professionalization Pressure		-.017	-.003		-.028	-.003
Society Pressure		.104*	.124**		.020	.043
Peer organizations' adoption		.174***	.162**		.091+	.074
Customer Demand		.048	.023		.142*	.097
Relative Advantage		-.022	-.010		-.012	.030
Interaction terms						
Policy Awareness * Relative Advantage			.017			.027
Policy Enforcement * Relative Advantage			.002			.055
Policy Awareness * Customer Demand			-.039			-.007
Policy Enforcement * Customer Demand			.017			-.069
Peer organizations' adoption * Relative Advantage			-.039			-.052
Professionalization Pressure * Relative Advantage			.026			.055
Society Pressure * Customer Demand			-.045			-.040
Adjusted R ²	.112	.252	.247	.070	.172	.170
F change	3.581	19.677	.347	2.639	13.355	.715
df 1	36	7	7	34	7	7
df 2	700	693	686	704	697	690
Sig. F change	.000	.000	.932	.000	.000	.660
F for this step	3.581	6.761	5.825	2.639	4.737	4.139
Sig.	.000	.000	.000	.000	.000	.000

+p<0.1. *p<0.05. **p<0.01. ***p<0.001
Interaction variables are centered.

Hypotheses 3 and 4 compare the relative importance of economic and institutional drivers for cost-increasing and cost-decreasing sustainable technologies. Table 3-8 summarizes the 95% confidence intervals (CIs) of standardized weights of institutional and economic drivers and their significant differences, following Cumming (2009). Results show that for cost-increasing sustainable technology adoption, the beta weight of policy awareness ($\beta=0.286$) is statistically larger than customer demand ($\beta=0.048$) and relative advantage ($\beta=-0.022$); peer organizations' adoption ($\beta=0.174$) is statistically larger than relative advantage at a significance level of .05. For cost-decreasing sustainable technology adoption, the beta weight of policy awareness ($\beta=0.281$) is statistically larger than relative advantage ($\beta=-0.012$). Therefore, Hypothesis 3, which assumes economic drivers have a larger effect than institutional drivers for cost-decreasing sustainable technology adoption, is not supported, while Hypothesis 4, which assumes institutional drivers have a larger effect than economic drivers for cost-increasing sustainable technology adoption, is partially supported.

Table 3-8: 95% Confidence intervals of drivers for sustainable process technology adoption

Drivers	Cost-increasing (N=746)			Cost-decreasing (N=748)		
	Beta	95% CI for Beta		Beta	95% CI for Beta	
		Lower	Upper		Lower	Upper
Policy Awareness (PA)	0,286 ^{CD, RA}	0,2	0,371	0,281 ^{RA}	0,192	0,371
Policy Enforcement (PE)	-0,004	-0,105	0,098	-0,023	-0,129	0,084
Professionalization Pressure (PP)	-0,017	-0,125	0,092	-0,028	-0,142	0,087
Society Pressure (SP)	0,104	0,024	0,184	0,02	-0,062	0,103
Peer organizations' adoption (MP)	0,174 ^{RA}	0,077	0,272	0,091	-0,011	0,194
Customer Demand (CD)	0,048 ^{PA}	-0,068	0,164	0,142	0,021	0,263
	-0,022 ^{PA, MP}	-0,125	0,081	-0,012 ^{PA}	-0,12	0,096

Note: The superscript indicates the significance of the beta weight between institutional and economic drivers ($p<.05$). According to Cumming (2009), if the 95% confidence intervals (CIs), calculated by standardized values, overlap by less than 50% of one CI arm, the beta weights are considered significantly different from each other ($p<.05$).

Hypotheses 5 to 9 suggested synergy effects between institutional and economic drivers. However, none of the synergy effects is statistically significant (see Model 3). Since including too many interaction terms may cause Type I errors, along with large standard errors (Fritz & Arthur, 2017), we also entered the interaction terms one by one. However, still no significant results were shown. Therefore, Hypotheses 5 to 9 are not supported by the data.

For both cost-increasing and cost-decreasing sustainable technology, environmental policy plays the dominant role in pressing firms to adopt sustainable technologies. In addition, peer organizations' adoption and society pressure are uniquely significant for the adoption of cost-increasing sustainable technologies, suggesting the importance of legitimacy to promote cost-increasing sustainable technologies. The effect of customer demand is only statistically significantly positive on the adoption of cost-decreasing sustainable technologies, suggesting the importance of the market in promoting the adoption of cost-decreasing sustainable technologies.

When interaction terms are entered into the model, the significance levels of policy awareness and society pressure and peer organizations' adoption for cost-increasing sustainable technologies do not change and their standardized coefficients remain almost the same. For cost-decreasing sustainable technology adoption, peer organizations' adoption has a weaker impact than for cost-increasing sustainable technology, which is only one-tail significant. Therefore, for the adoption of both cost-increasing and cost-decreasing sustainable technologies, economic and institutional drivers have complementary effects (both effects exist but do not reinforce each other's effect) rather than synergy effects.

Country (1=China, 0=the Netherlands) has a statistically significantly positive impact on the adoption of cost-increasing and cost-decreasing sustainable technologies in Model 1, indicating Chinese firms adopted more sustainable technologies than Dutch firms. This country effect disappears, however, after including the drivers, suggesting that drivers of sustainable technology adoption could well explain the reasons causing the different adoption behaviors between China and the Netherlands.

Compared with other manufacturing industries, firms in petroleum refineries and machinery industries adopted fewer cost-decreasing sustainable technologies. The number of employees has a significant effect on cost-increasing sustainable technologies, while turnover is relevant for cost-decreasing sustainable technologies. Compared with firms with more than 999 employees, firms with 20-49, 50-99, 100-249 and 250-499 employees adopted fewer cost-increasing sustainable technologies. Firms whose turnover is less than 2 million Euros or 12 million Yuan are less likely to adopt cost-decreasing sustainable technologies than firms whose turnover is over 50 million Euros or 300 million Yuan. Even though cost-decreasing sustainable technologies have the potential to save costs, they usually have a relatively long payback period. In contrast, even though cost-increasing sustainable technologies increase production costs, they have advantages, such as small upfront investment, fewer changes in the production process, and instant environmental performance enhancement. This result may indicate that firms with intensive labor input tend to solve environmental problems in a quick and easy way, while firms with higher capability of production market are more forward looking and tend to solve environmental problems from a long-term perspective.

3.5. CONCLUSION AND DISCUSSION

This paper presents an empirical analysis explaining sustainable process technology adoption in a sample of Chinese and Dutch manufacturing firms. The results confirm the role of economic and institutional drivers in promoting firms' sustainable technology adoption, even though not all drivers are significantly relevant for each type of sustainable process technology. Legitimacy built by governments, society and peer organizations appear to be the main driving forces for firms to adopt cost-increasing sustainable technologies. However, while policy awareness and peer organizations' adoption are still relevant, customer green demand is uniquely effective in promoting cost-decreasing sustainable technology adoption.

Policy awareness is the most important driver for the adoption of both cost-increasing and cost-decreasing sustainable technologies, though specific policy instruments, such as taxes, inspections and subsidies, have no significant effect. This may indicate that the message sent by environmental regulations about the legitimacy of adopting sustainable technologies is more important than the specific policy instruments that are designed to encourage or inspect firms' adoption behavior. This result may indicate that firms choose the easiest and quickest way to meet the requirements of society, while in terms of the demands from the market, they are more likely to choose those technologies with the largest cost-saving potential from a long-term perspective.

For the adoption of both cost-increasing and cost-decreasing sustainable technologies, policy awareness has statistically significant larger effects. Even for cost-decreasing sustainable technologies, the main driving force remains policy awareness. This result may indicate that at least for the moment, the economic stimuli of sustainable process technologies are not strong enough to encourage firms to adopt them spontaneously.

Whereas we expected synergy effects between institutional and economic drivers, because various researchers suggest those effects between economic and institutional factors (e.g., Bansal, 2005; Oliver, 1997), our empirical analysis showed no evidence of them. This result indicates that there are multiple pathways affecting firms' sustainable process technology adoption, but they do not work synergistically. There are two possible reasons explaining this result. First, it may relate to how firms perceive sustainable development. Building competitive advantage by a sustainable development strategy is still mainly a choice for several large firms that have the capability to invest in sustainable development, although smaller firms may also stand out by their sustainable products. However, regarding sustainable process technologies, firms may still aim at meeting the minimum requirements set by governments, society, peer organizations or customers. With this strategy in mind, managers only make decisions to meet requirements from each individual driver, even when multiple drivers are present simultaneously. Second, our result may signal that the institutional pressures are not well integrated with economic drivers, in which case these two sets of drivers are not able to reinforce each other's effects. In some cases, the realization of the benefits of sustainable technologies requires policy or society support, as shown by the examples of the adoption of cogeneration of heat and power technology (Chappin et al., 2009) and chlorine-free bleaching technology (Popp et al., 2011) discussed above. In the former case, policy instruments directly increase the adoption of economic benefits. In the latter case, the Greenpeace report on chlorine requires the channels of professionalization and society to influence other stakeholders and amplifies their impact. How different segments of society are integrated may affect whether a synergy effect will arise. Only when these two sets of drivers are well designed and can coordinate with each other will it be possible to realize their synergy effects.

This study first contributes to adoption theory by understanding the role of institutional and economic pressure. Traditional adoption models, such as the Technology

Acceptance Model (Davis et al., 1989) and the diffusion of innovation model (Rogers, 2003), barely include external factors when investigating technology and organizational characteristics (Frambach & Schillewaert, 2002). Even though several researchers have realized the importance of both economic and legitimacy concerns for organizational adoption (Bansal & Roth, 2000; Kennedy & Fiss, 2009; Tolbert & Zucker, 1983), most diffusion studies suggest that legitimacy works after economic concerns. Rogers (2003) suggested that after diffusion reaches a critical mass, it will be self-sustained, which is in line with Tolbert and Zucker (1983) institutional definitions of legitimacy. However, in the case of sustainable technology adoption, we found that the diffusion process could also be dominated by legitimacy that is built by governments, society and peer organizations.

Similarly, this study also contributes to sustainable technology adoption literature by incorporating a more comprehensive set of both economic drivers and institutional drivers. Prior studies mainly focused on the direct impact of traditional adoption factors, such as firms' characteristics, external pressures, networks and technology characteristics (e.g. Arvanitis & Ley, 2013; Frondel et al., 2007; Luken & Van Rompaey, 2008; Luken et al., 2008) or on environmental laws and regulations, and customer demand (Borghesi et al., 2015a; Demirel & Kesidou, 2011; Luken et al., 2008; Triguero et al., 2015; Triguero et al., 2013; Weng & Lin, 2011). This study also includes the relative advantages, mimetic pressures and normative pressures. With this full range of drivers, this study also compares their relative importance.

Furthermore, this study contributes to the sustainable technology adoption literature by comparing the impact of different drivers on different types of sustainable production process technologies using the typology of the United Nations Environment Programme (UNEP, 1999), distinguishing end-of-pipe technology from clean technology (Del Río González, 2005; Demirel & Kesidou, 2011; Hammar & Lofgren, 2010; Triguero et al., 2015), and taking into account cost-saving potential aspects. Prior studies often investigate single technology adoption or do not distinguish different types of sustainable and process technologies.

Lastly, this study contributes to adoption theory by exploring the conditional or synergetic effects of economic and institutional drivers on sustainable technology adoption. Prior studies investigated institutional interrelationships in case studies (e.g. Borghesi et al., 2015b; Chappin et al., 2009) or quantitatively tested the interaction effects of other factors such as firm size (Triguero et al., 2015), demand, technological uncertainty (Wu, 2013), ownership (Huang et al., 2009), industry district, cooperation (Cainelli et al., 2012), and country characteristics (Wagner, 2009). In this paper, by exploring the synergy effects of economic and institutional drivers, we tried to dive into the more fundamental adoption mechanisms of sustainable technologies, even though no synergy effects were found. This challenges either prior theoretical assumptions about institutional and economic drivers or the present setup of these drivers. Further research is still needed to confirm the complementary effect or to find possible ways to couple the effects of institutional and economic drivers.

There are some limitations of our study. First, our sample is not fully representative for populations of energy-intensive manufacturing firms in China and the Netherlands. Specifically, it is under-representative for small firms and over representative for large firms in both China and The Netherlands, and the Dutch sample has an over-representation for firms in the iron and steel industry and an under-representation for firms in the pulp, paper and print, and machinery industries. Second, the results are based on a cross-sectional survey investigation that does not incorporate time lags that reflect longer-term effects of determinants of firm adoption behavior. Future investigations will require a longitudinal study taking into account process technology adoption through time and incorporating the year of adoption. Third, even though hierarchical regression technique shows the changes in predictability associated with variables entered separately and allows more control variables and incomplete data in the model, it neglects the measurement errors for latent variables. Future research could consider Structural Equation Modelling to test the interaction effects for two latent variables. Fourth, while our aim is to contribute to the economic versus institutional forces debate, other researchers may want to investigate organizational and technological determinants in more detail, including organizational adopter responses and behavioral characteristics and technology compatibility and complexity.

4.

The effects of environmental regulations on managerial and technical sustainable responses of firms: The role of regulatory uncertainty and information transparency

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4.1 INTRODUCTION

Sustainable development is increasingly becoming part of public concern. Because of the deterioration of the global environment, the transition to more environmental sustainability is urgent (Goodland, 1995). In this paper, we focus on the environmental aspect of sustainable development, which requires efforts from various stakeholders, such as regulatory institutions, the community, customers, suppliers, employees and the media (Henriques & Sadosky, 1999). From an evolutionary perspective (Nelson, 1995), the demand for sustainable behavior introduces new criteria in the competitive selection process and triggers firms to make the corresponding changes.

The demand for sustainable behavior frequently takes the form of environmental regulations (Del Rio et al., 2011; Demirel & Kesidou, 2011; Luken et al., 2008; Sangle, 2011; Veugelers, 2012; Weng & Lin, 2011). Without environmental regulations, investments in the development and diffusion of sustainable technologies would likely be below a socially desirable level (Jaffe et al., 2005). However, even though most studies confirm a positive effect of environmental regulations on the sustainable behavior of firms (e.g., Luken et al., 2008; Sangle, 2011; Veugelers, 2012), some studies found no significant effects (e.g., Arvanitis & Ley, 2013; Leenders & Chandra, 2013; Lofgren et al., 2014; Triguero et al., 2013) or even a negative effect on sustainable process technology adoption under specific circumstances (e.g., Borghesi et al., 2015a; Popp, 2010). Moreover, the effectiveness of environmental regulations is questioned by researchers. For example, by encouraging some sustainable technologies environmental regulations may push other superior technologies out of the market (Jaffe et al., 2005). In addition, while environmental regulation is important, it may increase the costs of firms' investments in sustainable behavior by imposing universities or research institutes as partners (Mickwitz, Hyvattinen, & Kivimaa, 2008). Moreover, conflicting and overlapping policies and policy instruments cause confusion, complexity and higher costs to firms, which may result in negative effects on firms' adoption behavior (Borghesi et al., 2015b; Chappin et al., 2009). Consequently, environmental regulations may not always be effective in changing organizations' sustainable behavior.

In this study, we investigate the effectiveness of environmental regulations while combining two perspectives. First, disentangling environmental regulations into different aspects, we capture the broader picture of environmental regulations causing change within organizations. Regulatory uncertainty and information transparency are distinguished from policy awareness and enforcement as conditions impacting the effectiveness of regulations. From an evolutionary perspective (Nelson, 2009), environmental regulations represent new selection criteria, and organizational response strategies are organizations' adaptation to these new criteria. Environmental regulations, as a form of coercive pressure, tend to lead to isomorphism among organizations (DiMaggio & Powell, 1983). However, various factors, such as inconsistency between organizational goals and institutional pressures and uncertainty regarding the regulatory environment, may lead to different responses across firms (Hambrick,

Finkelstein, Cho, & Jackson, 2004; Oliver, 1991), resulting in varying levels of effectiveness of different forms of institutional pressure. Second, in organizational response strategies we distinguish between managerial and technical practices. Prior studies show that a firm may pursue different strategies to respond to external demands. Besides substantive adoption strategies, organizations may also have symbolic strategies that respond to institutional pressure (Campbell, 2007; Okhmatovskiy & David, 2012; Perez-Batres, Doh, Miller, & Pisani, 2012). These symbolic response strategies are adopted to buffer internal routines from external pressure, and can be easily abandoned (Meyer & Rowan, 1977; Westphal & Zajac, 2001). Moreover, firms may choose to avoid, defy or even manipulate institutional pressure (Oliver, 1991). Managerial and technical practices are regarded as two dominant sets of organizational behaviors that capture most organizational activities (Damanpour, 1987).

