MASTER-THESIS

Factors affecting the adoption of sustainable process technologies:

The manufacturing industries in the German context

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Abstract

To reach the SDG goals 12 and 13, formulated by the United Nations in 2012, especially companies of the manufacturing industries are requested to increase the sustainability of their production processes. Previous studies have assessed the factors that lead towards the adoption of sustainable process technologies with which this is achieved, from different perspectives. In a triangulation process consisting of a literature review comparison and a mixed-methods analysis, including an interview-based qualitative and a survey-based quantitative analysis, the influence of six of these factors is evaluated. The results show that state regulation is an important factor that pushes companies to adopt these technologies. Furthermore, Financial and Technological capabilities work as necessary conditions that have to be met before an adoption can take place. Additionally, the size of a firm functions as a pre-condition that in the end also yields positive influences in that matter. Contrary, Financial costs, meaning a disadvantageous cost-benefit ratio, shows a negative influence and furthermore an interaction with the regulation factor. This means that where the adoption of sustainable process technologies is economically not reasonable, regulation pressures become more important. Besides the findings, theoretical implications and practical recommendations are provided.

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1 Introduction

Currently, mankind is using 1.7 times more resources per year than the earth is able to reproduce in the same time; most fossil fuels and other resources determining the progress of our society will be depleted within the next century (‘Earth Overshoot Day 2017: Ressourcenbudget verbraucht’, 2017; Ruz, 2011). It is obvious that these developments do not correspond with a future in which the supply of our society is organized the way it is nowadays. Especially the developed western countries will have to transform major patterns of their resource intensive economies and behaviours in order to maintain and expand their prosperity.

In Germany, the production sector is responsible for almost three quarters of the total primary energy usage; the utilisation of natural energy resources. Of this usage, the manufacturing industries alone cause 38%. (‘Branchenabhängiger Energieverbrauch des verarbeitenden Gewerbes, 2016). This gives a first impression of the huge current impact of the manufacturing industries but also of the opportunities for improvement and savings that lie here. Beyond the pure energy usage and its consequences for the environment, this also affects the consumption of a large number of other resources. Although it is a tedious process including strong resistance of the industry, the German government sees itself in a pioneering role in creating a more sustainable economy and is willing to improve the current situation as for example the following statement shows:

‘It is all about a fundamental transformation of our business practices which affects all sectors – the industrial production, the mobility, the power generation, the thermal insulation, the energy efficiency.’ (Merkel, 2015).

These words of Angela Merkel following the Paris Agreement of 2015, together with the aspects mentioned before, clearly show the critical role of the industrial production, specifically that of the manufacturing industries, to approach the problems and challenges connected to the environment and climate protection. The United Nations therefore developed the sustainable development goals (SDGs) number 12 which deals inter alia with a more sustainable production and number 13 which focuses on climate action (‘Goal 12: Responsible Consumption and Production’, n.d.; ‘Goal 13: Climate Action’, n.d.). Governmental agreements like the one of Paris have a necessary role to play in achieving these development goals, as all countries and their economies are facing an example of the so-called ‘tragedy of the commons’. The difficulty in addressing necessary adjustments lies in the fact that some of

them will cause more costs and risks than benefits for single companies and whole economies, which seems to make some kind of intervention inevitable (Ostrom, 2008).

Technologically, countries can achieve the mentioned SDGs inter alia when the firms implement sustainable process technologies; a topic which attracts rising attention within the literature (Linnenluecke & Griffiths, 2013; Schiederig, Tietze & Herstatt, 2012). These more optimized technologies can reduce emissions, save energy and work more efficiently when it comes to material usage during the manufacturing process and by that contribute on a large scale to a cleaner and more responsible way of production (Babl, Schiereck & Flotow, 2014; Belis-Bergouignan, Oltra & Saint Jean, 2004; Dewick & Miozzo 2002; Kemp, Olsthoorn, Oosterhuis & Verbruggen, 1992; Luken, Van Rompaey & Zigova, 2008; Shrivastava, 1995). Although there is a wide consent within the literature in this field about the necessity for SDG 12 and 13 and the means to get there, the factors that finally determine the adoption of the mentioned sustainable process technologies seem to be diverse and strongly depending on the business ecosystem (Winn & Pogutz, 2013) as the quantitative literature review of Fu, Kok, Dankbaar, Ligthart and van Riel (2018) shows.

Sustainable process technologies are one stream of the current literature considering the development of sustainable technologies in general that are means to reach the SDG goals, while the second stream deals with the final product that can be sustainable like for example electric cars (del Río González, 2009). The scope of this thesis focuses purely on the first of these research streams. It will investigate how certain factors influence the adoption of sustainable process technologies, so the process starting with the problem formulation and ending with the implementation of the technologies after a decision has been made. Consequently, the research question this thesis will answer is the following:

What are the differential factors from the qualitative literature review and the quantitative literature review regarding the adoption of sustainable process technologies in the manufacturing industries and how does it work in the German context?

To answer the research question, the thesis will apply a triangulation of data and methods, which can be seen in figure 1.1, to reach a high validity and reliability in the results. Therefore, it starts with a summary of the quantitative literature review by Fu et al. (2018) in chapter 2, which will give an impression of the most important empirical findings in the field of sustainable process technology adoption in the manufacturing industries. Afterwards, chapter 3 will start off with a fully systematic literature review of the qualitative literature not covered

in the work of Fu et al. (2018). It will further consist of a comparison between the review of the quantitative and the qualitative studies, which highlights specific similarities and distinctions in the research streams. Thereby, the interest lies on whether these two methods of research yield different outcomes in the relations of the factors towards the sustainable process technologies. Out of this, hypotheses on six factors will be generated that lead to a conceptual model for the further analysis and will be the basis of the triangulation process at the core of this thesis.

After that, the methodology for the analysis of this thesis will be presented in the fourth chapter. In the fifth and sixth chapter, a mixed methods approach will be applied. First, a quantitative correlation analysis based on survey data gained in North Rhine-Westphalia and Rhineland-Palatinate will be conducted. As the second angle of the triangulation, this is done to reveal whether the similarities and differences of effects that are found for the six factors between the two literature streams are significant. Afterwards, as the last part of the triangulation, a qualitative analysis based on five exploratory interviews in chapter 6 will uncover the mechanisms and patterns in which the different factors influence the adoption of sustainable technologies.

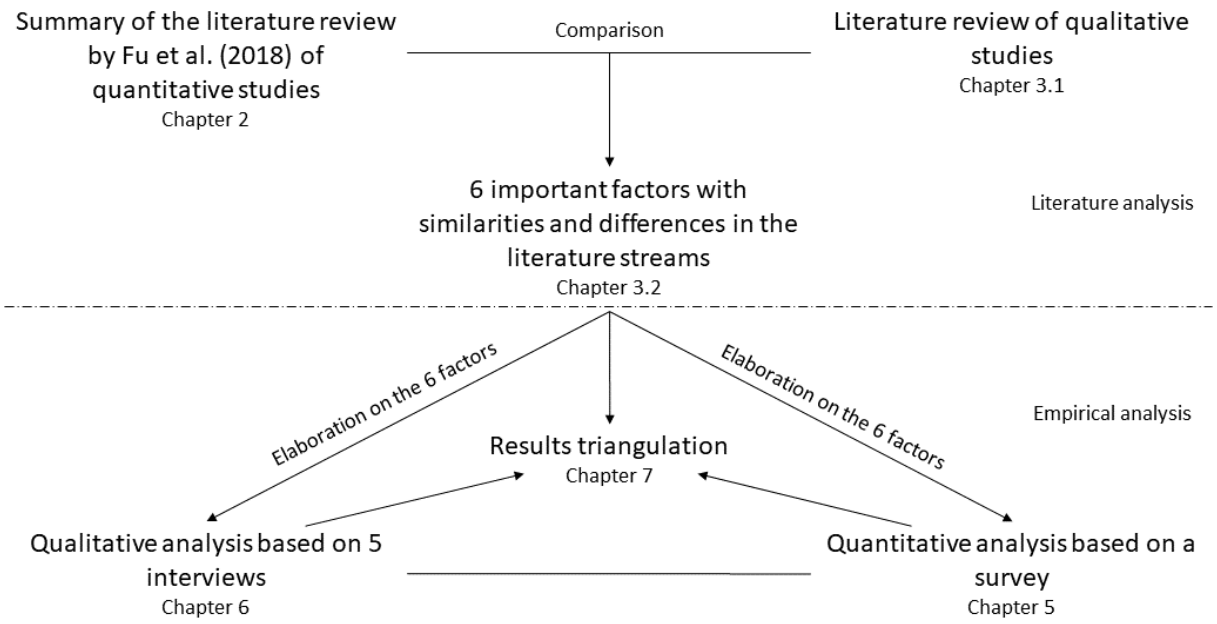

Figure 1.1: Representation of the conceptual analysis framework.

These results will be summarized, compared and discussed in the triangulation in chapter 7. Thereby, the overall influences of the six factors on the adoption of sustainable process technologies will be concluded. In a first step, the discussion of chapter 8 will answer the research question. This is followed by theoretical as well as practical implications which will give an outlook on further research in that matter and advise companies for a more successful adoption process.

2 Quantitative findings for the adoption of sustainable technologies

To grasp the difficulty and complexity of the numerous mechanisms that lead to the adoption of sustainable process technologies, it is essential to consider the existing literature on this topic. Therefore, as a first step, this chapter summarizes a systematic quantitative literature review as part of the work of Fu et al. (2018), which builds a basis to this thesis and will be referred to more often hereinafter. The paper deals with the adoption of sustainable process technologies in the manufacturing industries of the Netherlands and will function as a basis for the extension on the German case. This summary will reveal a number of underlying factors that are found to influence the adoption and their relations towards groups of sustainable technologies as tested by several articles.

Like shown in the beginning by the quote of Angela Merkel (2015), the growing public and political focus on environmental protection is increasing the pressure on the manufacturing industry, one of the biggest polluters, to act (Efficiency, 2007). According to Fu et al. (2018), there are three direct superordinate means through which this industry can reduce or avert its negative impacts on the environment by introducing sustainable technologies into its processes: reducing pollution, minimizing the usage of resources and using environmental friendly or energy-efficient materials, while the latter two can be combined to one factor.

As stated by Fu et al. (2018), besides these two means that play a role within company processes of production, the preparation and the after-production phases should be included to form a more holistic picture of an overall clean process, so that material or fuel substitution comes into play as well as the recycling process (del Río González, 2005). Finally, there are a number of scientific articles that deal not only with the influence on single process technologies, but with the adoption of sustainable technology in general, which is added here as another dependent variable next to these four specific groups of technologies (Fu et al., 2018). Therefore, this summary focusses on the influences on the adoption of the following technology categories: General sustainable technology, CO^2/ Emission reduction, Energy/ Material efficiency, Material/ Fuel substitution and Recycling.

In order to reveal what causes the adoption of the mentioned process parts in the manufacturing industry, 41 different independent variables that form a smaller number of factors can be found in the quantitative literature. According to Fu et al. (2018), these can be clustered into the categories: market pressures, legitimacy, information, firm characteristics,

technology characteristics and network characteristics. Table 2.1 gives a simplified overview of the results that Fu et al. (2018) find within the quantitative literature research, while representing the overall influences across technologies. Thereafter, the results are described in more detail by also describing the different relations towards the distinctive technologies.

Table 2.1

Simplified representation of the quantitative literature review by Fu et al. (2018)

Category	**Positive influence**	**Unclear influence**	**Negative influence**
Market pressures		Market pressures	
Legitimacy	Coercive legitimacy Mimetic legitimacy	Normative legitimacy	
Information	Information sources	Information uncertainty	
Firm characteristics	Foreign/ state ownership Internal support Human capital intensity Technological capability Environmental man. tools	Firm size Private ownership Export activities CSR Financial capability Resource intensity Knowledge stock Export activities CSR	
Technology characteristics	Relative advantage Compatibility		Financial cost
Network characteristics	Network characteristics		

Market pressures

Starting off with the market pressures on the adoption of sustainable process technologies, the impact of these influences remains questionable. As being referred to by Fu et al. (2018), some researchers find significant positive evidence for market stakeholders, customer demand, market competition and resource price on the dependent variables, while a similar number of researchers does not find any significances (e.g. see Arvanitis & Ley, 2013; Leenders & Chandra, 2013; Triguero, Moreno-Mondejar & Davia, 2013).

Legitimacy

Continuing with legitimacy, a category that deals with the influences of different institutions, a distinction must be made between coercive, mimetic and normative forces (Bansal & Roth, 2000; DiMaggio & Powell, 1983). For coercive pressures, the overall effect on the sustainable technology adoption is positive, while there is some variance between the different measures, the various technologies and company sizes (e.g. see Bonilla, Coria, Mohlin & Sterner, 2015; Borghesi, Cainelli & Mazzanti, 2015; Jimenez, 2005; Triguero, Moreno-Mondejar & Davia, 2015; Veugelers, 2012;). For mimetic means, the literature finds overall slightly positive effects, depending on the kind of technology, rather than an overall effect (Arvanitis & Ley, 2013; Bonilla et al., 2015; Popp, 2010). The impact of normative pressures remains unclear, as there are just a few studies covering these influences with differing outcomes (e.g. see Arvanitis & Ley, 2013; Luken et al., 2008; Zhang, Yang & Bi, 2013).

Information

Considering the dimension of information, the literature shows that perceived uncertainty hardly matters (Arvanitis & Ley, 2013; Weng & Lin, 2011). Information from various sources, on the contrary, have an overall positive effect on the adoption, while for example information gathered from other firms turn out to only have an influence on selective technologies like energy efficiency (Borghesi et al., 2015; Cainelli, Mazzanti & Montresor, 2012; Triguero et al., 2013).

Firm characteristics

The largest dimension, firm characteristics, contains a number of conceptually different factors of which the effects will now be presented. As referred to by Fu et al. (2018), the size of the firm has positive, negative as well as insignificant effects, depending to some extent on the particular technology and the taken perspective, while no overall consistent direction can be found (e.g. see Bellas & Nentl, 2007; Blackman & Bannister, 1998; Bonilla et al., 2015; Lofgren, Wrake, Hagberg & Roth, 2014; Maynard & Shortle, 2001). While ownership has a positive impact on certain technologies for state and foreign owned companies, private companies tend to avoid high costs that come with the adoption (e.g. see Arvanitis &Ley, 2013; Cainelli et al., 2012; Luken et al., 2008; Popp, 2010). For export activities, there has not been found a clear effect (e.g. see Arvanitis & Ley, 2013, Cainelli et al., 2012; Kounetas, Skuras & Tsekouras, 2011).

Responsibility only plays a positive role stemming from internal support but does not matter regarding Corporate Social Responsibilty (CSR) activities (Demirel & Kesidou, 2011; Huang, Ding & Kao, 2009; Weng & Lin, 2011). The human capital intensity shows that companies with a high employee quality tend to adopt most technologies more likely (e.g. see Antonioli, Mancinelli & Mazzanti, 2013; Arvanitis & Ley, 2013; Lofgren et al., 2014). Technological capability has a general positive effect when it is measured as a construct of multiple indicators (e.g. see Triguero et al., 2015; Zhang et al., 2013). While looking only at the R&D activities, this positive effect is very dependent on whether energy-saving technologies are adopted or general investments are done (e.g. see Arvanitis & Ley, 2013; Hammar & Lofgren, 2010).

Current studies find the influence of financial capability of a company not to be significant (Luken et al., 2008, Maynard & Shortle, 2001). The effects of resource intensity remain unclear as it depends on multiple factors (e.g. see Bonilla et al., 2015; Hammar & Lofgren, 2010). Possible influences of the knowledge stock are especially researched for the CO^2/emission reduction. For certain technologies, the literature has found a significant effect of the knowledge stock, dependent on investments in other technologies, while overall there is not found a significance (e.g. see Bonilla et al., 2015; Hammar & Lofgren, 2010; Popp 2010). Finally, environmental management tools do have an overall positive effect (e.g. see Leenders & Chandra, 2013; Prajogo, Tang & Lai, 2014; Theyel, 2000; Wagner, 2007).

Technology characteristics

Regarding the technology characteristics dimension, a perceived relative advantage is found to be significantly positively related to the general adoption of sustainable technology (e.g. see Zhang et al., 2013; Zhang, Fei, Zhang & Liu, 2015), while financial costs are negatively related (Sangle, 2011). Technologies compatible to the ones already used in the process seem to have a positive effect on the adoption (Arvanitis & Ley, 2013, Weng & Lin, 2011).

Network characteristics

For the last dimension, network characteristics, a positive relationship of membership depends on the type of external organization a company is member of and the specific technology adopted (e.g. see Borghesi et al., 2015; Maynard & Shortle, 2001). Cooperations in general yield a significant positive effect on the adoption of sustainable technologies (e.g. Triguero et al., 2015; Wu, 2013).

Summary

To conclude, the quantitative review by Fu et al. (2018) finds a number of factors that yield a positive effect towards the adoption of sustainable process technologies. Besides the coercive and mimetic legitimacy, also information from various sources can be found in this group. Furthermore, a number of firm characteristics, namely state and foreign ownership, responsibility from the internal support perspective, human capital intensity, technological capability measured as a construct and to a limited extent also measured by the R&D activities and finally the application of environmental management tools, seem to promote the adoption. The same accounts for the perceived relative advantage of technologies and the compatibility of the new technologies to the existing ones. Lastly, network characteristics also play a role, while the impact of the membership depends on the partners.

Besides these positive effects, some factors are found not to have a clear influence, according to the quantitative literature. The market pressures, normative legitimacy and information uncertainty belong to this group as well as the firm size, private ownership, export activities, responsibility from the Corporate Social Responsibility perspective, the financial capability of a firm, resource intensity and the knowledge stock of the company. Additionally, financial costs are the only variable that has a negative influence on the adoption.

As these results show, the researched variables in the current literature yield a variety of effects on the different technologies, which are not always consistent in the different articles. Nevertheless, this summary only dealt with the quantitative analysis of the mentioned relations while not explaining in detail the theory behind these relations or focussing on specific cases. This step will be done in the following chapter by investigating the qualitative and theoretical research that is done to this day.

3 Qualitative literature review, comparison and conceptual model

Building on the quantitative literature review of Fu et al. (2018), the following chapter provides a systematic review of the qualitative research in this field, which gives mainly access to theoretical models and more case-based studies. The findings of both reviews will then be compared, while looking specifically at possible differences. Within this comparison process, six hypotheses will be derived that make assumptions about the influences of the underlying factors. Based on these hypotheses the chapter will then lead to the conceptual model, which is underlying the core of the later analysis of the thesis.

3.1 Systematic literature review of the qualitative research findings

In line with the discussed review of Fu et al. (2018), the review of the qualitative literature is done in a systematic manner to give an exhaustive overview of the relevant literature and its results. In this way, it is possible to avoid bias that could otherwise occur in a selectively including behaviour by applying a transparent way of working. Finally, this approach allows for the discussion of the differences between the results of the different studies (Cook, Mulrow & Haynes, 1997; Tranfield, Denyer & Smart, 2003). Figure 3.1 gives an overview of the selection procedure applied here, which is described in more detail in appendix A. After a keywords search, duplications and articles published before 2008 are excluded. According to four main content criteria, the other articles are then sorted out if they do not meet all of them. In total, a number of 27 articles remains to be included into this review, fulfilling all mentioned criteria and by that dealing with the central matter of interest, namely the relations of different factors towards sustainable process technologies.

The 27 remaining articles are sorted (Appendix B) and categorized, in a first step, by quotes that give information about certain relations which are presented within the literature. These quotes are then ranked accordingly to their importance. The number one is assigned to central statements of mostly case studies in this matter that have a high explanation power regarding the factors that influence the adoption of sustainable process technologies. A two is given to statements that stem out of articles that are for example not solely considering the adoption. Finally, a three is given to, for example, theoretical papers, mostly without underlying reality cases. The quotes with the highest importance are considered first in the description of the influences in the following. The resulting coding table can be found in appendix C.

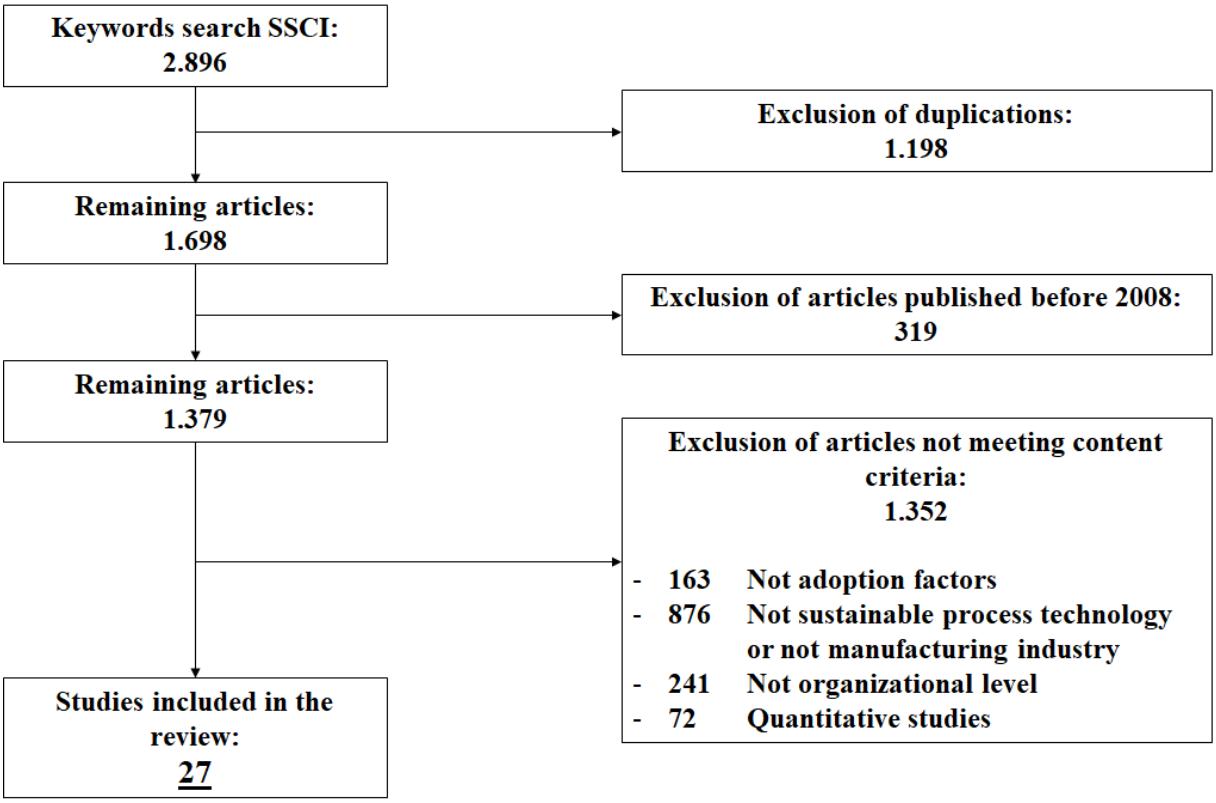

Figure 3.1. Representation of the article selection steps within the systematic literature review.

In the next step, these quotes are then sorted into a matrix with in total 32 independent variables in the rows and three dependent categories of sustainable process technologies in the columns, as can be seen in table 3.1. In order to be able to compare the two different reviews later on, this table is based on the one provided by Fu et al. (2018). Therefore, the independent variables and factors are here also clustered into the categories of market pressures, legitimacy, information, firm characteristics, technological characteristics and network characteristics. Nevertheless, due to the lower number of qualitative papers and the fact that none of them deals primarily with the topics of Material/ Fuel substitution or Recycling, those technologies of the preparation and the after-production phase are excluded to focus on the processes within the firms.

Most of the articles investigate the adoption of sustainable process technologies in general rather than highlighting one of the more generic categories, therefore those findings are clustered in the first column. Besides that, CO^2/ Emission reduction and Energy/ Material efficiency turn out to be relevant within the scope of this research as well. Furthermore, nine

independent factors that are considered in the quantitative analysis are excluded because there is no evidence for their influences within the qualitative literature. These nine variables also play a rather minor role within the quantitative research as only a small number of articles considers them (Fu et al., 2018). This means that they should be kept in mind but it seems that they do not belong to the most important factors.

In contrast to the review of Fu et al. (2018), variables that are found to not have an effect are not included as the large majority of the articles does not discuss those. This might be a bias within the qualitative literature as most of the research just focuses on the effects that do obviously matter, while all other possible variables do not seem to be of much interest in the academic discussion.

Table 3.1

Relationships between different independent variables and the sustainable process technologies represented by articles

	General sustainable technology		**CO^2/emission reduction**		**Energy/ material efficiency**	
	P	**N**	**P**	**N**	**P**	**N**
Market pressure						
Customer demand	(Rosen, 2013); (Förster, 2015); (Gil-Moltó & Varvarigos, 2013); (Wiggett & Marcelle, 2013)				(Wu et al., 2014)	(Ho et al., 2016)
Market competition	(Caparrós et al., 2013); (Xia et al., 2017); (da Silva et al., 2017)	(Nunes et al., 2016); (Kemp & Volpi, 2008)			(Zhu & Chertow, 2017); (Wu et al., 2014)	(Henriques & Catarino, 2016)
Resource price	(Rosen, 2013)					
Legitimacy						
Coercive pressures						
Regulation stakeholder			Caparrós et al., 2013); (Coria, 2009)	(del Río González, 2008)		
Regulation	(Wiggett & Marcelle, 2013); (Rosen, 2013); (Infante & Smirnova, 2016); (Nunes et al., 2016); (Sloan, 2011); (Förster, 2015); (Kemp & Volpi, 2008); (Rueda et al., 2017); (Wiggett & Marcelle,		(Bergguist et al., 2013); (Coria & Zhang, 2015); (Kemp & Volpi, 2008); (Hultman et al., 2012)		(Zhu & Chertow, 2017); (Arens et al., 2017); (Kemp & Volpi, 2008); (Wu et al., 2014)	(Ho et al., 2016)

	General sustainable technology		CO^2/emission reduction		Energy/ material efficiency	
	P	**N**	**P**	**N**	**P**	**N**
	2013); (da Silva et al., 2017);					
Voluntary standard	(Rueda et al., 2017)					
Governmental support	(Sloan, 2011); (da Silva et al., 2017)				(Zhu & Chertow, 2017); (Ho et al., 2016); (Henriques & Catarino, 2016)	
Economic support	(da Silva et al., 2017)					
Industry initiative					(Ho et al., 2016)	
Information						
Information uncertainty		(da Silva et al., 2017)		(Hultman et al., 2012)	(Zhu & Chertow, 2017)	(Trianni et al., 2013); (Henriques & Catarino, 2016)
Information sources	(da Silva et al., 2017)				(Zhu & Chertow, 2017); (Cagno et al., 2017); (Henriques & Catarino, 2016)	
Firm characteristics						
Firm size	(Förster, 2015)					
Ownership						
Public owned					(Wu et al., 2014)	
Private owned					(Wu et al., 2014)	
Responsibility						
Corporate social responsibility			(Diana et al., 2017)			
Internal support	(Li & Hamblin, 2016), (da Silva et al., 2017)		(Hultman et al., 2012); (Diana et al., 2017)		(Diana et al., 2017); (Cagno et al., 2017)	
Human capital intensity						
Quality			(Diana et al., 2017)		(Diana et al., 2017)	
Complementary			(Diana et al., 2017)		(Diana et al., 2017); (Ho et al., 2016)	
Technological capability						
Technological capability construct	(da Silva et al., 2017)				(Zhu & Chertow, 2017); (Ho et al., 2016);	

	General sustainable technology		CO^2/emission reduction		Energy/ material efficiency	
	P	**N**	**P**	**N**	**P**	**N**
					(Arens et al., 2017)	
R&D or expert	(da Silva et al., 2017)				(Henriques & Catarino, 2016)	
Innovative capability					(Ho et al., 2016); (Henriques & Catarino, 2016)	
Financial capability	(Nunes et al., 2016); (da Silva et al., 2017)				(Zhu & Chertow, 2017); (Trianni et al., 2013); (Arens et al., 2017); (Cagno et al., 2017)	
Resources intensity						
Resource cost	(Rosen, 2013)					
Knowledge stock						
Technology substitutes	(Wiggett & Marcelle, 2013); (da Silva et al., 2017); (Kemp & Volpi, 2008)		(Kemp & Volpi, 2008)		(Cagno et al., 2017)	
Adoption experience	(da Silva et al., 2017)					
Environmental man. Tools						
Environmental practice	(Kemp & Volpi, 2008)				(Wu et al., 2014)	
Certified systems	(Li & Hamblin, 2016)					
Technology characteristics						
Relative advantage	(Nunes et al., 2016); (da Silva et al., 2017)	(da Silva et al., 2017)	(Hultman et al., 2012)		(Arens et al., 2017); (Cagno et al., 2017); (Förster, 2015); (Wu et al., 2014)	
Financial cost		(Wiggett & Marcelle, 2013); (da Silva et al., 2017); (Förster, 2015); (Kemp & Volpi, 2008);				(Henriques & Catarino, 2016); (Ho et al., 2016)
Compatibility	(Wiggett & Marcelle, 2013)				(Ho et al., 2016)	
Network characteristics						
Membership	(Nunes et al., 2016)					
Cooperation	(Kemp & Volpi, 2008)	(Mathiyazhagan et al., 2013)	(Diana et al., 2017)		(Diana et al., 2017)	(Ho et al., 2016)

Note: P = Positive, N = Negative. Underlined texts highlight a hindrance towards the adoption of sustainable process technologies when the corresponding factor is not given.

