Do sustainable organizational practices and technologies reduce production costs within manufacturing companies?

Master Thesis

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1. Introduction

Climate change is real. Research has shown this in multiple ways and it is largely a result of human action (Intergovernmental Panel on Climate Change, 2013). Nowadays, we face increasingly severe natural disasters, loss of biodiversity and rising global temperatures and sea levels (Wagner, 2010), leading to enormous human, natural and economic losses (Thomas, 2017). As populations keep growing and their living standards continuously increase, sustainable use of the scarce resources needed to meet this tremendous demand, is essential (Gahm, Denz, Dirr, & Tuma, 2016). However, this is not what is currently being done. Big corporations are perceived to be largely responsible for these negative impacts on environment and society and therefore customers, governments and suppliers start to demand more from them, in terms of minimizing their negative impact (Klassen & Whybark, 1999; Lozano, 2015; Wagner, 2010). Particularly manufacturing firms receive much attention, as they are considered one of the primary polluters (Dessus & Bussolo, 1998). Since there is a continuously increasing demand for goods that these corporations need to satisfy, decreasing availability of natural resources and the urgency to lower CO2 emissions, it is crucial that manufacturing firms become more sustainable. *Sustainability* can be defined as: activities aiming to improve human living standards while increasing the availability of resources and ecosystems for future generations (Seliger, 2007).

However, this seems like an unattractive path to take for organizations, since they often believe that choosing to be more sustainable or environmental-friendly leads to reduced economic performance and competitiveness (Nidumolu, Prahalad, & Rangaswami, 2009; Pons, Bikfalvi, Llach, & Palcic, 2013). This relationship between environmental and economic performance of companies has been studied a lot, but there has not been reached a consensus yet (Pons et al., 2013). Some researchers claim it pays off to be green (Hart & Ahuja, 1996), since sustainable performance has a positive effect on economic performance (Al-Tuwaijri, Christensen, & Hughes Ii, 2004; Klassen & Whybark, 1999), but some studies are inclusive (Fu, 2019; Wahba, 2008) or did not confirm a positive relationship between environmental performance and economic performance (Friedman, 1970; Jaggi & Freedman, 1992; Wagner, Van Phu, Azomahou, & Wehrmeyer, 2002). Environmental management practices require investments, which often means a change in the cost structures of the organizations, that especially in the short term, could lead to a decrease in profits (Yang, Hong, & Modi, 2011). Hart (1995) explains that environmentally sustainable activities might seem counterintuitive, but environmentally oriented resources and capabilities can enable an organization to gain competitive advantage. Furthermore, Despeisse, Ball, Evans, and Levers (2012) concluded that enhancing an organization's environmental performance is related to competitive advantages and long-term cost reduction, which could be a very attractive motivational factor for manufacturing companies to invest in sustainable practices (Nidumolu et al., 2009). It is important to endeavour discovering whether sustainability and saving costs actually go hand in hand and how this could be achieved. Below some approaches or strategies for achieving this 'double stroke' are briefly described.

Research of Nidumolu et al. (2009) shows that sustainability within organizations often includes many technological and organizational innovations that lead to lower costs, for instance because of energy efficiency and waste reduction. Accordingly, some researchers think, that in order to create a more sustainable world and enhance sustainable manufacturing, new *sustainable technologies* have to be developed and implemented (O'Brien, 1999; Vanegas, DuBose, & Pearce, 1995). Implementing sustainable technologies contributes to reducing negative impacts of products and services on the environment (Shrivastava, 1995). Furthermore, it is proven that certain technologies can lead to a decrease in energy use by 18 to 26 percent (IEA, 2007) and many researchers believe that technological innovation enhances economic performance (Fujii, Iwata, Kaneko, & Managi, 2013). Therefore, it is relevant to examine whether this also applies to sustainable technologies.

Even though there have been quite some studies regarding the relationship between technology and performance, they often overlook the organizational side of these innovations (Vaessen, Ligthart, & Dankbaar, 2014). Schmidt and Rammer (2007) discovered that 26% of all organizational innovators in manufacturing state that changes in organizational practices can decrease their unit costs. *Sustainable managerial and organizational practices* involve energy management and environmental control, which enable an organization to effectively save energy and resources (Önüt & Soner, 2007; Schulze, Nehler, Ottosson, & Thollander, 2016). It is argued by some that environmental management practices can enhance efficiency and effectiveness and reduce the cost of manufacturing (Ngai, Chau, Poon, & To, 2013; Rao & Holt, 2005). However, others have found evidence that it could inhibit business performance (Klassen & Whybark, 1999), so there is no consensus yet (Pons et al., 2013).

Despite the fact that there are some studies that confirm the relationship between environmental performance and economic performance, there is little clarity regarding the relationship between environmental management, implementation of technologies, and performance outcomes such as production costs. There already is quite some literature on the relationships between technological and organizational innovations and business performance in general, but the empirical research on the effects of these practices in the context of sustainability is scarce, while this topic becomes increasingly more important nowadays. Since research has shown that investments in both managerial and organizational practices and technological investments can lead to lower production costs, higher operational efficiency and/or competitive advantage (Hayes and Jaikumar, 1988; Schmidt and Rammer, 2007; Vaessen et al., 2014; Ligthart, Vaessen, Kok, & Dankbaar, 2018), it is important to examine whether these have the same effect when they are investments in sustainable practices.

One of these effects, assumed in some studies, is a complementary relationship between technological and organizational innovations (Armbruster, Kirner, Lay, & Szwejczewski, 2006). It could be argued that simultaneous investments in managerial and organizational practices and technologies can have synergetic effects (Ligthart et al., 2018). This means that, when implemented together, they might have an even larger effect on energy consumption and production costs (Armbruster et al., 2006).