The objective of this study, therefore, is to investigate whether and how regulatory uncertainty and information transparency influence the effect of environmental regulations on organizations' sustainable behavior, which includes both managerial and technical practices. The structure of this paper is as follows. Section 2 reviews theories of organizations' sustainable behavior, discusses the effects of environmental regulations, and develops the hypotheses to be tested. In Section 3, we describe the sample and the measurement scales, and report the results of measurement model tests. Section 4 presents the results of the structural model tests. Finally, Section 5 discusses the main conclusions, contributions, implications, limitations and suggestions for future research.

4.2 THEORETICAL FRAMEWORK

4.2.1 Managerial and technical sustainable practices

From the adaptation perspective, Parsons (1956) identified three main levels - the institutional, the managerial and the technical level - that organizations adapt to the environment in a social system. However, various limits, such as legal and fiscal barriers, sunk cost, specialized personnel may prohibit organizations' adaptation (Hannan & Freeman, 1977). Based on their work, Cook, Shortell, Conrad, and Morrissey (1983) developed a general theory of organizational responses to regulations by integrating adaptation and natural selection perspectives. This theory assumes the essence of organizational responses is based on the relative 'costliness' of making organizational changes. To cope with the natural selection process, organizations make changes to adapt to regulations in their internal structure, starting from strategies, and products and services, and finally by the formation of inter-organizational arrangements (Cook et al., 1983). Similarly, in the management literature Damanpour (1987) distinguishes administrative innovation from technological innovation and argues that it is the most fundamental typology because it portrays the nature of innovation and represents changes in a wide range of tasks within the organization. In our study, we mainly focus on the intra-organizational changes, and label them managerial and technical activities. Since the technical and managerial practices involve different demands and constraints, and different

decision-making structures of individuals or groups, factors explaining these two types of response will be different (Kimberly & Evanisko, 1981).

Managerial practices are administrative activities that are indirectly related to the production operations, while technical practices are directly related to firms' production operations. Specifically, similar to the concept of administrative activity defined by Damanpour (1987), managerial adaptation practices are changes in the structure of organizations or their administrative processes, which include personnel management, rules of conduct and structure of the administrative staff, accounting practice and so on (Ruef & Scott, 1998). Birkinshaw, Hamel, and Mol (2008) define management innovation as a "management practice, process, structure, or technical that is new to the state of the art and is intended to further organizational goals". Technical practices are responsible for transforming production inputs into outputs (Parsons, 1956), focusing on core technologies, such as tools, techniques, devices, systems, or work procedure (Damanpour, 1987; Ruef & Scott, 1998).

Categorizing managerial practices that are sustainable, Aragón-Correa (1998) identified two types of approaches: information and education, and modern/voluntary prevention. The information and education approach includes training executives and other employees, environmental audits, and participation in natural environment programs; 'modern/voluntary prevention' includes the introduction of environmental aspects in administrative work, total quality programs with environmental aspects, and product life cycle analyses (Aragón-Correa, 1998). Henriques and Sadosky (1999) identified six environmental commitment practices: having an environmental plan; having a written document describing the environmental plan; communicating the environmental plan to shareholders or stakeholders; communicating this plan to employees; having an environmental, health, and safety unit, and having a board or management committee dedicated to dealing with environmental issues. Combining these two views, we define managerial sustainable practices as organizations' personnel arrangements regarding environment issues, the integration of environmental issues in the decision-making process and agreements or cooperation with relevant organizations, such as environmental experts, research institutes or NGOs, concerning environmental issues.

Technical sustainable practices are classified in different types of sustainable process technologies that could be adopted by firms to reduce negative impacts on the environment, such as end-of-pipe, recycling, material/energy efficiency and emission reduction technologies (e.g., Antonioli et al., 2013; Borghesi et al., 2015a; Demirel & Kesidou, 2011; Hammar & Lofgren, 2010). A sustainable technical practice is defined in our paper as the implementation of a sustainable technology in the production process.

Compared with managerial sustainable practices, we assume that technical sustainable practices are means to meet the environmental standards and maintain the legal legitimacy of the organization. However, managerial sustainable practices tend to go beyond legitimacy and are rooted in organizations' daily routines, indicating a more fundamental

change towards sustainable behavior. Managerial and technical sustainable practices, although related, are inherently executed by two distinct parts of the organization, decided and operated by different organizational units. However, managerial sustainable practices could also be antecedents of technical sustainable practices or organizations could skip the changes in their managerial routines and implement technical practices directly.

4.2.2 Effects of environmental regulation on organizational sustainable behavior

Governments exert environmental pressure mainly through laws and directives, and sometimes through agreements with specific firms. Even though environmental regulations are criticized, they are still considered the main force determining firms' sustainable behavior. Since environmental regulation builds a legitimacy for organizations to operate legally, the conformation firstly depends on organizations' awareness of the pressure. Inadequate recognition or awareness of institutional expectations limits organizations' conformation (Oliver, 1991). For example, Zhu et al. (2016) found that the awareness of related regulations influences organizations' adoption of environmental management practices. We define policy awareness as the extent of organizations' recognition of environmental regulations. Secondly, not only the extent of organizations' awareness of the environmental regulations matters, but also policy instruments such as fines, subsidies or taxes motivate firms' sustainable behavior. Different policy instruments have been recognized as such in prior studies, which are top-down regulation (legally and administratively enforced command and control regulation), interactive regulation (covenants and voluntary agreements), and positive and negative instruments (subsidies and taxes respectively) (Chappin et al., 2009). Jaffe and Stavins (1995) divide environmental regulations into three categories: market-based approaches such as taxes or subsidies, performance standards such as for pollution emissions; and technology standards such as industry standards. The different policy instruments either increase organizations' violation cost or alleviate organizations' investment cost. We define policy enforcement as the degree to which means of various policy instruments can increase organizations' benefits of complying and cost of noncomplying.

After realizing the requirements of laws and directives (policy awareness) and influenced by specific policy instruments (policy enforcement), corresponding changes at both the technical and managerial levels need to be made. Taking the chemicals-using or chemicals-producing industry as an example, environmental regulations affect controls on air, water quality, solid and hazardous waste, toxic substances, etc. (Ashford, 1993). To meet the requirements of environmental regulations concerning pollutant emissions or technology standards, technical practices, such as the implementation of pollution control devices, inputs or processes need to be changed. For example, to meet the requirements of CO₂ emission standards, end-of-pipe technologies that capture CO₂ emission generated or process changes that reduce the generation of CO₂ emission need to be implemented. In addition to causing organizations' technical responses, the key to success of environmental regulations is influencing both organizations' managerial knowledge and managerial

attitudes in the decision making process regarding technological change and environmental concerns (Ashford, 1993). Therefore, success environmental regulations should be capable to influence organizations' ways of working and decision-making as well. Changes in managerial practices may be required directly or indirectly by environmental regulations. For example, the implementation of new environmental projects may require communications with local citizens, which directly changes organizations' managerial process. In other cases, the environmental regulations do not require immediate changes in firms' managerial practices, but they could influence organizations' managerial attitudes towards environmental requirements (Ashford, 1993), in which case organizations may be more active in acquiring information about environmental solutions, for instance by employing environmental experts, visiting sustainable technology exhibitions, etc. Besides, complying with environmental regulations also requires managerial changes, such as employing personnel responsible for tracking changes in regulations, or cooperation with other organizations to improve environmental performance, etc. Based on the discussion of the two aspects of environmental regulation in affecting organizations' technical and managerial responses, we hypothesize that:

H1a: Policy awareness is positively related to managerial sustainable practices.

H1b: Policy awareness is positively related to technical sustainable practices.

H2a: Policy enforcement is positively related to managerial sustainable practices.

H2b: Policy enforcement is positively related to technical sustainable practices.

4.2.3 Moderating effects of regulatory contexts

The design and configuration of regulations and the balance of different political forces are pivotal for the effectiveness of regulations (Campbell, 2007). In this paper, we investigate the effectiveness of environmental regulation from two perspectives that reflect different regulatory contexts: regulatory uncertainty and information transparency.

Regulatory uncertainty

Regulatory uncertainty refers to the unpredictability of changes in regulations, relating to actions of governmental agencies that create and enforce regulations (Birnbaum, 1984). First, regulatory uncertainty relates to the fundamental direction of regulations and consensus concerning the regulation target (Hoffmann, Trautmann, & Schneider, 2008). It is reflected by unpredictable changes in regulations, or simply by increasing regulation (Birnbaum, 1984). If regulations change too frequently, organizations may become confused about the future direction and the durability of regulation. Second, discrepancy between various regulations may lead to regulatory uncertainty. For example, in China, even though clean development mechanisms are defined by the National Development and Reform Commission, together with the Ministry of Science and Technology, and the Ministry of Finance, the local governments still play an active part, resulting in different policy strategies, patterns of

involvement and adaptation to policy uncertainties across regions (Miao & Li, 2016). Because of the dominance of economic policy institutions over environmental policy institutions, it is likely that the implementation of environmental policy will be difficult if the environmental standards, instruments and programs run against economic interests (He, Lu, Mol, & Beckers, 2012). Similarly, Borghesi et al. (2015b) found differences in climate and energy policies between the EU and national levels. Since environmental regulations are issued by different institutes, the incongruities between regulations from different institutes could generate confusion. Finally, regulatory uncertainty relates to the execution of the regulations, such as the discrepancy between what is required by the regulations and the actual implementation. For example, in the European Emission Trading Scheme, the allocation of the carbon dioxide allowances and the execution of the defined measures and rules are not clear, causing regulatory uncertainty among organizations (Hoffmann et al., 2008).

Regulatory uncertainty provides organizations with more discretion to respond. From the perspective of institutional theory, when organizations face multiple legitimacy claims from the regulatory regime or inconsistency of different forms of institutional pressure, or the logics are ambiguous or lack specificity, they are more likely to ignore, reduce, adapt, and destroy the legitimacy issue, or delay compliance (Engau & Hoffmann, 2011; Greenwood, Raynard, Kodeih, Micelotta, & Lounsbury, 2011; Julia, 2008; Oliver, 1991; Raaijmakers, Vermeulen, Meeus, & Zietsma, 2015). Under the condition of environmental uncertainty, firms may invest more in their primary business activities than in environmental performance (Weng & Lin, 2011). From the perspective of evolutionary organizational theory, if the environment is uncertain, it does not constitute a systematic regime of selection (Hannan & Freeman, 1984). The uncertainty of the policies makes firms more risk-averse and less likely to make corresponding changes (Chappin et al., 2009). Therefore, even though they are aware of environmental regulations, under the condition of regulatory uncertainty, chances are higher that firms will ignore, reduce, defy or postpone compliance with the regulation, which could weaken the effectiveness of environmental regulations in changing organizations' technical and managerial behavior. We hypothesize that

H3a: Regulatory uncertainty has a negative moderating effect on the relationship between policy awareness and managerial sustainable practices.

H3b: Regulatory uncertainty has a negative moderating effect on the relationship between policy awareness and technical sustainable practices.

Secondly, regulatory uncertainty could also seriously affect the effectiveness of policy enforcement. Costantini, Crespi, and Palma (2017) found that both balance and comprehensiveness of policy instruments are able to enhance firms' innovation activities. However, when too many policy instruments are adopted, the effect of the policy mix tends to be reduced (Costantini et al., 2017). One possible explanation could be that too many policy instruments increase the inconsistency of policies, which results in conflict and

overlap among them. Borghesi et al. (2015b) argue that various regulatory instruments might negatively interfere with each other due to a lack of coordination. Regulatory uncertainty, such as a lack of long-term regulation, inconsistency between policies, laws, and regulations, and inconsistency of regulations between sectors and governmental levels are largely regarded as challenging renewable energy technology diffusion by firms (Negro, Alkemade, & Hekkert, 2012). Therefore, regulatory uncertainty will weaken the effectiveness of environmental regulations in changing organizations' corresponding technical and managerial responses. We hypothesize that

H4a: Regulatory uncertainty has a negative moderating effect on the relationship between policy enforcement and managerial sustainable practices.

H4b: Regulatory uncertainty has a negative moderating effect on the relationship between policy enforcement and technical sustainable practices.

Information transparency

Information transparency refers to the degree of visibility and accessibility of information (Zhu, 2002). In the field of regulation implementation, a transparent policy compels firms to provide information of their practices to the public (David, Archon, Mary, & Elena, 2006). According to Article 7(2) of the European Directive 2003/4/EC and Article 5 of Environmental Protection Law of the People's Republic of China, the subject of information in the context of environmental regulation refers to firms' environmental performance, environmental impact assessment report, and violation records.

First, information transparency increases the possibilities of societal supervision. Jiang and Bansal (2003) found that task visibility – the degree to which the firm's task is easily observable or attracts the attention of the public – could increase the possibility for firms to adopt ISO 14001 certification besides EMS (environmental management system), even though it is not required. Whether an organization can be easily observed by external audiences can influence its adoption behavior (Okhmatovskiy & David, 2012). Besides, the right-to-know program – a state-sponsored program that encourages citizens to participate in environmental regulation – could significantly reduce toxic emissions over time (Grant, 1997; Grant & Downey, 1995). Consequently, if regulations require firms to publish their environmental information, firms are more likely to have better environmental performance. The reason may be because that when environmental information is visible to the public, organizations are more possibly be scrutinized by external stakeholders, such as local citizens, NGOs, and mass media, which reinforces the legitimacy built by the environmental regulations. The effectiveness of the environmental regulations will increase through the efforts of these various stakeholders. Therefore, under the same level of firms' awareness of environmental regulations, the more the firms perceive their behavior to be transparent, the more they respond with the corresponding managerial and technical activities. We hypothesize that

H5a: Information transparency has a positive moderating effect on the relationship between policy awareness and managerial sustainable practices.

H5b: Information transparency has a positive moderating effect on the relationship between policy awareness and technical sustainable practices.

Second, information transparency affects organizations' perception of the justice of the regulation. In an environment in which most firms in an industry publish their environmental performance information, the seriousness of environmental regulations is reflected. Especially, when the fines that other firms pay are published, the cost of violating the environmental regulation is manifest. Therefore, information disclosure is regarded as a complement and support for classical enforcement (Mol, He, & Zhang, 2011). Information transparency not only reinforces the legitimacy built by the environmental regulations, but also strengthens the effects of policy instruments, which correspondingly lead firms to make managerial and technical changes. We hypothesize that

H6a: Information transparency has a positive moderating effect on the relationship between policy enforcement and managerial sustainable practices.

H6b: Information transparency has a positive moderating effect on the relationship between policy enforcement and technical sustainable practices.

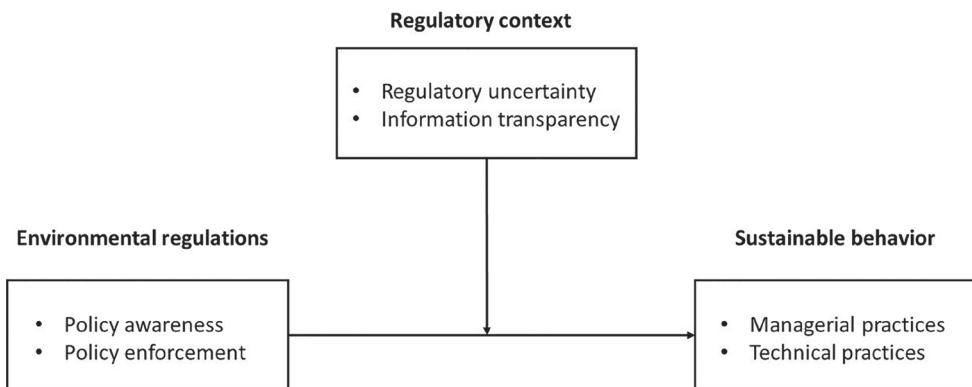


Figure 4-1 Conceptual model

4.3 METHODOLOGY

4.3.1 Sample

The sample consists of 758 cases representing manufacturing firms in China and the Netherlands. We focused on manufacturing firms because manufacturing firms account for nearly one third of the world's energy consumption and CO₂ emissions (International Energy Agency, 2007). A self-reporting questionnaire was used to collect data. To control for the data quality, trap questions, minimum time limits and strict criteria regarding industry and working department of the respondents were used to select qualified respondents and cases.