Market pressures

Starting off with the market pressures that have an influence on the company behaviour, customer demand is found to have a positive effect on the general adoption of sustainable process technologies. Rosen (2013) considers it as the second most likely factor that could lead to an adoption, while the Delphi foresight analysis of Förster (2015) also supports this view in line with the model of Gil-Moltó and Varvarigos (2013). Furthermore, a negative influence of low customer awareness is found by Wiggett and Marcelle (2013), which supports the importance of customer demand. Consequently, considering the energy and the material efficiency, the results are mixed. While Wu, Ellram and Schuchard (2014) highlight the importance of the western customers for Chinese manufacturing companies to adopt energy efficient technologies, for Ho, Abdul-Rashid and Ghazilla (2016) customer requirements are a key barrier to achieve material efficiency.

Market competition has an unclear relation towards the general adoption. The model of Caparrós, Pereau and Tazdaït (2013) highlights the importance of the labor market rigidity and the model of Xia, Yu, Gao and Cheng (2017) attributes an importance to the firm motivation caused by market competition. In line with that, da Silva, Méxas and Quelhas (2017) see a sore economic situation as one of the main hindrances. On the other hand, Nunes et al. (2016) think that the absence of short-term market pressure can benefit a successful adoption. Furthermore, Kemp and Volpi (2008) see risks due to market competition as a barrier. This is somewhat different again for the Energy/ Material efficiency. Although Henriques and Catarino (2016) find evidence in Portuguese companies that market competition has a negative influence on the adoption of energy efficient technologies, Zhu and Chertow (2017) as well as Wu et al. (2014) recognize a necessity to adopt those in order to be able to compete in the future. As for the final aspect of market pressure, the resource price is only examined by Rosen (2013), who finds increasing energy costs a significant factor for the general adoption of technologies.

To conclude on the influences of market pressure, the review finds diverging results towards the adoption of General sustainable technologies and Energy/ Material efficiency. For the first one, the customer demand and the resource price are found to be important, the latter seems to be mostly influenced by market competition. However, no study in this matter can be found for the category of CO^2/ Emission reduction.

Legitimacy

The following category of independent variables deals with the legitimacy and includes mainly coercive pressures that manufacturing companies are facing from institutional side (Bansal & Roth, 2002).

Regulation stakeholder does not receive much attention outside the quantitative literature and the influence on emission reduction remains unclear. Only three theoretical models focussing on emission trading systems, which means the regulation of competitors, can be found. Caparrós et al. (2013) conclude that those systems indeed lower the emissions by adopting new technologies. Coria (2009) finds similar evidence when it comes to auctioned permits. Nevertheless, del Río González (2008) suggests to include the timing of the adoption. The article argues that tradeable permits benefit the adoption of short-term oriented, low-cost technologies, which is a hindrance for the adoption of even more effective and long-term oriented technologies.

Most evidence in the literature is found for cases of state or local regulation, while its influences are positive for all three kinds of technologies. For the general technologies, several case studies as well as theoretical models highlight the influence of regulation and the compliance to it as one of the most important; in a lot of cases even the most important factor (Förster, 2015; Infante & Smirnova, 2016; Kemp & Volpi, 2008; Nunes et al., 2016; Rosen, 2013; Sloan, 2011; Wiggett & Marcelle, 2013). The studies that find a negative influence only do so for weak regulations, which again supports the statement above (da Silva et al., 2017; Rueda, Garrett, & Lambin, 2017; Wiggett & Marcelle, 2013).

Bergquist, Söderholm, Kinneryd, Lindmark and Söderholm (2013) in their case study in Sweden, Kemp and Volpi (2008) in their literature review and Coria and Zhang (2015) in their theoretical model also find a positive relation of regulation means towards the adoption of technologies for emission reduction, which proves that the overall relation is also positive here. However, the results for the adoption of Energy/ Material efficient technologies are not so clear. While the different studies of Zhu and Chertow (2017), Arens, Worrell, and Eichhammer (2017), Kemp and Volpi (2008) and Wu et al. (2014) highlight the positive influence of regulation also on the adoption of these technologies, Ho, Abdul-Rashid and Raja Ghazilla (2016) see in regulations a restriction in the free choice of material efficient technologies or the material itself. Only Rueda et al. (2017) find evidence for voluntary standards which powerful

companies can introduce also into their supply chain and which have a positive influence on the general adoption.

The positive impact of incentives by governmental support on sustainable technologies in general is highlighted in the theoretical model of Sloan (2011) as one of the major conclusions of the study, while da Silva et al. (2017) see a non-continuity in policy as a barrier for adoption, which supports the positive influence. Similar results can be found for the Energy/ Material efficient technologies. Zhu and Chertow (2017) find clear evidence for a positive impact in their multiple-case study, while Henriques and Catarino (2016) as well as Ho et al. (2016) see the lack of such incentives as major barriers for the adoption. Therefore, governmental support can be seen as an important factor. Economic support and industry initiative do not play a major role in the literature, as only the findings by da Silva et al. (2017) and Ho et al. (2016) name the absence of these factors as a hindrance for the adoption of sustainable technologies.

Therefore, legitimacy, in its coercive form, plays an important role in the decision of companies to implement sustainable technologies. Especially regulation has a high importance in a great number of studies, while the other mentioned means are not as broadly studied but remain an overall positive effect on the adoption of technologies.

Information

The category information is researched from the perspective of information uncertainty on the one hand and the importance of the information sources on the other. Da Silva et al. (2017) conclude that uncertainty of knowledge on how the economy will behave has a negative influence on the general adoption. Contrarily, Hultman, Pulver, Guimarães, Deshmukh and Kane (2012) argue that different uncertainties, especially about regulations, lead to companies adopting more emission reduction technologies to ensure their future position. Trianni, Cagno, Thollander and Backlund (2013) in contrast highlight the importance of a guaranteed business continuity, because if this certainty is not given, this will place a barrier on the implementation of energy efficient technologies. Henriques and Catarino (2016) point in the same direction, as they find that information gaps are a hindrance as well.

Da Silva et al. (2017) find out that the lack of information sources and specific information place a barrier for the implementation of General sustainable technologies. For the adoption of Energy/ Material efficient technologies, Zhu and Chertow (2017) and Cagno,

Trianni, Spallina and Marchesani (2017) both make clear that the availability of exhaustive information is one of the key factors, while Henrique and Catarino (2016) support this by recognizing a barrier in the lack of information.

Summarizing, information uncertainty seems to have a negative influence on the general adoption and on energy efficient technologies, while emission reducing technologies are found to be positively influenced by it. Having strong and multiple sources of information is considered an overall positive factor.

Firm characteristics

The following category of firm characteristics is the biggest of the five dimensions and is itself split-up into multiple subcategories which will be presented. Starting off with the firm size, only the study of Förster (2015) deals with this factor and finds an important role in the automotive supplier business, as the author recognizes this as a precondition for financial capabilities to invest into sustainable technologies in general. The effects of ownership are also hardly studied. Wu et al. (2014) find that state-owned companies are more influenced in their investment decisions by regulations, while private organisations consider the costs when deciding about energy efficient technologies.

Another subcategory is the one of a company's responsibility that covers the perspectives of corporate social responsibility and internal support. The first aspect is only examined within the case study of medium-sized manufacturing firms in Brazil by Diana, Jabbour, de Sousa Jabbour and Kannan (2017), which points out that the corporate culture towards sustainability determines the adoption of energy efficient technologies.

In the same direction points the article of Li and Hamblin (2016), which also argues with an environmentally-friendly culture towards the internal support of adopting sustainable technologies. Diana et al. (2017) and Hultman et al. (2012) argue that the support of managers for adoption plays an important role for the adoption of emission reducing technologies, which is also due to reputational reasons. Finally, Diana et al. (2017) also point out the importance of management support for Energy/ Material efficient implementations, while Cagno et al. (2017) identify a barrier in the missing support due to other interests. These results show that if top management feels responsibility, it does have an influence on the adoption of all three technologies.

Human capital intensity, as the following subcategory, is investigated from the perspective of the human resource quality and whether it is complementary to innovations. Both perspectives are mainly researched by the case study of Diana et al. (2017). On the one hand, they highlight the impact that employee training, as part of human resource quality, has on the successful implementation and, therefore, on the adoption of emission reduction and energy effective technologies. On the other hand, in the light of complementary aspects, they give a high value to the empowerment of employees as this gives them the possibility to successfully deal with the adoption tasks of emission reduction and energy efficient technologies. Additionally, Ho et al. (2016) identify a barrier for energy efficient technologies when the employees do not have sufficient complementary knowledge. These aspects together give a positive relation of human capital intensity towards the adoption of emission reduction and energy efficient technologies.

The technological capability of firms is a subcategory that is determined by different elements that are combined in the technological capability construct, by the R&D or expert activity and the innovative capability. Barriers for the adoption of sustainable technologies in general and for energy saving technologies are found when the technological capability is too low (Arens et al., 2017; da Silva et al., 2017). Furthermore, Ho et al. (2016) as well as Zhu and Chertow (2017) find important influences of the technological capabilities for implementing energy/ material efficient technologies.

The R&D or expert activity only works as a hindrance towards general and energy efficient technologies when the entrepreneurs lack the necessary knowledge on how to do so (da Silva et al., 2017; Henriques & Catarino, 2016). Furthermore, the innovative capability matters in the literature as a barrier towards Energy/ Material efficiency when a company does not have it (Henriques & Catarino, 2016; Ho et al., 2016). These results show that technological capability of a firm does indeed matter. In fact, it seems to work as a barrier for the adoption of sustainable technologies if the capability is not given, while there is no clear positive relation towards the adoption of sustainable process technologies.

Financial capability of a firm is a factor often mentioned in the literature. According to Nunes et al. (2016), especially the access to capital that is necessary to invest matters. If this is not given, it places a major hindrance in the adoption process (da Silva et al., 2017). Zhu and Chertow (2017) argue that energy-saving technologies will get implemented if the financial capabilities are given besides other requirements. Finally, three articles highlight the financial capabilities as one of the most important barriers towards energy efficient technologies (Arens

et al., 2017; Cagno et al., 2017; Trianni et al.,2013). Considering the statements of the articles towards the financial capabilities, they seem to work mostly as a hindrance as well when they are not given. Regarding resources intensity, which is seen from the perspective of resource cost, only the survey-based article of Rosen (2013) reveals that energy costs matter for the adoption of sustainable process technologies in general.

The following subcategory, knowledge stock, investigates the role of technology substitutes and adoption experience. Several negative relations are found for the substitutes of general technologies. It is argued that their requirements are often too costly (Wiggett & Marcelle, 2013). Additionally, technological knowledge of those is often not met in the companies (da Silva et al., 2017) and past investments in new technologies turned out to be sunk costs and therefore a psychological barrier that delays implementation (Kemp & Volpi, 2008). Nevertheless, these sunk costs can also push managers to adopt emission technologies, for example end-of-pipe solutions like filtration systems (Kemp & Volpi, 2008). Finally, energy efficient technologies are often not applied because of a lack of awareness of the substitutes (Cagno et al., 2017). Adoption experience only seems to work as a barrier when a firm does not possess it yet (da Silva et al., 2017). Out of this research, it seems that the knowledge stock, like the technological capability, is mostly relevant as a barrier when it is not present within a firm. Nevertheless, it can result in the adoption of emission reduction technologies as a form of second choice.

The final subcategory of firm characteristics is the one of environmental management tools. This includes environmental practices as well as certified systems. Regarding the first one, Kemp and Volpi (2008) find a generally positive evidence when companies are technologically advanced and equipped with an environmental management system. A similar picture occurs for the adoption of energy saving technologies where strategic factors play an important role (Wu et al., 2014). For the certified systems, the case study of Li and Hamblin (2016) shows that companies that are certified with the ISO14001 are further in their development towards cleaner and therefore more sustainable technologies. Although there is a small number of articles dealing with the subcategory of environmental management tools, there is an indication for a positive adoption relationship.

To conclude, the firm characteristics, the influences of the different factors are to some extent diverse. Some aspects seem to work as a necessary condition rather than a factor actively leading towards an adoption. This is the case for the technological and financial capability and

the knowledge stock, as their absence places a barrier for the adoption process. Whereas other factors such as the felt responsibility, the human capital intensity or the environmental management tools work as an active factor with a positive relation towards the technology adoption. Firm size and ownership aspects are not a major concern of the current literature.

Technology characteristics

Technology characteristics build the fourth category and are described by the perceived relative advantage they can bring for a company, the financial costs of a technology and the compatibility with the existing processes. Possible cost reductions as a main objective are an advantage that seem to influence the adoption process (Nunes et al., 2016). Nevertheless, da Silva et al. (2017) mention the possibility of a production disruption which can turn down the originally perceived advantages and therefore have a negative influence. Looking specifically at emission reduction technologies, Hultman et al. (2012) consider financial benefits as primary motivation. In the same direction points the broader argumentation for energy/ material efficient technologies (Arens et al., 2017; Cagno et all., 2017; Wu et al., 2014), while Förster (2015) also highlights the effects of cost reduction for these technologies.

This result is quite contrasted by the financial costs of technologies which turn out to be negatively related. Four different articles mention especially the high initial investments as a major hindrance for the general adoption of sustainable process technologies (da Silva et al., 2017; Förster, 2015; Kemp & Volpi, 2008; Wiggett & Marcelle, 2013). The same accounts for energy/ material saving technologies where the authors highlight the connected risk that these initial investments bear (Henriques & Catarino, 2016; Ho et al., 2016). Furthermore, Wiggett and Marcelle (2013) find that certain product requirements form a hindrance because a compatibility is not given. Ho et al. (2016) identify similar issues for the material saving technologies as these are facing problems in the material choice with new technologies. Concluding these results, technology characteristics have an overall positive effect when it comes down to relative advantages, while a missing compatibility and especially the financial costs work as a hindrance.

Network characteristics

The final category is the one of network characteristics, which describes the business network of a firm and is divided into membership and cooperation. As member of a corporate group, a company can benefit from the sharing of knowledge within the group, which is positively related to the adaption of sustainable technologies via competitiveness and cost reduction (Nunes et al., 2016). More studies are conducted on the topic of cooperation. Kemp and Volpi (2008) state that the knowledge exchange in a network leads to a diffusion of general technologies while Mathiyazhagan, Govindan, Noorul, Haq and Geng (2013) describe the problems of cooperation with suppliers that can be a barrier for the implementation of technologies. Diana et al. (2017) point out one result of their case study, which indicates that the environmental communication is a factor that influences adoption for emission reduction as well as energy-saving technologies. In the same direction as Mathiyazhagan et al. (2013) goes the argumentation of Ho et al. (2016), who highlight the problem of the cooperation with certain local suppliers that forms a barrier. In conclusion, membership and cooperation overall have a positive influence, but the network partner must be capable of delivering the needed input.

3.2 Comparison of the literature findings and hypotheses development

In the following step, the findings of Fu et al. (2018) will be compared to the findings of the qualitative literature review to point out the main similarities but especially the differences within the outcomes. This will be done while keeping in mind the distinctions already mentioned. For one, this is the cancellation of two dependent variables Material/ Fuel substitution and Recycling within the second review. These two will come back in the conceptual model and the analysis but they do not play a central role in this comparison and the hypotheses development because these are broadly formulated for all technologies. Furthermore, those independent variables for which there is no evidence in the qualitative review are also not considered here but should be kept in mind. Nevertheless, as these variables do not play a major role in the review of Fu et al. (2018) either, their importance seems to be too slightly for further detailed research. Lastly, the exclusion of researched but non-relevant relationships for the qualitative review should be considered.

The comparison will be done for each of the six main categories while especially variables that yield striking similarities or differences within the literature streams are

highlighted. Thereby, six hypotheses are developed. Two of them will be based on variables with important and similar results in both reviews, namely *regulation* and *financial costs*. Another two variables that lead to hypotheses are *information uncertainty* and *financial capability*, which achieve substantial results in the qualitative research which cannot be found within the review of Fu et al. (2018). Finally, two cases where this counts for the other way round, so variables that matter apparently more within the quantitative literature, namely *firm size* and *technological capability*, will be highlighted and hypothesized as well.

Market pressures

For the first category, the study of Fu et al. (2018) does not find a clear result whether the market pressures really matter or if they do not play a role in the adoption process while there is especially for the CO^2/ Emission reduction just one evidence. The review of qualitative studies does not find any article in this category dealing with those technologies. Furthermore, also the overall results of the qualitative literature remain uncertain. It seems that there is a positive effect of customer demand and the resource price, which is studied in just one article, but the market competition has not a clear positive relation. This means that the direction of the relation is not clear within the literature of the market pressures in total.

Legitimacy

Carrying on with the second category, only the coercive means can be compared that are found to have respectively a slightly positive or an unclear relationship within the quantitative articles, as the articles that incidentally also deal with mimetic and normative forces in the qualitative literature are attributed to other factors. The review of Fu et al. (2018) concludes that there is an overall positive effect with some variance across the technologies and variables. This is in line with the qualitative findings which see the coercive means as an important factor for the adoption of sustainable technologies.

The most studied influence variable across the literature is the coercive legitimacy measure of *regulation*. The review of Fu et al. (2018) names it an important determinant especially for the adoption of emission reducing and Energy/ Material efficient technologies but it also sets some limitations due to the kind of regulation and technology. The qualitative research points in the same direction. Several articles conclude a strong influence of different

regulations towards the adoption of all mentioned sustainable technologies (e.g. see Bergguist et al., 2013; Coria & Zhang, 2015; Kemp & Volpi, 2008; Rosen, 2013; Wiggett & Marcelle, 2013).

On the other hand, a number of articles also highlight the negative effects that a non-functioning or absent *regulation* has (da Silva et al., 2017; Hultman et al., 2012; Rueda et al., 2017; Wiggett & Marcelle, 2013). Only the article of Ho et al. (2016) identifies a negative influence of *regulation* as it limits the possible technology choices for the manufacturing process. Similar to the later following variable of financial costs, this study will investigate if the similar findings of the quantitative and qualitative literature can hold. Because of the great attention and the similarities found in the literature streams, the influence of *regulation* is a relation that is worth being a first cornerstone of this thesis. Therefore it is hypothesized as follows:

Hypothesis A1: *Regulation has an effect on whether a firm adopts sustainable process technologies of any kind.*

Information

Besides the positive effect of information sources that is found in both literature streams, another rather complex possible factor is the one of *information uncertainty*. While the review of Fu et al. (2018) identifies no significant influence for the uncertainty about technologies and competitor and customer behaviour, the variable additionally must be considered for example from the perspective of regulation and costs. The qualitative research finds an overall negative influence of *information uncertainty*, especially when the economics that come with the adoption are not known (Trianni et al., 2013; Henrique & Catarino, 2016; da Silva et al., 2017). Also, the uncertainty about future energy supply (da Silva et al., 2017), the risk of production disruption (Henrique & Catarino, 2016; Trianni et al., 2013) and the uncertainty of possible future *regulations* (Hultman et al., 2012) have a negative influence towards the adoption of sustainable process technologies.

Nevertheless, the uncertainty about future *regulations* can also have a positive effect under special circumstances as the example of Zhu & Chertow (2017) shows. The article claims that Chinese companies under strict *regulation*, implement technologies that are even more sustainable than the current rules demand because they want to prevent being closed instantly if the *regulation* becomes suddenly even stricter. These examples show the variety of effects

within this variable which is therefore a really interesting research object in the scope of this thesis to test the differing findings of the qualitative studies.

Hypothesis B1: *Information uncertainty has an effect on whether a firm adopts sustainable process technologies of any kind.*

Firm characteristics

To evaluate the effects of firm characteristics, it is necessary to compare the subcategories as the full dimension is too broad, and the results are, therefore, too diverse to derive a sound overall conclusion. Three of those subcategories yield very remarkable different results between the qualitative and the quantitative literature and are therefore hypothesized for the further course of analysis. First, the size of a company receives a rather broad attention in the quantitative literature, while only Förster (2015) deals with this as a main factor across the qualitative articles. A reason for that could be that the sample of most qualitative analyses consists of just a small number of cases which makes it harder to compare the *firm size*. The relation found in the qualitative research is unclear as there are positive, negative as well as insignificant influences of *firm size* on the adoption of sustainable technologies (Fu et al., 2018).

Withal, the review of Fu et al. (2018) concludes that small companies are often the faster adopters which explains the negative relations for a rising *firm size*, while bigger firms are most times equipped with more capital and knowledge or have likewise an easier access to them which explains the positive ones. The latter mechanism is in line with the mentioned qualitative finding of Förster (2015). As the ratio between articles in the qualitative and quantitative literature is so large and because of the various relations that can be found towards the adoption of technologies, it will be interesting to see which role the *firm size* plays in the analysis of this thesis.

Hypothesis C1: *Firm size has an effect on whether a firm adopts sustainable process technologies of any kind.*

Both studies identify limited evidence for ownership effects. While Fu et al. (2018) see a positive effect for state and foreign owned companies, the qualitative review finds this for state owned too, regarding existing *regulations*, while the result of private companies depending on the costs are similar. Further, there are currently no articles dealing explicitly with export activities, while the quantitative results to this factor are inconsistent. Regarding the

responsibility of companies, both studies see the internal support as an important positive variable while CSR seems not to matter much.

The second promising finding across the firm characteristics that shows different results in the literature streams regards the *technological capability* of a firm. According to the quantitative review of Fu et al. (2018), the *technological capability*, especially measured as a construct, has a clear positive effect. This holds for the adoption of sustainable process technologies in general and energy efficient technologies, while only the R&D or expert activities are not significantly positive related to emission reduction technologies. The other two technologies are not researched within the qualitative review, which means that these results can be neglected within this comparison.

Considering the qualitative literature, most of the relevant articles see the *technological capability* more as a necessary condition for the adoption process while they do not conclude an active effect towards it. It is argued that absent *technological capabilities* place a barrier towards the adoption because companies are not able to implement them (Arens et al., 2017; da Silva et al., 2017; Ho et al., 2016; Henriques & Catarino, 2016). Most of these texts claim that especially the necessary efforts to overcome this lack of *technological capability* would vanish the possible advantages of the adoption. Just two researchers see a positive relation like the review of Fu et al. (2018) (Ho et al., 2016; Zhu & Chertow, 2017). The question is therefore whether the *technological capability* is more than a necessary condition but in fact a reason for the adoption of sustainable technologies of different kinds. Accordingly, these findings of the quantitative studies should be researched in the course of the thesis.

Hypothesis C2: *Technological capability has an effect on whether a firm adopts sustainable process technologies of any kind.*

Furthermore, also the *financial capability* of a firm shows a disagreement between qualitative and quantitative findings that is important for further investigation. The conclusion of multiple qualitative articles has the *financial capability* of having sufficient access to capital at its core. This specific aspect receives no attention within the quantitative literature, which focusses in the scope of this variable on profitability, per capital income, and market share and therefore finds this factor to be inconclusive (Fu et al., 2018). In fact, the absence of access to capital places a major hindrance on a company's aspirations of introducing sustainable process technologies as it makes this hardly financeable (Arens et al., 2017; Cagno et al., 2017; da Silva et al., 2017; Trianni et al., 2013).

The other way round, Zhu & Chertow (2017) and especially Nunes et al. (2016) in their case study of a car manufacturer show that if a company has access to capital that makes it able to invest at a lower risk, it will more likely substitute older infrastructure by sustainable technologies. This described mechanism is related to the one of the mentioned financial costs with the difference that it deals with the side of how to finance those costs. Therefore, the qualitative literature indeed certifies a major role for the *financial capability*, specifically recognizing the access to capital.

Hypothesis B2: *Financial capability has an effect on whether a firm adopts sustainable process technologies of any kind.*

The resource intensity for which the qualitative review only finds one positive evidence due to resource costs is insignificant within the quantitative studies. Similar are the results regarding the knowledge stock which the qualitative studies also argue to be more of a necessary condition while the review of Fu et al. (2018) finds overall no significance. For the final factor of this category, environmental management tools, there are again some smaller differences in the outcomes as the quantitative studies do not see a significant influence, while the latter review concludes a positive relation besides having a low number of relevant articles.

Technology characteristics

The results for the first two variables of this category are similar: while a perceived relative advantage is overall positively related in both studies across all relevant technologies, especially the similar results for the *financial costs* of a technology are interesting. Both reviews agree upon the negative effect of those on the adoption of sustainable process technologies, the only clear overall negative effect found in the literature. A difference nevertheless can be found as only one article in the quantitative literature, namely Sangle (2011) considers this problem and identifies the initial costs as well as different running costs to matter. Contrarily, there are six articles within the qualitative review. Especially high initial investments that come with the substitution of old technologies by new ones are identified as a major hindrance because the risk that comes with it is often unpredictable (da Silva et al., 2017; Förster, 2015; Ho et al., 2016; Kemp & Volpi, 2008). Besides that, again in line with Sangle (2011), also higher costs for the production process are considered to have a negative relation towards the adoption (Henriques & Catarino, 2016; Wiggett & Marcelle, 2013). Therefore, it is interesting to know how the role of *financial costs* will be evaluated by the mixed-method analysis.

Hypothesis A2: *Financial costs have an effect on whether a firm adopts sustainable process technologies of any kind.*

A small difference occurs towards the compatibility to the existing equipment but the difference can be explained by the distinctive research settings that are looked at within the very few articles in this matter. While the qualitative research sees a hindrance when the requirements towards compatibility are too high, the quantitative results give a positive indication when the compatibility is given, which means that these findings are not contradicting.

Network characteristics

Finally, the reviews agree on the last category of network characteristics. Both see an overall positive relation for the adoption of sustainable process technologies while this is often dependent on the type of network or partner and its capabilities a firm is facing.

Summary

Most of the indicated relations between the different factors and the adoption of sustainable process technologies are assessed similarly within the qualitative and quantitative literature. Two important examples for that are the mentioned effects of *regulation* and *financial costs*. Nevertheless, this comparison shows that differences on a variable or factor level can be found and are therefore additionally also a legitimate basis of the further analysis. Consequently, the six hypotheses considering the similarities and differences between the quantitative and the qualitative literature, as shown in table 3.2, will be the core of the conceptual model presented in the next chapter. In its further course, this thesis will evaluate if the statements that the prior research streams present, regardless whether qualitative or quantitative, will hold under the specific research setting in the manufacturing industries of North Rhine-Westphalia and Rhineland-Palatinate.