Nevertheless, many organizations still believe that sustainable practices and technologies will only cost money (Nidumolu et al., 2009), while for the world to become more sustainable, it is crucial that manufacturing companies become more environmentally friendly. To convince them to become more sustainable, it is essential to prove that sustainable investments can lead to improvement of environmental performance (less energy consumption) as well as economic performance (lower production costs). Therefore, the aim of this study is to demonstrate to what extent investments in sustainable technologies and sustainable managerial and organizational practices reduce energy consumption and at the same time provide economic benefits in the form of decreasing production costs. For this reason, the accompanying research question is:

To what extent do investments in sustainable managerial and organizational practices as well as in sustainable technologies reduce energy consumption as well as total production costs per unit?

To be able to answer this main question, the following relevant sub questions need to be answered:

1. *What is the effect of sustainable technologies on energy consumption, and by extension on total production costs per unit?*

2. *What is the effect of sustainable managerial and organizational practices on energy consumption, and by virtue of that on total production costs?*
3. *What is the interaction effect of sustainable managerial and organizational practices and sustainable technologies on energy consumption, and by extension on the production costs?*

This study will contribute to the existing literature on technological and organizational innovations within firms, by investigating whether these investments being sustainable has the same effect as to be expected from the literature on technological and organizational innovations in general. Furthermore, it will provide empirical evidence on the relationship between technological and organizational innovations and their direct effect on energy consumption and production costs. Moreover, the literature on these innovations will be extended, by examining whether they together have a synergetic effect on energy consumption and production costs.

Next to that, this thesis will contribute to the literature in the field of sustainability, which is gaining importance every day. This will be done by examining whether implementing sustainable technologies and/or managerial and organizational practices can enhance not only environmental performance (by reducing energy consumption), but at the same time also improving their economic performance by reducing production costs. Furthermore, the mediating effect of energy consumption on production costs will be investigated. Hopefully, the results of this thesis will contribute to finding consensus on the relationship between environmental and economic performance.

The results will help management of manufacturing companies to make the decision whether or not to invest in sustainable managerial and organizational practices and/or sustainable technologies. In addition, they can give insight in how managers could make their business more sustainable while reducing energy consumption and production costs and what the effects of this particular method will be.

The social relevance of this study is that it contributes to the awareness that sustainability is essential, and it examines the economic effects of sustainable practices. The manufacturing industry has the capabilities to respond to their responsibilities in the development of sustainable production and outcomes (O'Brien, 1999). This study might give them an incentive to consider investing in sustainability.

The next section provides the theoretical background. This includes the most important literature regarding sustainable managerial and organizational practices and sustainable technologies and their influence on production costs. It also provides justification of the hypotheses and the presentation of the conceptual model. The method section describes the research data and the techniques used to collect and analyse the data. Subsequently, the empirical findings regarding the hypotheses will be presented in the results section. In the last section, a brief summary of the study, a discussion of the findings and an answer to the research question are provided. Furthermore, the theoretical and managerial implications, the study's limitations and recommendations for future research will be discussed at last.

2. Theoretical Background

2.1 Introduction

This chapter defines and elaborates on the most important theoretical concepts of this study. First, some theoretical background is given on manufacturing and the movement towards more sustainable manufacturing. Second, the concepts of energy consumption and production costs will be discussed. Thereafter, the concepts of sustainable technologies and managerial and organizational practices and their effects on energy consumption and production costs will be described. From this theoretical background, the hypotheses of the study are derived.

2.2 Sustainability and the key role of the manufacturing industry

Nowadays, manufacturing industries demand more of the world's natural resources every year and the systems are therefore not sustainable in the long term (Duflou et al., 2012; Gahm et al., 2016; O'Brien, 1999). The manufacturing industry is one of the biggest consumers of energy and raw materials (Despeisse et al., 2012). They account for approximately 24,4 percent of the total energy consumption in the European Union (Eurostat, 2012). Furthermore, they generate and release tremendous streams of waste and emissions that are damaging to the environment (Duflou et al., 2012). In 2007, the industry was responsible for 36 percent of worldwide CO_2 emissions (IEA, 2007). As such, it is clear that manufacturing must make a large contribution in moving towards a more sustainable society (Despeisse et al., 2012). Manufacturing companies could reduce their ecological footprint, for instance, through recycling of wastes, substituting non-renewable products or implementing new clean technologies (Getzner, 2002).

Manufacturing can be defined as: “All industrial activities from the customer to the factory and back to the customer, thus including all the different kinds of services that are connected to the manufacturing chain” (Garetti & Taisch, 2012, p. 84). Every manufacturing activity from input, through production processes, to outputs (used products and packaging disposal) is associated with environmental problems (Shrivastava & Hart, 1995). These are reasons why a trend towards more environmentally friendly manufacturing can be observed (Duflou et al., 2012).

As said before, *sustainability* is defined as activities with the goal to improve living standards while increasing availability of resources and ecosystems for future generations (Seliger, 2007). Sustainability is in current literature described as a complex concept, with multiple dimensions: economic, social and environmental performance. The manufacturing industry has an extensive impact on the economic and social dimension (Garetti & Taisch, 2012), since it contributes up to 22 percent of Europe’s Gross Domestic Product and 70 percent of the jobs in Europe rely upon the manufacturing industry (Manufuture, 2004). The industry has: “generated wealth, jobs and quality of life, while promoting and sustaining services, education, research and development” (Jovane et al., 2008, p. 645). Manufacturing also has a large impact on the environmental dimension, but not in a positive way.