The Chinese sample consists of 603 valid cases, collected by approaching IE expo China 2017 visitors and collaborating with a popular Chinese survey platform, KurunData. The IE expo is Asia's leading trade fair for environmental technology solutions, during which we invited qualified firm representatives to fill in the questionnaire. After data cleaning, 195 cases out of 351 responses were left as valid responses. KurunData is a popular online survey platform with more than 2.7 million members. 3388 invitations to fill in the questionnaire were sent out by KurunData and 648 members answered the questionnaire online, resulting in a 19.13% response rate. After data cleaning, 408 cases were left as valid responses.

The Dutch sample consists of 155 valid responses, collected on an online survey platform - Qualtrics. Invitations to fill in the questionnaire were posted by mail to all manufacturing firms in the Netherlands (nearly 9000), and 380 firm representatives answered the questionnaire, resulting in a response rate of 4.2%. After data cleaning, 155 cases were left as valid responses.

Missing values for each item and case were counted. No item had more than 10% missing values. The MCAR test ($\chi^2=100.002$, $df=104$, $Sig.=.593$) indicated that the missing values are completely random. Therefore, we adopted mean values to replace the missing values in the independent variables. Table 4-1 summarizes sample characteristics. Due to missing variables, cumulative percentages do not add up to 100% in every category. Additionally, our sample is largely representative regarding industry and firm size distribution. We collected Chinese and Dutch manufacturing firms data based on China's Third Economic Census Data (National Bureau of Statistics of China, 2013) and an electronic databank of the Netherlands (Statistics Netherlands, 2010) respectively. Due to the different industry classification standards, the representativeness of the industry distribution can only be estimated at the Classes level in the Netherlands (four levels are included: Section, Division, Group, and Classes) and at the Division level in China. Regarding firm size, data is only available for large (more than 1000 employees) and medium-sized (300-1000 employees) manufacturing firms in China, which are in total 59500 large- and medium-sized manufacturing firms, accounting for 2.6% of all manufacturing firms (National Bureau of Statistics of China, 2013). It appears that Chinese sample is over-representative for iron and steel, petroleum refineries, and non-ferrous metal industries, and it is also over-representative for large manufacturing firms. The

Dutch sample is over-representative for iron and steel, food and beverage industries, while under-representative for pulp, paper and print, machinery, and non-ferrous metal industries. Besides, the Dutch sample is under-representative for firms with less than 19 employees, and over-representative for firms with more than 99 employees.

Table 4-1: Sample characteristics

	Percentage (%)	Chinese Sample (%)	Chinese Population (%)	Dutch Sample (%)	Dutch Population (%)
Country					
Netherlands	20.4	-	-	-	-
China	79.6	-	-	-	-
Export					
Yes	63.5	59.2		80.0	
No	35.5	40.1		17.4	
Leading Firm					
Yes	49.6	45.8		64.5	
No	50.1	54.2		34.2	
Industry					
Iron and steel	8.4	5.5	1.7	20.0	0.3
Pulp, paper and print	5.3	6.3	5.3	1.3	9.2
Chemical and pharmaceutical	7.5	8.5	5.6	3.9	2.0
Machinery	28.6	32.3	35.1	14.2	30.2
Food and beverage	9.1	7.5	8.4	15.5	9.5
Non-metallic minerals	6.2	7.3	9.5	1.9	3.8
Petroleum refineries	3.8	4.6	0.3	0.6	0.1
Non-ferrous metal	4.2	5.3	1.2	0	0.4
Other manufacturing	26.8	22.7	32.9	42.6	44.6
Firm size					
0-19	5.1	2.5		15.5	87.2
20-49	12.3	8.8		25.8	7.2
50-99	17.8	16.3		23.9	2.8
100-249	23.2	24.5		18.1	2.9
250-499	13.5	14.4		9.7	
500-999	9.9	11.9		1.9	
1000 or more	18.2	21.6		5.2	
Turnover					
0-0.5	5.4	6.5		1.3	
0.5-2	18.2	19.7		12.3	
02-Oct	26.6	25.0		32.9	
Oct-50	23.6	22.4		28.4	
50 or more	25.2	25.7		23.2	
Ownership					
State-owned or holding	19.5	24.5		0	
Foreign-invested	16.1	15.4		18.7	
Private	60.2	55.1		80.0	
Collective	2.9	3.3		1.3	
Others	1.2	1.5		0	
Working department					
Production department	31.7	37.1		10.3	
Environmental protection	8.6	9.6		4.5	
Purchasing	8.8	10.6		1.9	
CEO or owner	15.0	5.6		51.6	
Technology/maintenance	29.2	36.5		0.6	
Others	6.7	0.5		31	

4.3.2 Scale development and measurement model test

Measurement of dependent variables. Two dependent variables were used in this study, managerial sustainable practices and technical sustainable practices (Table 4-2). Managerial sustainable practices were measured by a summated scale score of the items

that were developed regarding environmental personnel, the degree of the integration of environmental concerns in the decision-making process and agreements or cooperation with environmental related stakeholders. Environmental personnel is measured on an ordinal-scale, indicating no personnel, external consultants when necessary, an internal environmental expert, a group and a department dealing with environmental issues. Items for measuring the degree of integration of environmental concerns in the decision-making process and agreements or cooperation with related stakeholder are measured by a seven-point unipolar semantic scale and Likert scale, indicating the frequency that the firm is taking environmental concerns into account in its decision-making process or has agreements or cooperation with environmental related stakeholders. Activities concerning environmental issues and related environmental stakeholders with whom one could have agreements or cooperate were identified from prior studies (e.g., Abrahamson, 1991; Cainelli et al., 2015; Kounetas et al., 2011; Triguero et al., 2013; Zhu et al., 2016), then they were adapted into organizations' practical activities in the decision-making process and frequencies of having agreements or cooperation.

Various sustainable process technologies were identified according to the definition of clean production from the United Nations Environment Programme (UNEP, 1999) and prior studies (e.g., Frondel et al., 2007; Fu, Kok, Dankbaar, Ligthart, & van Riel, 2018; Hammar & Lofgren, 2010). Firms were asked whether these technologies were applicable, whether they had been adopted (in use or in the process of implementing or utilizing) or not (no plan or in the process of decision-making). The technical sustainable practices were calculated by an index score indicating the percentage of adopted sustainable technologies given the number of technologies that are potentially applicable for each firm.

Table 4-2: Dependent variable items, reliability coefficients, and descriptive

Construct/items	Loading	Mean	SD
Managerial environmental practices (Cronbach's Alpha=0.939)			
We have specialized personnel to deal with the environmental policies	0.49	3.06	1.45
The frequency that we discussed the changes in environmental policies to ensure that we meet every requirement	0.73	4.83	1.54
The frequency we take environmental policies into account when we are planning to update equipment	0.78	5.04	1.53
The frequency we apply for subsidies relating to sustainable technology	0.81	4.89	1.63
The frequency we have voluntary agreements with governmental agencies concerning our environmental performance	0.77	4.54	1.74
The frequency we ask environmental advice from external experts (e.g. consulting firms), research institutions, universities, when we are planning to implement new production technology	0.87	4.84	1.58
The frequency we ask suggestions from our internal environmental experts, when we are planning to implement new production technology	0.86	4.84	1.60
The frequency representatives of our firm visit sustainable technology exhibitions or conferences on sustainability	0.76	4.59	1.71
The frequency we ask opinions from local citizens when we have new construction projects	0.80	4.57	1.76
The frequency we consult opinions from NGOs about environmental issues, when we are planning to implement new production technology	0.83	4.57	1.72
The frequency we get involved in NGO's environmental projects	0.73	4.18	1.95
Percentage			
	Not adopted	Adopted	Not applicable
Technical environmental practices (Mean=0.67, SD=0.30)			
End-of-pipe technology to remove CO ₂ emission or air pollutants at the last stage of production	34.0%	40.4%	25.6%
End-of-pipe technology to remove water or soil pollutants at the last stage of production			
Modification of the production equipment, working procedures, machine instructions etc. to increase the efficiency of material use (e.g., less material, minimize waste)	25.2%	49.2%	25.6%
Modification of the production equipment, working procedures, machine instructions etc. to increase the efficiency of energy use	22.6%	68.6%	8.8%
Modification of the production equipment, working procedures, machine instructions etc. to reduce only emission generation	24.3%	67.8%	7.9%
Fuel substitution from coal or oil to natural gas or biomass	26.8%	57.9%	15.3%
Transition from producing gray electricity to green electricity based on solar, wind or water	28.9%	36.7%	34.4%
Replacement of hazardous or non-renewable inputs by less hazardous or renewable materials (e.g. biodegradable)	43.4%	36.0%	20.6%
Replacement of materials by recycled materials	33.8%	46.0%	20.2%
Reuse of the waste materials in the same process or for another useful application within the firm;	28.6%	57.8%	13.6%
Transformation of previously discarded waste into materials that can be reused or recycled for another application outside the firm;	28.2%	54.5%	17.3%
Use of recycled water or use water-saving technology	29.7%	55.0%	15.3%
	24.4%	58.2%	17.4%

Measurement of independent variables. Multi-item scales were developed for policy awareness, policy enforcement, regulatory uncertainty and information transparency (Table 4-3). Policy awareness is measured by firms' perception of their knowledge of various environmental regulations, following Zhu et al. (2016). Policy enforcement is measured by the impact of various policy instruments, including subsidies, taxation, and on-site inspections, adapted from definitions of policy enforcement in prior studies (Luken et al., 2008; Magat & Viscusi, 1990; Triguero et al., 2013). Regulatory uncertainty is measured by the frequency of change in environmental regulations, conflicts with other regulations, and whether the environmental regulations are strictly implemented, adapted from prior definition (Hoffmann, Trautmann, & Hamprecht, 2009) and measurement (Zhang et al., 2015). Information transparency includes the publication of firms' environmental performance, environmental assessment reports, and environmental punishments, according to

European Directive 2003/4/EC and Environmental Protection Law of the People's Republic of China. All items were measured on a seven-point unipolar Likert scale. Country, export, industry, number of employees, turnover, and working department of the respondents were used as control variables as in prior studies (e.g., Cainelli et al., 2012; Luken et al., 2008; Triguero et al., 2015).

Measurement model test. Confirmative factor analysis was conducted to test the reliability, and convergent and discriminant validity of the measurement instrument. The standardized regression weights and Cronbach's alpha are shown in Table 4-3. The results of convergent validity and discriminant validity tests are shown in Table 4-4. The Average Variance Extracted (AVE) and Composite Reliability (CR) above 0.5 and 0.6 respectively and the square root of the AVE exceed the correlations between factors indicate acceptable convergent validity and discriminant validity (Fornell & Larcker, 1981; Hair, Black, Babin, Anderson, & Tatham, 2008). Therefore, the measure model showed good results in terms of convergent and discriminant validity for all factors, except that the AVE of policy enforcement is slightly less than 0.5 (AVE=0.47).

4.3.3 Data analysis

Firstly, a regression analysis was conducted to test for multicollinearity, by evaluating the Variance Inflation Factor (VIF), residual plot, and the impact of control variables (Appendix C). Then common-method-bias was tested by Harman's single-factor and a common latent factor method (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003). Even though one general factor accounted for 51.46% of the covariance among all measures, the differences of standardized regression weights with and without the common latent factor are less than 0.2 in the measurement model, indicating a limited level of common-method-bias.

Then, Structural Equation Modeling (SEM) in AMOS (Arbuckle, 2014) was used to test the hypotheses, for two reasons. First, the aim of this paper is theory-oriented testing hypotheses, and SEM is suitable for the purpose of confirming theoretically assumed relationships (Reinartz, Haenlein, & Henseler, 2009). Second, since regression techniques neglect measurement errors, resulting in a particularly low power of interaction effects (McClelland & Judd, 1993; Steinmetz, Davidov, & Schmidt, 2011), SEM is more appropriate to test interaction effects between two latent continuous variables than regression analysis. Specifically, we adopted residual centering approaches to test the interaction effects in SEM, developed by Little, Bovaird, and Widaman (2006). This approach is suitable when the interaction terms are formed by two continuous variables, and it avoids the multicollinearity problem between the variables and their interaction terms. Uncentered indicators of both interaction variables were multiplied. Then the product indicators were regressed on all indicators of the interaction variables. The residuals of these regressions were used as indicators for the interaction terms in SEM. The error covariances of the product variable indicators that have a common component were specified. All main effects of latent variables were allowed to covary, while the interaction term was not allowed to covary with the main effect variable.

Table 4-3: Predictor items, reliability coefficients and descriptive

Construct/items	Loading	Mean	SD
Policy awareness (Cronbach's Alpha=0.915)			
National environmental regulation	0.87	5.14	1.55
National energy conservation and emission reduction regulation	0.91	5.01	1.66
Regional (provincial and municipal) resource saving and conservation regulations	0.88	5.02	1.67
Policy enforcement (Cronbach's Alpha=0.690)			
Current subsidy schemes for sustainable technology alleviate the financial burden when investing in these technologies	0.76	4.44	1.70
On average the environmental taxation and/or polluting discharge fees are higher than the cost of pollution treatment	0.64	4.38	1.64
We have got on-site environmental inspection or environmental audits by public authorities	0.64	4.57	1.72
Regulatory uncertainty (Cronbach's Alpha=0.800)			
National environmental regulation	0.84	4.23	1.60
National energy conservation and emission reduction regulation	0.77	3.73	1.78
Regional (provincial and municipal) resource saving and conservation regulations	0.76	3.71	1.87
Information transparency (Cronbach's Alpha=0.906)			
All firms in our industry publish detailed figures about their environmental performance	0.92	4.18	1.85
All firms in our industry publish information of their Environmental Impact Assessment Report	0.90	4.21	1.91
The fines paid for trespassing the environmental requirements (e.g. pollution discharge fees) are made public	0.79	4.16	1.94

Table 4-4: Convergent validity and discriminant validity test results

	AVE	CR	Factor 1	Factor 2	Factor 3	Factor 4
Policy awareness	0.78	0.92	0.88			
Policy enforcement	0.47	0.72	0.49	0.68		
Regulatory uncertainty	0.63	0.83	0.32	0.56	0.79	
Information transparency	0.75	0.90	0.54	0.66	0.58	0.87

Square root of AVE on the diagonal

4.4 RESULTS

Table 4-5 provides the descriptive statistics of and correlations between the dependent and independent variables. Regulatory uncertainty does not show the expected negative correlation with managerial practices and technical practices. The correlation between managerial practices and technical practices is 0.364, while their covariance is only 0.157, suggesting that they are two independent behaviors in organizations. Managerial practices are highly correlated with the independent variables.

Table 4-5: Descriptive statistics and correlation matrix (n=758)

	Mean	SD	1	2	3	4	5	5 Covariance
1 Policy awareness	5.057	1.505						
2 Policy enforcement	4.462	1.324	0.492					
3 Regulatory uncertainty	3.889	1.482	0.317	0.560				
4 Information transparency	4.181	1.745	0.540	0.660	0.581			
5 Managerial practices	4.199	1.444	0.602	0.776	0.595	0.774		
6 Technical practices	0.651	0.300	0.407	0.293	0.192	0.294	0.364	0.157

Note: All variables are significantly ($p < 0.05$) correlated (Pearson coefficients)

The result of a one-tailed test in SEM is shown in Table 4-6. Following Hair et al. (2008), for an acceptable model fit CFI should be larger than 0.92 (Model 1) or 0.90 (Model 2), SRMR should be less than 0.08, and RMSEA should be lower than 0.07. Therefore, both Model 1 and Model 2 show good model fit.

We hypothesized in H1 and H2 that policy awareness and policy enforcement have positive effects on both managerial and technical sustainable practices. Our findings (see model 2) show that policy awareness has a statistically significant positive effect on firms' technical sustainable practices ($\beta=0.321$, $p<0.001$), while policy enforcement is significantly positive for both managerial sustainable practices ($\beta=0.933$, $p<0.001$) and technical sustainable practices ($\beta=0.212$, $p=0.017$). Therefore, Hypothesis 1b, 2a and 2b are supported, while Hypothesis 1a is not supported.