Table 3.2

Representation of the hypotheses according to the independent categories

Categories	Hypotheses
Market pressures	
Legitimacy	**Hypothesis A1:** *Regulation* has an effect on whether a firm adopts sustainable process technologies of any kind.
Information	**Hypothesis B1:** *Information uncertainty* has an effect on whether a firm adopts sustainable process technologies of any kind.
Firm characteristics	**Hypothesis C1:** *Firm size* has an effect on whether a firm adopts sustainable process technologies of any kind. **Hypothesis C2:** *Technological capability* has an effect on whether a firm adopts sustainable process technologies of any kind. **Hypothesis B2:** *Financial capability* has an effect on whether a firm adopts sustainable process technologies of any kind.
Technology characteristics	**Hypothesis A2:** *Financial costs* have an effect on whether a firm adopts sustainable process technologies of any kind.
Network characteristics	

3.3 Conceptual Model of similarities and differences

Having compared the current literature on the topic of sustainable process technology adoption and developed six hypotheses, this section will present the resulting conceptual model as a basis for the data collection and analysis. As this research deals with the influence of a number of different variables and resulting factors on five different categories of sustainable process

technologies, the conceptual model represents these relationships. This model will afterwards be the basis for the data extraction in the quantitative as well as qualitative analysis.

The model presents the impact of the factors that are found to be similar in both streams of literature, namely the *regulation* and the *financial costs*. Furthermore, it shows on the one hand the variables of *information uncertainty* and *financial capability* that are substantially more important within the qualitative literature. On the other hand, it finally deals with the *firm size* and *technological capability* as those achieve more attention in the quantitative research. Building on the hypotheses stated before, these variables are assumed to be potentially influencing factors on the adoption of sustainable process technologies in general, CO^2/ Emission reduction, Energy/ Material efficiency, Material/ Fuel substitution and Recycling. The model can be seen in figure 3.2.

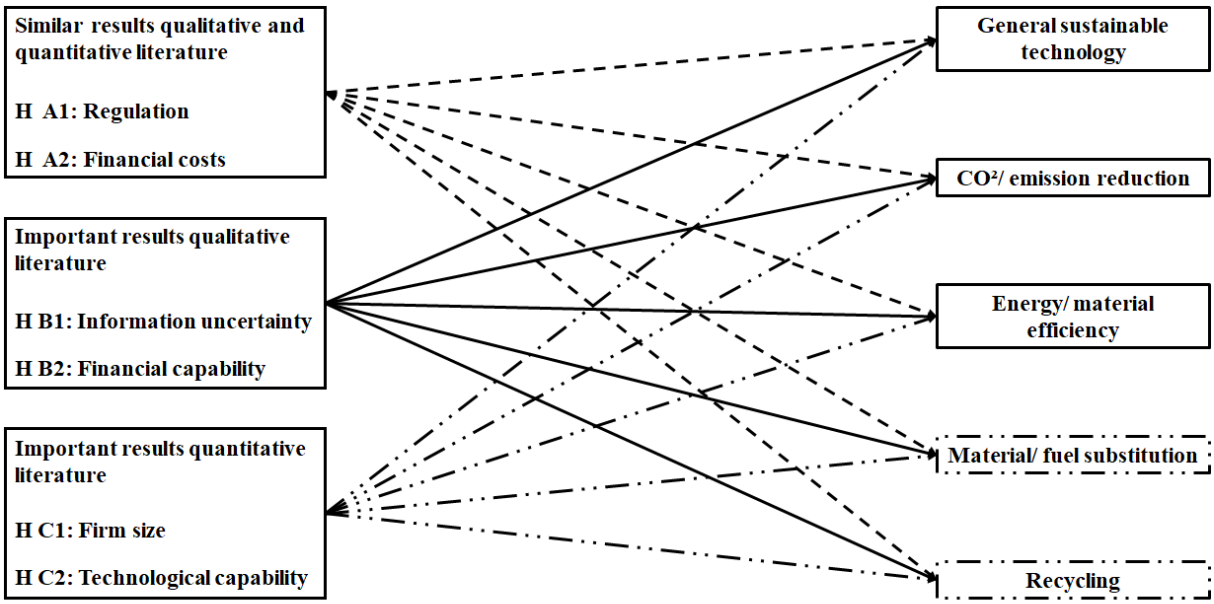

Figure 3.2. Representation of the conceptual model of this thesis. Solid border lines on the dependent side represent the categories of technologies investigated in qualitative studies. Dashed border lines show the technologies additionally researched in the quantitative stream.

This conceptual model will be the basis for the mixed-method analysis that completes the triangulation and is described in the following methodology section. The goal is to identify which of these relations can achieve a significance within the given research setting of the thesis. Furthermore, it will be interesting to see whether the quantitative and quantitative analysis show similar differences within this study as they do in the current literature.

4 Methodology for a mixed-methods approach

In this methodology part, the basis for the then following mixed-method analysis will be provided. In that matter, first the overall research setting, the applied sample and the data sources are uncovered. This is done separately for the quantitative and the qualitative analysis. Afterwards the variable construction that is based on the comparison of the two literature reviews, as presented before, will be shown. This is followed by the description of the two data analysis procedures. Finally, the ethics that are applied in this thesis will complement the methodology section.

4.1 Research Setting, Sample and Data Sources

The purpose of this study is to figure out which factors influence the adoption of sustainable process technologies in firms of the manufacturing industries in the German context. In doing so, the main focus lies on those six factors described in the conceptual model in figure 3.2. Whether companies belong into the manufacturing industries depends on whether their NACE code, a classification of industries, lies between 10 and 32 (NACE – Klassifikation der Wirtschaftszweige 2008, 2008). The two literature reviews show several different variables and cluster factors that are found to be relevant within the current literature. To check whether these findings can be confirmed, the thesis will proceed with a mixed-method analysis including a quantitative and a qualitative research that complete the triangulation of data and will be summarized thereafter as shown in the beginning in figure 1.1.

Quantitative research

As the first step of the mixed-method approach, this thesis contains a quantitative analysis. This is chosen to examine the hypotheses in the conceptual model by using quantitative means (Babbie, 2012; Field, 2013; Hair, Black, Babin & Anderson, 2014). The sample of the study consists of 33 companies of the manufacturing industries out of the German states North Rhine-Westphalia and Rhineland-Palatinate with more than 10 employees, which is a considerable number but too small to apply more advanced quantitative analyses such as factor analysis or multiple regression analysis (Hair et al., 2014).

The unit of analysis will be respondents on behalf of the companies they are working for (Babbie, 2012). Therefore, these people must be in a position that allows them to have an overview over the processes within the production of the corresponding firm. The aim is to come as close as possible towards a representative sample of companies, while a fully representative picture of the German context will not be possible due to the limited extent of this thesis and participating companies and the limitation to the two German states (Babbie, 2012). The data are collected using an online-survey with primarily closed questions. This is a translated and extended version of the questionnaire used by Fu et al. (2018). These extensions cover the factors of *financial costs*, *information uncertainty*, *financial capability* and *technological capability*, which are not central in the model of Fu et al. (2018) but, however, do add to the understanding of the relations within the conceptual model. The scales are mostly based on primarily used ones in current literature and can be found in appendix D. The questions mainly use a Likert semantic differential with a scale from 1-7 for the independent variables (Babbie, 2012; Field, 2013) and a scale with four steps for the dependent variables.

In a first preparation phase, the data will be cleaned by the cancellation of response sets and missing values. After that, the variables that belong to the independent factors are analysed univariately to check whether they are normally distributed and show a small number of missing values so that they can be used for further analysis. Variables that show different scales are recalculated so that all of them reach from one to seven. Once this step is done, a reliability analysis will be applied to check whether the variables that are measured for the representation of a certain factor also form this factor together and do not work in another direction. If the reliability, indicated by the value of Cronbach's alpha, can be increased significantly by the removal of one variable, then this is conducted as long as the loss of content is justified, which means that the pre-steps of the variable construction are then taken. (Field, 2013; Hair et al. 2014).

Similarly, the variables that measure the adoption of 12 different sustainable process technologies, which are part of the four different categories, are assessed individually. As they are of ordinal measurement level, this can give just a first impression of the deviation on whether these technologies are applicable for the companies and if so, whether they are adopted or not.

Qualitative research

Having analyzed the quantitative data, it is important to understand the mechanisms of the underlying relations that lead to the adoption and implementation of different sustainable technologies in a more holistic approach by using an explorative qualitative analysis from a realistic perspective (Babbie, 2012; Eisenhardt, 1989; Justesen & Mik-Meyer, 2012). In order to do so, the sample consists of five companies out of the manufacturing industries in Rhineland-Palatinate that will reveal their approaches. In an inductive but steered way, managers of these companies will be interviewed. Therefore, semi-structured interviews will be conducted that cover all factors and technology categories of the conceptual model. This will leave space for the interviewees to explain the corresponding mechanisms in an unbiased way (Gorden, 1998; Justesen & Mik-Meyer, 2012).

Thereby, the interviews will mainly target those factors that are at the core of the conceptual model to see the behaviour of the five researched companies towards those, while some additional information about the companies that might be important are gathered as well. To make the interviews comparable for later on in the process, a guideline of questions is followed that can be seen in appendix F. As a next step, after the interviews are done, they will be fully transcribed (Justesen & Mik-Meyer, 2012) and then prepared by using a type of inductive coding, similar to the one used for the review of the qualitative literature, this allows to find patterns in the data. These coded quotes of the interviewees will be referred to within the qualitative analysis accordingly to the course of the structure and serve as the basis of the analysis (Babbie, 2012; Corbin & Strauss, 2008; Yin, 2014).

4.2 Variable construction

The relevant variables for the analysis result out of the hypotheses and out of the conceptual model presented in figure 3.2.

Independent variables

The independent variables of this analysis are the factors, as presented in the conceptual model, that influence companies in their adoption decision regarding sustainable process technologies. These factors are based on the findings in the literature stated in chapter 2 and 3. For the

similarities of both research methods that could be found, those are the *regulation* a firm is facing at its location and the *financial costs* of new sustainable technologies. Additionally, resulting out of the qualitative research, the variables of *information uncertainty* and *financial capability* will be investigated. Finally, the *firm size* and *technological capability* will be the last two independent variables stemming mainly from the quantitative literature.

For the quantitative analysis, the factors are build up by calculating the overall mean of the corresponding variables. The resulting factors can be considered of interval measurement level and are eligible for a correlation matrix.

Dependent variables

The four different categories of sustainable process technologies plus the general category form the dependent variables of the analysis. Therefore, the relating dependent variables are: the sustainable technologies in general, the CO^2/ Emission reduction technologies, the Energy/ Material efficient technologies, technologies for Material/ Fuel substitution and Recycling technologies.

Also the variables representing these categories are factors build up out of a number of different sustainable process technology variables. Therefore, the percentage of adopted technologies that are applicable for the companies is calculated out of the variables for all categories in a first place. Thereafter, all technologies are taken together to form the general category.

4.3 Data analysis procedure of correlation and qualitative analysis

The quantitative analysis is done by means of correlation analysis. As mentioned above, this more basic bivariate approach is chosen because of the rather low number of participating companies, which makes a more extensive analysis like multiple regression impossible (Hair et al. 2014). Nevertheless, the results of the correlation will indicate whether or not a significant relation between the influence factors and the dependent categories of sustainable process technologies can be found. Because of the ordinal measurement level of the dependent variables, a Spearman correlation will be applied.

In order to reveal the relations between the independent and the dependent variables qualitatively, the gained codes of the qualitative research will be interpreted, compared and then reported. This is done firstly for every factor and for every dependent sustainable process technology individually to get a basis of understanding that shows how the interviewees experience these. Afterwards, those codes highlighting the relationship are analysed to reach a deeper understanding of the underlying mechanisms (Corbin & Strauss, 2008; Yin, 2014).

The last step of the analysis consists of the triangulation chapter. This is done to reach a holistic view by a data and methods triangulation, including the literature comparison, the quantitative and the qualitative analysis, to achieve a high degree of sense making of the relations (Babbie, 2012; Yin, 2014). Thereby, the perspective is taken further away from the level of detail and more based on the relation patterns that could be found in these previous three steps. In that way it is then possible to confirm or reject the six hypotheses stated before and thereby give final answers on the influences the factors have according to the collected data.

4.4 Research ethics

In line with the research ethics defined by the American Psychological Association (2017), some points are especially relevant here due to the outline and research setting of this thesis. The thesis will aim to provide a maximal open process with regard to the selection of articles relevant for the systematic literature review. The selection of participating companies will be dependent on whether their NACE code belongs to the manufacturing industry. Furthermore, the process will assure that only volunteers participate within the data generation process. Especially important in this matter is also the confidentiality and anonymity of the participants, which will be applied generally for all cases. In order to assure an objective data collection, the data gathering will make use of a previously used questionnaire as a basis and further of scales similarly used in current literature before (Fu et al., 2018; Hair et al., 2014). The interpretation and reporting of the data will happen in a preferably unbiased and objective way to avoid misunderstandings (Babbie, 2012). Additionally, implications for theory and managerial recommendations will be given in the last chapter of this thesis. After the thesis is conducted, the results will be send to all participants of the survey and especially of the interviews that indicated the wish to receive them.

5 Quantitative analysis of the survey results

Having worked out the similarities and differences within the two literature streams and presented the methodology of the mixed-method approach, the next analysis step is to reveal whether the quantitative data, that are gathered by the mentioned survey, support the hypotheses stated in 3.2. Unfortunately, it turned out to be extremely difficult to find respondents for the survey. In conversations with potential participants especially the survey scope of around 170 questions and the necessary time of at least 20 minutes was the main reason for the companies not to participate. Furthermore, the questions are rather specific, which means that only a few people within the companies can answer them properly, which again limited the chances of finding a respondent within the potential companies. Another specific reason is the new general data protection regulation, which was implemented almost exactly together with the start of the online survey. Although there is no violation of this law by the survey, many people were anxious about this, resulting in non-participation.

While 147 potential participants opened the survey, the final set consists of 33 respondents as the others did not fill out most of the survey and therefore had to be excluded. One of the 33 cases did not answer the general information but is still considered valid for the concepts tested in here besides the *firm size*. Nevertheless, the number of 33 participants does not allow for more advanced empirical research such as multiple regression models or partial least square analyses (Hair et al., 2014). Therefore, the quantitative results will have to be based on the descriptive univariate results and bivariate correlations to test the relational hypotheses stated earlier in table 3.2.

The first step is to analyze the key general information to get an overview of the represented companies in this data set and their corresponding industries, as well as the respondents and their positions. Afterwards, the analysis will be done according to the conceptual model of the thesis represented in figure 3.2, starting off with the measurement models of the two factors that are evaluated similar in both literature streams. Consequently continuing with the relevant results of the qualitative literature and ending with those factors that show striking results within the quantitative literature. Then, the measurement models of the dependent variables, the sustainable process technologies, will be presented. Finally, the structural model of this analysis is laid down and the associated correlation results are analysed.

5.1 Descriptive analysis of the sample characteristics

Within the questionnaire, several key facts are asked for that give an image of the background of the companies that participated. Considering the industries in which they are operating, a rather even distribution can be seen. The biggest of the given categories is the food and beverage industry, in which seven of the companies can be located while five are a part of the iron and steel or in the chemical and pharmaceutical industry. The smallest group is the pulp, paper and print industry with just one company.

Also the *firm size* indicator NoEmployees has a rather even distribution, as every given category consists of between three and seven cases, except for the highest as only two companies with more than 1000 employees have participated. The lowest category of 0-19 employees has, with 6 valid answers, a proportion of 18.8% of the overall answers.

Of the valid respondents, 31% indicate a revenue of more than € 50 million for their company, while 17.2% achieve less than € 2 million. 87.5% of the companies export their products into foreign countries and 87.1% of them have the legal form of a private company. Considering the research area, 51.6% of the companies are located in North Rhine-Westphalia and 48.4% in Rhineland-Palatinate. The Eifelkreis Bitburg-Prüm has, with ten cases, the highest representation and the city of Köln with six cases the second highest, while all other districts that host a company in the sample achieve one to two cases.

Regarding the respondents that participated in the survey, around a third has the position of CEO or is the owner of the company. The remaining participants work in a variety of different departments. Furthermore, the respondents on average work for 20.34 years in the corresponding industry, meaning that the overall experience can be seen as relatively high.

5.2 Independent variable assessment and factor development

The six factors that are based on the comparison of the two literature reviews, each represents a variety of procedures within and facts about a company that work in a similar way. Therefore, these factors are measured by multiple variables to guarantee that they contain a high validity, stemming from multiple angles that define the construct underlying them. Next to the construct validity, it is also important for the quantitative analysis, in order to be meaningful, that the

factors are reliable. This means that the variables which define the factor should have strong communalities and measure the concept accurately also for very different cases.

To form factors that show a high validity and reliability, it is important to first assess the measured variables univariately, while especially considering their distribution and potential missing values. This is done in a first step by using the frequencies option in SPSS. Once the variables are prepared and assessed to be reasonable for the further steps, the composition of the factors is conducted. As the total number of respondents is too low, a factor analysis is not applicable and therefore the factors are finally formed by means of a reliability analysis. This procedure of forming the measurement models is done for each one of the six factors according to the conceptual model, ending with the factors that will be used for the final correlations which can be seen in table 5.1.

Regulation

The first factor of the conceptual model is the one of *regulation*: the coercive pressures that oblige a company to adopt a sustainable process technology, for example to reach emission or efficiency goals. As these pressures are also measured by Fu et al. (2018), the same variables of the questionnaire are used here to form a rather broad factor consisting of 15 variables that can be seen in the measurement model of appendix E. Considering the variables individually, a normal distribution can be assumed and no adaptations have to be done for the further analysis, due to the central tendency or missing values (Field, 2013). One exception is the variable EnvironEmployees, which is not measured on a Likert scale from one to seven and has an arguably more ordinal measurement level, ranging from one to five. In order to form a scale of one to seven for this variable, as well for the later analysis, the values are adapted to steps of 1.5 instead of one.

As a factor analysis is not possible due to the low number of cases, which is under the minimum of 50 responses, only a reliability analysis can be done to see whether the 15 variables form a reliable factor (Hair et al., 2014). This is measured by Cronbach's Alpha, which has to reach a value of at least 0.70, while a level of 0.80 is desirable. In an iterative process, the reliability analysis should exclude variables that lead to a lower reliability of the factor. If the improvement of such an exclusion is less than 0.05 in the value of Cronbach's Alpha, the variable should be kept, as otherwise too much content and therefore validity gets lost for the purpose of a small improvement (Field, 2013).

For the case of *regulation*, the reliability analysis achieves a Cronbach's Alpha of 0.835, which indicates a high reliability. This could be improved to 0.847 but it is not worthwhile to exclude a variable for such a rather small improvement. This means that these variables will form a factor for the further analysis. In order to calculate the scale score for this factor, the mean of all variables are taken together.

Financial costs

Also the second factor that turned out similarly negative in the two literature streams has less than 10% missing values in all of its 5 variables and an acceptable central tendency.. The initial result of the reliability analysis shows an acceptable Cronbach's Alpha of 0.731, while the exclusion of item ROI which measures the return of investment, raises this value to 0.797. This is substantially higher, and also conceptually reasonable, as it does not represent a single matter of expense like the others do. Therefore, the decision is to exclude this variable. The remaining four variables form a factor that has a considerably high reliability.

Information uncertainty

Looking at the variables developed for the factor *information uncertainty*, it becomes obvious that those are mostly measures to achieve a certainty of information so that a high value in these indicates certainty and a low one uncertainty. The direction of the item TechChange nevertheless is rather unclear as it arguably creates more uncertainty on the one hand, but could also lead towards a tighter controlling system so that it will remain unchanged within this analysis.

The reliability analysis gives a really high Cronbach's Alpha of 0.885, while the mentioned variable in doubt does indeed have a positive correlation with all others. Even though Cronbach's Alpha could be slightly improved to 0.889 by excluding one variable, the decision is to let it remain in as the information loss would be bigger than the gained reliability.

Financial capability

As the second interesting result of the qualitative literature; *financial capability* turned out as a rather complex concept to evaluate. This is due to the behaviour of many companies in Germany

that are really protective when it comes to monetary information (Papon, 2015). This concept is measured within the survey by several management performance measures and two more opinion-based variables. Four of these items received more missing values than valid answers due to people not willing to answer the questions so that the assessment would remain extremely problematic. Furthermore, the reliability analysis shows a too small Cronbach's Alpha, even after the exclusion of variables.

This leads to the decision to work with the single variable CapitalAccess, which represents a dimension that does not achieve much attention within the quantitative literature studies, but is, however, a major variable in the qualitative literature. The representativeness for the whole concept of *financial capability* is nevertheless at least questionable and has to be seen really critically due to a low construct validity.

Firm size

For the factor *firm size*, the two variables will be kept as separate measures for the factor, as the categories for number of employees and revenue cannot reasonably be compared. Considering the variables univariately, it is noticeably that for the variable Revenues the missing values are with a total number of four above 10%. Because the variable is kept as such for the further analysis, a missing value analysis is not necessary but this characteristic of the variable should be kept in mind.

Technological capability

Looking at the measures of *technological capability* that are used in the questionnaire, the variable TechProblems works, in its theoretical meaning, the other way round than the others. Therefore this variable has to be reversed in a first step so that an increase in all variables mean a higher *technological capability*. Furthermore, the variable Warranty has only valid answers in the first three of the seven categories which indicates that the answer categories are probably chosen too wide. This makes an interpretation of the data really difficult, leading to the exclusion of this variable from the factor.

In the initial solution, the reliability analysis achieves a Cronbach's Alpha of 0.732, while with the exclusion of the variable Warranty, the value is improved to 0.778. This would be a sufficient reliability but it can still be improved substantially, to 0.845, by excluding the

mentioned reversed variable. Therefore, the decision is to do so, as the theoretical concept of the variable also works slightly different by not asking for explicit actions that prove the *technological capability*. Nevertheless, because the major difference in the literature streams is based on the question whether this *technological capability* works as a hindrance towards the adoption of sustainable process technologies, this single variable will also be assessed individually in the further analysis.

Having analysed the six factors individually, this will be done in the following part for the dependent variables representing the sustainable process technologies as well. Together the prepared factors will then be used to conduct the correlation analysis.

Table 5.1

Factor reliability analysis

Factors	**Origin of the variables**	**Cronbach's Alpha**	**no. of items**
Regulation	Qualitative and quantitative studies	.835	15
Financial costs	Qualitative and quantitative studies	.797	4
Information uncertainty	Qualitative studies	.885	9
Financial capability	Qualitative studies	.	1
Firm size	Quantitative studies	.	.
- Revenue			1
- NoEmployees			1
Technological capability	Quantitative studies	.845	7
(-TechProblems)		.	1

5.3 Dependent sustainable process technologies and scale score development

The dependent side of the hypothesized relations consists of the adoption of the four different sustainable process technology categories: CO^2/ Emission reduction, Energy/ Material efficiency, Material/ Fuel substitution and Recycling and the General sustainable process technologies. These concepts are measured by 12 different variables that each represent another generic technology. As table 5.2 shows, each of the four sustainable process technology categories that are at the core of this thesis consist of at least two of these 12 variables. The variables consist of five different answer categories: 1 'Not applicable to our firm', '2 No, no plan', 3 'No, we are preparing for decision making', 4 'Yes, we are in the process of implementation', 5 'Yes, we are utilizing it'. While the first category indicates that the technology is not applicable, the second and third can be summarized as non-adoptions and the last two as adoptions of the respective technology.

Table 5.2

Adoption of the generic sustainable process technologies

Sustainable process technologies	Adoptions	Non-Adoptions	Not Applicable
CO^2/ Emission reduction			
CO2Reduction	21	6	6
WaterGroundPollut	26	3	4
EmissionReduction	21	5	6
Energy/ Material efficiency			
MaterialEfficiency	26	4	3
EnergyEfficiency	21	7	5
Material/ Fuel substitution			
FuelSubstitution	26	2	5
GreenElectricity	11	15	7
MaterialSubstitution	20	8	4
RecyclSubstitution	22	4	7
Recycling			
WasteRecycInhouse	23	3	7
WasteRecyclExternal	18	4	11
WaterRecycling	19	6	8

Looking at the single technologies and their adoptions, all of them are applicable for the majority of the participating companies. Furthermore, besides the variable GreenElectricity, every of the technologies achieves more adoptions than non-adoptions which is an important fact for the further analysis. While checking the frequencies of the dependent sustainable process technology variables univariately, no problems with missing values can be noticed and a check for normal distribution would not be logical as they are all of ordinal measurement level. Therefore the scale score for the final dependent variables can be calculated out of these.

The scale scores for the five resulting variables, in accordance to the described answer categories, are calculated as a proportion of the applicable technologies that are adopted for every respondent firm. For the sustainable process technologies in general this is done by first calculating the number of adoptions of all technologies by the respondents companies within a new variable. After that, one variable is created that counts all applicable technologies and another variable that does the same for the non-applicable technologies. Finally, the scale score is represented in a third variable, which divides the adoptions by the applicable technologies and multiplies it by 100 to gain percentages.

The same procedure for calculating the scale scores is applied for the four types of sustainable process technologies by using just the corresponding variables. The five new variables all show an acceptable number of missing values, while they are treated still as of ordinal measurement level for the further analysis because the variety of potential percentage categories is very limited.

Table 5.3

Adoption probabilities of the sustainable process technology categories

Sustainable process technology categories	**Mean % of adoptions**
CO^2/ Emission reduction	81,72
Energy/ Material efficiency	81,67
Material/ Fuel substitution	74,24
Recycling	81,67
General sustainable process technology	79,52

Table 5.3 gives an overview of the mean adoption probability of the four different sustainable process technology categories together with the overall adoption of these technologies. While

CO^2/ Emission reduction have the highest adoption rate within the sample, Material/ Fuel substitution shows the lowest which is most probably due to the already mentioned variable GreenElectricity that did achieve less adoptions than non-adoptions. The sustainable process technologies in general achieve a mean of 79.52 % of adoptions of applicable technologies. These variables will be used in the following section to form a correlation matrix with the independent variables.

5.4 Structural model of the quantitative analysis and results

Having prepared the independent factors as well as the dependent sustainable process technologies variables by the corresponding measurement model, the actual correlation analyses can be performed. This is the central step of the quantitative analysis: to evaluate the influence that the six hauled out factors have on the adoption of sustainable process technologies. This is done by means of correlations between all independent factors and the sustainable process technologies variables. As the dependent variables can be considered to be of ordinal measurement ratio, a Spearman correlation is applied in order to see whether the correlations achieve a significance (Field, 2013). Furthermore, a one-tailed test will be conducted as the hypotheses of the influences have a certain influence direction each. The results of this analysis can be seen in the correlation matrix in table 5.4. These results will be analyzed for every independent factor again, in correspondence with the conceptual model.