The ecologically destructive industrialization of the past calls for new economic and organizational practices. Sustainable Development is a response to this (Shrivastava & Hart, 1995). *Sustainable Development* can be described as a process of change in which the orientation and direction of investments, technological development and institutional change and the use of resources are aligned with not only the present, but also the future needs (Jovane et al., 2008). Society, governments and companies embrace this in an attempt to balance economic development, social development and environmental protection (Fu, 2019). The manufacturing industry is in a unique position regarding sustainable development. Even though the manufacturing companies are seen as a main contributor to many social and environmental problems, they can also realize change, since they are one of the main drivers of economic growth (UN: World Commission On Environment and Development, 1987). As such, they have many opportunities to make a positive contribution to society and the environment.

This is one of the reasons why Sustainable Manufacturing is becoming an increasingly important subject (Garetti & Taisch, 2012). *Sustainable Manufacturing* is manufacturing with the smart use of resources, by creating products and solutions that are able to preserve the environment, while satisfying economic and social objectives. This can be done with new technologies, regulatory and organizational measures and consistent social behaviour (Garetti & Taisch, 2012).

Today's approaches of sustainable manufacturing mainly focus on efficiency and effective use of materials and energy, to reduce waste and inputs needed (Despeisse et al., 2012; Duflou et al., 2012; Herrmann, Schmidt, Kurle, Blume, & Thiede, 2014). Resource and energy efficiency will be a crucial determinant for being a successful manufacturer in the long-term (Lang-Koetz, Pastewski, Schimpf, & Heubach, 2010).

It would seem attractive for organizations to confirm to the lowest environmental standards for as long as possible. However, according to Nidumolu et al. (2009) it would be much smarter for organizations to treat sustainability as a goal today, so they have more time to experiment with materials, technologies and organizational practices. They can gain competitive advantage and develop competences that are be hard to match (Nidumolu et al., 2009). Moreover, according to Despeisse et al. (2012), investing in more sustainable business practices is linked to long-term cost reduction and it can provide competitive advantage.

2.3 Sustainability and energy consumption

Due to the industrialization the past decades, the total world consumption of energy is enlarging every year. As mentioned before, the energy used by the manufacturing industry is a large part of this total (Önüt & Soner, 2007). Therefore, the manufacturing industry and its energy consumption are the main subject of this thesis. The main energy sources used in the manufacturing industry, are: electricity, gas and oil (Önüt & Soner, 2007).

In order for manufacturing companies to use energy most effectively and maximize profits, energy management is crucial (Önüt & Soner, 2007). *Energy management* can be described as controlling, monitoring and improving activities, techniques and management of the manufacturing process in order to increase energy efficiency (Ates & Durakbasa, 2012; Bunse, Vodicka, Schönsleben, Brülhart, & Ernst, 2011). It leads to enhanced systems and it can be an effective tool to reduce energy consumption and the related energy costs and CO2 emissions (Ates & Durakbasa, 2012; Bunse et al., 2011; Schulze et al., 2016).

Energy efficiency implies the use of less energy while maintaining the same level of service (Önüt & Soner, 2007). According to the Intergovernmental Panel for Climate Change (IPCC), the energy efficiency in large national manufacturing sectors can be improved by approximately 25 percent on the short-term (Watson, Zinyowera, Moss, & Dokken, 1996), so they could make a substantial difference. Oikonomou, Becchis, Steg, and Russolillo (2009) state that energy efficiency refers to the implementation of a certain technology, which reduces the energy consumption without adjusting relevant behaviour. Implementing certain technologies can reduce energy consumption by 18 to 26 percent and CO_2 emissions by 19 to 32 percent (IEA, 2007). Next to implementation of technology, the movement towards higher energy efficiency also requires powerful managerial practices (Cooper, 1982).

When deciding whether to invest, most organizations mainly consider the initial investment. The potential future decrease in energy consumption costs is often neglected, while this could be of great importance (Bornschlegl, Bregulla, & Franke, 2016). However, manufacturers are slowly starting to realize that reducing energy consumption can be good for their environmental, as well as for their economic performance (Bornschlegl et al., 2016). The European Commission (2013, p.5) states: “Economic growth and resource efficiency are two sides of the same coin. They are both prerequisites for the sustainable growth of our modern societies and are essential to face the current environmental, social and economic challenges.”

2.4 Energy consumption and production costs in the manufacturing industry

The total production costs in manufacturing companies generally exist of different components, such as: labour cost, raw material cost, operational cost, maintenance cost and energy cost. Data from the Planbureau voor Leefomgeving (PBL, 2014) shows that in the industrial sectors, energy and material costs are the main expenses, varying between 20 and 60 percent of the total production costs. Energy costs can account for as much as 20 percent of manufacturers’ overall production costs (Mohr, Somers, Swartz, & Vanthournout, 2012).

Yet, according to Bornschlegl et al. (2016) and Önüt and Soner (2007), there often is a lack of attention to energy costs by the management, while they can make a considerable difference, not only in becoming more sustainable, but also in saving costs. This is often because of a lack of knowledge or because energy costs are seen as overhead costs, rather than as a separate cost category managers are directly responsible for (Caffal, 1995; Önüt & Soner, 2007). Even if energy costs is merely a small part of the production costs, saving energy costs can directly lead to a higher profit margin and it also means fewer CO_2 emissions (Bornschlegl et al., 2016). Research of Böttcher and Müller (2016) confirmed this, since their results indicated that enhancing carbon performance leads to improved economic performance. Moreover, research of Fujii et al. (2013) in Japanese manufacturing firms showed that improving environmental performance leads to enhanced economic performance due to a reduction in energy costs. Reducing energy costs can, for instance, be done by increasing the energy efficiency or implementing new management approaches (Weinert, Chiotellis, & Seliger, 2011).