Hypotheses 3a and 3b state that regulatory uncertainty has a negative moderating effect on the relationship between policy awareness and managerial/technical sustainable practices. Our findings show that regulatory uncertainty only has statistically significant negative moderating effect on the relationship between policy awareness and managerial sustainable practices ($\beta=-0.107$, $p=0.036$). Therefore, Hypothesis 3a is supported, while Hypothesis 3b is not. Hypothesis 4 stated that regulatory uncertainty has a negative moderating effect on the relationship between policy enforcement and managerial/technical sustainable practices. Our findings show that regulatory uncertainty has a statistically significant negative moderating effect for technical sustainable practices ($\beta=-0.221$, $p=0.043$) but not for managerial practices. Therefore, Hypothesis 4b is supported, while Hypothesis 4a is not supported.

Table 4-6: Standardized regression weights of SEM

Variables	Model 1		Model 2	
	Managerial practices	Technical practices	Managerial practices	Technical practices
Policy awareness	.026	.328***	.024	.321***
Policy enforcement	.945***	.233**	.933***	.212*
Regulatory uncertainty	-.076	-.029	-.069	-.025
Information transparency	.083	-.064	.092	-.046
Policy awareness * Regulatory uncertainty			-.107*	.208
Policy enforcement * Regulatory uncertainty			.073	-.221*
Policy awareness * Information transparency			.064	-.169
Policy enforcement * Information transparency			-.028	.201*
χ^2	1082.216		5567.620	
df	235		1609	
P	.000		.000	
CFI	.934		.900	
RMSEA	.070		.058	
SRMR	.0439		.0473	

* $p<0.05$, ** $p<0.01$, *** $p<0.001$ (one-tailed test)

Hypothesis 5 stated that information transparency has a positive moderating effect on the relationship between policy awareness and managerial/technical sustainable practices. No such moderating effect of information transparency was found. Therefore, Hypotheses 5a

and 5b are not supported. Hypotheses 6a and 6b stated that information transparency has a positive moderating effect on the relationship between policy enforcement and managerial/technical sustainable practices. We found a statistically significantly positive moderating effect on the relationship between policy enforcement and technical sustainable practices ($\beta=0.201$, $p=0.039$). Therefore, Hypothesis 6b is supported, while Hypothesis 6a is not. A summary of the results of the tests of the hypotheses is presented in Table 4-7.

Table 4-7: Hypotheses summary

Hypotheses	Result
H1a Policy awareness is positively related to managerial sustainable practices	No
H1b Policy awareness is positively related to technical sustainable practices	Yes
H2a Policy enforcement is positively related to managerial sustainable practices	Yes
H2b Policy enforcement is positively related to technical sustainable practices	Yes
H3a Regulatory uncertainty has a negative moderating effect on the relationship between policy awareness and managerial sustainable practices	Yes
H3b Regulatory uncertainty has a negative moderating effect on the relationship between policy awareness and technical sustainable practices	No
H4a Regulatory uncertainty has a negative moderating effect on the relationship between policy enforcement and managerial sustainable practices	No
H4b Regulatory uncertainty has a negative moderating effect on the relationship between policy enforcement and technical sustainable practices	Yes
H5a Information transparency has a positive moderating effect on the relationship between policy awareness and managerial sustainable practices	No
H5b Information transparency has a positive moderating effect on the relationship between policy awareness and technical sustainable practices	No
H6a Information transparency has a positive moderating effect on the relationship between policy enforcement and managerial sustainable practices	No
H6b Information transparency has a positive moderating effect on the relationship between policy enforcement and technical sustainable practices	Yes

‘Yes’ means the hypothesis is supported; ‘No’ means the hypothesis is not supported

Regarding control variables (see Appendix C), Country (1=China, 0=the Netherlands) has a significantly positive impact on both managerial and technical practices when only control variables are included, while this effect disappears after environmental regulation factors are included. Firms in the machinery industries adopted fewer technical practices than the other manufacturing industries. The ownership type does not affect organizations’ managerial and technical practices adoption at all. The number of employees and turnover have significant effects on both managerial and technical practices adoption. Compared with firms with more than 999 employees, firms with 0-19, 20-49, 50-99 employees adopt less managerial practices, while firms with 50-99, and 100-249 employees adopt less technical practices. Compared with firms with more than 50 million euros turnover, firms with 0.5-2 million euros turnover adopted less managerial practices, while firms having 0-0.5 and 0.5-2 million euros turnover adopted less technical practices. Regarding respondents’ working departments, respondents working in other departments reported more managerial practices adopted than respondents working in the technology centers.

4.5 CONCLUSION AND DISCUSSION

This paper presents an empirical analysis of the impact of environmental regulations on organizational sustainable behavior based on a survey of Chinese and Dutch manufacturing firms. The results confirm the effectiveness of environmental regulations as in prior studies (e.g., Demirel & Kesidou, 2011; Luken et al., 2008; Sangle, 2011; Veugelers, 2012). Specifically, the awareness of environmental regulations motivates firms to make technical

changes towards sustainable behavior, while policy enforcement appears to promote both managerial and technical sustainable practices. When we compare managerial practices and technical practices, technical practices involve direct measures to meet environmental requirements, while managerial practices are more fundamental preparations for a long-term change. This may explain why the awareness of environmental regulations is only effective in promoting direct action by firms, such as technology change to meet the requirements. However, awareness is apparently not enough to change managerial practices, which represent changes in the way of working and managing. Only when firms find that policy is clearly enforced by the use of specific policy instruments, they respond in both managerial and technical ways.

Regulatory uncertainty does have a negative moderating effect on the environmental regulation effectiveness. It weakens the effect of policy awareness on managerial sustainable practices and the effect of policy enforcement on technical sustainable practices. Information transparency only has a positive moderating effect on the relationship between policy enforcement and technical sustainable practices. Here, policy awareness directly influences firms' perception of their legitimacy to operate, while policy enforcement is more related to the 'costliness', such as the benefits of complying or the punishment of violation. Policy awareness does not have a significant effect on managerial sustainable practices, and if firms perceive uncertainty in the environmental regulations at the same time, it may even prohibit changes in the managerial practices. However, when firms are aware of environmental regulations, no matter whether it is uncertain or requires more information transparency, they make corresponding technical changes to maintain their legitimacy. Policy enforcement is related to managerial practices, which is not influenced by regulatory uncertainty and information transparency. However, the impact of policy enforcement on technical sustainable practices is more sensitive to different regulatory contexts, namely regulatory uncertainty and information transparency. There may be two reasons behind this phenomenon. First, it may be because that technical practices are more visible by governmental inspections, society supervision, and peer organizations, since it could be easily reflected by environmental performance indicators and emissions could be easily inspected by governmental officers and local citizens. Second, technical practices may involve more capital investments, compared with managerial environmental practices, since clean technologies are usually embodied in expensive equipment (Del Río González, 2005).

This study contributes to institutional theory by studying one form of coercive pressure – environmental regulations – and investigating possible situations when institutional pressure may not lead to isomorphism. Prior research studied possible situations that may cause organizations to respond differently from simply compliance (e.g., Hambrick et al., 2004; Oliver, 1991; Raaijmakers et al., 2015). This study additionally investigates whether the characteristics of the institutional pressure itself could lead to different response strategies, which is essential to better understand the underlying mechanism of institutional pressure in leading the isomorphism process. Our results show the effect of coercive pressure,

such as regulations is influenced by the regulatory context, indicating that the effectiveness of environmental regulations could be improved by designing or creating a better regulatory context.

This study contributes to organizational adoption studies by disentangling managerial and technical practices. Regarding the ecological aspect of sustainable development, prior studies either use performance indicators, such as business wastage, CO2 emission (e.g., Azevedo, Carvalho, Duarte, & Cruz-Machado, 2012) or adoption behavior (e.g., Antonioli et al., 2013; Theyel, 2000; Veugelers, 2012) to measure organizations' environmental improvements. Even though these methods are capable of measuring organizations' sustainable behavior, they cannot capture the whole picture of organizational change. The distinction between managerial behavior and technical behavior allows for the inclusion of a wide range of organizational tasks, which is more comprehensive to describe organizational sustainable activities.

This study also contributes to the environmental regulation literature by exploring more specific impacts of different types of regulation. Even though prior studies investigate the impact of environmental regulation extensively, most studies tested the existence of public regulation (e.g., Arvanitis & Ley, 2013; Demirel & Kesidou, 2011; Leenders & Chandra, 2013), or the importance of regulations or regulatory stakeholders (e.g., Huang et al., 2009; Sangle, 2011; Triguero et al., 2015; Triguero et al., 2013). Only few studies compared different aspects of environmental regulations. For example, Veugelers (2012) studied both current environmental regulations and expected environmental regulations, Camison (2010) compared different policy instruments, Borghesi et al. (2015a) studied both the existence of regulations and the stringency thereof, and Popp (2010) investigated two environmental regulations in different stages. Our study tested the impact of two other aspects of environmental regulation, the awareness of environmental regulations and policy enforcement by means of specific instruments. We have argued that environmental regulation is affecting firm behavior in two different directions: firstly, it is affecting the social legitimacy of firm behavior; secondly, it is affecting behavior by dealing out punishments and rewards. Our study shows that these two directions do have a different impact on firms' behavior and also in different regulatory contexts. Thus, this study provides an alternative perspective in analyzing the function of environmental regulations.

Finally, we analyzed the effect of regulatory context factors, regulatory uncertainty and information transparency, which can help to explain the different effects of environmental regulations. Even though most prior studies confirmed the significant effect of environmental regulation on firms' sustainable behavior, when it comes to specific environmental laws, the results are inconclusive. We found that information transparency could significantly reinforce the impact of environmental enforcement on firms' technical behavior, while in the context of regulatory uncertainty, firms are less likely to make corresponding changes. Therefore, this study contributes to environmental regulation literature by suggesting that the regulatory context is also important in determining the impact of regulations.

This paper could provide policy makers some guidance for promoting organizational sustainable behavior. First, it demonstrates policy makers that environmental regulations serve as legitimacy to regulate organizations' behavior, which is effective to promote direct changes regarding environmental performance, such as technical sustainable practices. However, if the aim of the environmental regulations is to change organizational sustainable behavior fundamentally, such as changing the organizational working way and decision-making process towards sustainability, special environmental instruments are needed. Policy instruments that could increase the cost of noncomplying and benefits of complying are effective to promote organizations' both managerial and technical responses. Second, this paper shows the importance of regulatory contexts in affecting the effectiveness of environmental regulations. Building a better regulatory environment, such as reducing the regulatory uncertainty and increasing the information transparency, is especially relevant for the effect of policy enforcement on organizations' technical responses, even though the presence of environmental regulations is capable to promote organizations' technical responses. Therefore, in order to promote organizations' sustainable behavior maximally, policy makers need to think about not only the presence of environmental regulation and specific policy instruments, but also the regulatory contexts that is capable to increase the effectiveness of environmental regulations.

One limitation of this study is that it does not consider time lag effects. Organizational change is not instantaneous, and the required time may vary greatly for different types of behavior. A longitudinal study that examines organizational environmental changes responding to environmental regulations over time is required, which is also important to provide firm managers with useful information about the transition process to sustainable development. Another limitation of this study is that we only focused on intra-organizational response behavior, while the sustainable development often requires collaborative efforts with suppliers, customers, governments, society and even competitors. Future research could also focus on the inter-organizational structures and changes regarding sustainable behavior.

5.

Conclusion

5.1 SUMMARY

The overall research question of this dissertation was: *which factors influence organizational sustainable process technology adoption and how are they interrelated?* We addressed this question with three studies, shifting from a broad focus to a specific focus: identifying possible ways to promote the adoption of different types of sustainable process technologies (Chapter 2), comparing economic factors with institutional factors in relation to cost aspects of sustainable process technologies (Chapter 3), and specifying the regulatory conditions under which environmental regulations affect technical sustainable practice compared with managerial sustainable practice (Chapter 4). The next paragraphs summarize the key findings from each chapter.

Chapter 2 reports on a systematic literature review aiming to classify different types of sustainable process technologies, to extensively explore the factors that affect sustainable process technology adoption, and to investigate potential reasons for the differences in effects found across studies. Sustainable process technology adoption is mostly used as a container concept including technologies that are often not specified or measured. However, those studies that specify the technologies reveal that ‘CO₂/emission reduction technology’ and ‘energy/material efficiency technology’ are more widely studied than ‘material/fuel substitution’ and ‘recycling technologies’. The most widely studied categories of factors influencing sustainable process technology adoption are institutional factors and firm characteristics. Coercive pressure, market pressure, technological capabilities, internal support, adoption experience, certified systems, and cooperation are recognized as the most important factors influencing sustainable process technology adoption. Firm characteristics (e.g., firm size, ownership) and technology types (e.g., end-of-pipe technology vs. cleaner technology) may influence the effects of these factors. Moreover, the influential factors for each type of sustainable process technology also differ. For example, CO₂/emission reduction technology requires more policy support, while energy/material efficiency technology requires more market demand, technology capability and cooperation.

Chapter 3 investigates the relative importance of economic drivers and institutional drivers and their interrelationships for the adoption of sustainable process technologies. Our results show that policy awareness, society pressure and adoption by peer organizations are drivers of the adoption of cost-increasing technologies, while policy awareness, adoption by peer organizations and customer demand are drivers for the adoption of cost-decreasing technologies. Policy awareness has the most important effect on the adoption of either type of sustainable process technology. However, of the economic drivers, only customer demand is associated with cost-decreasing sustainable process technology adoption. Instead of the expected synergy effects between economic and institutional drivers, we only find complementary effects. Overall, multiple drivers are identified affecting firms’ sustainable process technology adoption, even though they do not work synergistically.

Chapter 4 examines the effects of environmental regulations on organizations' sustainable behavior – distinguishing technical practices (i.e., process technologies) from managerial practices – in different regulatory contexts. We studied two aspects of environmental regulations: a signal for legitimacy (policy awareness) and the effects of specific policy instruments (policy enforcement). Our results show that policy awareness is positively related to technical sustainable practices, while policy enforcement is positively related to both managerial and technical sustainable practices. Although managerial and technical sustainable practices are both reflecting sustainable organizational response behavior, they have different driving mechanisms. Moreover, regulatory uncertainty mitigates the effect of policy awareness on managerial sustainable practices as well as the effect of policy enforcement on technical sustainable practices. Information transparency reinforces the effect of policy enforcement on technical environmental practices only. The results suggest the importance of not only the presence of environmental regulations but also the necessity to distinguish technical from managerial practices and to build a better regulatory context.

5.2 CONTRIBUTION AND IMPLICATIONS

Whereas the last sections of each of the Chapters 2-4 specify the detailed contributions and implications of each of the studies, the following section provides the overarching contributions of this dissertation to theories and extant literature, and presents the implications for firm managers and policy makers.

5.2.1 Theoretical contribution

This project contributes to organizational adoption theory by including an institutional perspective and revealing its importance compared with traditional technology adoption factors. Prior adoption theories, such as the diffusion of innovation model (Rogers, 2003), the technology acceptance model (Davis et al., 1989), and the theory of planned behavior (Ajzen, 1991), emphasize the importance of technology characteristics (e.g., perceived usefulness and ease of use), communication channels, adopter characteristics and perceived behavioral control. Even though the roles of change agents and subjective norms are also identified, these studies tend to focus on individual perceptions influenced by personal relationships. Compared with individual adoption behavior, organizational adoption is more sensitive to the broader political and economic environment. Later studies in the field of organizational adoption behavior realized the importance of legitimacy (Abrahamson, 1991; Bansal & Roth, 2000; Kennedy & Fiss, 2009; Tolbert & Zucker, 1983), and most research in the field of sustainable technology adoption pointed to the significant role of environmental regulations. The findings of this dissertation do not only show the importance of environmental regulations in promoting sustainable development in firms (Chapters 2 and 4), but also of other aspects of legitimacy, such as the effect of mimetic pressure and society pressure (Chapter 3). The

peculiarities of sustainable process technologies, such as requiring more external pressure and involving more stakeholders make the adoption and diffusion processes more complex compared with traditional (non-sustainable) innovations, calling for new theories to be built for sustainable process technology adoption. Chapter 3 shows that institutional and economic drivers have complementary effect instead of a synergy effect on sustainable process technology adoption, therefore underlining the importance of both factors. Different from traditional innovation diffusion, in which case benefits of innovations are firstly recognized and then legitimated (Tolbert & Zucker, 1983), the adoption of sustainable process technology could be firstly legitimated after which its benefits could be more easily accepted by firms. Together, these findings challenge the conventional technology adoption and diffusion mechanisms, emphasizing not only the effect of regulations but also of other types of institutional pressures.