Table 5.4 *Correlation matrix*

		Coercive P	Fin Costs	Info Cert	Tech Cap	Tech Problems	Fin Cap	Revenues	Employees	Perc AST	Percem AST	Perceff AST	Percmf AST	Percre AST
Coercive P	Correlation Coefficient	1,000												
Fin Costs	Correlation Coefficient	**,427****	1,000											
Info Cert	Correlation Coefficient	**,754****	0,095	1,000										
Tech Cap	Correlation Coefficient	**,786****	0,189	**,670****	1,000									
Tech Problems	Correlation Coefficient	0,172	0,068	0,118	0,182	1,000								
Fin Cap	Correlation Coefficient	0,213	-0,002	**,342***	**,321***	0,027	1,000							
Revenues	Correlation Coefficient	**,465****	-0,081	**,612****	**,481****	0,272	**,398***	1,000						
Employees	Correlation Coefficient	**,399***	-0,211	**,584****	**,467****	0,109	**,368***	**,805****	1,000					
perc AST	Correlation Coefficient	0,119	-0,046	-0,091	0,212	0,194	-0,097	0,018	-0,174	1,000				
percem AST	Correlation Coefficient	0,165	-0,234	0,080	**,312***	0,124	-0,026	0,234	-0,029	**,747****	1,000			
perceffAST	Correlation Coefficient	**,368***	0,177	0,270	**,502****	-0,073	**,348***	0,193	-0,042	**,581****	**,427***	1,000		
percmf AST	Correlation Coefficient	0,038	0,185	-0,187	0,075	0,214	**-,311***	-0,172	-0,191	**,656****	0,169	0,221	1,000	
percreAST	Correlation Coefficient	0,094	-0,046	-0,083	0,078	0,133	0,044	0,118	-0,207	**,802****	**,737****	**,535****	**,351***	1,000

Note: The number of cases is 33. Information uncertainty is measured by the factor InfoCert that measures the certainty of information.

Regulation

For the *regulation* variable CoerciveP, no significance can be found towards the adoption of sustainable process technologies in general. This means that the important role that is found within both literature streams cannot be confirmed by the data of the survey. Furthermore, only the correlation with the Energy/ Material efficient technologies shows a positive significant result at an α of 0.05. This supports the findings of the current literature that has a strong focus on this variable but also on the Material/ Fuel substitution. Nevertheless, as all other results are not significant, the results cannot prove the positive relation of the coercive means of *regulation* towards the other technologies. This means that the hypothesis A1 has to be rejected for all but the Energy/ Material efficient technologies for which it is approved.

Financial costs

For the correlations of *financial costs* with the sustainable process technologies in general, as well as with the four different technologies, no significance can be found in the data. These results do not confirm the negative findings that are found within the quantitative and qualitative studies, which means that the influence of this factor remains questionable. Hypothesis A2 therefore has to be rejected according to the data of the survey.

Information uncertainty

Similar to the factor of *financial costs*, also the correlations of the different sustainable process technologies as well as with the general variable do not show any significance at an α of 0.05. This is in line with the results of the quantitative literature review by Fu et al. (2018), which also does not find significant results. Contrarily, it does not confirm the negative effects that are found in the qualitative studies and that are basis to the hypothesis B1 which has to be rejected due to these results.

Financial capability

The factor *financial capability*, as explained above, consists just of one variable that assesses whether the company has sufficient capital to invest into sustainable process technologies. This means that the results have to be reviewed critically, as this variable is not considered in current

quantitative studies but plays a central role within qualitative studies. The factor shows no significant result towards the sustainable process technologies in general which is not in line with the findings of qualitative studies. Looking at the single technologies, the Energy/ Material efficient technologies show a positive significant relation towards this factor, which confirms the literature results.

Another significant result can be found for Material/ Fuel substitution. This relation, nevertheless, is a negative one which is conceptually difficult to explain as it works contrary to the hypothesized effects. The two other technologies do not have a significant relation with the *financial capabilities* which speaks against the literature results. Overall, also the hypothesis B2 has to be rejected for all but the Energy/ Material efficient technologies.

Firm size

For this factor, no significant relations can be found for the two indicators Revenues and Employees. These results do not give more clarity about the influence of this factor, which shows a variety of different effects in current literature. Due to these results, hypothesis C2 has to be rejected as no effect can be determined.

Technological capability

Conducting the correlations for the sustainable process technologies in general, the *technological capability* factor comes closest of all towards a significant result at an α of 0.05, but still not a significant one. Also the correlation of the single variable TechProblems, indicating issues with the implementation of technologies in the past, has no significant relation towards the adoption of sustainable process technologies in general.

Within the single technologies, this factor achieves two significant results. *Technological capabilities* are the only factor correlated with CO^2/ Emission reduction technologies. Furthermore, it also correlates at a highly significant level with Energy/ Material efficient technologies, while the other two technologies are not significantly related. Checking again for the variable TechProblems, which has no significant relations, the results support the positive effect of this factor towards the first two mentioned technologies, while the hindrance that it could place as found in the qualitative literature is not proven to be valid. This supports the findings of the quantitative literature studies in contrast to the qualitative ones, which

conclude a more positive effect for this factor than a hindrance. All in all, the hypothesis C1 is confirmed for the CO^2/ Emission reduction and Energy/ Material efficient technologies and rejected for the two other ones plus the sustainable process technologies in general.

Summary

Concluding the findings of the survey-based quantitative analysis, the final correlation matrix does not show many significant results. For the sustainable process technologies in general, as the main dependent variable representing the full range of technologies tested in here, no significant relation could be found. This is contrary to all hypotheses stated above as it means that no influences of the factors under investigation are determined.

The evaluation of the hypotheses regarding the single categories of sustainable process technologies, is different to some extent, although no significant result can be found due to Recycling technologies. Considering the Material/ Fuel substitution technologies, one significant negative relation is found towards *financial capabilities,* which has to be reviewed rather critically as it is theoretically hard to explain and contrasts hypothesis B1 in its direction. For the CO^2/ Emission reduction technologies, also one significant relation is shown in the matrix, towards *technological capability*. This positive relation is in line with the hypothesis C1 and can therefore be considered an important result of the quantitative analysis. Nevertheless, the strongest pattern can be found towards the Energy/ Material efficiency technologies for which significant positive correlations are determined with *regulation, financial capability* and *technological capability*. This is the most striking result of the quantitative analysis as it supports three of the six hypotheses. Figure 5.3 shows these patterns of relations as results of the correlation matrix.

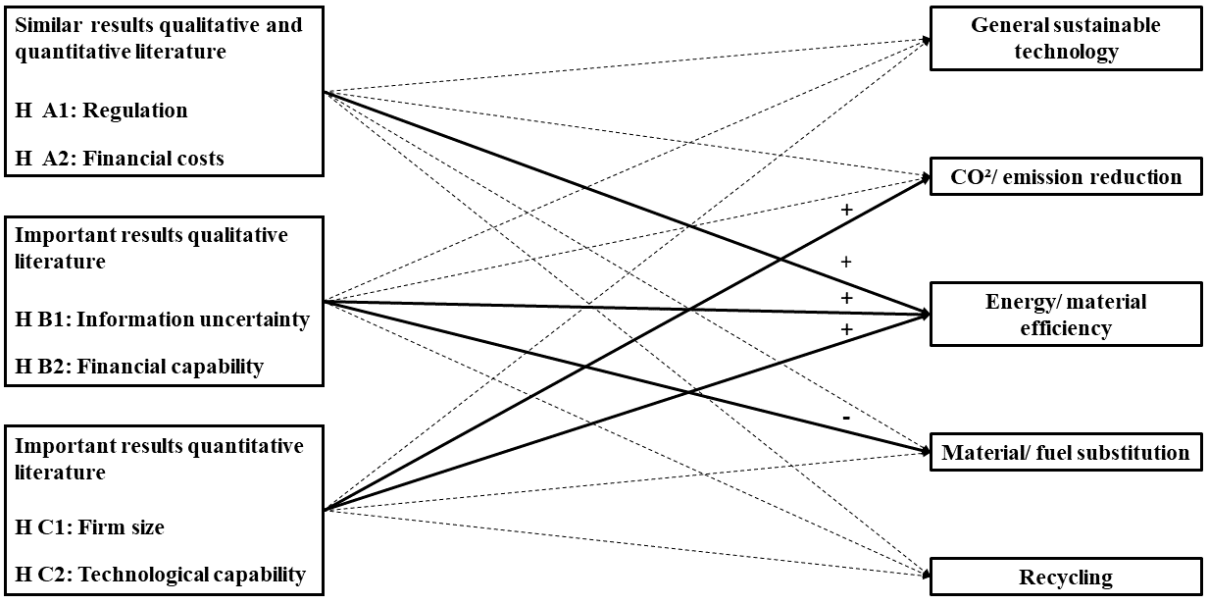

Figure 5.3: Representation of the significant results of the quantitative analysis in the conceptual model. Arrows in bold print represent significant relations while dashed lines represent non-significant ones.

Besides the interesting findings mentioned above, the overall results show that due to the collected data, the factors under consideration with the smaller exception of *technological capability* do not have major influences on whether sustainable process technologies are adopted in the manufacturing industries or not. This is in contrast with most of the findings in current literature. Nevertheless, the results can only be seen as a first indication as only correlation analyses were performed and not more substantial measures such as regressions analysis that could for example indicate the influencing variable in a relation.

Furthermore, the significant relations between the dependent factors are reasonable to consider, as these could be indicators for possible mediator effects. Especially the two *firm size* indicators Revenues and Employees are significantly correlated to all others, besides the *financial costs* factor, and the TechProblems variable. This could mean, that the size of the firm is actually decisive for some of the significant relations found in the matrix. Although this cannot be tested within this analysis, it should be kept in mind for the further process of this thesis. To investigate the research problem further, a qualitative analysis based on five interviews will be performed in the following chapter to build up the third block of the triangulation that is the core of this thesis.

6 Qualitative analysis of five business cases

The last remaining angle of the triangulation applied in this thesis consists of a qualitative analysis. For that, five managers of different companies were interviewed while focussing especially on the six defined independent variables and thereby revealing the mechanisms that lead towards the adoption of sustainable process technologies or build a hindrance towards them. The five chosen companies are all from the manufacturing industries but rather different in their size and specific industries as table 6.1 shows. The different *firm sizes* and industries will provide a broad variety of experiences with the adoption of sustainable process technologies and therefore raise the validity of the results.

Of the five interviewees, those of Firm A and B are commercial manager or director, respectively and are therefore involved especially in adoption decisions from the business management perspective. Nevertheless, they both also have insights into the technological processes of their companies. A similar perspective holds the interviewee of Firm E. As owner and managing director of his company, he is the one who makes the final adoption decisions. In the position of a Production Technology Development (PTD) Manager, the interviewee of Firm C is deeply involved into all decisions and implementations of new production technologies with a focus on the technological side. Finally, the interviewee of Firm E as an environmental specialist is focussing mostly on emission reduction and recycling issues and can therefore provide, similarly to the one of company C, statements from the operational perspective. The involvement of different perspectives ensures that the statements are not too much biased by a certain position within a company.

Table 6.1

Cases of the qualitative analysis

Company	**Industry**	**Interviewee**	**Size**
Firm A	Metal	Commercial manager	Medium
Firm B	Construction	Commercial director	Medium
Firm C	Food	PTD Manager	Large
Firm D	Engineering	Managing director (owner)	Small
Firm E	Automotive supplier	Environmental specialist	Large

This qualitative analysis is built up similarly to the quantitative analysis. In a first step, the independent factors are discussed in accordance to the statements provided by the five interviewees. Then the sustainable process technologies are regarded in a second step, to get more detailed insights about the processes the interviewees are referring to. Finally, the relation of the factors and the sustainable process technologies will be analyzed and evaluated to gain the third angle of the triangulation process. This will be mainly done by looking at the dependent technologies in general and only considering a certain category when there is an important difference that is worthwhile to discuss. The basis of this analysis are the coded quotes of the interviewees, which are ranked by their importance of explanation.

6.1 Independent variable assessment

Before any conclusions about potential influences of the independent factors can be made, it is important to see how the interviewees understand and evaluate these for their companies. Therefore, this will be revealed to especially understand the conditions and context under which the factors univariately work within the very different companies.

Regulation

The first variable which turns out to yield very important and similar results in the two literature streams is the one of state *regulation* that force companies to implement for example certain standards, which then exert pressures to adopt different kinds of sustainable process technologies.

In the evaluation of this factor, the interviewees of the different companies perceived the size of these pressures in different ways as the quotes in table 6.2 show. The managers of firm A and D highlighted their technical standard which is close to the optimum level especially regarding Energy/ Material efficiency. Because this is a necessity in order to compete in both of their industries, state *regulations* do not affect those companies as they keep on operating above the legal standards. This is also the usual case for firm E as the MNE group has developed its own standards, which are in general higher than German law demands it.

Nevertheless, the interviewee of firm E also mentioned differences with regard to specific laws applied in different states within Germany, that indeed exert an influence on the

company. Stronger affected are the two remaining companies. Firm B in general gives *regulation* compliance the highest priority and the manager stated that the influence is noticeable in the company. In a rather special situation, within the small sample of five companies, is firm C as it is operating in the food industry. Therefore, coercive *regulation* forces from different sides are at stake here and exert pressures into different directions.

Table 6.2

Interview statements regarding the factor Regulation

Interview	**Quote**	**Relative importance**
Firm A	Nein, also wir direkt sind davon [Druck durch Regulatorik] nicht so sehr betroffen. Weil wir ja unsere Öle zum Beispiel zukaufen. Und [...] unser Lieferant darf uns ja nur das liefern, was auch genehmigt ist […] von der staatlichen Behörde.	1
Firm B	Es geht nicht an jeder Stelle, weil der Gesetzgeber uns dazu zwingt. Dann kommt das nicht mehr auf die Betriebswirtschaft drauf an, sondern dann geht's darum, muss gemacht werden und dann muss man das auch in Kauf nehmen.	1
Firm D	Dadurch, dass wir uns in 2008 weit über dem Standard platziert haben, […] spüren wir […] bis heute dahingehend keinen Druck.	1
Firm A	Wir versuchen alles was wir neu kaufen oder neu investieren […] dass das immer […] der aktuellste Stand ist und auch nicht besser zu bekommen ist.	1
Firm C	Wir haben IFS Audits, also International Food Standard. Und auch in diesem International Food Standard ist […] ein Punkt beschrieben, dass man sich an gesetzliche Vorgaben hält und das wird dann auch in Audits überprüft.	2
Firm E	Die E internen Ziele sind in der Regel strenger als die, die wir in der deutschen Gesetzgebung haben.	2
Firm E	Wir hatten alles was die […] Rheinland-Pfälzische VHWS vorgeschrieben hat […] Nur in der neuen AWSV wird das ein bisschen […] anders organisiert.	3

Financial costs

High *financial costs* of new sustainable process technologies, meaning all costs that a company faces due to those like for example acquisition or running costs, are found to work as a barrier towards the adoption within the qualitative as well as the quantitative literature. Looking at the statements of the interviewees in table 9, it becomes clear that this definition has to be extended to some extent. First of all, in the interviews with firm B, C and D, all three stated that the isolated consideration of the costs of any investment is not a major concern for the decision but just one aspect. Only the interviewee of firm E mentioned that an investment for an adoption could not be covered by the budget the plant gets from the group.

Although, as the PTD manager of firm C stated, the operating costs should be kept as small as possible, the costs in all companies are considered together with the benefits that can be expected from an adoption. Cost efficiency and a better economic result is what the companies want to achieve in general, not per se a cost reduction. Therefore, the factor of *financial costs* has to be evaluated while keeping this in mind. Furthermore, the different matter of expenses are taken together in most of the companies, while firm A and C especially mentioned the running costs as the main focus point.

Table 6.3

Interview statements regarding the factor Financial costs

Interview	Quote	Relative importance
Firm B	Also die Größe einer Investition würde uns von dieser Investition nicht abhalten. Wenn wir sie als sinnvoll und auch betriebswirtschaftlich [als] sinnvoll erachten […] würden.	1
Firm C	Der [reine Investitionspreis] spielt erstmal keine so große Rolle.	1
Firm D	Eigentlich spielt da eher das Gesamtpaket eine Rolle. […] Die Kosten der Maschine ist […] ja auch nur ein Punkt.	1
Firm C	Zum einen guckt man halt auf die [...] Betriebskosten so niedrig wie möglich zu halten. Das korreliert ja meistens direkt auch mit der […] Nachhaltigkeit.	1
Firm E	Was ein Problem ist, für neue Technologien, meiner Meinung nach ist immer ein K-packs Problem, also ein finanzielles Problem. Weil jedes Werk hier bei uns in der Region hat ein Budget bekommen für verschiedene Bereiche, das wird regional festgelegt oder auch global.	1
Firm A	Kosteneffizienz [ist der mögliche betriebswirtschaftliche Nutzen von nachhaltigen Technologien].	2
Firm B	Ja also wie sicherlich im Interview jetzt schon ein paar Mal angeklungen, […] legen wir sehr viel Wert darauf, dass wir die Technologien auch nur dann einsetzen, wenn sie betriebswirtschaftlich Sinn machen.	2
Firm E	Es muss immer eine Kosten-Nutzen-Analyse gemacht werden.	2
Firm E	Ich denk das wird ein Mix aus beidem sein [Anschaffungs- und laufende Kosten]	3
Firm A	Also grundsätzlich sind die laufenden Kosten immer die wichtigsten. […] Weil wenn die natürlich nahe null sind, dann spielt es keine Rolle aber bei uns sind laufende Kosten schon ein Thema. […] Die sind wichtiger [als] der Einkaufspreis.	3

Information uncertainty

Regarding the *information uncertainty* about future developments, mainly four different uncertainties have to be considered, as can be seen in table 6.4. The first one is the technology development itself. Here especially firm C and D show rather big differences in their behaviour,

as firm C has specified stuff to monitor different developments and also closely works together with its suppliers in that matter. Contrarily, firm D does not monitor the market for new technologies but recognizes a need internally and then searches for an adequate solution.

The second uncertainty deals with the *regulation* that the companies are facing in the future. Firm D, as the only company, seems to a certain extent not to be concerned about these developments because they, as already mentioned, apply higher standards than the law demands. Firm A and B do receive information about these matters but are also both not concerned with getting this information long time in advance. The two biggest companies firm C and E, nevertheless, have specialized staff for *regulation* issues.

Thirdly, the cost development of the technologies is normally going down, while the speed seems to be difficult to predict, which results in the fact that the companies of the sample are not planning long ahead in this manner. Finally, the *information uncertainty* about the behaviour of competitors does not seem to matter for these companies as there is a rather open communication within the industries and especially the associations.

Table 6.4

Interview statements regarding the factor Information uncertainty

Interview	**Quote**	**Relative importance**
Firm C	Wenn man jetzt auf die [...] Energieseite guckt, ist das ja [...] ganz klar die Aufgabe vom Energiemanager, die zukünftigen [...] Themen sich anzugucken. [...] Und was wir hier sowieso alle [...] aus der Technik machen ist ein sehr intensiver Kontakt mit den Lieferanten.	1
Firm D	Wir schauen uns nicht an: Was gibt es alles auf dem Markt? Was könnte für uns interessant sein? Wir schauen uns an: Was braucht der Betrieb? Und dann […] was gibt es diesbezüglich auf dem Markt?	1
Firm B	Was die Regularien im Markt angeht, klar hat man da so einen gewissen Vorlauf von [...] vielleicht einem Jahr. Aber kein Mensch weiß wie in drei Jahren, [...] was es da für Veränderungen geben könnte. Keine Ahnung weiß ich nicht. Wir sehen da auch nicht so weit [...] raus.	1
Firm A	Staatliche Regulatoren kriegen wir in der Regel von unseren Verbänden gesagt. [...] Inwiefern das dann uns betrifft, das müssen wir natürlich selber analysieren und erkennen. [...] also wir sehen einen Preisverfall [...] oder eine Preissenkung. Allerdings sehen wir auch im Moment, grade im Hartmetall, exorbitante Preissteigerungen im Rohmaterial.	1
Firm E	Wir haben bei uns in der Region, also in unserer Europazentrale jemanden sitzen, der zum Beispiel in so einem REACH-Gremium sitzt.	1
Firm C	Ja […], wir haben ein Rechtskataster.	1
Firm E	Für Anlagen zum Umgang mit wassergefährdenden Stoffen gibt es jetzt ja eine bundeseinheitliche Verordnung. [...] Es ist halt meine Aufgabe regelmäßig zu prüfen in welchen Bereichen gab es eine Änderung, ist sie für uns relevant, inwiefern ist sie für uns relevant?	2

Firm D	Das [Kostenrückgang der Technologien] wissen wir.	2
Firm B	Die kennen sie im Prinzip alle. […] Sind im [Verband] zusammengeschlossen und die treffen sich ein, zweimal im Jahr. Von daher weiß im Prinzip jeder so ungefähr was der andere macht.	2
Firm C	Es gibt ja den […] Verband […]. Das heißt die meisten kennen sich untereinander, […] da findet der Austausch, sagen wir mal auf so einer operativen [...] Ebene statt.	2

Financial capability

The next considered influence factor is the one of *financial capability*, which is in the quantitative literature studies assessed mostly by management performance figures and extended in the qualitative studies by a focus on access to capital. In the interviews it turned out that this factor in general indeed can be a major point of interest by the firms, considering any form of investment. As the statement of the interviewee of firm A in table 6.5 shows, in line with the qualitative literature studies, this is especially the case if the access to capital is not given. Nevertheless, this factor seems not to matter too much with regard to the investment decisions of the sample companies as they do not have restrictions in this matters that could block an investment as the statements of firm D and C show.

Table 6.5

Interview statements regarding the factor Financial capability

Interview	**Quote**	**Relative importance**
Firm A	Hauptfaktor [finanzielle Möglichkeiten]. [...] Ich kann nicht investieren, wenn ich das Geld nicht dafür habe.	1
Firm D	Wir in unserem Unternehmen nein. […] Wir hätten die [finanziellen] Möglichkeiten, das [investieren] zu tun, wenn Sinnhaftigkeit dahinter steckt.	1
Firm C	Ne. Da [verfügbares Kapital] haben wir keine Restriktion.	2

Firm size

Regarding the factor *firm size*, very few general comments were made by the interviewees. The PTD manager of firm C emphasized the experiences of the whole company network in a big company, which can be used in general to make a first evaluation about any kind of investment or changes. As already mentioned above, the sample companies are of very different size. While firm D can be considered a small company, firm A and B are medium-sized companies and firm C and E are large companies (Union, 2003).

Table 6.6

Interview statements regarding the factor Firm size

Interview	Quote	Relative importance
Firm C	Das ist ja auch dieser Vorteil, wenn man ein relativ großer Konzern ist, man kann auch über sein Netzwerk schonmal hören, haben andere schonmal was in die Richtung gemacht, haben die Erfahrung.	1

Technological capability

The factor *technological capability* of a company describes the know-how that is inherent in the skills of a company's employees as well as the technical equipment that is available in the firm or in one of its plants. Besides the interviewee of firm A, all of the representatives agreed that the employees of their companies are high-performing and although they would almost always need to be taught on how to apply new technologies, no limitations would arise out of that. Furthermore, also other technical hindrances are in general not at stake within the sample companies. A problem mentioned by firm A and B is that the main suppliers of technologies, especially new machines, do not develop really new innovations, which to some extent limits the possible *technological capability* of these firms.

Table 6.7

Interview statements regarding the factor Technological capability

Interview	Quote	Relative importance
Firm B	Also sehe ich überhaupt gar keine Probleme, [...] was [...] den Platz angeht, den haben wir. Und die fachlichen Fähigkeiten unserer Mitarbeiter, das wird kein Problem für die sein. Wir werden Sie sicherlich ein bisschen qualifizieren müssen auf diesen neuen Maschinen, aber wir haben leistungsstarke Mitarbeiter [...] die clever sind, die auch was lernen wollen, [...] ne, sehe ich kein Problem.	1
Firm C	Also aus technischer Sicht [gibt es keine Hindernisse]	1
Firm D	Wenn etwas neues implementiert wird, dann sind die Mitarbeiter nie soweit. [...] Das ist aber auch kein Kriterium das nicht einzuführen, vielmehr wird mit Schulungen und [...] Weiterbildungen so geteached, dass es effizient wird und selbst nach dem teachen braucht es eine gewisse Einarbeitungszeit je nach technologischer Einführung zwischen drei und sechs Monaten, bis man wirklich langsam Effizienz bekommt.	2
Firm E	Also an der Qualifikation der Mitarbeiter würde ich jetzt grundsätzlich nicht zweifeln.	2
Firm E	Das ist kein Problem. Wir haben hier [ein] sehr ausgeklügeltes Trainingsprogramm. Also wenn neue Sachen eingeführt werden, dann wird grundsätzlich jeder Mitarbeiter drin geschult.	2

Interview	Quote	Relative importance
Firm A	Wir haben oft nur zwei, drei Maschinenhersteller im jeweiligen Bereich, die in Frage kommen, oft sind‘s teilweise sogar nur noch ein oder zwei.	3
Firm B	Wir haben im Augenblick keine speziellen neuen Technologien [...] auf die wir uns vorbereiten beziehungsweise die wir im Auge haben. […] Was bahnbrechendes neues, sehen wir, zumindest am Horizont, im Augenblick nicht.	3

Summary

The univariate consideration of the six factors, based on the five interviews that were held, give a first impression on how these exert there influences in general and especially on how they are perceived by the companies and interviewees. The broadest focus of the statements lies on the *regulation* and *financial costs*, which seem to be at the center of interest for the interviewees. Thereby, the *financial costs* variable had to be extended to the actual economic considerations to get a better grasp on how this factor works in reality, which will be important for the relations that are discussed later on. Especially the factors of *financial capability* and *firm size* did not receive as much attention as other factors; only a few statements on their general characteristics could be found. All in all, this first overview gives some insights in how companies from different industries and size can experience the factors at stake in some points very similarly. Whether these similarities hold also for the relations with the adoption of sustainable process technologies will be revealed later on. The following step will give some insights into the sustainable process technologies that play a role in the assessed companies, to show also a basis for the dependent variable.

6.2 Sustainable process technologies

To get a first impression on what the interviewees mean in further detail when they speak about sustainable process technologies and the influences that lead to their adoption, some of the companies’ specific technologies will be revealed in this step. Thereby, the distinction of the four different generic categories of sustainable process technologies will be the guideline to see whether or not the companies are actively considering all of them and how. This is done to give some background information of the dependent variables and to be able to classify the

statements of the interviewees about the relations towards the influence factors, as they are often rather general.

Material/ Fuel substitution

The first generic category of sustainable process technologies is the one of Material/ Fuel substitution, which describes technologies that work with more sustainable materials or fuel compared to the ones normally used before. This is a point of interest in all of the five companies while some of them attach a higher value to it than others. For example, firm B does not see a substitution of the major material in its process, namely wood. Contrarily, while firm C has an interest in a more effective cleaning process by new cleaning agents, firm E and D are using own sources of water for their processes. Firm E also has the goal to become free of solvents in the production. Furthermore, firm A and E use new materials in the production process to create products that achieve more sustainability in there usage. Finally, more sustainable ways of energy production, especially photovoltaics, played a role in most of the interviews. These aspects together show that such substitutions can be done to achieve a large variety of different goals and that almost every company considers technology adoptions in this field.