2.5 The effect of sustainable technologies on energy consumption and production costs

Sustainable technologies can be defined as technologies that reduce negative impacts of products and services on the environment by reducing pollution and resource consumption or using less energy-intensive or polluting materials (Fu, 2019; Shrivastava, 1995). According to Schramm and Hackstock (1998), they play a major role in the movement towards cleaner production and they are an effective means to achieve Sustainable Development (Fu, 2019; Schramm & Hackstock, 1998) or other sustainable objectives of manufacturers (Despeisse et al., 2012; Garetti & Taisch, 2012). Next to that, sustainable technologies can help to develop a positive relation between social and economic needs and environmental constraints (Garetti & Taisch, 2012).

Consumption of energy can be decreased by developing and implementing new technologies that do not depend on traditional types or amounts of energy and materials, such as technologies that generate energy from solar radiation or wind power (Vanegas et al., 1995). In line with that, He and Wang (2017) state that technologies that use waste heat and reduce energy consumption are key determinants of energy saving. Furthermore, existing empirical evidence shows that energy-saving technologies can lead to direct and continuous improvement in energy efficiency (by effectively saving energy and materials) and in the reduction of energy consumption and energy costs (IEA, 2007; Pons et al., 2013; Zhang & Wang, 2008). Research of Sahu and Narayanan (2010) on the determinants of energy intensity of Indian manufacturing sector confirmed this. They observed the Indian manufacturing output and energy consumption pattern from 2000-2008, with a sample of 28.120 observations. The results showed that importing more new technologies leads to higher energy efficiency. Likewise, Guo and Fu (2010) found that implementation of new technologies caused a remarkable decrease in energy consumption in the past decades in the steel industry in China. Examples of environmental technologies are: on-site generation of energy, re-use of energy, use of renewable energy or smart-grid saving measures (Weinert et al., 2011).

Next to this beneficial effect on energy consumption, Zhang and Wang (2008) state that implementing new sustainable technologies can also provide economic benefits ("non-energy benefits"), such as an increase in productivity or a decrease in production costs.

Research of Worrell, Price, and Martin (2001) confirmed this. They analysed the potential for efficiency of the steel production processes in the US iron and steel industry by establishing a baseline (1994) of energy use and CO2 emissions and examining 47 energy-efficient technologies and measures. The results showed that implementing energy-saving technologies and measures can lead to higher energy efficiency, lower CO2 emissions and lower production costs. Schramm and Hackstock (1998) also state that clean technologies are the most important determinant of industries' economic growth.

Still, technological innovations are often substantial investments, which might lead to future revenues in the long-term, but that is not a certainty (Schmidt & Rammer, 2007). Furthermore, though it is sometimes stated that sustainable technologies can be a direct source of competitive advantage (Shrivastava, 1995), the empirical evidence suggesting that sustainable technologies directly lead to lower production costs is rather scarce and the literature on this topic is not unanimous.

However, there have been quite some studies about the effect of technological innovations on business performance or production costs in general. Numerous studies validate the relation between technology and business performance, such as a study of twenty companies in the US where Hayes and Jaikumar (1988) refer to, showing that technological manufacturing systems can reduce 75 percent of the total product costs. Furthermore, Tassey (2007) for instance states, that technological innovations are the major driving force behind growth in productivity and economic benefits. In addition, they can be a direct source of competitive advantage (Bansal & Roth, 2000; Shrivastava, 1995). Nidumolu et al. (2009) conducted research on sustainable initiatives of thirty large organizations for a longer period of time. It showed that sustainable manufacturing often entails many organizational and technological innovations that both reduce inputs, such as resources and energy.
Next to that, it is established that sustainable technologies increase energy efficiency (Pons et al., 2013), which can lead to lower energy consumption (Schulze et al., 2016) and therefore it is expected that they also lead to lower production costs. Therefore, the first hypothesis reads:

H1: The larger an organization's investment in sustainable technologies, the larger the saving on energy consumption and by extension the lower the production costs.

2.6 The effect of sustainable managerial and organizational practices on energy consumption and production costs

Organizational innovation can be defined as the implementation of a new, not earlier used, organizational method regarding a change in business practices, external relations or organization of work(places), with the aim to enhance the innovative capacity or performance, for instance quality or efficiency (OECD & Eurostat, 2005).

Sustainable managerial and organizational practices go beyond meeting legal standards and maintaining legitimacy. They encourage sustainability in daily routines and help bringing the organization towards more sustainable production (Fu, 2019). Sustainable managerial and organizational practices include, for example, instruments for Product Life Cycle (PLC) Analysis and embedding environmental aspects into Total Quality programs and into administration (Aragón-Correa, 1998; Bratt, Hallstedt, Robèrt, Broman, & Oldmark, 2011). Instruments for PLC analysis are increasingly used to evaluate the environmental impact of inputs and outputs of entire value chains (Garetti & Taisch, 2012; Nidumolu et al., 2009). Many of these instruments are standards on managerial and organizational practices, such as ISO 14001 and eco-labelling. (Boiral & Gendron, 2011; Duflou et al., 2012). They aim to encourage implementation of control systems (Boiral & Gendron, 2011) and guarantee the quality and environmental performance of the products manufactured (Bratt et al., 2011).

Sustainable managerial and organizational practices often relate to energy management and environmental control. According to Weinert et al. (2011), developing and implementing new energy monitoring and management approaches has great potential to reduce energy consumption. Energy management and environmental control via sustainable managerial and organizational practices can increase energy efficiency (Ngai et al., 2013; Schulze et al., 2016; Weinert et al., 2011) and could therefore, as a result, lead to reduced energy consumption and lower energy costs (Ates & Durakbasa, 2012; Schulze et al., 2016). This was confirmed by research conducted by Gordić et al. (2010) on the Serbian car manufacturer Zastava. Their results showed that introducing energy management led to a decrease in energy consumption of approximately 25 percent. Furthermore, research has shown that implementing an energy management system (EMS) can lead to a decrease of 25 percent on total energy consumption (Gordić, Babić, Jovičić, Šušteršič, Končalović, & Jelić, 2010). An example of a certified EMS, is the ISO 50001 standard (Bornschlegl et al., 2016; Schulze et al., 2016). This standard helps organizations to set energy efficiency goals, plan and prioritize interventions, measures and investments, monitor energy management performance and establish continuous improvement in energy efficiency (Ngai et al., 2013).