This project contributes to sustainable development studies specifying different types of sustainable behavior and revealing the corresponding adoption mechanisms. Because influential factors vary for the adoption of different types of technology (Del Río González, 2009; Ettlie et al., 1984), we only focused on sustainable process technology in Chapter 2. Adapted from the definition of clean production from the United Nations Environment Programme and prior studies, four types of sustainable process technology have been identified, which are CO₂/emission reduction, energy/material substitution, energy/material efficiency, and recycling technology. Prior studies found different influential factors for different types of sustainable process technologies. For example, environmental regulations are more important for the adoption of CO₂/emission reduction technology than for energy efficiency technology, while adoption of energy/material efficiency technologies requires more market demand, technology capability and cooperation than CO₂/emission reduction technologies. In Chapter 3, we further hypothesized that influential factors may differ between sustainable process technologies, because these technologies differ in their economic potential for firms after they are adopted. Therefore, we further classified these types of sustainable process technologies into cost-increasing and cost-decreasing sustainable process technologies. The results in Chapter 3 confirm the expectation that society pressure is particularly relevant for the adoption of cost-increasing technologies while customer demand is particularly important for the adoption of cost-decreasing technologies. Statistically, we found that for adoption of cost-increasing sustainable process technologies, policy awareness is more important than customer demand and relative advantage, and that adoption by peer organizations is more important than relative advantage. Even though policy awareness is still more important for the adoption of cost-decreasing sustainable process technologies than relative advantage, these results show the different driving forces for the adoption of cost-increasing and cost-decreasing sustainable process technologies. In Chapter 4, we extended the scope of sustainable process technologies to cover not only technical behavior but also managerial behavior. Because organizations do have different managerial and technical responses to environmental regulations, adoption theory should

not be limited to a technology perspective with technical practices, but also include managerial practices when it comes to sustainable behavior. Moreover, the classifications used in this project indicate that various adoption mechanisms are at play in organizational sustainable behaviour. The distinctions between i) different types of sustainable process technologies (e.g., CO₂/emission reduction technology vs. energy/material efficiency technology), ii) technologies with different economic impact (e.g., cost-increasing vs. cost-decreasing sustainable process technology) and iii) managerial and technical sustainable practices, can support future researchers to capture a broader picture of organizational sustainable changes.

This project contributes to institutional theory by highlighting its importance in changes organizations' behavior in the case of sustainable process technology adoption and by investigating possible situations when organizations may have different response strategies under institutional pressure. Results in this dissertation repeatedly confirm the importance of institutional pressure in changing organizational sustainable behavior, such as environmental regulations (Chapters 2, 3 and 4), peer organizations' adoption (Chapters 2 and 3), and society pressure (Chapter 3). This result is plausible when taking into consideration the peculiarities of sustainable technologies. Institutional pressure could force organizations to internalize the externalities of environmental problems. This is why, compared with other drivers, institutional pressure is more important in changing organizational sustainable behavior. Furthermore, this project explores possible situations when institutional pressure may lead to heterogeneous responses. While institutional pressure is a force for isomorphism between organizations, prior researchers have explored possible reasons for the variety across organizations under institutional pressures. For example, Oliver (1991) discussed how institutional antecedents, such as cause, constituents and content of institutional pressures result in different response strategies, which are: acquiesce, compromise, avoid, defy or manipulate. Others suggested that institutional complexity, which occurs when organizations are confronted with incompatible prescriptions from multiple institutional logics, arising from conflicting or ambiguous institutional demands could delay organizations' compliance, (Greenwood et al., 2011; Raaijmakers et al., 2015). This project further explores organizations' response to institutional pressure – environmental regulations – under different regulatory conditions, discussing whether the regulatory context influences an organization's response strategy. Chapter 4 showed that the effectiveness of institutional pressures, especially regulatory pressure, depends on the presence of enforcement mechanisms, such as the basic direction and consensus concerning the regulation target, and justice and clearness of the regulations. This result provides another perspective explaining different organizational response strategies under institutional pressures.

Finally, this project offers important contributions to organizational sustainable behavior studies by explaining some of the inconsistent findings in earlier research. Chapter 2 investigated the inconsistent effects in prior studies by comparing not only different types of technologies, but also the measurements of dependent and independent variables

and samples. Chapter 3 explained how driving forces are different for cost-increasing and cost-decreasing sustainable process technologies, indicating different adoption logics for technologies that have different economic consequences for organizations. The results of Chapter 4 show that the effects of environmental regulations do not only vary for managerial and technical practices, but that they also vary in different regulatory contexts. Regulatory context factors include regulatory uncertainty and information transparency. All the results reveal that when building a coherent model for sustainable technology adoption, special attention needs to be paid to the peculiarities of the different types of sustainable technologies, the type of influential factors, and context factors with regard to political, societal and industrial environments, but also organizations' internal environments. Only in this way, a solid theory for organizational sustainable behavior can be built.

5.2.2 Management and policy implications

From a practical perspective, this dissertation provides firm managers and policy makers concrete guidance for promoting organizational sustainable development. Findings of this dissertation inform firm managers about important factors that could facilitate organizational sustainable behavior. Our systematic literature study shows the importance of general technology capabilities, and that high human resource quality, and cooperation with other organizations, such as business partners, suppliers and research institutes are important for organizations' sustainable process technology adoption (Chapter 2). Adoption of sustainable technology is not a one-step process, not simply a decision but requires intensive work in preparation (e.g., information searching) and implementation (e.g., operational institutionalization and re-invention) processes. By using the insights into essential capabilities for organizational sustainable development, firm managers can better facilitate a successful transition to sustainable development.

This project is especially relevant for policy makers who are responsible for promoting sustainable development. First, the results show that more targeted regulations and instruments should be designed and used for various types of sustainable process technologies. Even though environmental regulation is essential for all types of sustainable process technology adoption, its impact is not equal for different types of sustainable process technologies. Policy makers should bear in mind that the legitimacy that is built by environmental regulations is a fundamental mechanism for promoting organizational sustainable behavior. Therefore, if the aim of the regulations is to control CO₂/emission, environmental regulations can be especially effective. However, if the policy makers aim from a long-term perspective to fundamentally change organizations' way of working and decision-making towards sustainability, which relates more to the benefits of complying and cost of noncomplying, supportive policy instruments, such as taxes or subsidies and fines are needed.

Besides, policy makers need to realize that organizations' sustainable behavior cannot only be changed by environmental regulations, but also by society pressure and

peer organizations' behavior. Considering the reinforcing effect of information transparency, policy makers should not only focus on organizations' adoption behavior, but also take the perspective of building an environmentally friendly societal and industrial environment. For example, involving society in the supervision systems, and establishing industrial sustainable communities could be possible means to promote sustainable development.

Finally, even though environmental regulations can promote all types of sustainable process technology adoptions, the adoption and diffusion of cost-decreasing sustainable process technologies can be promoted by market mechanisms, such as customer demand. However, our study does not find empirical evidence for synergy effects between economic drivers and institutional drivers. An explanation may be found by taking a supply chain perspective. From a supply chain perspective, policy makers need to realize that sustainable behavior is not an individual organizational action in response to institutional pressures, but an action related to the whole supply chain. Regulations should not only focus on the adopting organizations but also on technology suppliers and customers, in which case adoption and diffusion policies need to be designed in coordination with innovation policies and economic policies. Possible measures to promote sustainable behavior of the whole supply chain, such as encouraging use of life-cycle analysis, may be needed.

5.3 Limitations and an agenda for future research

Although this dissertation increases our knowledge about organizations' sustainable process technology adoption, there are some limitations and much remains to be advanced theoretically and practically. Further research could expand our definitions of sustainable process technology and behavior, and explore the underlying mechanisms regarding other perspectives on organizational sustainable development.

5.3.1 Beyond the boundaries of sustainability, technology and behavior

This dissertation is limited to the study of intra-organizational adoption of process technologies that have environmental benefits. Sustainable technology can also be implemented in a consumer product, a service or a business model. Since most sustainable process technologies are developed by professional firms that provide environmental solutions (Kemp et al., 1992), the focus on sustainable process technologies resulted in an adopter perspective rather than an innovator or supplier perspective. Adoption takes the view of the customer or user who implements process technology (as a production process innovation), whereas development takes the view of the supplier that develops process technology as a product innovation. In this dissertation, we consider the development of technology, but only from a customer/user perspective. Adoption generally is about the decision and implementation of technologies bought off the shelf (e.g., end-of-pipe technologies) or purchased made-to-order (e.g., clean technologies) from suppliers. When it concerns sustainable process technologies though, it may also involve development when the process technology is designed, manufactured and implemented by the user firm which

may or may not be done in co-operation with suppliers. Since a concentrated perspective is necessary for a reliable and robust result, future research could focus on other types of sustainable technologies, and investigate factors that explain the development of these technologies, which requires a different theoretical frame of reference to understand the underlying mechanisms. Generally speaking, a product innovation perspective will always have to focus on the potential market for the new product, which may be influenced by regulation and other institutional pressures.

Finally, this dissertation studied intra-organizational sustainable behavior. Though we studied different types of intra-organizational sustainable behaviors distinguishing technical from managerial practices, sustainable behavior is not only concerned with the behavior of an individual organization, but also with collective behavior. Future research could expand organizations' sustainable behavior to an inter-organizational level, because sustainable development could be a cooperative activity among suppliers, customers, and other stakeholders, including competitors. In this case, diffusion perspectives and organizational networking theories could be useful in explaining inter-organizational sustainable behavior. In addition to collective inter-organizational sustainable behavior, the impact of organizations on environmental institutions, such as organizations' lobbying to affect the formulation and implementation of environmental laws and regulations, is also essential to understand sustainable development at an institutional level.

5.3.2 Other perspectives on organizational sustainable development

Our discussion of sustainable technology adoption has not been exhaustive with regard to all possible perspectives that can be taken on organizational behavior. At least two further directions of possible research can be mentioned.

First, this dissertation studied sustainable behavior at the level of individual organizations, taking the overall economic system for granted, although we pointed to the possible importance of interaction between organizations. Systemic sustainable development involves structural changes over a long period, and requires co-evolutionary changes in technology, culture, legislation, and organizational forms (Loorbach, van Bakel, Whiteman, & Rotmans, 2010). The managerial and technical organizational behavior we studied will be related in the long term to changes in the economy and society. Longitudinal studies that investigate the complete sustainable development process in organizations, including changes in sustainable behavior over time, are necessary to unveil the relationships between various factors of influence and different forms of behavior. Such studies will be better able to explain the differences between organizations' sustainable development strategies and growth paths, which could provide managers with additional practical suggestions for sustainable behavior.

Second, this dissertation mainly took an adopter perspective, while other perspectives, such as a supplier perspective, a technology development perspective and an institutional perspective are indispensable to draw the full picture of organizational

sustainable development. From a supplier perspective, economic and environmental performance of sustainable technologies needs to be evaluated. Future research needs to investigate which characteristics of sustainable technologies are valuable in the market, and how to promote the innovation and development of sustainable technologies. Combined with an adopter perspective, research from a supplier perspective could provide policy makers not only with promoting measures for sustainable technology adoption but also for sustainable technology innovation, which is essential to coordinate the adoption/diffusion policy and innovation policy. From a technology development perspective, each organization has its unique technology structure and development path. With this perspective, within organizations, technology lock-in and strategies regarding the complementarity between various sustainable technologies need to be studied. Beyond organizations, technology S-curves or technology life cycle analysis could be used to describe and predict sustainable technology development. From the institutional perspective, even though we incorporated institutional theory in the adoption model, investigating how institutional pressures influence sustainable technology adoption and how regulatory contexts affecting the effectiveness of environmental regulations, we did not delve into institutional settings. Further research could examine how the design of the political system, the enforcement power of different institution agencies, or the legitimate ways of policy making influence organizations' sustainable behavior. From this perspective, institutional voids and institutional complexity problems need to be further analyzed, which could enhance the effectiveness of institutional drivers.

5.3.3 Methodological limitations

Besides the limitations and future research suggestions regarding the content of the project, there are some limitations regarding the methodologies used in this project. The following paragraphs explain these limitations from the perspective of the sample and the regression techniques used in this project, respectively.

Regarding the sample used in this project, first, we focused on manufacturing industries, more specifically on eight energy-intensive industries. However, industry-specific factors may affect organizations' sustainable choices. For example, whether the industry is capable to develop sustainable technologies by themselves, whether the sustainable technology supply industry is mature, or whether the industry is involved in global competition could affect whether organizations have enough options of sustainable technologies and whether the quality of sustainable technologies is good enough to promote firms' sustainable technology adoption. Future research could focus more specifically on each industry situation regarding organizational sustainable behavior. Moreover, our sample is not fully representative of Chinese and Dutch manufacturing industries. It is under-representative for small firms and over-representative for large firms for both Chinese and Dutch firms. Besides, the Dutch sample is over-representative for the iron and steel industry, and under representative for the pulp, paper and print industry, and machinery industries.

Lastly, we only asked one person in each organization to report about their firm's sustainable behavior. Even though we took several measures to choose qualified respondents, such as requiring respondents' position and working department, there is still a risk of subjectivity and biases.

Regarding the regression techniques used in the project, first, correlation analysis is not equal to a causality test. In this project, we only tested the correlations between influencing factors and organizational sustainable behavior, instead of causality, and we measured the independent variables and dependent variable at the same time, neglecting any time-lagged effects. Future research could conduct longitudinal studies and causality tests, such as time-to-event analysis to investigate organizations' sustainable behavior. Second, the regression techniques used in Chapters 3 and 4 are not the same. In Chapter 3, we adopted hierarchical regression analysis to test the hypotheses, while in Chapter 4 we adopted Structural Equation Modeling (SEM). There are advantages and disadvantages regarding each methodology. SEM is a more theory-driven technique and it takes measurement errors into account when testing the hypotheses, while hierarchical regression analysis looks for the best fitting model and can take control variables into account. We changed the regression technique in Chapter 4 mainly because Chapter 4 is strongly theory-oriented and most control variables are not significant.

5.4 CONCLUDING REMARKS

'Sustainable' is a comparative term, since newer technologies can always be more sustainable than the previous generation with the continued development of science and technology. Promoting the adoption of sustainable technologies and being sustainable are permanent hot topics for policy makers and firm managers. With the development of public awareness and the changing economic and political environment, the underlying mechanisms of sustainable technology adoption could also change. This dissertation explored the factors influencing sustainable process technology adoption systematically, and then used the context of Dutch and Chinese manufacturing firms to test the hypothesized effects of economic and institutional drivers. Whether they are developed or developing nations, sustainable development is a common goal for all countries worldwide. Developed countries have the advantages of advanced technology and well-organized markets, while developing countries could try to use latecomer advantages, expecting to realize economic development and sustainable development in one-step. Even though China and the Netherlands may face different phases of development, they showed some similarities regarding sustainable process technology adoption. Country had a significant effect in the analyses presented in both Chapters 3 and 4, when it was used as control variable in the model. However, this effect disappeared, when various institutional factors were included. This result indicates that the country difference in sustainable process technology adoption could be explained by organizations' perceptions of the various driving forces.

Even though factors influencing adoption vary between different types of sustainable process technologies, coercive pressure is perceived as one of the most influential factors. Despite the effectiveness of environmental regulations, however, it is still necessary to investigate how organizations can be encouraged to go beyond what is required by the laws and regulations. The legitimacy created by environmental regulations is important for firms if they want to make technical changes, while the managerial changes that need to be encouraged in order to make sustainability an integral part of long-term firm behavior require specific policy instruments support.

We found that customer demand, as one of the economic drivers, is only influential for cost-decreasing sustainable process technologies. This result indicates that organizations may have predominantly economic considerations regarding the adoption of cost-decreasing sustainable process technologies. Because our research showed that the regulatory context can influence the effectiveness of coercive pressures and that the synergy effect between economic drivers and institutional drivers appears to be absent, policy makers need to think more about building a comprehensive regulatory environment for sustainable development, in which all these different driving forces are better aligned, not only economic drivers and regulatory drivers but also the other types of institutional drivers.