Table 6.8

Interview statements regarding the sustainable process technology category Material/ Fuel substitution

Interview	Quote	Relative importance
Firm C	Chemikalieneinsatz, [...] weil wir ja [...] CIP-Reinigungen haben. Also wir reinigen ja mindestens alle 24 Stunden alle produktführenden Teile mit Lauge Säure. Und da gibt's natürlich immer Optimierungen, sei es durch Temperaturen oder durch Einsätzen von vorkonfektionierten Reinigungsmitteln. [...] Jetzt gibt's halt Reinigungsmittel die speziell auf die Verschmutzung hin einer X zugeschnitten sind, dementsprechend braucht man davon weniger [...] oder kann es [...] mit niedrigerer Temperaturen fahren, was natürlich auch direkt wieder einen Einfluss hat.	1
Firm E	Wir haben hier […] eine Pumpwasserstation, wo wir Flusswasser sozusagen entnehmen. Das bereiten wir hier auf.	1
Firm D	Ich […] fange mein Regenwasser auf, ich nutze mein Regenwasser, ich filtere das, wir können also hier Regenwasser auch bis zum Trinkwasser filtern.	2
Firm B	Also wir werden nichts anderes als Holz verwenden.	2
Firm E	In unserer Region [als Teil des Konzerns], [gibt es] das Bestreben Lösungsmittelfrei zu werden. Also dass wir nicht mehr lösungsmittelhaltige Stoffe einsetzen.	2
Firm E	Wo wir ein Projekt haben ist […], dass wir vom Stahlcort auf Polyestercort umsteigen.	3

Interview	Quote	Relative importance
Firm A	Von Stahl läuft immer mehr weg Richtung Hartmetall. Ist allerdings nicht umweltfreundlicher. Allerdings kann man da mit Beschichtungen mehr machen. Das heißt die Beschichtung kostet dann eventuell mal zehn Euro mehr, so ein Werkzeug, aber [...] dafür anstatt zehn Stück brauch ich nur noch drei Stück. Und das heißt natürlich das Werkzeug ist noch genauso schlecht für die Umwelt wie das davor auch, aber [...] es braucht wesentlich weniger.	3
Firm A	Beim Strom, ist [es] ja heute üblich, dass die ganzen großen Stromanbieter auch einen bestimmten […] Prozentsatz an […] grüner Energie […] verwenden. […] Ich kenne keinen Großen bei dem das nicht so ist.	3
Firm B	Wir hatten eine Fläche frei und [...] da wir […] sehr stark auch mit Photovoltaik unterwegs sind, wollten wir ihnen [den Kunden] natürlich auch eine Photovoltaikanlage hier bei uns zeigen.	3

CO^2/ Emission reduction

The second category describes technologies that lead to lower emissions, with a special focus on CO^2 emissions. Compared to the other three categories of technologies, these achieve the least attention within the sample companies. Nevertheless, some examples could be found here. Firstly, firm C is achieving a CO^2 reduction by burning the sewer gas from the sewer treatment plant that is attached to the company. Furthermore, firm E changed all burning activities in and around the production from oil to gas, which is a fuel substitution for the purpose of CO^2 reduction. This is in line with the actions of firm B, which is isolating the roof to avoid a high heating oil consumption and by that achieving also less CO^2 emissions.

Table 6.9

Interview statements regarding the sustainable process technology category CO^2/ Emission reduction

Interview	Quote	Relative importance
Firm C	Was eine CO2-Reduktion ist in dem Sinne, ist, dass wir [...] unser eigenes Klärgas verbrennen. [...] Und da jetzt auch im Zuge des […] Ausbaus des Standort darüber nachgedacht wird, den Anteil an Klärgas noch zu erhöhen, also eine zweite Faulung hinzustellen und dann Klärgas zu verbrennen.	1
Firm E	Ich weiß, dass wir vor […] Jahren […] die Verbrennung […] auf Erdgas umgestiegen sind.	1
Firm B	Letztes Jahr und auch dieses Jahr haben wir in ein neues Dach investiert. [...] Sonst hatten wir immer einen riesen großen Ölverbrauch, […] der hat sich deutlich reduziert	2

Energy/ Material efficiency

Efficiency of materials and energy is probably the most important category across the five companies. While all of the companies mentioned a continues process of improving efficiencies, the foci are different. Firm A and B have a clearer focus on avoiding waste of materials and generating precision. Contrary, firm C and D are mostly watching the energy consumption of their production very precisely. For firm E it is rather unclear where the key consideration lies but it is strongly involved into efficiency issues like the example in table 6.10 of the exhaust air system that has a heat recovery shows.

Table 6.10

Interview statements regarding the sustainable process technology category Energy/ Material efficiency

Interview	Quote	Relative importance
Firm A	Vor zwei Jahren haben wir eine Kühlung bekommen. [...] Das ist sehr nachhaltig, weil wir dadurch unsere Ausschussquote erheblich reduzieren konnten und stabile Prozesse haben. Das heißt natürlich da unser Rohmaterial nicht ganz so umweltfreundlich hergestellt wird brauchen wir weniger Rohmaterial, was auf der Seite schon positive Bilanzen bringt und dann die ganze Fertigung, die Schritte die halt doppelt gemacht werden mussten, weil man halt Ausschuss gefahren hat. Die fallen ja alle weg.	1
Firm C	Durch Einführung von Lean vor drei, vier Jahren […] ist ja auch das ganze Thema Verschwendung bisschen [...] nach oben gehoben worden und […] Leute sind mittlerweile sehr sensibel, was […] so Themen angeht.	1
Firm D	Was das energetische angeht, sind wir, glaube ich, ganz gut bewaffnet. Wir sind mit den Schweißtechnologien ganz vorne dabei, sodass wir [...] so stromeffizient, wie es geht unterwegs sind. Sobald Akkus ins Rennen kommen, würden wir unseren eigenen Strom gerne dann natürlich [...] nutzen, Wasser [...] haben wir alles soweit reduziert, energetisch haben wir hier alles auf Niedrigniveaustandard	1
Firm A	Wir [...] machen die ganzen Rohre neu. […] Die haben weniger Reibung, [dadurch] brauchen wir bis zu 50% weniger Öl, weil das Öl dort schneller durchfließt. [...] Dann haben wir vorne neue Düsen, wo wir genauerer am Prozess sind die Kühlung [...] an den Ort bekommen wo wir es brauchen. [...] Und beides zusammen reduziert natürlich auch die Motorleistung die ich brauche um [...] den ganzen Prozess am Laufen zu halten. Und ich brauche dann natürlich wieder weniger Kühlung.	2
Firm B	Wir haben vor zwei Jahren […] eine neue […] Zuschneidemaschine erworben, […] die dann quasi auch […] dazu führt, dass computergesteuert, […] der Holzverschnitt deutlich sich reduziert […] hat.	2
Firm E	Ich weiß, dass da im letzten Jahr eine neue Abluftanlage installiert wurde, die auch Wärmerückgewinnung betreibt.	2

Recycling

Next to the CO^2/ Emission reduction category, also the one of Recycling does not achieve as much attention as the other two groups of sustainable process technologies. Table 6.11 shows some of the examples mentioned in the interviews, which indicate what the companies do, especially regarding the waste separation which is the dominant action in that field. Regarding the recycling, there is a trend in wording that can be found, as some of the interviewees explicitly mentioned that these materials are no longer waste 'Abfall' but reusable materials 'Wertstoffe'. This shows that the understanding is switching from finding solutions to get rid of these materials to a thinking that is based on finding new utilizations.

Table 6.11

Interview statements regarding the sustainable process technology category Recycling.

Interview	Quote	Relative importance
Firm B	Im Wesentlichen [...] sind das [...] Holzabfälle die wir haben und Fermacell Platten die sauber getrennt werden. So ein bisschen was an Plastik. Aber das sind [...] im Wesentlichen nur Umverpackungen […] also die Trennen wir sehr sehr […] genau.	1
Firm C	Wir haben einen [...] Abfallbeauftragten, der eigentlich den ganzen Tag [...] nichts anderes macht, als [...] zu gucken, also wir haben […] sehr viele verschiedene Container, […] um unsere […] Hilfsstoffe und […] Packstoffe auch sauber zu trennen.	1
Firm E	Das ist die Buffing, so heißt das, die ist eingehaust worden und da ist auch eine entsprechende Absaugung installiert worden. Da ist mit dem [...] Containerdienst der [...] das, wir nennen das Raumehl, also diese ganz feinen schwarzen Gummischnipsel von der Lauffläche, das Raumehl, dann entsprechend absaugt.	2

Summary

As the example technologies in this chapter have shown, all four categories of sustainable process technologies are considered in the interviewed companies; a relevance of them can now be concluded. Nevertheless, the evaluation of these categories is slightly different. While Energy/ Material efficient technologies are clearly the ones all companies are permanently busy with, Recycling and especially CO^2/ Emission technologies do not seem to have the highest priority in the daily operations. The reason for this will be one of the questions in the next chapter, that will most importantly dive into the actual relations between the independent factors presented in 6.1 and the sustainable process technologies.

6.3 Relations found in the qualitative analysis

After the independent influence factors and the dependent sustainable process technologies have been analyzed univariately, it is now the central importance to point out the mechanisms of whether and how the factors exert their influences on the adoption of those technologies. This is again done according to the six factors which will be followed by a verification of each of the hypotheses stated above. Thereby, the dependent sustainable process technologies are evaluated in general while only major differences between them will be shown. This is due to the overall more general statements of the interviewees. To get an image on what kind of technologies they are most probably referring to, part 6.2 delivers a good basis of understanding.

Regulation

As already shown in the univariate assessment of the independent factors, firm A and D are not affected by *regulation* forces that pressure them to adopt sustainable process technologies. This is because of the continuously highest standards these two companies adopt due to the market competition. Nevertheless, the other participating companies do feel the pressure of for example environmental laws. The first statements of firm E, B and C show that in some cases, like new constructions or gas emissions, the *regulation* is that strict that it just has to be applied and gets strongly supervised by the legislator. Under these circumstances, a clear relation towards the adoption of sustainable process technologies can be found. Nevertheless, company B and C also mentioned negotiations, by themselves or their associations with the legislator, that lead to a delay of the adoption as this is favourable for these companies compared to an immediate strict *regulation*. In fact, this again proves the point that a more strict *regulation* leads to a more sustainable way of producing as it would not allow such a delay.

An interesting point here is that the *regulation* seems not to affect Energy/ Material efficient technologies in a way that makes those even more sustainable. Firm A and D do not mention any *regulation* issues also because they are working in a highly efficient way and firm B and E do not see any coercive pressures in that direction either. Only firm C is in that regard in a special situation as a food producer. According to the interviews statement, the production could be more efficient if *regulation* would not forbid this, so that *regulation* here even shows

a negative effect. This is due to the fact that health issues in this industry have a higher priority in the legislation.

To evaluate hypothesis A1, a positive influence of an increase in *regulation* pressures can be concluded for the sustainable process technologies in general. Nevertheless, this does not account for Energy/ Material efficient technologies, as there is in most cases no relational effect to be observed.

Table 6.12

Interview statements regarding the influences of Regulation

Interview	**Quote**	**Relative importance**
Firm E	Ich bin jetzt auch grade im Moment dabei ein Anzeigeverfahren für drei neue Heizpressen [...] vorzubereiten und auch bei der Behörde einzureichen. […] Wenn man was neues baut ist das der aktuelle Standard, den man dann einfach umsetzen muss.	1
Firm B	Wir haben jetzt [...] ein neues Umweltkonzept machen müssen. Einen externen Umweltbeauftragten haben wir jetzt beauftragt damit sich unsere Prozesse nochmal anzugucken. [...] Wo denn welche Abfälle [...] anfallen und wie wir die am Besten im ersten Schritt vermeiden.	1
Firm C	Das ganze Thema […] klimaschädliche […] Kühlgase und sowas. [...] Ich meine: das ist ja auch vom Gesetzgeber, also da führt ja auch kein Weg dran vorbei.	1
Firm C	Es gibt ja die […] Abfallverordnung für Industriebetriebe, [...] seit […] letztem Jahr . [...] Also da wird ja auch vom Gesetzgeber sehr drauf geachtet	2
Firm C	Man könnte viele Sachen mit Sicherheit deutlich optimierter fahren, aber es ist gesetzlich […] nicht erlaubt.	2
Firm B	Im Augenblick ist es so, dass [...] unser [...] Bundesverband noch durchgesetzt hat, dass wir im Wesentlichen unsere Materialien alle in einem Abfallbehälter entsorgen können. [...] Wir merken allerdings jetzt Tendenzen, dass dies dass wohl zukünftig nicht mehr zulässig wäre.	2
Firm C	Und es spielt auch immer eine Rolle wer auf der anderen Seite sitzt, also wer in der Behörde sitzt. Wenn man da einen hat, der relativ [...] industrienah oder praxisgerecht arbeitet ist das kein Problem. Wenn man da einen hat der wirklich nur seine Gesetze durchgeht [...] und dann Sachen anfordert. Dann schickt man die hin und dann kommt ein halbes Jahr oder vier Monate oder vier Wochen kommt dann zurück, ok das war gut, jetzt brauch ich noch das.	3

Financial costs

As already mentioned in the univariate assessment of the factor *financial costs* in part 6.1, in most of the cases the costs cannot be regarded in isolation. Normally, they are considered

together with the benefits that they achieve. This means that when the interviewees spoke about too high costs of technologies, they actually meant in relation to the benefits that these technologies bring. The only slight deviation from this is the already mentioned case of firm E, where single plants can suffer from a too low budget they get assigned from the group, which works like a missing access to capital. Having this in mind, the factor *financial costs* in that sense turned out to be the most important one for all of the five companies as they all highlighted the importance of economic sense making in adoption decisions of sustainable process technologies as table 6.13 shows.

Another striking point is the distinction between the technologies that has to be made here. Energy/ Material efficient technologies often lead to lower production costs and are therefore the technologies mostly mentioned in this regard, different than before with the *regulation* factor. Recycling and Material/ Fuel substitutions are also able to create a benefit under certain circumstances while CO^2/ Emission reduction technologies are not adopted in the companies directly for cost reasons. This is only the case when technologies that also emit less pollutions are first of all beneficial, for example due to their Material/ Fuel substitution or Energy/ Material efficiency.

Regarding hypothesis A2, this means that *financial costs* in isolation in general do not have an effect on the adoption of sustainable process technologies. Nevertheless, if the factor is broadened up to economic considerations by a comparison of the costs and benefits, there is a clear negative effect of a high cost-benefit ratio to be seen. This seems not to be true for CO^2/ Emission reduction technologies as those mostly do not get adopted on basis of economic reasons because they are barely able to create benefits for companies.

Table 6.13

Interview statements regarding the influences of Financial cost

Interview	**Quote**	**Relative importance**
Firm A	Wir kaufen keine Technologien ein, die nicht Prozesssicher funktionieren. Und natürlich ist das auch eine Preissache. Wenn ich etwas am Markt nicht verkauft bekomme, weil es zu teuer ist, dann lohnt […] die Anschaffung nicht.	1
Firm B	Für die Dämmwolle sind wir jetzt in den Überlegungen auch so eine Maschine [...] uns anzuschaffen. Bisher ist Holz optimiert worden und damit würde dann auch der Dämmstoff sauberer geschnitten und damit optimaler eingesetzt werden können. [...] Aber [ist] mit hohen Kosten verbunden, [...] da zögern wir im Augenblick noch ein bisschen.	1

Interview	Quote	Relative importance
Firm A	Allerdings ist es so, alles was gut für eine Nachhaltigkeitsbilanz ist, sprich Stromverbrauch, Materialverbrauch, ist auch nachher wieder gut was das Rechnen angeht. Also wenn ich weniger Strom verbrauche, hab ich weniger Kosten.	1
Firm C	Wir müssen versuchen so günstig wie möglich zu produzieren. Dementsprechend ist […] mit Sicherheit der […] haupttreibende Faktor […] die Kostenersparnis.	1
Firm D	Dennoch ist es so, dass man aktuell noch Trinkwasser relativ günstig kriegt und für die Investition, die es braucht, Regenwasser aufzubereiten, das macht leider keinen Sinn. Da, glaube ich aber, wird sich in den nächsten Jahren schon verändern.	1
Firm B	Also [...] letztendlich auch die[...] finanziellen Gegebenheiten haben [...] dazu geführt, dass wir da noch stärker [...] trennen. [...] Wenn die Alternative ist deutlich mehr zu bezahlen wenn ich sie [Abfälle] alle zusammen werfe, dann muss man als Wirtschaftsunternehmen, [...] sich schon dieser Herausforderung stellen und einfach sagen wir trennen dann sauber.	2
Firm B	Letztes Jahr und auch dieses Jahr haben wir in ein neues Dach investiert. [...] Sonst hatten wir immer einen riesen großen Ölverbrauch. […] Der hat sich deutlich reduziert.	2
Firm C	Egal, ob wir jetzt über Blockheizkraftwerke, [...] Absorptionskälteanlagen, [...] Schlammverbrennung, also Klärschlammverbrennung über Pyrolyse [...] nachdenken, also ich denke die Verfahren sind alle da. Das Problem ist, dass die wirtschaftlich halt nicht immer so gut sind.	2
Firm C	Wir hatten ein richtig schönes Konzept, […] für eine Kombination aus Photovoltaik, Windenergie […] einer Speicherlösung. Das wäre eigentlich eine schöne runde Sache gewesen, aber war einfach betriebswirtschaftlich nicht abzubilden.	2
Firm A	Alles was wir haben an abgeschnittenem Material [...] das [wird] dann wieder in den Kreislauf eingebracht. [...] Das Material ist einfach zu teuer […] um das irgendwo auf eine Deponie zu bringen.	3
Firm C	Viele Sachen sind ja auch Wertstoff und man kriegt tatsächlich noch Geld dafür, wenn man es sehr sauber oder sehr rein […] abliefert […], man hat einen höheren Aufwand, aber unterm Strich ist es eine schwarze Null.	3

Information uncertainty

Although there are differences in the monitoring of the technology development, which is the first of the four information uncertainties, this does not have an effect on the adoption of such technologies for the five sample companies. The reason for that is, that the development works more as pre-condition and none of the companies describes itself as a first adopter of technologies that would maybe go into bigger risks, as especially the statements of firm A, B, C and D in table 6.14 show.

A slightly negative effect can be found for the uncertainty over new *regulation*. Although the interviewee of firm B stated that he is not concerned about the *regulation* too far

in advance, he argues that without external help it is often not possible to comply with the laws due to unawareness which delays the adoption of sustainable process technologies. Furthermore, the environmental specialist of firm E reported that the *regulation* awareness for her is often really short-term which seems to be a communication issue inside the company that has special staff for *regulation* monitoring.

For the third *information uncertainty*, regarding the costs development of the technologies, firm A, C and D stated that they usually become cheaper over time while special circumstances can also cause rising costs. Nevertheless, as already described in 6.1, the exact speed is not really clear so that the companies wait until they think that an adoption economically makes sense. This is arguably a positive effect of *information uncertainty* towards the adoption of sustainable process technologies because if the companies knew the exact speed of the cost development, they would probably even wait longer until the perfect timing is reached and not already invest as soon as it is economically reasonable.

Because of the openness across the industries of the companies in the sample, no effect can be concluded for the uncertainty about the competitor behaviour. This is supported by the statements of firm A and B that show a more conservative approach of being later adopters and not being affected too much by competitors. Although small effects can be found due to the *regulation* and *financial costs* uncertainty, overall the hypothesis B1 has to be rejected based on the interviews as no clear influence for all four uncertainties can be observed.

Table 6.14

Interview statements regarding the influences of Information uncertainty

Interview	**Quote**	**Relative importance**
Firm A	Es ist ein permanentes Weiterentwickeln von den Technologien wie vorhin schon beim 3D Druck erzählt. [...] Den gibt es heute auch schon für unsere Materialien. Allerdings nicht die Qualität die wir brauchen. Und das heißt, das kann sein, dass die Qualität in zwei Jahren da ist, es kann sein, dass sie erst in fünf Jahren da ist, es kann aber auch sein, dass die in fünf Jahren da ist, aber erst zahlbar in zehn Jahren.	1
Firm A	In der Regel kann man sagen, dass, wie bei unseren Werkzeugen auch, bei den Technologien die Preise immer fallen umso länger sie am Markt sind. [...] Wir sehen das jetzt bei Maschinenherstellern. Lieferzeiten auf Grund der guten wirtschaftlichen Lage sind Minimum ein Jahr, eher zwei. [...] Da sind eher Preissteigerungen der Fall, obwohl die Technologie eigentlich schon länger am Markt ist.	1
Firm A	Deshalb würde ich jetzt nicht, nur weil ein Konkurrent das macht, automatisch auch drauf springen, weil das nicht wirtschaftlich ist und	1

Interview	Quote	Relative importance
	dementsprechend auch, wenn man das zu oft macht, ein Unternehmen […] gefährden kann.	
Firm B	Wir haben bisher immer gute Erfahrungen damit gemacht erstmal zu gucken [...] wie andere das einsetzen. Also wir sind jetzt nicht dadurch geprägt, dass wir als Unternehmen [...] Vorreiter in neuen Technologien sein wollen. [...] Sondern wir sind eher davon geprägt, [...] dass wir standardisierte Verfahren haben wollen, die andere dann schonmal ausprobiert haben und wir sind nicht Vorreiter.	1
Firm C	Ich denke grade in dem Bereich ist das unheimlich schwer da Vorhersagen zu machen und [...] ich glaub [...] irgendwann ist einfach der Punkt, das ist genauso wie wenn man zu Hause eine Investition tätigt, irgendwann muss man sagen so, ich mach das jetzt, ich kauf das jetzt und gut ist.	1
Firm D	Wenn die [nachhaltigen Prozesstechnologien] leistungsfähig in einem akzeptablen Preis-Leistung-Niveau sind, dann schlagen wir da zu, ja.	1
Firm E	Aber ansonsten was Technologien angeht, [...] das ist immer erst so Achtung da kommt was [Regulatorik] […] Also jetzt nicht, dass wir da jetzt großartig Handlungsspielraum haben […] oder da mit eingreifen könnten.	1
Firm B	Man muss ja fairerweise sagen, [...] manchmal weiß man ja gar nicht, dass das was man dort tut nicht korrekt ist. Man versucht das immer nach bestem Wissen und Gewissen zu machen, aber insbesondere im Bereich Umweltschutz [...] kommt man dort ohne externe Hilfe dem Grunde nach nicht klar.	2
Firm D	Das [Technologieentwicklung] kriegen wir schon so ein bisschen mit, ohne dass wir da irgendein Monitoring betreiben. Das nein, aber mitkriegen tun wir das dann schon, ja. Und sobald es da Sinn macht, steigen wir ein.	2

Financial capability

Closely connected to the isolated *financial costs* of sustainable process technologies are the *financial capabilities* of a company. Although this is currently not an issue for most of the sample companies, firm A describes that indeed there has been a technology it would have liked to adopt but the risk was too big. The interviewee stated that the company probably would have adopted it, if it had more *financial capabilities*, specifically access to capital. Firm B reported the same from a situation some years ago when the company did not have the money to invest even in technologies that obviously made economically sense.

Regarding the statements of the five interviewees, the *financial capabilities* of a company do not actively lead towards adoptions of sustainable process technologies. Nevertheless, it does play a negative role once these capabilities in form of access to capital are not given so that it then works as a hindrance. Therefore, hypothesis B2 can be confirmed here with the restriction to the described mechanism.

Table 6.15

Interview statements regarding the influences of Financial capability

Interview	Quote	Relative importance
Firm A	[Wenn wir deutlich größer wären] wäre die Wahrscheinlichkeit größer gewesen [die Beschichtungsanlage einzuführen].[...] Bezieh[ungsweise], die Größe alleine [...] vielleicht nicht, entscheidend ist aber auch die Kapitalstärke. [...] Nur weil ich größer bin, bin ich nicht Kapitalstärker.	1
Firm B	Ich glaube das kann man an [unserem] Unternehmen [...] eigentlich sehr sehr gut sehen, [...] dass das sehr wichtig ist, [...] wie das Unternehmen wirtschaftlich dasteht. [...] Weil wenn man sich die Investitionstätigkeiten in den letzten fünf, sechs Jahren anguckt, [...] dort eh ist sehr viel investiert worden. In neue Maschinen, in neue Technologien. [...] Und das ist nur deshalb möglich, weil man wirtschaftlich erfolgreich ist. In den Jahren davor, [...] waren einfach die Ressourcen gar nicht da. Selbst wenn man gewollt hätte, in [...] solche am langen Ende sinnvollen [...] Abläufe zu investieren, hätte man es nicht machen können, weil die finanziellen Ressourcen nicht da waren und im Zweifelsfall die Bank auch gesagt hätte, ne wollen wir nicht investieren, weil die Payback-Phase ist uns einfach zu lang. Und jetzt haben wir die Möglichkeit zu sagen, selbst wenn sich eine Investition erst in fünf, in acht Jahren [...] rentiert, [...] wir machen das einfach.	1

Firm size

Although the factor *firm size* was not often referred to during the five interviews, some statements highlight its importance for the adoption of sustainable process technologies. Thereby, it often works as a pre-condition for other factors, like the correlations in the quantitative analysis already surmised. The interviewee of firm A stated that its industry consists of medium-sized companies and that these therefore do not have the capabilities like bigger groups and cannot not invest as much in R&D. This shows that especially the *financial capabilities* are affected by the size. Furthermore, this statement also seems to argue that the risk of a bigger investment and therefore the factor *financial costs*, is not as important for bigger companies as another statement of this interviewee regarding the technological and *financial capabilities* showed before as well.

Besides firm A, especially the interviewee of firm C clearly highlighted the advantages of a bigger *firm size*. In his eyes, the company would get into technological problems with the adoption of new sustainable process technologies if it did not have the size that it currently has. Having this in mind, there might be a relation in the fact that only the two biggest companies in the sample did not mentioned technological problems. Furthermore, he also stated that the

regulation would become a problem if the company was smaller as it could not directly discuss with the legislator and would therefore get into trouble once it gets a message over the details of a new *regulation* which increases the *information uncertainty* over the *regulation*. While firm B and D did not explicitly mention any effects of the *firm size*, the interviewee of firm E did not believe that the employee teaching in new technologies is dependent on the *firm size* which is a rather specific point.

Taking those statements and connections to other factors together, hypothesis C1 can be accepted as the size of a firm has a clearly positive influence towards the adoption of sustainable process technologies. This is because it removes the hindrance of *financial capability* issues more likely, furthermore also equips a company with more *technological capabilities* so that they do not get into adoption problems and finally it helps in applying new *regulation*s faster.

Table 6.16

Interview statements regarding the influences of Firm size

Interview	**Quote**	**Relative importance**
Firm A	Da wir eine sehr kleine Branche sind, die hauptsächlich Mittelstand [...] und eigentümergeführt ist, haben wir natürlich nicht die Möglichkeiten wie ein Daimler. Dementsprechend wird bei uns in dem Bereich nicht oder generell nicht so viel geforscht, weil die Kapazitäten dazu einfach nicht da sind. Wenn wir eine 80-Mann Abteilung hätten, die sich nur um Entwicklung oder Optimierung kümmert, wären wir wahrscheinlich weiter [als] wir es heute sind. Aber das ist einfach bei der Größe nicht möglich.	1
Firm C	Natürlich [bekämen wir technische Probleme wenn wir die Größe nicht hätten]. [...] Also ich denke [...] die Technologien [...] und die Zusammenhänge [...] sind so komplex, dass wenn man nicht [...] ein paar Experten auf dem Gebiet hat, [...] ist man da verloren.	1
Firm C	Wenn man im eigenen Haus Experten hat, die sich mit den Themen auskennen, wissen, wie man mit den Behörden reden muss, was die Behörden verlangen und mit den Behörden auch auf Augenhöhe [...] diskutieren [...]und über das Gesetz oder die Vorlagen [...] reden können, ist das alles gar nicht so wild. Wenn man aber keinen hat und kriegt einfach nur [...] den Bescheid von der Behörde, dann denk ich [...] kann es ein Problem sein. Und auch da spielt einfach die Größe und das Wissen was man am Standort hat [...] eine extreme Rolle um den Druck einfach [besser zu kompensieren].	2
Firm E	Nein ehrlich gesagt [glaube ich nicht, dass die Unternehmensgröße die Schulung von Mitarbeitern vereinfacht].	3

Technological capability

In line with the general statements about the qualifications of their employees in part 6.1, just the interviewee of firm A identifies adoption problems for sustainable process technologies due to the necessary learning time of the staff while the others do not see an issue there. Furthermore, firm A and D see technological problems that arise externally to their companies by the general technological development of the suppliers or, in case of firm B, by the cooperation with external firms that work for the company. Only the biggest companies C and E do not identify any technological problem that could lead to a non-adoption of sustainable process technologies.