Next to improvement of environmental performance, Shrivastava (1995), among others, argues that environmental management and control could also enhance business performance. However, there are also researchers that state that environmental management can have an negative impact on business performance (Klassen & Whybark, 1999). Previous research outcomes are ambiguous and contradictory (Yang et al., 2011). Yet, according to Ngai et al. (2013), sustainable management practices can increase effectiveness and efficiency and contribute to lowering production costs. As said before, research of Nidumolu et al. (2009) showed that sustainable manufacturing often entails organizational innovations. This can reduce inputs and thereby also contribute to decreasing production costs. Moreover, Böttcher and Müller (2016) conducted research on 108 German automotive suppliers. This research demonstrated that implementing energy management systems fosters energy efficiency and, by enhancing carbon performance, also leads to improved economic performance.

Despite the growing interest in the topic of sustainable organizational practices, the empirical evidence has been rather weak and fragmented, probably because of the different perspectives and empirical instruments used by the different disciplines (Armbruster et al., 2006). The available literature on organizational and managerial practices in general suggests that they are an immediate source of competitive advantage, because they can enhance productivity, quality, flexibility and lead time (Armbruster et al., 2006). Furthermore, the dominant belief in some disciplines is that organizing in a different way may have the same diminishing effect on unit costs as cost-reducing process innovation (Vaessen et al., 2014).

Since sustainable managerial and organizational practices are likely to effectively save resources and energy, thereby leading to lower energy costs and contributing to lower production costs (Ates & Durakbasa, 2012; Bunse et al., 2011; Ngai et al., 2013; Schulze et al., 2016), the second hypothesis reads:

H2: The larger an organization's investment in sustainable managerial and organizational practices, the larger the saving on energy consumption and by extension the lower the production costs.

2.7 The interaction effect of managerial and organizational practices and sustainable technologies on energy consumption and production costs

The introduction of a new technology might imply the necessity for innovation in other non-technological aspects of the production process, such as new managerial and organizational practices (Schmidt & Rammer, 2007). Schmidt and Rammer (2007) state that organizations that combine technological innovations and non-technological innovations (for example organizational innovations) achieve higher cost reductions and can experience a positive impact on the profit margin.

In line with that, Damanpour and Evan (1984) describe that to enhance business performance, a balanced, parallel implementation of technological and organizational innovations is more effective than implementing either one of those alone. This is because implementation of new technologies often asks for or is intertwined with new organizational practices. Weinert et al. (2011) also claim that in order to exploit the potential of sustainable technologies, analytical energy management methods are required. Furthermore, according to Daveri (2002), only introducing technological innovations is not enough to drive growth in productivity, unless parallel implementation of organizational changes in the production modes takes place. It has even been argued that technological innovation without organizational changes could have a negative impact on a firm’s economic performances (Armbruster et al., 2006).

Moreover, Armbruster et al. (2006) state that organizational and technological innovations have a complementary relationship. This means that combining them could lead to a larger effect on performance and upskilling than their sum, and implementing them simultaneously can have synergetic effects (Ligthart et al., 2018). Vaessen et al. (2014) conducted a research using the data from the European Manufacturing Survey (EMS) 2006, which was carried out in nine countries within Europe by a consortium of universities and research institutes. Their results showed that for manufacturing companies, combining new technologies and organizational practices is the best strategy to improve business performance. They concluded that effective alignment of technological and non-technological innovations is crucial for operational performance.

There is not much empirical evidence on this interaction between technological and organizational practices in the context of sustainability yet. However, the existing literature on these innovation in general suggests that a combination could lead to lower production costs (Schmidt & Rammer, 2007) and larger effects on business performance (Ligthart et al., 2018;

Vaessen et al., 2014). Therefore, the third hypothesis states:

H3: The more extensively an organization combines sustainable managerial and organizational practices with sustainable technologies, the larger its additional savings on energy consumption and by extension the lower the production costs.

2.8 Conceptual model

The conceptual model in Figure 1 is derived from the theory discussed above. It shows the hypotheses that sustainable technologies and sustainable managerial and organizational practices in manufacturing companies lead to lower energy consumption and by extent also to lower production costs per product. Furthermore, it shows the hypothesis of the interaction effect that the combination of those to probably leads to even lower energy consumption and by extent to lower production costs.