Our research studied organizational sustainable behavior at a micro level, opening the black box of firms' behavior by investigating the relationships between firms' perception of various influencing factor and their adoption of sustainable technology. However, a successful technology transition requires radical changes not only in technologies, but also in regulations, industrial networks, infrastructure, culture, etc. (Geels, 2002), in which case a multi-level perspective on socio-technical transitions is needed (Foxon, 2011; Smith, Voß, & Grin, 2010). Researchers in the field of macroeconomics, policy, science and technology, organizational behavior, etc. need to draw their insights together to provide better suggestions for sustainable development, which is still a challenge.

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APPENDICES

Appendix A: 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).

Appendix B: Overview of articles on sustainable process technology adoption

Authors	Title	Dependent variable label and measurement	Sample size	Quality assessment	Journal Impact Factor 2016
(Antonioni 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 - CO₂ =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 & 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
(Bellas & 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 & Sangale, 2015)	What drives successful implementation of pollution prevention and cleaner technology strategy? The role of innovative capability	<p>Implementing pollution prevention strategy (Seven-point Likert scale for the following items)</p> <p>1. In my organization, there is wide spread understanding on pollution prevention policy</p> <p>2. My organization has implemented best housekeeping practices to reduce in-house pollution</p> <p>.....</p> <p>Implementing clean technology strategy (Seven-point Likert scale for the following items)</p> <p>=1 if firm adopted cleaner technology</p> <p>1. My organization is planning to develop/adopt clean technology</p> <p>2. My organization is planning to adopt cleaner production processes</p> <p>.....</p>	689 India firms	<p>1. Logistic regression (2-tailed test: 1% level of significance)</p> <p>2. No control variable information, such as firm size and industry</p>	4.01
(Blackman & Bannister, 1998)	Community pressure and clean technology in the informal sector: An econometric analysis of the adoption of propane by traditional Mexican brickmakers	<p>Adoption of clean technology (propane)</p> <p>=1 if brickmakers adopted propane</p> <p>=0 otherwise</p>	76 informal (or even small-scale) traditional brick kilns in Mexico	<p>1. Probit adoption function estimation (2-tailed test: 5% level of significance)</p> <p>2. Small sample</p> <p>3. One industry-brickmaker</p>	2.305
(Bonilla et al., 2015)	Refunded emission payments and diffusion of NOx abatement technologies in Sweden	<p>NO_x abatement technology adoption – Post-combustion technology</p> <p>=1 if the boiler has post-combustion technology installed</p> <p>=0 otherwise</p> <p>NO_x abatement technology adoption – Combustion technology</p> <p>=1 if the boiler has combustion technology installed</p> <p>=0 otherwise</p> <p>NO_x abatement technology adoption – Flue gas condensation technology</p> <p>=1 if the boiler has flue gas condensation technology installed</p> <p>=0 otherwise</p>	524 boilers under the Swedish NO _x charge system	<p>1. Co_x proportional hazard model (2-tailed test: 5% level of significance)</p>	2.965
(Borghesi et al., 2015a)	Linking emission trading to environmental innovation: Evidence from the Italian manufacturing industry	<p>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?</p> <p>Environmental innovation-ECOEN</p> <p>=1 if reduced energy use per unit of output marked as Yes;</p> <p>=0 otherwise</p> <p>Environmental innovation-ECOCO</p> <p>=1 if reduced CO₂ "footprint" (total CO₂ production) by your enterprise marked as Yes;</p> <p>=0 otherwise</p>	6483 Italian firms	<p>1. Probit regression (2-tailed test: 5% level of significance)</p>	4.495
(Cainelli et al., 2015)	Adoption of waste-reducing technology in manufacturing: Regional factors and policy issues	<p>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?</p> <p>Adoption of waste-reducing technology – ECOWA</p> <p>=1 if recycled waste, water or materials marked as Yes;</p> <p>=0 otherwise</p>	6483 Italian firms	<p>1. Probit regression (1-tailed test: 10% level of significance)</p>	1.701

(Cainelli et al., 2012)	Environmental Innovations, Local Networks and Internationalization	<p>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?</p> <p>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</p> <p>CO₂ abatement technology =1 If CO₂ abatement is marked as Yes; =0 otherwise</p> <p>Emissions abatement technology =1 If emission reductions gene rating effects on soil, water, air is marked as Yes; =0 otherwise</p>	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: Empirical evidence in Spain	<p>Reactive environmental productive practices (end-of-pipe) comparison between 2002 & 2005</p> <p>Preventive environmental production practices comparison between 2002 & 2005</p>	1151 Spanish firms	1. No regression (variance analysis: 5% level of significance)	2,481
(Demirel & Kesidou, 2011)	Stimulating different types of eco-innovation in the UK: Government policies and firm motivations	<p>End-of-pipeline Pollution Control Technologies Firms' investment in End-of-pipe pollution control technologies (EOP)</p> <p>Integrated Cleaner Production Technologies Firms' investment in integrated cleaner production technologies (International Energy Agency)</p>	289 UK firms	1. Tobit model (2-tailed test: 5% level of significance)	2,965
(Hammar & 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	<p>Investment in end-of-pipe technology =1 if investment in end of pipe technology during a year =0 otherwise</p> <p>Investment in clean technology =1 if investment in clean technology during a year =0 otherwise</p>	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	<p>Adoption of Green Technical Innovation (Five-point Likert scale for the following items)</p> <ol style="list-style-type: none"> 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)	10 Hierarchical 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	<p>Environmental projects or activities carried out in the last five years (Five-point Likert scale; totally; to a certain extent; considering; no; not applicable)</p> <p>Radical Multimedia Innovations</p> <p>The combination of items for Incremental Innovations and Process change</p> <p>Radical Innovations on waste management</p> <ol style="list-style-type: none"> 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 <p>Incremental Innovations</p> <ol style="list-style-type: none"> 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 <p>Process change</p> <ol style="list-style-type: none"> 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 	322 SMEs in Chile (Chemical; Foundry; Sawmill; Swine)	1. No regression (propensity-scores analysis; 5% level of significance)	1,389
(Kounetas et al., 2011)	Promoting energy efficiency policies over the information barrier	<p>INF</p> <p>=1 If the firm is informed about energy saving technologies</p> <p>=0 otherwise</p> <p>Emerging information (EMRINF)</p> <p>=0 if not informed</p> <p>=1 if merely or partial informed</p> <p>=2 if full informed</p> <p>Epidemic information (EPINDINF)</p> <p>=0 if not informed</p> <p>=1 if merely or partial informed</p> <p>=2 if full informed</p>	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 & Chandra, 2013)	Antecedents and consequences of green innovation in the wine industry: the role of channel structure	<p>5-point scales that measure the prominence of specific green innovation activities in the firm</p> <p>Use of organic products and processes</p> <ol style="list-style-type: none"> 1. Seek organic certification 2. Produce bio-dynamic wine 3. Use green and innovative chemicals <p>Recycling activities in the winery</p> <ol style="list-style-type: none"> 1. Package products in recyclable materials 2. Recycle materials for bottling 3. Recycle waste materials from wine making 	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

(Lofgren et al., 2014)	Why the EU ETS needs reforming: an empirical analysis of the effect on company investments	<p>Large investment in carbon abatement measures =1 if the firm has made an investment equal to or above €1 million =0 otherwise</p> <p>Small investment in carbon abatement measures =1 if the firm has made an investment below €1 million =0 otherwise</p>	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 ETS adoption by manufacturing plants in developing countries	<p>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)</p> <p>Adoption of ED/OD =1 if extended delignification (ED), oxygen delignification (OD) is adopted =0 otherwise</p> <p>Adoption of ECF =1 if elemental chlorine-free bleaching (ECF) is adopted =0 otherwise</p>	99 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 & Shortle, 2001)	Determinants of cleaner technology investments in the US bleached kraft pulp industry	<p>Adoption of post-combustion techniques =1 if post-combustion technique is adopted =0 otherwise</p> <p>Adoption of combustion modification techniques =1 if combustion modification technique is adopted =0 otherwise</p>	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 Coal-fired Power Plants	<p>Adoption of post-combustion techniques =1 if post-combustion technique is adopted =0 otherwise</p> <p>Adoption of combustion modification techniques =1 if combustion modification technique is adopted =0 otherwise</p>	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
(Prajogo et al., 2014)	The diffusion of environmental management system and its effect on environmental management practices	<p>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")</p> <ol style="list-style-type: none"> 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 of manufacturing firms and non-manufacturing firms	3,339
(Sangle, 2011)	Adoption of Cleaner Technology for Climate Proactivity: a Technology-Firm-Stakeholder Framework	<p>Adoption of Cleaner Technology (CT) for climate Proactivity =1 if they already using CT; or had taken decisive steps to use CT =0 otherwise</p>	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 CO2 'footprint' (total CO2 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 CO2 emission (ECOCO) =1 if the firm introduced a product (good or service), process, organizational or marketing innovation that reduced CO2 'footprint' (total CO2 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, innovation and patenting: Evidence from German manufacturing firms	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
(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 & 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 CCP 20: Evaluate the possibilities of recyclability in operational activities CCP 21: Increase the use of renewable resources CCP 26: Use energy-saving equipment	107 Malaysian manufacturers	1. No regression (Kruskal-Wallis H test)	5,715

(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

Appendix C: Unstandardized coefficients of the heteroscedasticity-consistent standard error regression analysis

[illegible]

Technology criteria									
Number of applicable									
Environmental regulations									
Policy Awareness	.161***	.161***	.167***	.166***					
Policy Enforcement	.433***	.443***	.441***	.441***					
Regulatory uncertainty	.312***	.385***	.459***	.442***					
Information transparency	.272***	.272***	.267***	.266***					
Regulatory uncertainty_sq	-.026*	-.036*	-.045***	-.043*					
Interaction terms									
Policy Awareness * Regulatory uncertainty		.001		-.007					
Policy Enforcement * Regulatory uncertainty		.017		.012					
Policy Awareness * Information transparency			.009	-.001					
Policy Enforcement * Information transparency			.038*	.038+					
R²									
F for this step									
df 1	3313	.7702	.7705	.7738	.1601	.2946	.2955	.2986	.2992
df 2	14,7677	87,4649	84,0721	82,6987	5,2869	11,0148	10,4727	10,6602	10,0586
Sig.	.29	.34	.36	.38	.30	.35	.37	.37	.39
	.713	.708	.706	.704	.692	.687	.685	.685	.683
	.000	.000	.000	.000	.000	.000	.000	.000	.000

+p<0.1. * p<0.05. **p<0.01. ***p<0.001
Interaction variables are centered

APPENDIX D SURVEY OF SUSTAINABLE TECHNOLOGY ADOPTION IN MANUFACTURING FIRMS

Thank you very much for participating in this research of Radboud University (in The Netherlands), sponsored by China Scholarship Council. If you would like receive a report of this research, please send an email to the email address on the business card.

The aim of this survey is to acquire a better understanding on how to help manufacturing firms to adopt production technologies that are saving energy, material and reduce pollution. There are no right or wrong answers. It is important that you answer all the questions regarding to your firm's production site.

We ensure you the anonymity and confidentiality of the firm and respondent participating in this scientific study. The data collected from this questionnaire will only be published on an aggregated level; no individual firms can then be identified.

This survey contains four sections:

1. Current situation regarding sustainable technology adoption in your firm.
2. Factors affecting sustainable technology adoption.
3. Environmental factors of sustainable technology adoption.
4. General information about your firm.

The average time to complete the questionnaire is 15 minutes. Please fill out all the questions.

Thank you again for your participation.

If you have any further questions, please do not hesitate to contact us:

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Section 1: Sustainable technology adoption status quo

Sustainable technology is defined as a technology that is **used in the production process**, which can **reduce the generation or release of pollutants**, and/or **reduce the usage of production materials and energy**.

1.1 Please indicate in which industry is your firm's main activity

- ☐ Iron and steel ☐ Pulp, paper and print ☐ Chemical and pharmaceutical
☐ Machinery ☐ Food and beverage ☐ Petroleum refineries
☐ Non-metallic minerals (e.g. glass, ceramic, bricks, cement, concrete, plaster and stone products)
☐ Non-ferrous metal (e.g. aluminum, lead, tin, zinc, copper, casting of metals)
☐ Others (Please indicate)

1.2 Please indicate to what extent your firm has adopted the following sustainable measures

	No		Yes		Not applicable to our firm
	no plan	we are preparing for decision making	we are in the process of implementation	we are utilizing it	
1. End-of-pipe technology to remove CO ₂ emission or air pollutants at the last stage of production	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2. End-of-pipe technology to water or soil pollutants at the last stage of production	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3. Modification of the production equipment, working procedures, machine instructions etc. to increase the efficiency of material use (e.g. less material, minimize waste)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4. Modification of the production equipment, working procedures, machine instructions etc. to increase the efficiency of energy use	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5. Modification of the production equipment, working procedures, machine instructions etc. to only reduce emission generation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6. Fuel substitution from coal or oil to natural gas or biomass	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7. Transition from producing gray electricity to green electricity based on solar, wind or water	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
8. Replacement of hazardous or non-renewable inputs by less hazardous or renewable materials (e.g. biodegradable)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9. Replacement of materials by recycled materials	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10. Reuse of the waste materials in the same process for another useful application within the firm	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
11. Transformation of previously discarded waste into materials that can be reused or recycled for another application outside the firm	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
12. Use of recycled water or use water-saving technology	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Section 2: Factors affecting firms' sustainable technology adoption

This section focuses on the firm's own behaviors. Please answer the following questions according to the firm's current or past experience.

2.1 Does your firm know the following types of laws and regulations?	Not at all				Extensive knowledge		
	1	2	3	4	5	6	7
1. National environmental regulations (such as China Environmental Protection Law; China Environmental Impact Assessment Law; China Clean Production Promotion Law; China Circular Economy Promotion Law)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2. National energy conservation and emission reduction regulations (such as China Energy Conservation Law; China Atmospheric Pollution Prevention and Control Law; China Solid Waste Pollution Prevention Law)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3. Regional (provincial and municipal) resource saving and conservation regulations (circular economy, cleaner production etc.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

2.2 To what extent do you agree with the following statements?	Not at all				Strongly agree		
	1	2	3	4	5	6	7
1. Most firms in our industry have plans to save energy and reduce emission	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2. Most firms in related industries (supplier, customers, and industries that produce substitute product or similar product) have plans to save energy and reduce	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3. The leading firms in our industry have plans to save energy and reduce emission	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4. When external experts or consulting firms give suggestions, they always take environmental issues into account	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5. When internal experts give suggestions, they always take environmental issues into account	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6. When suppliers introduce their new products, they always take environmental issue into account	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7. Sustainable technology always improves the economic performance of our firm	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
8. Sustainable technology has insignificant benefits of energy saving and emission reduction in short-term	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9. Sustainable technology always improves the reputation of our firm	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10. Sustainable technology always improves our product quality	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
11. Sustainable technology has reduced safety-related incidences compared to the technologies we used before	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
12. It is a common view in the firm that the environmental policies will be stricter in the future	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
13. For new construction projects (e.g. new building, production line or plant), government agency monitors and examines the validity and reliability of the environmental assessment report strictly	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

2.3 How often did your firm discuss the following issues in formal meetings of the management team in the last year?	Never				Every time		
	1	2	3	4	5	6	7
1. The changes in environmental policies to ensure that we meet every requirement	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2. The environmental performance of other firms in our industry (e.g. competitors)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3. The environmental performance of firms in related industries	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4. Sustainable technologies that were adopted by leading companies in our industry	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5. Successful sustainable technology implementation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

2.4 What was the frequency of the following activities in the last three years?	Never				Very frequently		
	1	2	3	4	5	6	7
1. We have voluntary agreements with governmental agencies concerning environmental performance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2. Firms in our industry have been exposed to complaints about environmental issues by local citizens or NGOs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3. We get involved in NGO's environmental projects	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4. Representatives of our firm visit sustainable technology exhibitions or conferences on sustainability	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5. We got on-site environmental inspection or environmental audits by public authorities	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6. Industrial associations urged us to conform to environmental policies	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7. Our industry's environmental problems were exposed by news media	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
8. Our firm has been criticized about environmental issues by local citizens, NGOs, or media	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

2.5 What was the frequency of the following activities in the last three years?	Never				Every time		
	1	2	3	4	5	6	7
1. When we are planning to update equipment, we take environmental policies into account	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2. When we are planning to implement new production technology, we ask environmental advice from external experts (e.g. consulting firms, research institutions, universities)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3. When we are planning to implement new production technology, we ask suggestions from our internal environmental experts	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4. When we are planning to implement new production technology, we consult opinions from NGOs about environmental issues	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5. When we have new construction projects, we ask opinions from local citizens	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6. We apply for subsidies relating to sustainable technology	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

2.6 To what extent do the following statements apply to your firm?	Not at all				Very much		
	1	2	3	4	5	6	7
1. Current subsidy schemes for sustainable technology alleviate the financial burden when investing in these technologies	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2. On average, the environmental taxation and/or polluting discharge fees are higher than the cost of pollution treatment	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3. Our customers demand green products	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4. Our major customers require us to achieve environmental certification (e.g. ISO 14001, ISO 5001)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5. Our customers will withdraw the contract if we do not meet their requirements of environmental performance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6. Our customers request detailed information on energy saving and emission reduction to ensure our environmental compliance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7. Sustainability is incorporated in our mission statement	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
8. Environmental criteria are taken into consideration in our production processes	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9. The top managers are highly committed to energy conservation and emission reduction	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10. Our employees lack environmental awareness	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
11. The requirements for various environmental indicators are difficult to meet in the Environmental Impact Assessment	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

2.7 Does your firm employ people who are professionally concerned with environmental policies?

- ☐ No, we didn't employ people to deal with environmental policies
- ☐ No, we hired external consultants for advice on environmental policies
- ☐ Yes, there is one employee dealing with environmental policies
- ☐ Yes, we have a group of people dealing with environmental policies
- ☐ Yes, we have a separate department dealing with environmental policies

Section 3: Environmental factors of firms' sustainable technology adoption

This section is not only about your firm, but also other firms, technology suppliers and environmental policies. Please answer the following questions according to your firm's experience, and your view of the current situation in the whole industry.