Concluding, similar to the factor of *financial capability*, hypothesis C2 can be confirmed while the argumentation of the participants is in line with the findings of the current qualitative studies that identify also hindrances for the adoption of sustainable process technologies in missing technological capabilities.

Table 6.17

Interview statements regarding the influences of Technological capability

Interview	**Quote**	**Relative importance**
Firm A	Eine Beschichtungsanlage [hätten wir gerne eingeführt]. [...] Einmal das Kapital in Form von Maschinen. Das andere in Form von Personal und Knowhow. Weil das eine Sache gewesen wäre oder ist, die man über Jahre aufbauen muss. [...]	1
Firm D	Beispielsweise der Strom auf dem Dach. Den würden wir gerne intern viel mehr einsetzen, wenn es die Möglichkeit einer […] praktikablen Speicherung gäbe. […] Da sind wir leider technologisch nicht auf dem Stand, dass man es […] vernünftig speichern [kann].	1
Firm A	Ja das [technologische Probleme] gibt's immer wieder auch vom Maschinenhersteller [...] zum Beispiel grade jetzt im Bereich erneuerbare Energien. [...] Hat man ja oft so, dass ein Windrad nachts zum Beispiel auch [Strom] produzieren könnte. Und dann wäre es [...] ganz praktisch, wenn die Maschinen nachts auch laufen würden. [...] Aber bisher können wir nicht bei allen Maschinen die wir kaufen auch mannlos laufen lassen. Und da hat es dann das Problem technisch, [...] dass wir diese Zeiten nicht nutzen können.	2
Firm B	Die größte Herausforderung wird sein, denen [Subunternehmern] klar zu machen, dass sie diese Abfälle quasi genauso sortieren und genauso in diese Behältnisse reinwerfen die wir ihnen dort zur Verfügung stellen.	2
Firm C	Ich glaube die die technischen Fähigkeiten sind gar nicht mal das Problem. [...] Egal ob wir jetzt über Blockheizkraftwerke, [...] Absorptionskälteanlagen, [...] Schlammverbrennung, also Klärschlammverbrennung über Pyrolyse [...] nachdenken, also ich denke die Verfahren sind alle da.	2

Summary

As the third angle of the triangulation that is applied in this thesis, the qualitative analysis was done to reveal the mechanisms on how the six independent factors exert their influences on the dependent sustainable process technologies. After an univariate consideration of how the interviewees of five different companies perceive the influence factors, a small overview of the different technologies applied in the firms was given. As figure 6.1 shows, the results of the analysis differ to a reasonable extend to those of the quantitative analysis done in chapter 5.

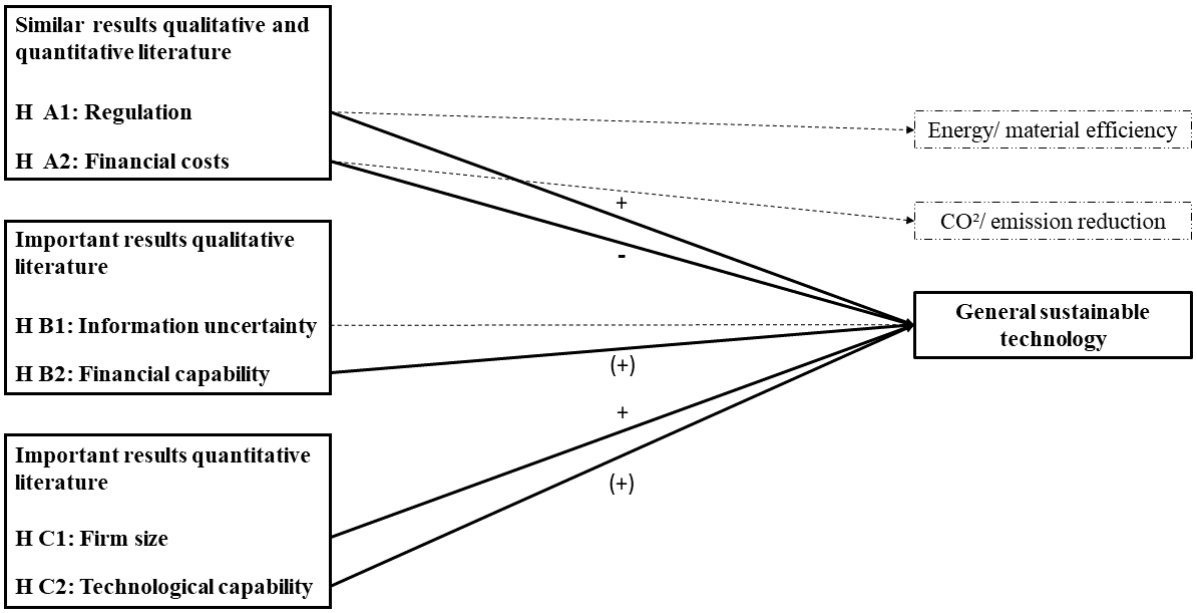

Figure 6.1: Representation of the significant results of the qualitative analysis in the conceptual model. Arrows in bold print represent noticeable effect while the dashed lines represent no effect.

Regarding the factor *regulation*, a clear positive effect could be found towards the adoption of sustainable process technologies in general. That is not the case for Energy/ Material efficient technologies. This is an interesting result, as for the next factor, namely *financial costs*, these technologies are the most important ones as they are a major mean to save costs in the production process while the CO^2/ Emission reduction technologies are most times not profitable. Out of these observations, there is strong evidence for an interaction between the factors *financial costs* in the sense of economic behaviour and *regulation*. Once a sustainable process technology is profitable by itself, no *regulation* is needed to push it forward, but for other cases *regulation* is the mean to make the production process more sustainable.

For the *information uncertainty*, no general influence could be found. The findings for both, Financial as well as *technological capability* are to some extend similar. Both are in general given in most of the companies and therefore do not affect the adoption of sustainable process technologies in that sense. Nevertheless, they both place a hindrance if the capabilities are not given. This is clearly in line with the findings of the qualitative studies in that matter. Lastly, *firm size* is found to exert its rather strong positive influence on the adoption of sustainable process technologies mostly via multiple other factors and can therefore be regarded as a major pre-condition. In the following chapter, these results will be compared to those of the literature reviews and the quantitative analysis in the triangulation to see how valid and reliable the observed relations are.

7 Triangulation of the mixed methods and literature comparison

In the course of this thesis, three different analyses have been applied to evaluate six factors from different perspectives that might influence the adoption of sustainable process technologies. In a first step, a comparison of two literature reviews, of quantitative studies on one hand and qualitative studies on the other, was done. As a result of this, the mentioned six factors that represent similarities and differences in these literature streams were highlighted, namely *regulation*, *financial costs*, *information uncertainty*, *financial capability*, *technological capability* and *firm size*. This is the basis for a quantitative survey-based analysis and a qualitative one based on five interviews with companies. This chapter will now summarize and compare the results of these three analyses by focussing especially on the influence patterns that were found. This again is done for each of the six factors to evaluate the validity and reliability of the findings.

Regulation

In the comparison of the two literature streams, they show similar effects of the first two factors. First, both of them found in the vast majority of the studies a high importance of the factor *regulation* that affects the adoption of sustainable process technologies in a positive way. For the quantitative studies, this especially accounts for the CO^2/ Emission reduction and the Energy/ Material efficient technologies, while the qualitative articles see furthermore a more general positive influence.

Considering the quantitative analysis of this thesis which was done by means of correlation analysis, these results can only be found to a really limited extend, as only the relation toward the Energy/ Material efficient technologies shows a significant positive result, which is therefore partly in line with the findings of the literature review of the qualitative studies by Fu et al. (2018). Finally, the results of the qualitative study give a quite opposite picture of the mechanism as it finds a high importance especially for the CO^2/ Emission reduction technologies and also for Material/ Fuel substitution and Recycling, but not for the Energy/ Material efficient ones as there seems to be an interaction with the *financial costs* factor.

These rather inconsistent influence patterns of the different analyses make a precise evaluation of the factor rather difficult. As all angles found considerable influences on certain

sustainable process technologies so that hypothesis A1 is supported because *regulation* has an effect. Nevertheless, there seems to be a bias due to the form of study that is applied, as the current quantitative studies in the literature, also the one applied here, yield different outcomes than the qualitative ones including this qualitative study. This point will be discussed in the last chapter regarding the implications for theory.

Financial costs

The other factor that shows similar results in both literature streams is the one of *financial costs*. While the quantitative literature review by Fu et al. (2018) finds just one article in that matter, there are six qualitative ones describing the negative influence of the costs. Considering the quantitative study of this thesis, no significant influence of the costs could be found towards the adoption of sustainable process technologies. Contrary, the qualitative analyses based on the interviews revealed that the factor has to be seen more as a cost-benefit ratio in reality. Under these circumstances, the results find this factor to be the most important one leading to non-adoptions when the costs and therefore the ratio are too high and the other way round. This is not the case for CO^2/ Emission reduction technologies as these are normally are not able to yield any profits so that the cost aspect is regarded less here. In this point there is an interaction effect with the *regulation* factor to be seen that will be covered in the last chapter as well.

Considering hypothesis A2, again a difference has to be made between qualitative and quantitative studies. Out of the literature review and the mixed-methods, it seems like the qualitative approach in literature and in this study values the influence of this variable way stronger than the quantitative one. Overall, the hypothesis is accepted as a clear negative influence can be found on the qualitative side while the described difference is again a point of discussion for further theory application.

Information uncertainty

While this factor yields some considerable negative effects on the adoption of sustainable process technologies in the qualitative studies of the current literature, these cannot be found to that extend in the German context, neither in the qualitative nor in the quantitative analysis. Because also the quantitative studies in the literature do not find an influence due to *information*

uncertainty in general, the assumption is that different uncertainties play only a role in specific situations and cannot be generalized. Therefore hypothesis B1 has to be rejected.

Financial capability

The evaluation of the factor *financial capability* is to some extend difficult. This is due to measurement differences as the qualitative studies in the current literature focus on the access to capital a company has, which is not measured in the quantitative ones. The hindrance of having too little access to capital to finance new sustainable process technologies is found in multiple articles and the interviews within the quantitative analysis of this thesis. As the quantitative analysis of this thesis shows a significant positive as well as negative effect towards two different categories of sustainable process technologies, the validity of the measurement model that consists of just one variable is at least questionable.

Therefore, the hypothesis B2 is accepted, mostly based on the qualitative studies in the literature and the qualitative analysis in this thesis, while the evidence is not that clear in the quantitative studies or the quantitative analysis. In this regard, *financial capability* seems to play mostly a role when it is not given in form of access to capability and makes it therefore impossible to invest.

Firm size

In the quantitative literature, a variety of effects of the factor *firm size* can be seen, ranging from positive to negative, while it is barely part of qualitative studies. Nevertheless, the quantitative analysis of this thesis does not help to reveal the influence direction as no significant results could be found towards the different technology categories but only towards some of the other factors. This brings up the assumption that there are effects of *firm size* on these other factors which is supported by the findings of the qualitative analysis, which indicates this factor to be a pre-condition of multiple other factors that lead towards an adoption of sustainable process technologies. Although this pattern of influence is comparable rather weak in its validity, the conclusion is to accept hypothesis C1 as there are some effects of the size of a company to be found, especially in the qualitative analysis.

Technological capability

Regarding the *technological capability*, the positive effects on the adoption of sustainable process technologies that are found in quantitative studies of the literature as referred to by Fu et al. (2018), are partly confirmed by the quantitative analysis of this thesis as this factor yields positive significant results towards CO^2/ Emission reduction and Energy/ Material efficient technologies. Although no significant effect towards sustainable process technologies in general could be found, it is the strongest factor in the model.

Contrary, qualitative studies are focussing on the hindering effect of not having technological capabilities. This is confirmed by the qualitative analyses of this thesis. These two different approaches do not necessarily have to contradict each other. Having a stronger *technological capability* could mean, that the hindrance that a weak capability could place can be overcome and these companies can adopt more sustainable process technologies. Therefore, the hypothesis C2 is accepted as the *technological capabilities* have an influence.

Summary

This triangulation brought together the results of the three different analysis steps within the thesis that are represented in figure 7.1. Thereby, the level of influence patterns as results of these analyses was considered to compare and weight the different angles and form a more holistic picture of the mechanisms at stake. Very striking are the differences found between the approach of qualitative research on the one hand and quantitative research on the other. In most cases the results of the interview-based qualitative analyses yielded very similar outcomes like the other qualitative studies in the current literature. This accounts also for some of the survey-based quantitative analysis and its counterparts, while the differences between the approaches is sometimes more than just in the level of detail which is a point for general considerations about academic theories. All in all, five of the six hypotheses stated in 3.2 are accepted as for all factors but *information uncertainty* an influence on the adoption of sustainable process technologies was found. Only the factor *financial costs* shows a negative influence while the other four are overall positively related.

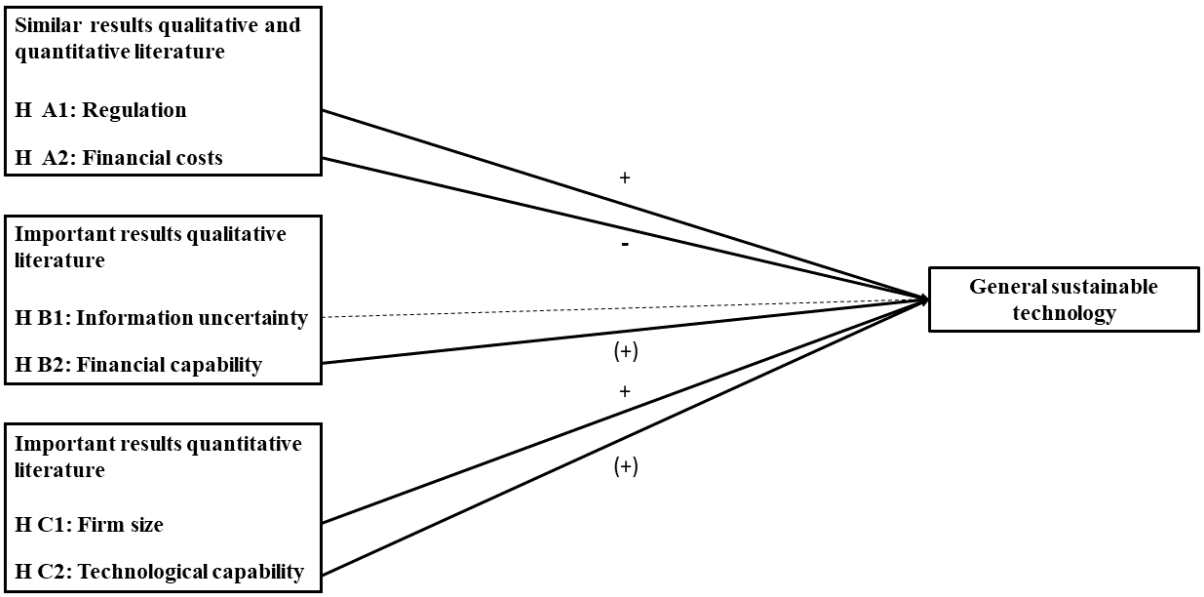

Figure 7.1: Simplified representation of the triangulation results in the conceptual model. Arrows in bold print represent the acceptance of a hypothesis while the dashed lines represent a rejection.

8 Discussion

Having presented the main findings of the tripartite analysis of this thesis, summarized in a triangulation, the final discussion will consist of three different parts. In the first, the research question stated in the beginning of the thesis is going to be answered by picking up results and circumstances of the research. This is done to deliver a conceptual as well as empirical answer. In the second part, three different findings of this thesis will be discussed to demonstrate different ways on how academic theory can profit from the insights of this thesis. Furthermore, a number of practical managerial recommendations, mainly for companies of the manufacturing industries, will be given. In the final step, the limitations part will give some insights about the course of this thesis and highlight weak as well as strong points of the research that is done.

8.1 Answering research question

In the progress of this thesis, the following research question has been tackled:

What are the differential factors from the qualitative literature review and the quantitative literature review regarding the adoption of sustainable process technologies in the manufacturing industries and how does it work in the German context?

In order to answer this question conceptually and therefore focussing especially on the first part of it, current literature was considered. In line with the systematic literature review of Fu et al. (2018) who did this for the quantitative studies, the same procedure was applied for the more qualitative studies, consisting mostly of theoretical articles and cases studies. In the following step, these two were then compared. The findings yielded a variety of smaller differences and similarities between the results in the different literature streams.

Two factors that show similar and important results in both streams are the one of *regulation*, describing coercive means of the state that lead to the adoption of sustainable process technologies on the one hand and *financial costs* of new technologies on the other hand. Furthermore, differences between the influences of the factors of *information uncertainty* and *financial capability* of a company on the adoption are found while the qualitative articles show interesting results for these two. Lastly, two more factors with differential findings over their influences are the *technological capability* of a company and the *firm size* for which especially the quantitative studies showed reasonable effects.

These are the six factors on which the course of this thesis is build up and on which the mixed-methods were applied afterwards. Therefore, the answer on the first part of the research question is, that the factors *regulation, financial costs, information uncertainty, financial capability, technological capability* and *firm size* are the differential factors in the qualitative literature review and the quantitative literature review regarding the adoption of sustainable process technologies in the manufacturing industries.

Regarding the question of the German context, the mixed-method approach was done in a survey-based quantitative analysis and an interview-based qualitative analysis. Thereby, the German 'Bundesländer' of North Rhine-Westphalia and Rhineland-Palatinate were chosen as samples. The results of these analyses were then taking together in a final triangulation, bringing in also the insights from the current literature again and giving final answers on the hypothesis stated in the comparison of the initial literature reviews.

All in all, the factor *information uncertainty* is found to not have a considerable influence on the adoption of sustainable process technologies in the manufacturing industries considering the German context. Contrary, especially the *regulation* in its positive and even more the extended *financial costs* factor in its negative influence are really important findings of the analysis. These two seem to furthermore have an interaction which will be discussed hereafter. The factor *technological capability* shows an important function as being more of a necessary condition for the adoption. This is a similar mechanism to the one found for *financial capability* where the access to a sufficient amount of capital is central. Finally, the *firm size* works as an important pre-condition for other factors that lead towards the adoption and therefore also has an indirect positive influence. This means that four of the factors under consideration have a positive, one a negative and one no effect on the adoption of sustainable process technologies in the German context.

8.2 Theory implications

In this thesis, the question of factors that lead towards the adoption of sustainable process technologies was raised and answered, but which insights remain for the theory on the broader issue of sustainability in the manufacturing industries? Three different striking points that were dealt with in the course of this thesis will be highlighted in this part to give an idea of potential future research and to make aware of underlying structural shortcomings of this and other

studies. The first point that will be focused on is the difference in findings across the qualitative studies on the one hand and the quantitative studies on the other. In a second point, the meaningfulness of focussing on just one aspects of a value chain or final product will be discussed. The last aspect will deal with the balancing function of the factors *regulation* and *financial costs* that was found in the analysis process.

Qualitative vs. Quantitative research

The basis of the triangulation process in this thesis is build up by the differences in qualitative and quantitative studies that are found in the current literature. These differences appear due to the number of articles that differ to a great extend depending on the topic. One example is the factor *financial costs* which yields similar outcomes due to the content but there is only one quantitative article on that topic while six qualitative ones are dealing with this topic. Even more important, also differences in the influences could be found. For example the quantitative studies see positive effects for the factors *financial* and *technological capability*, while multiple qualitative articles describe these as necessary conditions that have to be overcome before a sustainable process technology is adopted. Very similar differences also could be found in the two analyses applied, as the qualitative analysis is almost completely in line with the qualitative literature and the quantitative results also show very similar patterns to those of the studies done before.

These findings point at a more structural problem of the individual research methods that yield those different outcomes. While quantitative methods are applied mostly to generate a generalization of the findings and define an influence direction, qualitative studies are done to reveal influence mechanisms of one or few cases (Barbour, 1999). These advantages of both methods cannot be reached by the contrary approach so that either the detailed mechanisms or the generalizability are suffering and the results are often incomplete. Therefore, depending on the research topic, there is a need to apply both types of methods to gain a more realistic and holistic picture of the problem at stake in a form of triangulation as applied in this thesis (Hurmerinta-Peltomäki & Nummela, 2006; Kinn & Curzio, 2005; Mason, 1993). Such a mixed-method approach seems to be the exception which is also due to the trend of publishing results piecewise and as soon as possible and consolidated mind-sets of researchers and their schools towards a corresponding method (Hurmerinta-Peltomäki & Nummela, 2006).

Therefore, the practice of scientific publications in this matter should be thought through and the choice of the research method should become more dependent on the actual problem at stake than on the mind-set of schools.

Product life cycle assessment

As stated in the beginning of the thesis, sustainable process technologies are one of the two streams in literature dealing with the sustainable technologies in general, while the other stream is considering the sustainability of the final products (del Río González, 2009). Both of them can be means to reach the described SDG goals 12 and 13. Nevertheless, the adoption of a sustainable process technologies is not a guarantee that these goals are actually reached, as this is just a limited consideration of the problem at stake. Some examples are given in the interviews of the qualitative analysis, where a new technology is not more sustainable during the production process but the final product is instead. What would be the evaluation of for example an electric car, where the production process is often way less sustainable than the conventional production and therefore contrary to the SDG goals (Väyrynen & Salminen, 2012) while the final product again is more sustainable (Helmers & Marx, 2012)?

To avoid wrong conclusions about sustainability that are based on a narrowed view on a problem, the whole value chain starting with the sourcing of resources and also including the final usage and disposal of the product should be considered in future research if possible. In that way, partial sustainability improvements for example in one production process at the expense of deteriorations somewhere else can be uncovered. This can be seen as a pre-step and facilitator towards circular economy considerations on a micro-level (Ghisellini, Cialani & Ulgiati, 2016).

Interaction of *Regulation* and *Financial costs*

Another striking result, especially of the qualitative analysis of this thesis, is an interaction effect between the factors *regulation* and *financial costs*. As already mentioned previously, coercive *regulation* pressures seem to have the least influence on Energy/ Material efficient and the highest on CO^2/ Emission reduction technologies. The opposite is the case for the *financial costs* in its extended version, considering the costs of sustainable process technologies in a relation to the benefits they yield which is in line with (Frondel, Horbach, & Rennings, 2007).

In the interviews, the participants pointed out, that all but the CO^2/ Emission reduction and in some cases Recycling technologies are not profitable. This means that the state *regulation* in the German context mostly intervenes into market processes, when the sustainable process technologies do not yield any economic profits on their own and are therefore not implemented by the companies on a voluntary basis. This recognition is similar to those for the Chinese and Dutch case as found by Fu et al. (2018) who make a broader distinction between cost-increasing and cost-decreasing sustainable technologies. Having this mechanism in mind, future research should consider a uniform assessment of these factors instead of regarding them only individually.

8.3 Practical implications

While the theory can learn from the results of this thesis, also advices can be given to companies and authorities that are dealing in this environment. First of all, the examples of firm A and D showed that it can be of advantage to position the company already far in advance above the legal standards that will still be valid over some years while it is not even necessary to be an early adopter of new sustainable process technologies. In doing this, especially smaller companies can focus their capacities on their main operations and do not have to worry about legal issues. A noticeable example for this is firm B that had to get external help for the legal compliance and is furthermore trying to delay certain laws through its association and thereby binding resources. Furthermore, being as material and energy efficient as possible most times also yields financial benefits for companies which justifies an adoption of sustainable process technologies.

Like the results of this thesis have shown, a bigger *firm size* shows correlations with all of the factors that have positive influences on the adoption of sustainable process technologies. Also some of the interviewees pointed out the importance of a company's size in that matter and pointed out the facilitating effects that it can bring. Therefore, companies should strive for expansion as this eases the adoption process in the long-term while short-term effects of growing should be considered.

Besides the mentioned theoretical implication that the assessment of a whole product life cycle yields, it can also be an inspiration for considerations of a stakeholder analysis. Because many stakeholders, including the society, have an interest in the sustainability of a

product and all its attached production processes, the manufacturing industries have to take different aspects into account. Thereby, it is especially important to work closely together with all suppliers in the overall value chain of a certain product to avoid partial improvements at the expense of deteriorations in the overall sustainability result. Like the idea of CO^2 certificates for products, stated by firm A, this would assure that the intended effect of sustainability actions is reached.

As a last point, the manager of firm A also pointed out that current bureaucracy in Germany is a big hindrance for companies to apply for financial support as it takes most times too long and takes thereby most of the benefits especially regarding smaller investments. Therefore, legal authorities should reconsider faster ways of financial support and more room for maneuver for companies in the subsidizing process of sustainable process technologies to achieve faster and more adoptions of these technologies.

8.4 Limitations

In this hindsight, a final evaluation of the strong and weak points, especially of the three different analyses, will be done to give some insights in the progress of the thesis. Regarding the initial systematic literature review of the qualitative studies, the strengths of this approach lie in the explanation of the different influences of the factors and its extensiveness which reduces the bias due to a more objective selection process of relevant articles. Nevertheless, also smaller shortcomings can be seen here due to the fact that the qualitative literature review is based solely on articles that can be found with the Social Science Citation Index, so that there might be more relevant articles that are not mentioned here. Additionally, the selection process of the articles as described in appendix A might have shortcomings and therefore also excluded relevant articles.

The quantitative analysis has its main strength in the reliability and validity of its factors that are composed mostly of multiple indicator variables which together achieve really high Cronbach's Alpha values and are therefore suitable for the analysis. Furthermore, the representation of industries is rather broad and equally given, so that the results do not only account for a specific one. A major weak point is the low number of participants, which is mostly caused by the length of the survey and the limited group of people in a company that is eligible for filling it out in the combination with their shortage in time. This made the actually

planned multiple regression analysis impossible so that only a correlation analysis could be conducted. Another point could be the difficulty of the questions which some participants indicated in the survey.

Finally, the qualitative analysis is also strong in its industry variety and the expertise of the interviewees that could answer almost all of the questions. Also the level of detail explained is comparably high which makes the information valuable to understand the mechanisms that lead to the adoption of sustainable process technologies. A weakness is that the five interviewed companies are all from Rhineland-Palatinate and none from Nord Rhine-Westphalia, which should not yield a difference in the results but is still a point of consideration. Although the aim was to be completely neutral with regard to the interview and the questions asked, it cannot be ruled out that the answers are biased in any direction and would have been different with another set of questions or another interviewee.

Regarding the research ethics, all points stated in the methodology part were complied. Especially due to the insights that were delivered by the five interviews, the anonymity of the participating interviewees and their corresponding companies had a really high importance in the course of this thesis. In this process, all of them received the full transcript of their interview to give the opportunity for corrections and comments. Furthermore, they will receive the thesis hereafter to create a high degree of transparency. Besides them, also the participants of the survey were offered to receive the results and their anonymity was insured. All in all, the triangulation of the mixed-method together with the systematic literature review gives the thesis results a high validity and reliability as it is not too much biased by the choice of one single research method. Some considerable findings that can help developing theory as well as improving operations and regulation processes could be achieved. In this way, the results of the thesis can help to reach the SDG goals 12 and 13.

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Appendices

Appendix A

Steps in the systematic literature review

In order to generate an unbiased literature review, a systematic approach was conducted which makes it possible to compare studies with each other (Cook et al. 1997, Tranfield et al. 2003). Sticking close to the model of Fu et al. (2018), in a first step a key word search was done in the Social Science Citation Index which is based in the Web of Science™ Core Collection of Thomson Reuters. Here, the timespan was set from 1945 until February 2018. As relevant fields, the sections 'environmental studies', 'environmental sciences', 'management' and 'business' were chosen. Furthermore, only articles in the English language were considered. The combination of 'sustainable', 'technology' and 'adoption' together with multiple synonyms were chosen as key words. The following table 1 shows the number of articles that could get generated by every of these search terms:

Table 1

Results of the keywords search

Keywords search results	**no. of articles**
sustainable technology adoption	300
green technology adoption	210
eco technology adoption	57
ecological technology adoption	62
environmental technology adoption	656
clean technology adoption	130
energy-saving technology adoption	58
energy-efficiency technology adoption	123
material-saving technology adoption	1
sustainable technology implementation	289
green technology implementation	123
eco technology implementation	27
ecological technology implementation	63
environmental technology implementation	499

clean technology implementation	107
energy-saving technology implementation	61
energy-efficiency technology implementation	129
material-saving technology implementation	1
	2896

As this keywords search also generates duplications, these had to be filtered out in a following step so that afterwards every article was just represented once. After this step there were 1.698 articles remaining.