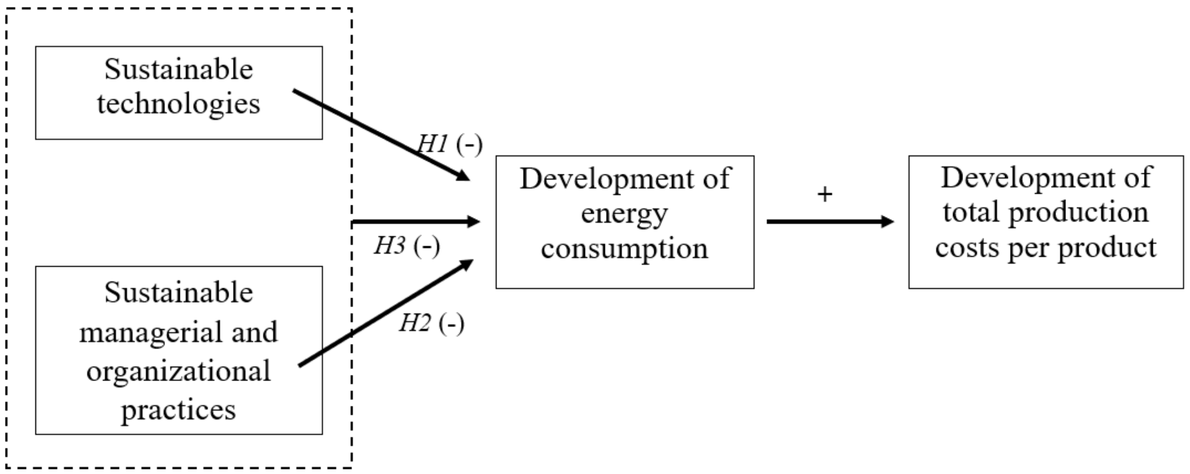

Figure 1: Conceptual model

3. Methodology

3.1 Introduction

This chapter describes the research process and the methods used to answer the research question. First, the research design will be presented and the research unit will be elaborated on. Second, the dependent and independent variables are operationalized and the control variables are defined. Thereafter, the validity and reliability of the research are discussed and the analysis method will be described. Lastly, the research ethics are considered.

3.2 Research Design

To test the hypothesized relationships between the variables described in the conceptual model, a quantitative study has been performed. Empirical data was collected by a survey and this numerical information was used to acquire scientific insights (Field, 2013). Analysis of this data provides the opportunity to find relationships and statistical patterns. Based on that, a determination was made on whether to accept or reject the hypotheses, and conclusions could be derived (Vennix, 2016).

The data in this master thesis are drawn from the European Manufacturing Survey 2015. The European Manufacturing Survey (EMS) is conducted every three years by a group of universities and research institutes across Europe (Vaessen et al., 2014). The EMS 2015 refers to the period 2012-2014 and it focuses on implementation of new organizational and managerial practices and new manufacturing technologies, as well as on different indicators of business performance such as production costs and return on sales (Vaessen et al., 2014). The EMS of 2015 is chosen, because it is the most recent version with the most questions about sustainable technologies and sustainable managerial and organizational practices. Reasons why other versions were not chosen are, for example, that in the EMS 2012, merely items on sustainable technology were included (and no items on sustainable organizational practices), and that in the version of 2009 ‘development of energy consumption’ was not included.

The research unit consists of Dutch organizations registered in the Chamber of Commerce database (registration is compulsory for legal public or private organizations) that are economically active in the industry sector and have ten employees or more. The different subsectors that fall within the industry sector are SBI 10 to SBI 33. The survey was sent to all business locations of these manufacturing companies in the Netherlands (not merely to the headquarters) and was to be filled in by the company director, the production manager or the R&D manager of that location.

3.3 Operationalization

3.3.1 Dependent variable and Mediator

The dependent variable 'Development of production costs' is measured by item 12: "How have the total production costs per unit developed within the year 2014?"

The mediating variable 'Development of energy consumption' is measured by the items 'Development of power consumption' and 'Development of oil and gas consumption'.

A seven-point Likert scale was used for all three items, with answer possibilities from 'decreased with 10% or more' to 'increased with 10% or more'.

3.3.2 Explanatory variables

Sustainable technologies

The EMS 2015 measured many different technologies. This thesis focuses on "Sustainable Technologies" and this variable is constructed from the Energy and Resource Saving Technologies (8.1.2) and the Technological Measures to Diminish Energy Consumption (8.2). The items measuring 'Energy and resource saving technologies' are:

- Control systems that stop machines with under-use (i.e. PROFI-energy)
- Automated management systems for more energy efficient production
- Systems serving kinetic and process energy recovery (i.e. recovering waste heat)
- Technologies for energy and heat generation by means of solar, wind and hydropower, biomass or geothermal energy

The items that measure 'Technological measures to diminish energy consumption' are:

- Systems for construction parts, machines or installations that switch them off when they are not used
- Improving existing machines or installations
- Premature replacement of existing machines or installations by new ones

The companies could choose per technology whether they had introduced it (1) or not (0). If not, they could declare whether they were planning to introduce it before 2018. If they had introduced it, they had to fill in: what year they used it for the first time, whether they had upgraded it since 2012 and the extent to which they applied the technology (low/medium/high).

Sustainable managerial and organizational practices

The European Manufacturing Survey of 2015 also measured the implementation of different organizational practices, such as organization of work and organization of production. This research focuses on the practices regarding Energy and Environmental Control, which construct the variable "Sustainable managerial and organizational practices". The items in the EMS 2015 belonging to this variable are:

- Certified energy management system according to ISO 50001 (previously: EN 16001)
- Instruments for product life cycle assessment (for example: EU Ecolabel, Cradle-to-Cradle certificate or ISO-14020)
- Impact and performance measurements of social and environmental corporate activities

Companies could answer the question on whether they had introduced the organizational or managerial practices with 'No' (0) and, if not, whether they were planning to before 2018, or 'Yes' (1). The additional information they had to give for this answer category was in what year the practices were applied for the first time and to what extent (low/medium/high).

3.3.3 Control variables

The EMS 2015 recorded the implementation of innovations in technology and organizational practices. To be able to examine the effect of sustainable technologies and managerial and organizational practices on energy consumption and production costs, all other technologies and organizational practices must be controlled for. Furthermore, the effects of the independent variables are controlled for by the effects of the size of the manufacturing firm and the manufacturing subsectors.

The variable 'Other Technologies' was constructed by the technologies of the categories: Automation and robotization, Machining technologies for new materials, Additive production technologies and Digital factory or IT networks. The variable 'Other Managerial and Organizational Practices' was constructed by the practices of the categories: Organization of the work, Organization of production, Production management and control and Human Resource Management.

Table 1 shows the indicators used, the answer possibilities and the corresponding question in the survey for all variables.