3.1 To what extent do you agree with the following statements?	Not agree at all				Strongly agree		
	1	2	3	4	5	6	7
1. It is easy to understand the requirements that environmental regulations and laws set for our company	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2. All firms in our industry publish detailed figures about their environmental performance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3. All firms in our industry publish information of their Environmental Impact Assessment Report	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4. The fines paid for trespassing the environmental requirements (e.g. pollution discharge fees) are made public	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5. Environmental standards are the same across regions	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6. In our industry, the price competition is fierce	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7. For the quality assurance purpose, please select strongly agree	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
8. There is a lack of advanced sustainable technology or sustainable material available on the market	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9. Suppliers adapt their sustainable technology well to our production situation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10. Sustainable technology suppliers provide good after-sales service	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
11. Our firm is an active member in our industry association	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
12. I can answer all the questions in the questionnaire from our firm's perspective	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

3.2 To what extent does the following apply to your firm?	None				All		
	1	2	3	4	5	6	7
1. The number of our competitors that are located in the same region with us is	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2. The number of supplier and customer firms in the supply chain that are located in the same region with us, is	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

3.3 To what extent does the following apply to your firm?	Not at all				A lot		
	1	2	3	4	5	6	7
1. There is a room for negotiations about the payment of environmental taxes and/or pollution discharge fees in our region	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2. We contribute to the local government's total tax revenue	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3. We sell our products to public authorities	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4. Our market share has been growing in the last five years	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5. The number of firms in our industry is increasing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6. The number of our direct competitors is increasing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

3.4 What was the frequency of the following events in the last three years?	Never				Very frequently		
	1	2	3	4	5	6	7
1. Environmental regulations and laws with regard to our industry change	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2. Environmental regulations and laws impose requirements on our firm that are in conflict with requirements made by other regulations	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3. We supply personnel to public authorities as advisors on environmental issues	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4. We have been consulted in the governmental policy-making process with regard to environmental issues	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5. Our firm is informed by its suppliers about the latest sustainable technology	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6. Our firm has long-standing collaborative relationships on environmental projects with other firms in our industry	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Section 4: General information

4.1 What is the number of employees in your firm?

- ☐ 0-19 ☐ 20-49 ☐ 50-99 ☐ 100-249
☐ 250-499 ☐ 500-999 ☐ 1000 or more

4.2 Do you consider your firm to be one of the leading firms in your industry?

- ☐ Yes
☐ No

4.3 Please indicate the ownership of your firm

- ☐ State-owned and state-holding enterprise
☐ Foreign-invested enterprise ☐ Private enterprise
☐ Collective enterprise ☐ Others (Please indicate)

4.4 Firm Address: Province City

4.5 What is your firm's annual turnover?

- ☐ 0-0.5 million ☐ 0.5-2 million ☐ 2-10 million
☐ 10-50 million ☐ more than 50 million

4.6 Does your firm export products to foreign countries?

- ☐ Yes
☐ No

4.7 Is your electricity that your firm purchases based on renewable sources, such as wind, water or solar?

- ☐ Yes
☐ No

4.8 In which department do you work in your firm?

- ☐ Production department ☐ Financial department
☐ Environmental protection department
☐ Sales department ☐ Procurement department
☐ Human resources department ☐ CEO or owner
☐ Technology center ☐ Others (Please indicate)

4.9 How many years have you been working in this industry? Years

4.10 Have you participated in firm's sustainable technology adoption project before?

☐ Yes

☐ No

4.11 Have you understood the questions in the questionnaire?

From 1 (not at all) to 7 (very well), please give the rate.

4.12 What do you think are the main barriers for firms to adopt sustainable technology?

Thank you very much for your participation. Please make sure you have completed all the questions. If you would like to receive a summary of our research results, please send us a separate email to ask for it. If you have further questions or opinions towards firm's dilemmas of sustainable technology adoption, you are quite welcomed to share your opinions with us.

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SUMMARY (IN ENGLISH)

Introduction

Sustainable development is embraced by governments, society and firm managers in order to balance between economic development, social development and environmental protection. In the firm level, sustainable development is a multidimensional concept, including environmental integrity, economic prosperity and social equity (Bansal, 2005), and it requires a social learning process with the full involvement of stakeholders and planners, formal legislation as well as ethical principles (Ali & Peder, 2007). Although corporate responsible behavior is appreciated by society, adopting sustainable technologies by firms will not happen automatically. Therefore, how to realize sustainable development is still an important challenge facing firms and governments.

Theories explaining firms' adoption behavior complement and overlap each other, there is still no theory explaining organizational sustainable behavior specifically. For example, the Diffusion of Innovation Theory and the Technology Acceptance Model emphasize technology and adopter characteristics in adoption decisions. Stakeholder theory and evolutionary theory relate to relevant stakeholder identification or selection criteria and organizational adaptation ability. Institutional theories focus on external mandatory, cognitive and normative pressures. The natural-resource-based view and corporate social responsibility emphasize the responsibility of organizations and ways how to be sustainable. Besides, since sustainable technology is a broad concept, it is unknown if the underlying adoption mechanism differs for different types of sustainable technology. Therefore, in this project, we specifically focus on sustainable process technologies, try to understand factors that influencing different types of sustainable process technologies and their effectiveness.

Research question

In this project, we focus on the environmental aspects of sustainable development in firms, particularly on the organizational adoption of sustainable process technologies, emphasizing the implementation aspects from a user perspective. Sustainable technologies are defined as technologies that can reduce negative effects on the environment by reducing or preventing pollution, reducing resource consumption, or using less polluting or energy-intensive materials. The research question of this dissertation is: *Which factors influence organizational sustainable process technology adoption and how are they interrelated?*

To answer this question, we conducted three studies, exploring from general factors to ones that are more specific. A systematic literature review was conducted to get an overview of factors influencing sustainable process technology adoption by firms, identifying possible ways to promote the adoption of different types of sustainable process technologies (Chapter 2). Two strands of factors are identified as important based on prior studies and theories, which are economic drivers and institutional drivers. A more detailed analysis regarding the relative importance of these two strands of factors and their

interrelationships is conducted in relation to cost aspects of sustainable process technologies in Chapter 3. Since environmental regulation is still the main driving force for sustainable process technology adoption, a more focused investigation regarding the effectiveness of environmental regulations was conducted, specifying the regulatory conditions under which environmental regulations affect technical sustainable practice compared with managerial sustainable practice (Chapter 4).

The Results

The next paragraphs summarize the key findings from each chapter.

Factors affecting the adoption of sustainable process technologies: A systematic literature review (Chapter 2)

Chapter 2 is a systematic literature review that extensively explores the factors that affect sustainable process technology adoption. Most importantly, it classifies different types of sustainable process technologies and investigates potential reasons for the differences in effects found across studies. Coercive pressure, market pressure, technological capabilities, internal support, adoption experience, certified systems, and cooperation are recognized as the most important influencing factors. Sustainable process technology adoption is mostly used as a container concept including various types of technologies. Studies that specify the technologies are mostly focused on ‘CO₂/emission reduction technology’ and ‘energy/material efficiency technology’ instead of ‘material/fuel substitution’ and ‘recycling technologies’. Firm characteristics (e.g., firm size, ownership) and technology types (e.g., end-of-pipe technology vs. cleaner technology) may explain the different effects of factors across studies. Moreover, the influential factors for each type of sustainable process technology also differ. For example, CO₂/emission reduction technology requires more policy support, while energy/material efficiency technology requires more market demand, technology capability and cooperation.

What influences manufacturing firms to adopt sustainable process technologies? The relative importance of economic and institutional drivers (Chapter 3)

Chapter 3 investigates the relative importance of economic drivers and institutional drivers and their interrelationships for the adoption of cost-increasing and cost-decreasing sustainable process technologies. The results show that policy awareness, society pressure and adoption by peer organizations are positively related to the adoption of cost-increasing technologies, while policy awareness, adoption by peer organizations and customer demand are positively related to the adoption of cost-decreasing technologies. Policy awareness has the most important effect on the adoption of either type of sustainable process technology. Customer demand, as the only significant economic driver, is only associated with cost-

decreasing sustainable process technology adoption, indicating that if the sustainable technology have economic saving potentials organizations may take economic factors into consideration. Instead of the expected synergy effects between economic and institutional drivers, we only find complementary effects. Overall, drivers vary for cost-increasing and cost-decreasing sustainable process technologies, and institutional drivers and economic drivers do not work synergistically.

The effects of environmental regulations on managerial and technical sustainable responses of firms: The role of regulatory uncertainty and information transparency (Chapter 4)

Chapter 4 examines the effects of environmental regulations on organizations' technical and managerial sustainable response in different regulatory contexts. Two responsibilities of environmental regulations are identified: a signal for legitimacy (policy awareness) and the effects of specific policy instruments (policy enforcement). Our results show that policy awareness is positively related to technical sustainable practices, while policy enforcement is positively related to both technical and managerial sustainable practices. Moreover, regulatory uncertainty mitigates the effect of policy awareness on managerial sustainable practices as well as the effect of policy enforcement on technical sustainable practices. Information transparency reinforces the effect of policy enforcement on technical sustainable practices only. The results suggest the importance of not only the presence of environmental regulations but also a better regulatory context for increasing the effectiveness of environmental regulations.

CONTRIBUTIONS

Theoretical contribution

This project contributes to organizational adoption theory by revealing the importance of institutional pressures compared with traditional technology adoption factors. Traditional individual adoption models emphasize technology characteristics, communication channels, adopter characteristics and perceived behavioral control, while organizational adoption is more sensitive to the broader political and economic environment. Even though later studies realized the importance of institutional pressures (Abrahamson, 1991; Bansal & Roth, 2000; Kennedy & Fiss, 2009; Tolbert & Zucker, 1983), most research in the field of sustainable technology adoption only focus on environmental regulations. This dissertation shows not only the importance of environmental regulations (Chapters 2 and 4), but also other aspects of institutional drivers, such as mimetic pressure and normative pressure (Chapter 3). Chapter 3 shows a complementary effect between institutional and economic drivers, indicating the importance of both aspects.

This project contributes to sustainable technology adoption studies by specifying different types of sustainable behavior and revealing their corresponding

adoption mechanisms. Because influential factors vary for the adoption of different types of technology (Del Río González, 2009; Ettlie et al., 1984), we only focused on sustainable process technology. Four types of sustainable process technology have been identified, which are CO₂/emission reduction, energy/material substitution, energy/material efficiency, and recycling technology. Chapter 3 further confirms the expectation that influential factors may differ between sustainable process technologies that have different economic potential for firms. For example, we found that society pressure is particularly relevant for the adoption of cost-increasing technologies while customer demand is particularly important for the adoption of cost-decreasing technologies. Even though policy awareness is still more important for the adoption of both cost-increasing and cost-decreasing sustainable process technologies, these results show the different adoption mechanisms for these two types of sustainable process technologies. In Chapter 4, we cover not only technical behavior but also managerial behavior, showing that organizations do have different managerial and technical responses to environmental regulations. The distinctions between i) different types of sustainable process technologies (e.g., CO₂/emission reduction technology vs. energy/material efficiency technology), ii) technologies with different economic impact (e.g., cost-increasing vs. cost-decreasing sustainable process technology) and iii) managerial and technical sustainable practices, can support future researchers to capture a broader picture of organizational sustainable changes.

This project contributes to institutional theory by investigating possible situations in which organizations may have different response strategies under institutional pressure. Institutional pressure is a force for isomorphism between organizations, and prior researchers have explored possible reasons for the variety across organizations under institutional pressures. For example, Oliver (1991) discussed how institutional antecedents, such as cause, constituents and content of institutional pressures result in different response strategies. Others suggested that institutional complexity could delay organizations' compliance (Greenwood et al., 2011; Raaijmakers et al., 2015). This project investigates organizations' response to environmental regulations under different regulatory conditions, exploring how regulatory context influences an organization's response strategy. Chapter 4 showed that regulatory uncertainty and information transparency could affect the effectiveness of environmental regulations, which provides another perspective explaining different organizational response strategies under institutional pressures.

Finally, this project contributes to organizational sustainable behavior studies by explaining some of the inconsistent findings in earlier research. Chapter 2 investigated the inconsistent effects in prior studies by comparing different types of technologies, measurements of dependent and independent variables and samples. Chapter 3 showed that driving forces are different for cost-increasing and cost-decreasing sustainable process technologies, indicating different adoption mechanisms for technologies that have different economic consequences. The results of Chapter 4 show that organizations' managerial and technical responses could be vary in different regulatory contexts. The possible reasons for the

inconsistent findings indicate that special attention needs to be paid to the peculiarities of the different types of sustainable technologies, the type of influential factors, and context factors with regard to political, societal and industrial environments, and organizations' internal environments when building an adoption model for sustainable process technologies.

Managerial and policy implications

This dissertation provides firm managers and policy-makers concrete guidance for promoting organizational sustainable development of firms. Findings from the systematic literature study as part of this dissertation emphasize the importance of general technology capabilities, high human resource quality, and cooperation with other organizations, such as business partners, suppliers and research institutes, since they can help organizations to improve sustainable technology adoption. By gaining the knowledge about essential capabilities for organizational sustainable development, firm managers can better facilitate a successful transition to sustainable development.

This project is especially relevant for policy makers for promoting sustainable development. First, the results show that regulations and instruments should be designed more specifically for various types of sustainable process technologies, since their impact is not equal for different types of sustainable process technologies. The legitimacy built by environmental regulations is a fundamental mechanism for promoting organizational sustainable behavior, so it is especially effective to control CO₂/emission. From a long-term perspective to fundamentally change organizations' way of working and decision-making towards sustainability, supportive policy instruments, such as taxes or subsidies and fines are needed. Besides, since organizations' sustainable behavior can also be changed by society pressure, peer organizations' behavior and the effectiveness of environmental regulations could be affected by regulatory uncertainty and information transparency, policy makers should also think about building an environmentally friendly, societal and industrial environment, such as involving society in the supervision systems and establishing industrial sustainable communities to promote sustainable development.

Finally, even though environmental regulations are important for the adoption of all types of sustainable process technologies, market mechanisms, such as customer demand could also promote the adoption of sustainable process technologies that have economic saving potentials, such as cost-decreasing sustainable process technologies. Even though no synergy effect has been found between economic drivers and institutional drivers, policy makers need to realize that sustainable behavior is an action related to the whole supply chain. Regulations need to be designed in coordination with innovation policies and economic policies, focusing on not only the adopting organizations, but also technology suppliers and customers.