Table 2

Filtering out duplications

Filtering out duplications	
Original no. of articles	2896
Duplications	1198
Remaining	**1698**

At this point, exclusion criteria had to be developed. As the number of publications in this field is clearly rising in the last years and because this thesis will rather focus on newer developments, the first criterium was to just include articles that were written within the last 10 years so that all literature that got published before 2008 was excluded which left 1379 articles. The fact that this step excluded only 319 articles, or 18,8 % of the total amount, is a clear indicator that the issue of the sustainable technology adoption became increasingly important for science in the recent years (Fu et al., 2018).

The following four criteria were assessed simultaneously by evaluating the content of the articles. As the first criterium, all articles got sorted out that do not deal with adoption factors for sustainable process technologies. This means that, for example, articles dealing with the influences of the corresponding technologies on other things like company performances were not seen to be relevant. No difference was made whether the technology got purchased or developed by the company itself. In line with the definition of Rogers (2003) the adoption process starts with the sensing of a new technology and ends with the completed integration of

it in the daily work. Articles with a dual focus on processes and products were only considered from their process perspective.

Table 3

Exclusion of articles published before 2008

Publications from 2008 on	
Original no. of articles	1698
Published before 2008	319
Remaining	**1379**

The next criterium is twofold. On the one hand, articles that did not deal with sustainable process technology in the preparation, production or after-production phase were excluded. This means that literature that focusses at, for example, the resulting product and does therefore not deal with the process of its manufacturing were not considered. Furthermore, this criterium excluded everything that did not deal with the manufacturing industry defined by the NACE classification 10-32 (NACE – Klassifikation der Wirtschaftszweige 2008, 2008). This excluded several articles that dealt with for example agriculture, power generation, services, transportation and mobility and it solutions. In total, this criterium was responsiblefor the most exclusions, namely 876.

As a third criterium, the level of the research was considered. Here, only articles at the organizational level could remain as this is the level of interest. With this step, mainly articles were excluded that dealt with the behaviour of individuals or communities towards energy saving and research that dealt with the behaviour of whole regions or countries and not with its organizations.

Finally, in contrast to the review of Fu et al. (2018), all articles that applied a quantitative approach to research the adoption factors got excluded. In some cases, where these articles also included a bigger theoretical part or approached the problem also in a qualitative way, these articles were still considered besides their quantitative analysis. Consequently, there are 27 qualitative or theoretical articles from 2008 on left, which focus on adoption factors for sustainable process technologies in the manufacturing industry on an organizational level.

Table 4

Exclusion by criteria

Exclusion criteria	
Original no. of articles	1379
Not adoption factors	163
Not sustainable process technology or not manufacturing industry	876
Not organizational level	241
Quantitative studies	72
Relevant articles for the literature review	**27**

Appendix B

Table 5

List of articles included in the qualitative literature review

List of articles ID	Article
1	Mathiyazhagan et al. (2013)
2	Ho et al. (2016)
3	Trianni et al. (2013)
4	Zhu & Chertow (2017)
5	Hultman et al. (2012)
6	Bergguist et al. (2013)
7	Rueda et al. (2017)
8	Arens et al. (2017)
9	Cagno et al. (2017)
10	Wiggett & Marcelle (2013)
11	Gil-Moltó & Varvarigos (2013)
12	Caparrós et al. (2013)
13	Rosen (2013)
14	Infante & Smirnova (2016)
15	Li & Hamblin (2016)
16	Nunes et al. (2016)
17	Sloan (2011)
18	Henriques & Catarino (2016)
19	del Río González (2008)
20	Diana et al. (2017)
21	da Silva et al. (2017)
22	Coria & Zhang (2015)
23	Xia et al. (2017)
24	Coria (2009)
25	Förster (2015)
26	Kemp & Volpi (2008)
27	Wu et al. (2014)

Appendix C

Table 6

Coding of the qualitative literature review

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
1	The result of this study shows that Problem in maintaining the environmental awareness of suppliers (B1) barrier is acting as a key barrier for the implementation of GSCM. Industries need to give special attention and first priority to remove this barrier.	1	N	Cooperation	General sustainable technology	Interpretive Structural Modeling (ISM)	Companies
2	In our study, we found that E&E companies emphasized that the customer requirement constitutes a significant barrier that restrains them from practicing material efficiency.	1	N	Customer Demand	Material efficiency	Semi-Structured Interview and Analytical Hierarchy Process	Companies
2	The second barrier in implementing material efficiency is the lack of external support. External support in this study refers to that given by third parties, such as local government, local recyclers, industry experts or consultants.	2	N	Governmental support	Material efficiency	Semi-Structured Interview and Analytical Hierarchy Process	Companies
2	The second barrier in implementing material efficiency is the lack of external support. External support in this study refers to that given by third parties, such as local government, local recyclers, industry experts or consultants.	2	N	Industry initiative	Material efficiency	Semi-Structured Interview and Analytical Hierarchy Process	Companies

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
2	Technology availability in a company is an important factor to enable the efficient use of materials	2	P	Technological capability	Material efficiency	Semi-Structured Interview and Analytical Hierarchy Process	Companies
2	Some of the companies in this study mentioned that the available regulations have limited their choice in selecting an appropriate manufacturing process or alternative materials.	2	N	Regulation	Material efficiency	Semi-Structured Interview and Analytical Hierarchy Process	Companies
2	For manufacturing companies, implementing a new strategy requires investment, especially in terms of purchasing new technology, acquiring permits, and material sourcing.	2	N	Financial cost	Material efficiency	Semi-Structured Interview and Analytical Hierarchy Process	Companies
2	In this study, E&E companies were found to be facing product design restrictions in the implementation of material efficiency. Some E&E manufacturers have difficulty in substituting with recycled materials, as it may influence the product quality and functionality, and may result in reduced demand from consumers.	3	N	Compatibility	Material efficiency	Semi-Structured Interview and Analytical Hierarchy Process	Companies
2	It was found that local suppliers are less capable in terms of supplying green materials. For that reason, E&E manufacturers need to source the green materials from overseas suppliers, which are usually more expensive. One of the reasons is that local suppliers lack the knowledge and technology to produce green materials.	3	N	Cooperation	Material efficiency	Semi-Structured Interview and Analytical Hierarchy Process	Companies

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
2	To achieve material efficiency, engineers need to improve their technical knowledge, especially in terms of the use of materials, product design, and the manufacturing process	3	N	Complementary	Material efficiency	Semi-Structured Interview and Analytical Hierarchy Process	Companies
2	Implementing environmental strategies requires an organization to change in terms of either the context of management or the technical aspects [38]. However, not every change is easy and some changes require complicated adjustments, high cost investment and a strong commitment from the company's stakeholders.	3	N	Innovative capability	Material efficiency	Semi-Structured Interview and Analytical Hierarchy Process	Companies
3	The lack of resources for energy efficiency in terms of time and capital, as expressed by the barriers Lack of budget funding, Other Priorities for Capital Investments, Lack of time and other priorities, and Access to capital.	1	N	Financial capability	Energy Efficiency	Semi-structured interviews supported by a questionnaire	Companies
3	The importance of guaranteeing the continuity of the business, expressed as the relevance of the barriers concerning the cost of production disruption, hassle and inconvenience, and of the barriers related to the technical risks.	1	N	Information uncertainty	Energy Efficiency	Semi-structured interviews supported by a questionnaire	Companies
4	To improve competitiveness incrementally, firms are willing to make moderate changes to their production by incorporating additional energysaving equipment,which is based on their informational, organizational and financing capabilities and driven by policy support and industrial contexts.	1	P	Market competition	Energy Efficiency	Multiple-case design	Companies

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
4	To improve competitiveness incrementally, firms are willing to make moderate changes to their production by incorporating additional energysaving equipment, which is based on their informational, organizational and financing capabilities and driven by policy support and industrial contexts.	1	P	Governmental support	Energy Efficiency	Multiple-case design	Companies
4	To improve competitiveness incrementally, firms are willing to make moderate changes to their production by incorporating additional energysaving equipment,which is based on their informational, organizational and financing capabilities and driven by policy support and industrial contexts.	1	P	Information sources	Energy Efficiency	Multiple-case design	Companies
4	To improve competitiveness incrementally, firms are willing to make moderate changes to their production by incorporating additional energysaving equipment,which is based on their informational, organizational and financing capabilities and driven by policy support and industrial contexts.	1	P	Technological capability construct	Energy Efficiency	Multiple-case design	Companies
4	To improve competitiveness incrementally, firms are willing to make moderate changes to their production by incorporating additional energysaving equipment, which is based on their informational, organizational and financing capabilities and driven by policy support and industrial contexts.	1	P	Financial capability	Energy Efficiency	Multiple-case design	Companies

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
4	To survive or increase market share under strict control of local production capacity, firms bargainwith local authorities and seek a preferred position under local regulation, based on their capabilities and superior performance in energy efficiency. Such performance relies on substantial investment in new, more efficient production facilities and adoption of additional energy-saving devices.	2	P	Regulation	Energy Efficiency	Multiple-case design	Companies
4	To survive or increase market share under strict control of local production capacity, firms bargainwith local authorities and seek a preferred position under local regulation, based on their capabilities and superior performance in energy efficiency. Such performance relies on substantial investment in new, more efficient production facilities and adoption of additional energy-saving devices.	2	P	Information uncertainty	Energy Efficiency	Multiple-case design	Companies
5	Most of the interviewees argued that financial benefits were their primary motivation for undertaking low-carbon CDM projects in both sectors and countries.	3	P	Relative advantage	CO^2/ Emission reduction	Interviews from multiple plants in two sectors in two countries	Plant level
5	Some managers identified non-financial reputational factors as their primary motivation for pursuing CDM projects.	3	P	Internal support	CO^2/ Emission reduction	Interviews from multiple plants in two sectors in two countries	Plant level
5	Under fluctuating regulatory regimes with real immediate costs and uncertain CDM revenue, managers favored projects that often did not require carbon revenue to be viable.	3	N	Information uncertainty	CO^2/ Emission reduction	Interviews from multiple plants in two sectors in two countries	Plant level

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
6	The empirical findings in this paper suggest that the Swedish regulatory approach comprised many of the key elements of an efficient policy-induced transition towards radically lower emissions in the industrial sector.	1	P	Regulation	CO^2/ Emission reduction	Case Study	Companies
7	Enforcement of social and environmental regulations at countries of origin is a key factor that deters companies from adopting very strict standards, even if they have a brand value to enhance. Companies such as Mars or Starbucks face weak institutions in countries in West and East Africa that prevent them from introducing very strict standards.	2	N	Regulation	General sustainable technology	Case Study	Companies
7	Companies with available cleaner technologies, effective law enforcement and control over the supply chains, as well as a brand to protect, can capitalize on their environmental efforts by introducing strict standards, such as third-party certifications.	3	P	Voluntary standard	General sustainable technology	Case Study	Companies
8	Economics are a key driver for the diffusion of EETs. The diffusion of the selected EETs rarely happened at payback periods above 3 years.	1	N	Relative advantage	Energy Efficiency	Case Study	Companies
8	Access to capital is also a key barrier, mentioned both in literature and by the interviewees. Good and bad economic prospects on the national or global level and as for the company determine how easily or not a company can access capital.	1	N	Financial capability	Energy Efficiency	Case Study	Companies

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
8	The case of TRT at Hamborn 8 seems to have been impacted by policy intervention. Several members of ThyssenKrupp claim that the blast furnace would not have been equipped with TRT if the company had not faced pressure from the local government.	3	P	Regulation	Energy Efficiency	Case Study	Companies
8	In this analysis, four out of five cases that have not implemented a selected EET yet (Table 5) put forward site-specific constraints as a key barrier.	2	N	Technological capability construct	Energy Efficiency	Case Study	Companies
9	Economic barriers constitute by far the largest barriers to energy efficiency.	3	N	Financial capability	Energy Efficiency	Multiple-case study methodology (Empirical)	Companies
9	In second place, we can find behavioural barriers, such as other priorities and lack of interest in energy efficiency issues.	3	N	Internal support	Energy Efficiency	Multiple-case study methodology (Empirical)	Companies
9	That in the third position we find the barrier lack of awareness.	3	N	Technology substitutes	Energy Efficiency	Multiple-case study methodology (Empirical)	Companies
9	Our findings seem to suggest that enterprises recognize the primary relevance of economic drivers, such as information about real energy costs.	3	P	Relative advantage	Energy Efficiency	Multiple-case study methodology (Empirical)	Companies

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
9	Additionally, interviewees have pointed out the need of having trustworthy, clear and available information (average score of 3.53, 3.52 and 3.32, respectively). Indeed, standardizing the set of information offered to companies appears as a strong driver for EEMs adoption, reducing the time by decision-makers to analyse gathered information.	3	P	Information sources	Energy Efficiency	Multiple-case study methodology (Empirical)	Companies
10	Almost 80% of the 28 firms are motivated by regulations, in particular, international regulations. In addition to being the most frequently reported motivating factor, the policy and regulatory framework was considered to be most important.	2	P	Regulation	General sustainable technology	mixed methods approach	Companies
10	The coded qualitative responses describe most frequently the lack of mandatory environmental regulations and low awareness amongst customers and employees in South Africa as hindering the practice of ecodesign.	2	N	Regulation	General sustainable technology	mixed methods approach	Companies
10	The coded qualitative responses describe most frequently the lack of mandatory environmental regulations and low awareness amongst customers and employees in South Africa as hindering the practice of ecodesign.	2	N	Customer demand	General sustainable technology	mixed methods approach	Companies

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
10	The coded qualitative responses describe most frequently the lack of mandatory environmental regulations and low awareness amongst customers and employees in South Africa as hindering the practice of ecodesign.	2	N	Technology substitutes	General sustainable technology	mixed methods approach	Companies
10	More important in hindering firms were conflicts with product requirements and costs which outweighed benefits.	2	N	Financial costs	General sustainable technology	mixed methods approach	Companies
10	More important in hindering firms were conflicts with product requirements and costs which outweighed benefits.	2	N	Compatibility	General sustainable technology	mixed methods approach	Companies
11	This reduction in demand due to consumers' environmental activities generates incentives for firms to adopt the clean technology even in the absence of emissions taxes or technology spillovers.	3	P	Customer demand	General sustainable technology	Theoretical	Companies
12	An emission trading system lowers emissions by reducing production and by improving abatement technologies.	3	P	Regulation stakeholder	General sustainable technology	Theoretical	Companies
12	We have shown that increasing labor market rigidity it is possible to maintain output and to favor advanced technology adoption.	3	P	Market competition	General sustainable technology	Theoretical	Companies
13	Regulatory requirements are most likely to influence organizations' use of green design practices and procedures	2	P	Regulation	General sustainable technology	Extensive survey of engineers and engineering students	Individuals asked about company behaviour

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
13	Client demand was cited as the second most likely factor	2	P	Customer demand	General sustainable technology	Extensive survey of engineers and engineering students	Individuals asked about company behaviour
13	Rising energy costs was also indicated to be significant factor.	2	P	Resource price	General sustainable technology	Extensive survey of engineers and engineering students	Individuals asked about company behaviour
13	Rising energy costs was also indicated to be significant factor.	2	P	Resource cost	General sustainable technology	Extensive survey of engineers and engineering students	Individuals asked about company behaviour
14	In particular, the model shows that reinforcing the rule of law actually leads to an enlargement of the production sector opting for environmentally friendly technologies, increasing social welfare.	3	P	Regulation	General sustainable technology	Theoretical	Companies
15	The questionnaire results clearly indicate that the companies having the ISO14001 certification are more likely to be one step ahead in actively pursuing cleaner production.	1	P	Certified systems	General sustainable technology	Case Study	Companies
15	It is important to conclude that it is an environmentally-friendly culture which makes the difference in terms of the companies' cleaner production, besides ISO14001 certification	2	P	Internal support	General sustainable technology	Case Study	Companies
16	The main objectives for manufacturing and facilities management continue to be compliance with environmental legislation and cost reduction.	1	P	Regulation	General sustainable technology	Case Study	Company

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
16	The main objectives for manufacturing and facilities management continue to be compliance with environmental legislation and cost reduction.	1	P	Relative advantage	General sustainable technology	Case Study	Company
16	Being part of a larger international automotive group, Waltham had access to greater investment to improve the old infrastructure and (consequently) environmental performance.	1	P	Financial capability	General sustainable technology	Case Study	Company
16	The extended payback (5 years) benefits the adoption of environmentally friendly technologies when they do not meet short-term return on investment goals.	2	P	Market competition	General sustainable technology	Case Study	Company
16	Waltham has recently had access to the database for sharing knowledge with other companies in the group. This increased environmental awareness applies pressure to be more competitive and to reduce costs further.	2	P	Membership	General sustainable technology	Case Study	Company
17	The second main lesson from this study is that penalties and incentives can have a significant impact on behaviour.	3	P	Governmental support	General sustainable technology	Theoretical	Companies
17	The second main lesson from this study is that penalties and incentives can have a significant impact on behaviour.	3	P	Regulation	General sustainable technology	Theoretical	Companies
18	It was found that in Portuguese enterprises barriers vary considerably by sector: for manufacturers they include perceived cost and risk of production disruption, lack of time, the cost of obtaining information, competing priorities for capital investments, and information or incentive gaps.	3	N	Financial costs	Energy Efficiency	Questionnaire	Companies

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
18	It was found that in Portuguese enterprises barriers vary considerably by sector: for manufacturers they include perceived cost and risk of production disruption, lack of time, the cost of obtaining information, competing priorities for capital investments, and information or incentive gaps.	3	N	Information uncertainty	Energy Efficiency	Questionnaire	Companies
18	It was found that in Portuguese enterprises barriers vary considerably by sector: for manufacturers they include perceived cost and risk of production disruption, lack of time, the cost of obtaining information, competing priorities for capital investments, and information or incentive gaps.	3	N	Innovative capability	Energy Efficiency	Questionnaire	Companies
18	It was found that in Portuguese enterprises barriers vary considerably by sector: for manufacturers they include perceived cost and risk of production disruption, lack of time, the cost of obtaining information, competing priorities for capital investments, and information or incentive gaps.	3	N	R&D or expert	Energy Efficiency	Questionnaire	Companies
18	It was found that in Portuguese enterprises barriers vary considerably by sector: for manufacturers they include perceived cost and risk of production disruption, lack of time, the cost of obtaining information, competing priorities for capital investments, and information or incentive gaps.	3	N	Market competition	Energy Efficiency	Questionnaire	Companies

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
18	It was found that in Portuguese enterprises barriers vary considerably by sector: for manufacturers they include perceived cost and risk of production disruption, lack of time, the cost of obtaining information, competing priorities for capital investments, and information or incentive gaps.	3	N	Information sources	Energy Efficiency	Questionnaire	Companies
18	It was found that in Portuguese enterprises barriers vary considerably by sector: for manufacturers they include perceived cost and risk of production disruption, lack of time, the cost of obtaining information, competing priorities for capital investments, and information or incentive gaps.	3	N	Governmental support	Energy Efficiency	Questionnaire	Companies
19	This paper has shown that, under certain conditions, there might be conflicts and trade-offs between short-term and long-term emissions mitigation because, in a situation where currently expensive technologies have a large potential for cost reductions through learning effects and R&D investments, the implementation of incentive-based mitigation policies, such as tradable permits, will encourage the diffusion of currently low-cost abatement technologies, but provides a small incentive to make the diffusion of expensive ones attractive, which is a necessary condition for these technologies to realise their cost-reduction potential through learning effects.	3	N	Regulation stakeholder	CO^2/ emission reduction	Theoretical	Companies

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
20	Alpha and Beta confirmed that support from the senior management team is vital for a new technology or new practice to be well implemented.	1	P	Internal support	CO^2/ emission reduction	Case Study	Companies
20	Alpha and Beta confirmed that support from the senior management team is vital for a new technology or new practice to be well implemented.	1	P	Internal support	Energy Efficiency	Case Study	Companies
20	A factor related to the involvement of employees, but which was not expected, is the empowerment factor. Both companies proved to have their employees involved in the process of implementation and to have given them some autonomy to change the application of these technologies, as well as the opportunity to improve them. In this way the employees were motivated to work better and to better adapt to changes, and thus, satisfaction with the work performed was higher.	1	P	Complementary	Energy Efficiency	Case Study	Companies
20	A factor related to the involvement of employees, but which was not expected, is the empowerment factor. Both companies proved to have their employees involved in the process of implementation and to have given them some autonomy to change the application of these technologies, as well as the opportunity to improve them. In this way the employees were motivated to work better and to better adapt to changes, and thus, satisfaction with the work performed was higher.	1	P	Complementary	CO^2/ emission reduction	Case Study	Companies

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
20	In the context of an environmental cultural change, environmental communication is one factor that was common to the two companies and confirmed by both.	1	P	Cooperation	CO^2/ emission reduction	Case Study	Companies
20	In the context of an environmental cultural change, environmental communication is one factor that was common to the two companies and confirmed by both.	1	P	Cooperation	Energy Efficiency	Case Study	Companies
20	A company whose environmental culture is solid probably makes use of environmental practices as well as technologies. This facilitates the implementation of any other practice or environmental technology that may be necessary, making the process easy, fast, and smooth.	1	P	Corporate social responsibility	CO^2/ emission reduction	Case Study	Companies
20	Another factor confirmed by the two companies is the environmental training factor. Without the proper training of its staff, a company cannot make effective use of any environmental technology or practice adopted, and therefore, it will be useless and a waste of resources in the long run.	2	P	Quality	CO^2/ emission reduction	Case Study	Companies
20	Another factor confirmed by the two companies is the environmental training factor. Without the proper training of its staff, a company cannot make effective use of any environmental technology or practice adopted, and therefore, it will be useless and a waste of resources in the long run.	2	P	Quality	Energy Efficiency	Case Study	Companies

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
21	The lack of incentive policies for the deployment of clean technologies (RF2) was considered by 97.30% to be a Restrictive Factor, with 2.70% disagreeing.	1	N	Governmental support	General sustainable technology	Questionnaire	Companies
21	As for the uncertainty of the energy future due to a lack of clarity about the generation and distribution of energy (RF4), 89.19% agreed, 2.70% disagreed and the remaining 8.11% were indifferent to this matter	1	N	Information uncertainty	General sustainable technology	Questionnaire	Companies
21	The instability generated by the non-continuity of public policies (RF3) obtained 81.08% agreement, 10.81% disagreement and 8.11% indifference.	1	N	Governmental support	General sustainable technology	Questionnaire	Companies
21	It is observed that 59.46% answered that legislation is deficient or its application is inadequate (RF1); 2.7% disagreed; and 37.84% were indifferent.	1	N	Regulation	General sustainable technology	Questionnaire	Companies
21	It was agreed by 100% of respondents that the absence of financial incentives for the introduction of clean technologies (RF10) constitutes a Restrictive Factor.	1	N	Economic support	General sustainable technology	Questionnaire	Companies
21	The cost of capital also obtained 100% agreement, as represented by the high interest rates (RF11)	1	N	Financial capability	General sustainable technology	Questionnaire	Companies
21	The unfavorable economic moment (RF13) obtained 91.89% agreement, 5.41% indifference and 2.70% disagreement	1	N	Market competition	General sustainable technology	Questionnaire	Companies

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
21	The reduction in cash flow due to the cooling of the market with little sale of ceramic products (RF7) obtained a concordance of 86.49%, with a difference of 8.11%, and 5.41% considered it indifferent.	1	N	Market competition	General sustainable technology	Questionnaire	Companies
21	As observed, 81.08% agreed that the initial cost of investment being high may not be supported by the company (RF6), and 18.92% considered it insignificant.	1	N	Financial cost	General sustainable technology	Questionnaire	Companies
21	The lack of knowledge about the economics generated by the implementation of clean technology, i.e., the cost benefit generated (RF12), obtained 64.86% agreement, while 24.32% were indifferent and 10.81% disagreed.	1	N	Information uncertainty	General sustainable technology	Questionnaire	Companies
21	Considering the possibility of the implementation of clean technologies leading to disruption of production in factories and increased cost was considered to be restrictive (RF14), 51.35% agreed, 35.14% disagreed and 13.51% considered this Factor unimportant.	1	N	Relative advantage	General sustainable technology	Questionnaire	Companies
21	Regarding the teaching and research infrastructure, considering the few centers of research and development for the ceramist sector (RF18), the respondents agreed 100%.	1	N	R&D or expert	General sustainable technology	Questionnaire	Companies
21	One-hundred percent of respondents also agreed with the lack of technical knowledge (RF19) being a Restrictive Factor.	1	N	Technology substitutes	General sustainable technology	Questionnaire	Companies

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
21	One-hundred percent of respondents also agreed with the lack of technical knowledge (RF19) being a Restrictive Factor.	1	N	Adoption expertise	General sustainable technology	Questionnaire	Companies
21	It is observed that the lack of specialists and skilled labor (RF16) was considered to be a Restrictive Factor by 91.89%; 8.11% considered it insignificant.	1	N	R&D or expert	General sustainable technology	Questionnaire	Companies
21	As for the internal infrastructure not allowing the necessary changes at reduced costs when expressive values are required (RF20), 91.89% agree with this Factor being restrictive, and 8.11% consider it insignificant.	1	N	Technological capability construct	General sustainable technology	Questionnaire	Companies
21	The lack of technological information about the segment of ceramic industries and possible improvements with the implementation of clean technologies, (RF17) obtained 62.16% agreement, 27.03% disagreement and 10.81% indifference.	1	N	Information sources	General sustainable technology	Questionnaire	Companies
21	Of the respondents, 78.38% considered the lack of knowledge about clean technology by entrepreneurs (RF24) to be a Restrictive Factor; 13.51% disagreed, and 8.11% considered it insignificant.	1	N	R&D or expert	General sustainable technology	Questionnaire	Companies
21	Likewise, the lack of awareness about the importance of reducing energy consumption, coupled with a low valuation of this input (RF22), was agreed with by 59.46% and disagreed with by 40.54%.	1	N	Relative advantage	Energy Efficiency	Questionnaire	Companies

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
22	The fact that the technology adoption rate is influenced by monitoring strategy is good news for a regulator who wants to achieve a given level of aggregate emissions but has political constraints on the level of the emission standard to be imposed.	3	P	Regulation	CO^2/ emission reduction	Theoretical	Companies
23	But eventually it is the intuitive motivation of the enterprises themselves, triggered by the market, that boosts them to achieve competitive advantage as well as sustainability through adoption of green technology, which is consistent with previous research.	3	P	Market competition	General sustainable technology	Theoretical	Companies
24	The study concludes that when the output demand is more elastic, the regulator speeds up technological diffusion by using auctioned permits instead of emission taxes or freely allocated permits.	3	P	Regulation stakeholder	CO^2/ emission reduction	Theoretical	Companies
25	In general, the main driver for implementing developments is cost-reduction, achieved by either resource or energy savings.	2	P	Relative advantage	Energy/ Material efficiency	Delphi foresight method	Industry level for different kind of firm sizes
25	Furthermore, customer demands and legal stipulations will positively affect the adaptation of new technologies or processes.	2	P	Customer demand	General sustainable technology	Delphi foresight method	Industry level for different kind of firm sizes
25	Furthermore, customer demands and legal stipulations will positively affect the adaptation of new technologies or processes.	2	P	Regulation	General sustainable technology	Delphi foresight method	Industry level for different kind of firm sizes