Table 1: Operationalization of variables

Variable	Items	Minimum answer possibility	Maximum answer possibility	Corresponding question
Dependent variable	Development of production costs per unit in 2014	Decreased with 10% or more	Increased with 10% or more	12
Mediator	Development of power consumption in 2014	Decreased with 10% or more	Increased with 10% or more	22.2
	Development of oil and gas consumption in 2014	Decreased with 10% or more	Increased with 10% or more	22.3
Explanatory variables	Sustainable technologies	0	7	8.1.2 and 8.2
	Sustainable managerial and organizational practices	0	3	3.4
Control variables	Other technologies	0	19	8.1.1, 8.1.3, 8.1.4, 8.1.5
	Other managerial and organizational practices	0	15	3.1, 3.2, 3.3, 3.5
	Size of firm (Number of employees)	Open question		21
	Manufacturing subsectors	Open question		1.2

3.4 Validity and Reliability

There are two forms of validity: internal and external validity. Internal validity means the extent to which the instrument measures what the researcher intended to measure (Vennix, 2016). The European Manufacturing Survey is very in-depth, with detailed questions, and it is conducted every three years, so every time it is adapted and improved. This makes every version of the instrument more accurate and contributes to a high internal validity of the data.

It is an international survey, composed through lots of meetings with different researchers from fifteen different countries. In these gatherings, all the items, the formulation of the questions, and the structure of the survey, are extensively discussed. Next to that, the researchers conducted a test-survey to improve the internal validity. Furthermore, the EMS recorded when the innovations were first introduced. This was generally before the measurement of the performance outcomes, which makes the possibility of reverse causation between innovation and performance less likely. This all contributed largely to the internal validity. The EMS 2015 includes all (indicators of) variables of this study, which means that this dataset is appropriate for this research.

External validity relates to the degree to which the results are generalizable towards the whole population (Vennix, 2016). The organizations in the sample were randomly included, which means that the results might be generalizable to other manufacturing companies. However, the results of this thesis regard only manufacturing companies in the Netherlands, so they might not be generalizable to manufacturing companies of other countries. Furthermore, the population is unknown, so it is hard to determine the representativeness of the conclusions of this study. The researchers did a number of things to improve the response and thereby the external validity of this study. For example, they sent two reminders to the participants and they offered the participating companies a free benchmark report. This gave the companies the opportunity to compare themselves to other companies on different indicators.

Reliability of a study is also important. This is the extent to which measurements would give the same results, were the study to be done again in the same exact settings (Vennix, 2016). In order to increase the reliability when constructing the survey, the researchers created very specific, detailed questions, that did not regard opinions, but objective information, such as: practices, investments and performance outcomes.

3.5 Data Analysis Method

To test the three hypotheses, a linear regression analysis was conducted. Regression analysis is applicable here, because it is used to predict the values of the dependent variable ‘development of production costs’ influenced by multiple explanatory variables (‘sustainable technologies, ‘sustainable managerial and organizational practices’ and their interaction). Furthermore, it gives the opportunity to see if the effects of these multiple independent variables disappear or diminish when the variable ‘development of energy consumption’ is added, and if the relation is thus mediated (Field, 2013).

3.6 Research Ethics

This research was conducted in an ethically responsible way. The researcher stated the aim of the survey and gave the participant the opportunity to contact him if there were any questions. The participants stayed anonymous and names of business or executives were left out throughout the whole process.

4. Results

4.1 Introduction

In this chapter, the results derived from the SPSS analysis will be discussed. First, the response of the survey is discussed. Thereafter is described how the variables are constructed. Then the univariate and bivariate analyses and finally the multivariate regression analyses and their results are discussed.

4.2 Response

In 2015, the European Manufacturing Survey was sent to 6146 business locations in the Netherlands, of which 502 started the questionnaire. Of those, 177 valid cases could be derived (Table 2). The fact that the measuring instrument was highly detailed, might be a reason why the response rate was merely 2.9% (Vaessen et al., 2014).

Table 2: Sample Dutch organizations registered in the Chamber of Commerce database

	Count	**Percentage of total**
Population #	8195	
Valid addresses contacted by letter and 2 reminders	6146	100%
Started online questionnaire	502	8,2%
# cases with Industry info	345	5,6%
# cases with Size	194	3,2%
# valid cases	**177**	**2,9%**

Unfortunately, 18% of the respondents had missing values on the items that measure ‘Development of energy consumption’. Since this is more than 10%, those 32 respondents were deleted from the dataset (Hair, Black, Babin, & Anderson, 2014). Therefore, in this study, a dataset of 145 respondents was used. This is more than enough, since according to Hair et al. (2014), a minimum of 100 respondents is preferred.

Table 3: Statistics of the variable 'Development of Energy Consumption'

		Change in development power consumption 2014	**Change in development oil natural gas consumption 2014**
N	Valid	145	146
	Missing	32	31

In Table 4, the different subsectors and the number of respondents belonging to the different categories are displayed.

Table 4: Distribution of different subsectors

Industry	**Count**	**% of total**
1,00 Metals and metal products	28	19,3%
2,00 Food, Beverages and Tobacco	19	13,1%
3,00 Textiles, Leather, Paper and Board	15	10,3%
4,00 Construction, Furniture	24	16,6%
5,00 Chemicals (energy and non-energy)	14	9,7%
6,00 Machinery, Equipment Transport	28	19,3%
7,00 Electrical and Optical equipment	17	11,7%
Total	**145**	**100%**

4.3 Variable Construction

The dependent variable 'development of production costs' is measured by the item 'percent change in production costs per product unit in 2014'. Hereafter is described how the other variables were constructed.