SAMENVATTING (IN DUTCH)

Introductie

Duurzame ontwikkeling wordt omarmd door overheden, de samenleving en bedrijven om een balans te vinden tussen economische ontwikkeling, sociale ontwikkeling en milieubescherming. Op bedrijfsniveau is duurzame ontwikkeling een multidimensionaal concept, inclusief milieu-integriteit, economische welvaart en sociale rechtvaardigheid (Bansal, 2005), en het vereist een sociaal leerproces met de volledige betrokkenheid van belanghebbenden en planners, formele wetgeving en ethische principes (Ali & Peder, 2007). Hoewel maatschappelijk verantwoord ondernemen door de samenleving wordt gewaardeerd, zal de adoptie van duurzame technologieën door bedrijven niet automatisch plaatsvinden. Daarom is het realiseren van duurzame ontwikkeling nog steeds een belangrijke uitdaging voor bedrijven en overheden.

Theorieën over het adoptiegedrag van bedrijven vullen elkaar aan en overlappen elkaar, er is nog steeds geen theorie die duurzaam gedrag specifiek verklaart. De innovatiediffusie theorie en het technologie-acceptatiemodel benadrukken bijvoorbeeld de technologie en kenmerken van adopters bij adoptiebeslissingen. Stakeholdertheorie en evolutietheorie hebben betrekking op relevante stakeholderidentificatie of selectiecriteria en organisatorisch aanpassingsvermogen. Institutionele theorieën richten zich op externe verplichte, cognitieve en normatieve druk. De op natuurlijke hulpbronnen gebaseerde visie en maatschappelijk verantwoord ondernemen benadrukken de verantwoordelijkheid van organisaties en manieren om duurzaam te zijn. Bovendien, aangezien duurzame technologie een breed concept is, is het onbekend of het onderliggende goedkeuringsmechanisme verschilt voor verschillende soorten duurzame technologie. Daarom richten we ons in dit project specifiek op duurzame procestechnologieën, proberen we factoren te begrijpen die verschillende soorten duurzame procestechnologieën beïnvloeden en hun effectiviteit.

Onderzoeksvraag

In dit project richten we ons op de milieuaspecten van duurzame ontwikkeling in bedrijven, in het bijzonder op de organisationele acceptatie van duurzame procestechnologieën, waarbij de implementatieaspecten vanuit gebruikersperspectief worden benadrukt. Duurzame technologieën worden gedefinieerd als technologieën die negatieve effecten op het milieu kunnen verminderen door vervuiling te verminderen of te voorkomen, het gebruik van hulpbronnen te verminderen of minder vervuilende of energie-intensieve materialen te gebruiken. De onderzoeksvraag van dit proefschrift is: welke factoren beïnvloeden de organisationele adoptie van de duurzame procestechnologie en hoe hangen deze samen?

Om deze vraag te beantwoorden hebben we drie onderzoeken uitgevoerd, van algemene naar meer specifieke factoren. Een systematisch literatuuronderzoek werd uitgevoerd om een overzicht te krijgen van factoren die van invloed zijn op de acceptatie van duurzame procestechnologie door bedrijven, en mogelijke manieren te vinden om de

adoptie van verschillende soorten duurzame procestechnologieën te bevorderen (hoofdstuk 2). Twee soorten factoren worden als belangrijk geïdentificeerd op basis van eerdere studies en theorieën, de economische en institutionele drijfveren. Een meer gedetailleerde analyse van het relatieve belang van deze twee factoren en hun onderlinge relaties wordt uitgevoerd in verband met de kostenaspecten van duurzame procestechnologieën in hoofdstuk 3. Omdat milieuregulering nog steeds de belangrijkste drijvende kracht is voor de adoptie van duurzame procestechnologie, is een meer gericht onderzoek naar de effectiviteit van milieuregels uitgevoerd, met vermelding van de wettelijke voorwaarden waaronder milieuregels de technische duurzame praktijk beïnvloeden in vergelijking met duurzame managementpraktijken (hoofdstuk 4).

De resultaten

De volgende paragrafen vatten de belangrijkste bevindingen van elk hoofdstuk samen.

Factoren die van invloed zijn op de adoptie van duurzame procestechnologieën: een systematisch literatuuronderzoek (hoofdstuk 2)

Hoofdstuk 2 is een systematisch literatuuroverzicht waarin uitgebreid wordt ingegaan op de factoren die van invloed zijn op de acceptatie van duurzame procestechnologie. Het belangrijkste is dat het verschillende soorten duurzame procestechnologieën classificeert en mogelijke redenen onderzoekt voor de verschillen in effecten die in studies worden aangetroffen. De vanuit de overheid opgelegde druk, marktdruk, technologische capaciteiten, interne ondersteuning, adoptie-ervaring, gecertificeerde systemen en samenwerking worden erkend als de belangrijkste beïnvloedende factoren. Duurzame acceptatie van procestechnologie wordt meestal gebruikt als een containerconcept met verschillende soorten technologieën. Studies die de technologieën specificeren, zijn meestal gericht op 'CO₂/emissiereductietechnologie' en 'energie/materiaal-efficiëntietechnologie' in plaats van 'materiaal/brandstofvervanging' en 'recyclingtechnologieën'. Vaste kenmerken (bijv. Bedrijfsgrootte, eigendom) en technologietypes (bijvoorbeeld end-of-pipe technologie versus schonere technologie) kunnen de verschillende effecten van factoren in verschillende studies verklaren. Bovendien verschillen de invloedrijke factoren voor elk type duurzame procestechnologie ook. De CO₂/emissiereductietechnologie vereist bijvoorbeeld meer beleidsondersteuning, terwijl energie/materiaal-efficiëntietechnologie meer marktvraag, technologievermogen en samenwerking vereist.

Wat beïnvloedt productiebedrijven van duurzame procestechnologieën? Het relatieve belang van economische en institutionele factoren (hoofdstuk 3)

Hoofdstuk 3 onderzoekt het relatieve belang van economische drijfveren en institutionele drijfveren en hun onderlinge samenhang voor de adoptie van kostenverhogende

en kostenverlagende duurzame procestechnologieën. De resultaten laten zien dat beleidsbewustzijn, maatschappelijke druk en acceptatie door peer-organisaties positief zijn in verband met de invoering van kostenverhogende technologieën, terwijl beleidsbewustzijn, goedkeuring door peer-organisaties en de vraag van klanten positief zijn in verband met de invoering van kostenverlagende technologieën. Beleidsbewustzijn heeft het belangrijkste effect op de adoptie van beide soorten duurzame procestechnologie. De vraag van de klant, als de enige belangrijke economische drijfveer, hangt alleen samen met kostenbesparende acceptatie van duurzame procestechnologie, wat aangeeft dat als de duurzame technologie economisch besparingspotentieel heeft, organisaties mogelijk rekening houden met economische factoren. In plaats van de verwachte synergie-effecten tussen economische en institutionele factoren, vinden we alleen aanvullende effecten. Over het algemeen verschillen de adoptiefactoren voor kostenverhogende en kostenverlagende duurzame procestechnologieën en werken institutionele factoren en economische factoren niet synergetisch samen.

De effecten van milieuregelgeving op de manageriële en technische duurzame respons van bedrijven: de rol van onzekerheid van regelgeving en transparantie van informatie (hoofdstuk 4)

Hoofdstuk 4 onderzoekt de effecten van milieuregelgeving op de technische en manageriële duurzame respons van organisaties in verschillende regelgevende contexten. Twee verantwoordelijkheden van milieuregels worden geïdentificeerd: een signaal voor legitimiteit (beleidsbewustzijn) en de effecten van specifieke beleidsinstrumenten (handhaving van het beleid). Onze resultaten laten zien dat beleidsbewustzijn positief gerelateerd is aan technische duurzame praktijken, terwijl handhaving van beleid positief gerelateerd is aan zowel technische als manageriële duurzame praktijken. Bovendien vermindert de onzekerheid over de regelgeving het effect van beleidsbewustzijn op duurzame managementpraktijken en het effect van handhaving van beleid op technische duurzame praktijken. Transparantie van informatie versterkt het effect van beleidsuitvoering op technische duurzame praktijken alleen. De resultaten wijzen op het belang van niet alleen de aanwezigheid van milieuregels, maar ook een betere regelgevingscontext om de effectiviteit van milieuregelgeving te vergroten.

CONTRIBUTIES

Theoretische contributies

Dit project draagt bij aan de organisationele adoptietheorie door het belang van institutionele druk te onthullen in vergelijking met traditionele technologie-adoptiefactoren. Traditionele individuele adoptiemodellen leggen de nadruk op technologische kenmerken, communicatiekanalen, kenmerken van adopters en waargenomen gedragscontrole, terwijl organisationele acceptatie gevoeliger is voor de bredere politieke en economische omgeving.

Hoewel latere studies het belang inzagen van institutionele druk (Abrahamson, 1991; Bansal & Roth, 2000; Kennedy & Fiss, 2009; Tolbert & Zucker, 1983), richten de meeste onderzoeken op het gebied van duurzame technologie-adoptie zich alleen op milieuregelgeving. Dit proefschrift toont niet alleen het belang van milieuregelgeving (Hoofdstukken 2 en 4) aan, maar ook van andere aspecten van institutionele factoren, zoals mimische druk en normatieve druk (Hoofdstuk 3). Hoofdstuk 3 toont een complementair effect tussen institutionele en economische factoren aan, waarbij het belang van beide aspecten wordt aangegeven.

Dit project draagt bij aan duurzame technologie-acceptatiestudies door verschillende typen duurzaam gedrag te specificeren en de bijbehorende adoptiemechanismen te onthullen. Omdat invloedrijke factoren variëren voor de acceptatie van verschillende soorten technologie (Del Río González, 2009; Ettlie et al., 1984), hebben we ons alleen gericht op duurzame procestechnologie. Er zijn vier soorten duurzame procestechnologie geïdentificeerd, waaronder vermindering van CO₂/emissie, substitutie van energie/materiaal, energie/materiaal-efficiëntie en recyclingtechnologie. Hoofdstuk 3 bevestigt de verwachting dat invloedrijke factoren kunnen verschillen tussen duurzame procestechnologieën met een ander economisch potentieel voor bedrijven. Wij hebben bijvoorbeeld geconstateerd dat druk vanuit de samenleving met name relevant is voor de invoering van kostenverhogende technologieën, terwijl de vraag van klanten vooral belangrijk is voor de invoering van kostenverlagende technologieën. Hoewel beleidsbewustzijn nog steeds belangrijker is voor de goedkeuring van zowel kostenverhogende als kostenbesparende duurzame procestechnologieën, tonen deze resultaten de verschillende adoptiemechanismen voor deze twee soorten duurzame procestechnologieën. In hoofdstuk 4 behandelen we niet alleen technisch gedrag, maar ook managementgedrag, wat aantoont dat organisaties verschillende management- en technische antwoorden hebben op milieuregels. Het onderscheid tussen i) verschillende soorten duurzame procestechnologieën (bijv. CO₂/emissiereductietechnologie versus energie/materiaal-efficiëntietechnologie), ii) technologieën met verschillende economische gevolgen (bijv. kostenverhogende versus kostenverlagende duurzame procestechnologie) en iii) management en technische duurzame praktijken, kunnen toekomstige onderzoekers helpen om een breder beeld te krijgen van duurzame veranderingen in de organisatie.

Dit project draagt bij aan de institutionele theorie door mogelijke situaties te onderzoeken waarin organisaties verschillende responsstrategieën onder institutionele druk kunnen hebben. Institutionele druk is een kracht voor isomorfisme onder organisaties en eerdere onderzoekers hebben mogelijke redenen gezocht voor de variëteit bij organisaties die onder institutionele druk staan. Oliver (1991) bijvoorbeeld, besprak hoe institutionele antecedenten, zoals oorzaak, bestanddelen en inhoud van institutionele druk, resulteren in verschillende responsstrategieën. Anderen suggereerden dat institutionele complexiteit de naleving door organisaties kan vertragen (Greenwood et al., 2011; Raaijmakers et al., 2015). Dit project onderzoekt de reactie van organisaties op milieuregels onder verschillende regelgevingsvoorwaarden, en onderzoekt hoe regelgevingscontext de reactiestrategie

van een organisatie beïnvloedt. Hoofdstuk 4 liet zien dat onzekerheid in de regelgeving en transparantie van informatie van invloed kunnen zijn op de effectiviteit van milieuregelgeving, wat een ander perspectief biedt voor het uiteenzetten van verschillende strategieën voor organisatierespons onder institutionele druk.

Ten slotte draagt dit project bij aan onderzoek naar duurzaam gedrag van organisaties door enkele inconsistente bevindingen in eerder onderzoek te verklaren. Hoofdstuk 2 onderzocht de inconsistente effecten in eerdere studies door het vergelijken van verschillende soorten technologieën, van metingen van afhankelijke en onafhankelijke variabelen en van steekproeven. Hoofdstuk 3 liet zien dat de drijvende krachten voor kostenverhogende en kostenverlagende duurzame procestechnologieën verschillend zijn, wat wijst op verschillende adoptiemechanismen voor technologieën die verschillende economische gevolgen hebben. De resultaten van hoofdstuk 4 laten zien dat de management- en technische reacties van organisaties kunnen variëren in verschillende regelgevende contexten. De mogelijke redenen voor de inconsistente bevindingen wijzen erop dat speciale aandacht moet worden besteed aan de eigenaardigheden van de verschillende soorten duurzame technologieën, het type invloedrijke factoren en de contextfactoren met betrekking tot politieke, maatschappelijke en industriële omgevingen en de interne omgeving van organisaties bij het bouwen van een adoptiemodel voor duurzame procestechnologieën.

Implicaties voor bedrijven en overheden

Dit proefschrift biedt managers van bedrijven en beleidsmakers van overheden concrete richtlijnen voor het bevorderen van duurzame ontwikkeling van bedrijven. De bevindingen van het systematische literatuuronderzoek als onderdeel van dit proefschrift benadrukken het belang van algemene technologische capaciteiten, hoge kwaliteit van personeel en samenwerking met andere organisaties, zoals zakenpartners, leveranciers en onderzoeksinstituten, omdat deze organisaties kunnen helpen bij een betere adoptie van duurzame technologie. Door de kennis over essentiële capaciteiten voor duurzame ontwikkeling van organisaties te verwerven, kunnen bedrijfsmanagers een succesvolle overgang naar duurzame ontwikkeling beter faciliteren.

Dit project is vooral relevant voor beleidsmakers voor het bevorderen van duurzame ontwikkeling. Ten eerste tonen de resultaten aan dat voorschriften en instrumenten specifiek moeten worden ontworpen voor verschillende soorten duurzame procestechnologieën, aangezien hun impact niet gelijk is voor verschillende soorten duurzame procestechnologieën. De legitimiteit die wordt opgebouwd door milieuregels, is een fundamenteel mechanisme voor het bevorderen van duurzaam gedrag van organisaties, dus het is vooral effectief om CO₂/emissies te beheersen. Vanuit een langetermijnperspectief om de manier van werken en besluitvorming van organisaties fundamenteel te veranderen in de richting van duurzaamheid, zijn ondersteunende beleidsinstrumenten, zoals belastingen of subsidies en boetes, nodig. Aangezien duurzaam gedrag van organisaties ook kan worden veranderd door maatschappelijke druk, kunnen het gedrag van collega-organisaties en

de effectiviteit van milieuregels worden beïnvloed door onzekerheid over regelgeving en informatietransparantie, beleidsmakers moeten ook nadenken over het bouwen van een milieuvriendelijke, sociale en industriële omgeving, zoals het betrekken van de samenleving in de toezichtsystemen en het opzetten van industriële duurzame gemeenschappen om duurzame ontwikkeling te bevorderen.

Hoewel milieuvoorschriften belangrijk zijn voor de acceptatie van alle soorten duurzame procestechnologieën, kunnen tot slot de marktmechanismen, zoals de vraag van klanten, ook bevorderlijk zijn voor de acceptatie van duurzame procestechnologieën met economisch besparingspotentieel, zoals kostenbesparende duurzame procestechnologieën. Hoewel er geen synergetisch effect is gevonden tussen economische factoren en institutionele factoren, moeten beleidsmakers zich realiseren dat duurzaam gedrag een actie is die verband houdt met de hele toeleveringsketen. Verordeningen moeten worden ontworpen in coördinatie met innovatiebeleid en economisch beleid, waarbij de aandacht niet alleen uitgaat naar de adopterende organisaties, maar ook naar technologieleveranciers en klanten.