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
25	Large investments necessary to adapt production changes will negatively affect the implementation of new technologies.	2	N	Financial cost	General sustainable technology	Delphi foresight method	Industry level for different kind of firm sizes
25	The size of the company is expected to be of high relevance: larger automotive suppliers have the financial means to invest.	2	P	Firm size	General sustainable technology	Delphi foresight method	Industry level for different kind of firm sizes
26	One reason for this is that environmental policies and the implementation thereof differ between regions and nations. This means that clean technologies will thus diffuse at different rates in countries, as shown by the example of fuel injection.	3	P	Regulation	General sustainable technology	Literature review	Companies
26	For clean processes, sunk cost effects are found to play an important role delaying the diffusion of new processes or leading adopters to choose end-of-pipe solutions	3	N	Technological substitutes	General sustainable technology	Literature review	Companies
26	For clean processes, sunk cost effects are found to play an important role delaying the diffusion of new processes or leading adopters to choose end-of-pipe solutions	3	P	Technological substitutes	Emission reduction	Literature review	Companies
26	Regulation is important especially for end-of-pipe technologies but also for cleaner processes.	3	P	Regulation	Emission reduction	Literature review	Companies
26	Regulation is important especially for end-of-pipe technologies but also for cleaner processes.	3	P	Regulation	Energy/ Material Efficiency	Literature review	Companies

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
26	Either way, diffusion requires knowledge exchange and is tied up with innovation, in the company and in organizations outside the innovating company.	3	P	Cooperation	General sustainable technology	Literature review	Companies
26	Economic aspects will be especially important for new processes because of the high investment costs and product quality consequences.	3	N	Financial cost	General sustainable technology	Literature review	Companies
26	Together this suggests that technologically advanced companies with environmental management systems are more likely to adopt a clean technology owing to their greater receptivity or ‘‘absorptive capacity’’ for clean technology.	3	P	Environmental practice	General sustainable technology	Literature review	Companies
26	On the other hand, the expectation of further improvements in the quality-price ratio may induce some adopters to delay their purchase.	3	N	Financial cost	General sustainable technology	Literature review	Companies
26	Risk-averse adopters are reluctant to buy a more expensive innovation even if the expected benefits from the usage of the innovation are correspondingly higher.	3	N	Market competition	General sustainable technology	Literature review	Companies
27	Our analysis suggests that equipment investment decisions are based on a combination of factors including financial considerations (ROI), long-term production projections, and the strategic factors of competitiveness and institutional pressures.	2	P	Relative advantage	Energy Efficiency	Case Study	Companies

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
27	Our analysis suggests that equipment investment decisions are based on a combination of factors including financial considerations (ROI), long-term production projections, and the strategic factors of competitiveness and institutional pressures.	2	P	Environmental practice	Energy Efficiency	Case Study	Companies
27	Our analysis suggests that equipment investment decisions are based on a combination of factors including financial considerations (ROI), long-term production projections, and the strategic factors of competitiveness and institutional pressures.	2	P	Market competition	Energy Efficiency	Case Study	Companies
27	Our analysis suggests that equipment investment decisions are based on a combination of factors including financial considerations (ROI), long-term production projections, and the strategic factors of competitiveness and institutional pressures.	2	P	Regulation	Energy Efficiency	Case Study	Companies
27	As the next section explains, state-owned companies' investment decisions tend to be driven and supported by government policies, whereas the non-state-owned companies are more cost-driven.	2	P	Public owned	Energy Efficiency	Case Study	Companies
27	As the next section explains, state-owned companies' investment decisions tend to be driven and supported by government policies, whereas the non-state-owned companies are more cost-driven.	2	P	Private owned	Energy Efficiency	Case Study	Companies

ID	Quote	Relative importance	Coding	Determinants	STA (DV)	Methodology Type of analysis	Unit of analysis
27	Non-state-owned suppliers are influenced by primarily their key Western buyers and are thus more prudent in equipment-oriented EE initiatives due to lack of external support.	2	P	Customer demand	Energy Efficiency	Case Study	Companies

Appendix D

Table 7

Used questions of the survey questionnaire

Concept	ITEM	Variable type	Measurement level	No categories	Left category	Right category	Scale based on
Descriptives	Please indicate in which industry is your firm's main activity	numeric	ordinal	Pulp, paper and print; iron and steel; non-metallic minerals; chemical and pharmaceutical; non-ferrous metal; petroleum refineries; food and beverage; machinery; other			Fu et al. (2018)
Descriptives	Firm Address	numeric	ordinal	OPEN			Fu et al. (2018)
Descriptives	In which department do you work in your firm?	numeric	ordinal	Production department; Financial department; Environmental protection department; Equipment power department; Sales department; Purchasing department; Human resources department; CEO or owner; Others			Fu et al. (2018)
Descriptives	How many years have you been working in this industry?	numeric	ordinal	OPEN			Fu et al. (2018)
Sustainable Technology	End-of-pipe technology to remove CO2 emission or air pollutants at the last stage of production	numeric	ordinal	Not applicable to our firm; No, no plan; No, we are preparing for decision making; Yes, we are in the process of implementation; Yes, we are utilizing it			Fu et al. (2018)

Concept	ITEM	Variable type	Measurement level	No categories	Left category	Right category	Scale based on
Sustainable Technology	Reuse of the waste materials in the same process or for another useful application within the firm;	numeric	ordinal	Not applicable to our firm; No, no plan; No, we are preparing for decision making; Yes, we are in the process of implementation; Yes, we are utilizing it			Fu et al. (2018)
Sustainable Technology	Transformation of previously discarded waste into materials that can be reused or recycled for another application outside the firm;	numeric	ordinal	Not applicable to our firm; No, no plan; No, we are preparing for decision making; Yes, we are in the process of implementation; Yes, we are utilizing it			Fu et al. (2018)
Sustainable Technology	Use of recycled water or use water-saving technology	numeric	ordinal	Not applicable to our firm; No, no plan; No, we are preparing for decision making; Yes, we are in the process of implementation; Yes, we are utilizing it			Fu et al. (2018)
Sustainable Technology	End-of-pipe technology to remove water or soil pollutants at the last stage of production	numeric	ordinal	Not applicable to our firm; No, no plan; No, we are preparing for decision making; Yes, we are in the process of implementation; Yes, we are utilizing it			Fu et al. (2018)
Sustainable Technology	Modification of the production equipment, working procedures, machine instructions etc. to increase the efficiency of material use (e.g. less material, minimize waste)	numeric	ordinal	Not applicable to our firm; No, no plan; No, we are preparing for decision making; Yes, we are in the process of implementation; Yes, we are utilizing it			Fu et al. (2018)

Concept	ITEM	Variable type	Measurement level	No categories	Left category	Right category	Scale based on
Sustainable Technology	Modification of the production equipment, working procedures, machine instructions etc. to increase the efficiency of energy use	numeric	ordinal	Not applicable to our firm; No, no plan; No, we are preparing for decision making; Yes, we are in the process of implementation; Yes, we are utilizing it			Fu et al. (2018)
Sustainable Technology	Modification of the production equipment, working procedures, machine instructions etc. to reduce only emission generation	numeric	ordinal	Not applicable to our firm; No, no plan; No, we are preparing for decision making; Yes, we are in the process of implementation; Yes, we are utilizing it			Fu et al. (2018)
Sustainable Technology	Fuel substitution from coal or oil to natural gas or biomass	numeric	ordinal	Not applicable to our firm; No, no plan; No, we are preparing for decision making; Yes, we are in the process of implementation; Yes, we are utilizing it			Fu et al. (2018)
Sustainable Technology	Transition from producing gray electricity to green electricity based on solar, wind or water	numeric	ordinal	Not applicable to our firm; No, no plan; No, we are preparing for decision making; Yes, we are in the process of implementation; Yes, we are utilizing it			Fu et al. (2018)
Sustainable Technology	Replacement of hazardous or non-renewable inputs by less hazardous or renewable materials (e.g. biodegradable)	numeric	ordinal	Not applicable to our firm; No, no plan; No, we are preparing for decision making; Yes, we are in the process of implementation; Yes, we are utilizing it			Fu et al. (2018)

Concept	ITEM	Variable type	Measurement level	No categories	Left category	Right category	Scale based on
Sustainable Technology	Replacement of materials by recycled materials	numeric	ordinal	Not applicable to our firm; No, no plan; No, we are preparing for decision making; Yes, we are in the process of implementation; Yes, we are utilizing it			Fu et al. (2018)
Coercive Pressures	National environmental regulations (such as China environmental protection law; China Environmental Impact Assessment Law; China clean production promotion law, China circular economy Promotion law)	numeric	metric	7	Not at all	Extensive knowledge	Fu et al. (2018)
Coercive Pressures	Industrial associations have urged us to conform to environmental policies	numeric	metric	7	Never	Very frequently	Fu et al. (2018)
Coercive Pressures	We have voluntary agreements with governmental agencies concerning our environmental performance	numeric	metric	7	Never	Very frequently	Fu et al. (2018)

Concept	ITEM	Variable type	Measurement level	No categories	Left category	Right category	Scale based on
Coercive Pressures	We have specialized personnel to deal with the environmental policies	numeric	ordinal	No, we have not employed people to deal with environmental policies; No, we have 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			Fu et al. (2018)
Coercive Pressures	The changes in environmental policies to ensure that we meet every requirement	numeric	metric	7	Never	Every time	Fu et al. (2018)
Coercive Pressures	When we are planning to update equipment, we take environmental policies into account	numeric	metric	7	Never	Every time	Fu et al. (2018)
Coercive Pressures	We apply for subsidies relating to sustainable technology	numeric	metric	7	Never	Every time	Fu et al. (2018)
Coercive Pressures	When external experts or consulting firms give suggestions, they always take environmental issues into account	numeric	metric	7	Not agree at all	Strongly agree	Fu et al. (2018)

Concept	ITEM	Variable type	Measurement level	No categories	Left category	Right category	Scale based on
Coercive Pressures	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)	numeric	metric	7	Not at all	Extensive knowledge	Fu et al. (2018)
Coercive Pressures	Regional (provincial and municipal) resource saving and conservation regulations (circular economy, cleaner production etc.)	numeric	metric	7	Not at all	Extensive knowledge	Fu et al. (2018)
Coercive Pressures	It is a common view in the firm that the environmental policies will be stricter in the future	numeric	metric	7	Not agree at all	Strongly agree	Fu et al. (2018)
Coercive Pressures	Current subsidy schemes for sustainable technology alleviate the financial burden when investing in these technologies	numeric	metric	7	Not at all	Very much	Fu et al. (2018)
Coercive Pressures	On average, the environmental taxation and/or polluting discharge fees are higher than the cost of pollution treatment	numeric	metric	7	Not at all	Very much	Fu et al. (2018)
Coercive Pressures	The requirements for various environmental indicators are difficult to	numeric	metric	7	Not at all	Very much	Fu et al. (2018)

Concept	ITEM	Variable type	Measurement level	No categories	Left category	Right category	Scale based on
	meet in the Environmental Impact Assessment						
Coercive Pressures	We have got on-site environmental inspection or environmental audits by public authorities	numeric	metric	7	Never	Very frequently	Fu et al. (2018)
Coercive Pressures	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	numeric	metric	7	Not agree at all	Strongly agree	Fu et al. (2018)
Financial Costs	The up-front costs of the sustainable technologies are comparably expensive.	numeric	metric	7	Not agree at all	Strongly agree	Sangle (2011)
Financial Costs	The running costs of the sustainable technologies are comparably expensive.	numeric	metric	7	Not agree at all	Strongly agree	Sangle (2011)
Financial Costs	The trainingscosts of the sustainable technologies are comparably expensive.	numeric	metric	7	Not agree at all	Strongly agree	Sangle (2011)
Financial Costs	The Return on Investment of the sustainable technologies is comparably high.	numeric	metric	7	Not agree at all	Strongly agree	Sangle (2011)
Financial Costs	The implementation of sustainable technologies in the current production	numeric	metric	7	Not agree at all	Strongly agree	Arvanitis & Ley (2013)

Concept	ITEM	Variable type	Measurement level	No categories	Left category	Right category	Scale based on
	process is comparably expensive.						
Information Uncertainty	The actual performance of sustainable technologies is accurately assessed already before the adoption.	numeric	metric	7	Not agree at all	Strongly agree	Arvanitis & Ley (2013)
Information Uncertainty	The future cost development of sustainable technologies has a high importance within the decision making process.	numeric	metric	7	Not agree at all	Strongly agree	Arvanitis & Ley (2013)
Information Uncertainty	The possible competitor behaviour towards sustainable technologies is accurately analyzed within my company.	numeric	metric	7	Not agree at all	Strongly agree	Weng & Lin (2011)
Information Uncertainty	The customer behaviour towards sustainable technologies is analyzed extensively by my company in advance (e.g. market research).	numeric	metric	7	Not agree at all	Strongly agree	Weng & Lin (2011)
Information Uncertainty	My company is constantly analysing beginning early developments in the social-economic environment in order to react on them.	numeric	metric	7	Not agree at all	Strongly agree	Schäffer (2007)

Concept	ITEM	Variable type	Measurement level	No categories	Left category	Right category	Scale based on
Information Uncertainty	My company is constantly analysing early changes in the social-political environment in order to react on them.	numeric	metric	7	Not agree at all	Strongly agree	Schäffer (2007)
Information Uncertainty	My company has an effective defined system to attain important information for the decision making process.	numeric	metric	7	Not agree at all	Strongly agree	Schäffer (2007)
Information Uncertainty	The technology in our industry is changing fast.	numeric	metric	7	Not agree at all	Strongly agree	Schäffer (2007)
Information Uncertainty	Our reporting contains non-financial key figures (e.g. market development, innovation rate etc.) as a supplement to financial data.	numeric	metric	7	Not agree at all	Strongly agree	Schäffer (2007)
Financial Capability	How high is the profit of your firm as a percentage of sales after taxes (Net profit margin)?	numeric	metric	8	negative, 0-3%, 3.1-5%, 5.1-10%, 10.1-20%,		Luken et al. (2008)

Concept	ITEM	Variable type	Measurement level	No categories	Left category	Right category	Scale based on
					20.1-30%, higher than 30% I do not want to answer this		
Financial Capability	How high is the market share of your company in the main industry as a percentage?	numeric	metric	8	negative, 0-3%, 3.1-5%, 5.1-10%, 10.1-20%, 20.1-30%, higher than 30% I do not want to answer this		Luken et al. (2008)
Financial Capability	What is the liquidity of your company? (Current Ratio=liquid assets / current liabilities * 100%)	numeric	metric	8	negative, 0-3%, 3.1-5%, 5.1-10%,		Arvanitis & Ley (2013)

Concept	ITEM	Variable type	Measurement level	No categories	Left category	Right category	Scale based on
					10.1-20%, 20.1-30%, higher than 30% I do not want to answer this		
Financial Capability	How high is the net cash flow of your company around?	numeric	metric	OPEN			
Financial Capability	My company has access to sufficient capital to invest into sustainable technologies.	numeric	metric	7	Not agree at all	Strongly agree	
Financial Capability	The financing costs of my company are high.	numeric	metric	7	Not agree at all	Strongly agree	
Firm size	What is your firm's annual turnover?	numeric	ordinal	5	0-0.5 million; 0.5-2; 2-10; 10-50; More than 50		Fu et al. (2018)
Firm size	Number of employees in the whole firm	numeric	ordinal	7	0-19; 20-49; 50-99; 100-249;		Fu et al. (2018)

Concept	ITEM	Variable type	Measurement level	No categories	Left category	Right category	Scale based on
					250-499; 500-999; 1000 or more		
Technological Capability	My company exercises a systematic and extensive search for new technologies.	numeric	metric	7	Not agree at all	Strongly agree	Luken et al. (2008)
Technological Capability	There are enough technically specialized employees in my company.	numeric	metric	7	Not agree at all	Strongly agree	Luken et al. (2008)
Technological Capability	In my company there is an extensive quality management system.	numeric	metric	7	Not agree at all	Strongly agree	Luken et al. (2008)
Technological Capability	The production technology in my company is working on a really advanced level.	numeric	metric	7	Not agree at all	Strongly agree	Luken et al. (2008)
Technological Capability	My company carried out a lot of changes in the production technology over the last 12 months.	numeric	metric	7	Not agree at all	Strongly agree	Luken et al. (2008)
Technological Capability	How long is the average warranty claim of your products?	numeric	metric	OPEN			Luken et al. (2008)

Concept	ITEM	Variable type	Measurement level	No categories	Left category	Right category	Scale based on
Technological Capability	The share of rejected goods from the overall production is really high.			7	Not agree at all	Strongly agree	
Technological Capability	The number of linkages with other firms, technology centres and Universities is really high.	numeric	metric	7	Not agree at all	Strongly agree	Luken et al. (2008)
Technological Capability	My company performs most of the R&D activities itself.	numeric	metric	7	Not agree at all	Strongly agree	Arvanitis & Ley (2013)
Technological Capability	Lack of technological know-how was responsible for problems or delays in the implementation process of sustainable technology in the past.	numeric	metric	7	Not agree at all	Strongly agree	

Appendix E

Table 8

Measurement models of the six independent factors

Regulation		
Variable	**Mean**	**Std. Deviation**
EnvironRegulation	5,18	1,610
IndustRegulPressure	2,15	1,642
VoluntAgreements	2,76	1,855
EnvironEmployees	2,95	2,137
EnvironPolicyChanges	3,39	1,676
EquipmentRegulation	5,45	1,622
SubsidiesApplication	3,06	2,076
EnergyEmissionRegul	4,64	1,817
CleanProduction	4,58	1,904
StrictFutureRegul	5,21	1,709
SubsidiesSupport	3,45	2,265
Tax/SolutionCosts	3,48	1,482
HardRequirements	3,84	1,241
Audits	3,24	2,194
GovernmentControl	5,03	1,531
	Cronbach's Alpha	**0,833**
Financial costs		
Variable	**Mean**	**Std. Deviation**
PreliminaryCosts	4,75	1,136
RunningCosts	3,94	1,501
TrainingCosts	3,94	1,389
IntegrationCosts	4,50	1,566
	Cronbach's Alpha	**0,797**

Information uncertainty		
Variable	**Mean**	**Std. Deviation**
Performance	4,45	1,734
CostDevelopment	5,21	1,763
CompetitorBehaviour	3,31	1,958
CustomerBehaviour	3,06	1,819
SocioEcoDevelop	2,76	1,768
InfoSystem	3,52	1,623
TechChange	3,22	1,408
NonfinanceIndikators	3,12	1,996
SocioEcoChanges	2,91	1,684
	Cronbach's Alpha	**0,885**
Financial capability		
Variable	**Mean**	**Std. Deviation**
CapitalAccess	4,22	1,699
Technological capability		
Variable	**Mean**	**Std. Deviation**
TechSearch	5,27	1,464
TechStaff	5,42	1,347
QualityManSystem	5,56	1,664
ProductTech	4,94	1,619
TechChanges	5,39	1,870
TechConnections	4,03	2,102
OwnR&D	4,50	1,951
	Cronbach's Alpha	**0,833**
Firm size		
Variable	**Mode**	**Std. Deviation**
Revenue	2	1,897
NoEmployees	5,5	1,650

Appendix F

Table 9

Interview script

Thema	Frage	Zeit (Min)
Intro	- Mich selbst vorstellen - Ziel der Untersuchung ist herauszufinden welche Faktoren die Einführung von nachhaltigen Prozesstechnologien in Unternehmen des verarbeitenden Gewerbes beeinflussen. - Nachhaltige Prozesstechnologien definieren. - Fragen ob man das Interview aufnehmen darf für den Zweck der vollständigen Transkribierung. - Alle Angaben werden anonymisiert (z.B. Firma X). - Das Gespräch wird ca. eine Stunde dauern.	**5 (5)**
A	***Zunächst ein paar allgemeine Fragen zu Ihrer Person und der Ausrichtung Ihres Unternehmens*** **Wer sind Sie und was ist Ihre Rolle im Unternehmen?** (Größte Aufmerksamkeit auf den industriellen Bereich) **Auf welche Art sind Sie persönlich an der Nachhaltigkeit in der Produktion beteiligt?** (Fokus auf Tätigkeiten und Aktivitäten) **In welchem Markt operiert Ihr Unternehmen genau?** (Welche Aktivitäten werden ausgeführt) **Unternehmensstrategie: Was versucht Ihr Unternehmen in den nächsten 5 Jahren zu erreichen?** (Allgemeine Ziele? Spezifisch für den Bereich nachhaltiger Technologien?)	**5 (10)**
B	***Nun zu den Bedingungen, die Sie in Ihrem Unternehmen vorfinden*** **Wie viele Mitarbeiter hat Ihr Unternehmen?** **Was bedeutet Nachhaltigkeit für Ihr Unternehmen?** (Produktion, Marketing/ Verkauf, Forschung & Entwicklung, Design) **Welche Nachhaltigkeitsaktivitäten (in der Produktion) entwickelt Ihr Unternehmen?** (In welchen Phasen der Einführung: Kenntnisnahme der Existenz, konkrete Pläne, Beschlüsse, Implementierung, Überwachung, Resultate, Effekte)	**10 (20)**

	Welche Herausforderungen sehen Sie für Ihr Unternehmen bei der Einführung nachhaltiger Technologien hinsichtlich der technischen Fähigkeiten? (Voraussetzungen für eine Einführung gegeben? Beispiele)	
C	***Kommen wir zu den nachhaltigen Prozesstechnologien, die in Ihrem Unternehmen eine Rolle spielen.*** **Welche nachhaltigen Produktionstechnologien werden in Ihrem Unternehmen verwendet/ gedenken Sie zu verwenden?** (End-of-pipe / Prozessoptimierung / Materialsubstitution/ Recycling) (Kenntnisnahme der Existenz, konkrete Pläne, Beschlüsse, Implementierung, Überwachung, Resultate, Effekte) **Welche nachhaltigen Prozesstechnologien sind potentiell verfügbar/ relevant für Ihr Unternehmen?** (Arten / Preis / Lieferanten) **Auf welche Art sind in den vergangenen drei Jahren konkrete Nachhaltigkeitsresultate festgestellt worden oder sind in Zukunft zu erwarten?** (Energie, Wasser, Emissionen (CO^2), Materialien, Verpackungen, Abfall)	**10 (30)**
D	***Als nächstes würde ich gerne auf die externen Einflüsse auf die Entscheidungen in Ihrem Unternehmen, beispielsweise von Gesetzesseite, zu sprechen kommen*** **Wie und in welchem Maß fühlen Sie Druck durch Vorschriften? Durch welche Gesetze und Vorschriften?** (Bundesregierung, Landesregierung, Kommunen) **Wie reagieren Sie darauf?** (Beispiele? Transparenz? Gegenseitige Widersprüche? Steuern/ Verwaltungsaufwand?)	**10 (40)**
E	***Jetzt kommen wir auf die zukünftigen Rahmenbedingungen und deren Auswirkungen auf die Entscheidungen für Ihr Unternehmen zu sprechen*** **Welche Rolle spielen Ihnen zur Verfügung stehende Informationen zur zukünftigen Entwicklung bestimmter Technologien?** (Regulatorik, Preisentwicklung, technische Entwicklung)	**5 (45)**
F	***Abschließend noch einige Punkte zu den verschiedenen Betriebswirtschaftlichen Gesichtspunkten die bei der Einführung von nachhaltigen Prozesstechnologien eine Rolle spielen könnten*** **Was ist der (mögliche) betriebswirtschaftliche Nutzen des Gebrauchs von nachhaltigen Technologien für Ihr Unternehmen?** (Innovation, Konkurrenzposition, Kundenwerbung, Zugang zu neuen Märkten, Preis/ Mehrwert, Reputation, Marketing)	**10 (55)**

	Inwieweit spielen Kostenabwägungen eine Rolle hinsichtlich der Einführung von nachhaltigen Technologien? (Anschaffungskosten? Laufende Kosten? Vergleich zu alternativen Technologien?) **In wie fern ist die Einführung von nachhaltigen Technologien abhängig von den finanziellen Möglichkeiten Ihres Unternehmens?** (Zugriff auf Kapital, Wirtschaftskraft des Unternehmens) **Wie verhält sich Ihre Branche bezüglich nachhaltiger Technologien und wie beeinflusst dies Ihre Entscheidungen?** (Wettbewerb, Industrietrend)	
Outro	- Vielen Dank! - Getroffene Absprachen noch einmal wiederholen (Anonymität etc.) - Anbieten die fertige Arbeit und das Transkript zuzuschicken.	**5 (60)**

A = Orientierungsfragen

B = Unternehmensmerkmale

C = Einführung nachhaltiger Prozesstechnologien

D = Institutioneller Druck/ Externe Einflüsse

E = Informationen zur zukünftigen Entwicklung

F = Betriebswirtschaftliche Abwägungen

Appendix G

Research Integrity Form - Master Thesis

Name:	**Student number:**
Didier Niederprüm	s4760115
RU e-mail address:	**Master specialisation:**
d.niederprum@student.ru.nl	Strategic Management

Thesis title:
Factors affecting the adoption of sustainable process technologies: The manufacturing industries in the German context
Brief description of the study:
To reach the SDG goals 12 and 13, formulated by the United Nations in 2012, especially companies of the manufacturing industries are requested to increase the sustainability of their production processes. Previous studies have assessed the factors that lead towards the adoption of sustainable process technologies with which this is achieved, from different perspectives. In a triangulation process consisting of a literature review comparison and a mixed-methods analysis, including an interview-based qualitative and a survey-based quantitative analysis, the influence of six of these factors is evaluated. The results show that state regulation is an important factor that pushes companies to adopt these technologies. Furthermore, Financial and Technological capabilities work as necessary conditions that have to be met before an adoption can take place. Additionally, the size of a firm functions as a pre-condition that in the end also yields positive influences in that matter. Contrary, Financial costs, meaning a disadvantageous cost-benefit ratio, shows a negative influence and furthermore an interaction with the regulation factor. This means that where the adoption of sustainable process technologies is economically not reasonable, regulation pressures

become more important. Besides the findings, theoretical implications and practical recommendations are provided.

It is my responsibility to follow the university's code of academic integrity and any relevant academic or professional guidelines in the conduct of my study. This includes:

- **providing original work or proper use of references;**
- **providing appropriate information to all involved in my study;**
- **requesting informed consent from participants;**
- **transparency in the way data is processed and represented;**
- **ensuring confidentiality in the storage and use of data;**

If there is any significant change in the question, design or conduct over the course of the research, I will complete another Research Integrity Form.

Breaches of the code of conduct with respect to academic integrity (as described / referred to in the thesis handbook) should and will be forwarded to the examination board. Acting contrary to the code of conduct can result in declaring the thesis invalid

Student's Signature:  **Date: 12.08.2018**

To be signed by supervisor

I have instructed the student about ethical issues related to their specific study. I hereby declare that I will challenge him / her on ethical aspects through their investigation and to act on any violations that I may encounter.

Supervisor's Signature: _____Date:

Appendix H

Student number : s4760115

Student name : Didier Niederprüm

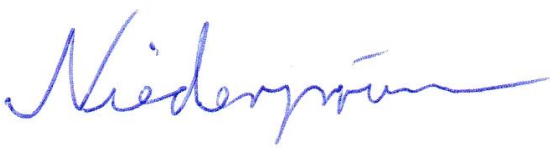
Thesis title : Factors affecting the adoption of sustainable process technologies:

The manufacturing industries in the German context

x Yes, I grant permission to make available my thesis with the above title in the Radboud Thesis Repository.

☐ No, I do not grant permission to make available my thesis with the above title in the Radboud Thesis Repository.

Signature: Date:



12.08.2018

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