4.3.1 Explanatory variables

The three independent variables of this study are: Sustainable technologies, sustainable managerial and organizational practices, and the interaction variable of those two. In order to check whether these variables and the control variables 'other technologies' and 'other managerial and organizational practices' could be constructed from the items named in chapter 3, reliability analyses were performed. This gives a value of Cronbach's alpha, which is a measure of internal consistency of the variable. If this value is lower than .6 the internal consistency is poor, variables with values around .8 are good (Field, 2013).

Table 5: Reliability analyses main variables

Variable	Number of items	Cronbach's alpha
Sustainable manag. & organizational practices	3	,286
Sustainable technologies	7	,615
Energy consumption	2	,756
Other technologies	19	,773
Other manag. & organizational practices	15	,673

'Sustainable managerial and organizational practices' was constructed by the sum of the three items named in section 3.4.2. However, Table 5 shows that this constructed variable has a Cronbach's alpha of .29. This is very bad and if an item were to be deleted, the reliability would not improve. Therefore, the three items that constructed this variable are taken into the analysis as three separate independent variables: 'Certified Energy Management System (EMS)', 'Instruments for product life cycle (PLC) assessment' and 'Performance measurements of social and environmental activities'.

The independent variable 'Sustainable technologies' was constructed by the sum of seven items that measured the presence of certain sustainable technologies (0 = no, 1 = yes; see section 3.4.2). The respondents could therefore get a score of 0 to 7 on the variable 'sustainable technologies'. The Cronbach's alpha of this variable was .62 (Table 5), which is not great, but sufficient. Deleting an item would not improve the value by more than .05, so it is taken into the regression analysis with all 7 items (Field, 2013).

In order to construct the three interaction variables, the variables measuring 'sustainable managerial and organizational practices' are multiplied by the mean-centred variable 'sustainable technologies'. This interaction variables are used to measure whether implementing both sustainable technologies as well as sustainable managerial and organizational practices at the same time has a different effect on energy consumption and production costs than implementing merely one of those.

<u>4.3.2 Mediator</u>

The mediator 'Development of Energy Consumption' was computed by taking the mean of the variables 'Change in development energy consumption 2014' and 'Change in development oil natural gas consumption 2014'. Cronbach's alpha was .76 (Table 5), so it can be concluded that this variable is reliable (Field, 2013).

4.3.3 Control variables

In order to construct the control variable ‘Industry’, all respondents were assigned a score between 1 and 7, based on their answer on the open question regarding which subsector their business operates in. The respondents that merely answered with “industry” were divided equally among the seven categories.

In order to make sense of the values, seven dummies were created. Respondents scored 0 on every dummy except for the industry dummy they belong to (yes = 1). From the seven dummies, none of them is significant, however ‘Chemicals’ has the highest t-value (Table 6, *Appendix 1*), which means it varies most from the other categories. Therefore, only this dummy is included in the regression analysis as a control variable (0 = other industry, 1 = Chemical industry).

The control variable ‘firm size’ is computed from the item ‘number of employees’. The respondents were assigned to five groups ranging from ‘less than 20 employees’ to ‘more than 250 employees’.

The control variables ‘Other technologies’ and ‘Other managerial and organizational practices’ (‘other org.’) are computed by the sum of all the items regarding technologies and managerial and organizational practices that were not part of the variables regarding sustainable technologies and practices. This means that for ‘Other technologies’ the scores varied from 0 to 19 and for ‘Other managerial and organizational practices’ from 0 to 15.

4.4 Univariate Analysis

Table 7 shows that two of the items measuring sustainable managerial and organizational practices are only implemented by a few companies. Even though the computed variable ‘sustainable managerial and organizational practices’ was not reliable and could not be taken into the other analyses, the statistics of this variable showed that merely one company had implemented all three of the sustainable organizational practices and twelve companies implemented two of the practices. 48 companies implemented one practice, but most companies (84) in the response set did not implement a sustainable managerial or organizational practice at all.

The respondents could get a score from 0 to 7 on the variable ‘sustainable technologies’. Therefore, the mean is also rather low (1.64), which implies that little respondents implemented many sustainable technologies. The levels of skewness and kurtosis for the variable ‘sustainable technologies’ are sufficiently low (skewness / SE skewness = 3.08 and kurtosis / SE kurtosis = 1.44), so there was no need to transform this variable (Field, 2013).

Since the items regarding sustainable managerial and organizational practices are dichotomous variables (they only take on two values), the distribution will always be skewed. Therefore, examining skewness and kurtosis of these items would be rather pointless. No transformation could lead to the dichotomous variables becoming similar to a normal distribution (Hox, Moerbeek, & Van de Schoot, 2017), so they are left this way.

Table 7: Statistics independent variables

		Certified EMS	**Instruments of LCA**	**Performance measurm. social &env. activities**	**Sustain. technol.**	**Interaction var. 1**	**Interaction var. 2**	**Interaction var. 3**
Valid	No	137	130	93	43			
	Yes	8	15	52	102			
	Total	145	145	145	145	145	145	145
	Missing	0	0	0	0	0	0	0
Mean		,0552	,1034	,3586	1,6414	,1034	,2276	,8069
Std. Deviation		,2291	,3056	,4813	1,5031	,6092	,8720	1,4734
Skewness		3,937	2,632	,596	,619	7,606	4,381	1,687
Std. Error of Skewness		,201	,201	,201	,201	,201	,201	,201
Kurtosis		13,692	4,994	-1,668	-,574	65,595	20,318	1,619
Std. Error of Kurtosis		,400	,400	,400	,400	,400	,400	,400
Minimum		,00	,00	,00	,00	,00	,00	,00
Maximum		1,00	1,00	1,00	6,00	6,00	6,00	6,00

Furthermore, Table 8 shows that the values for skewness and kurtosis from the dependent variable and the mediating variable are sufficiently low.

Table 8: Statistics dependent variable and mediator

		Development in energy consumption	Percent change in production costs per product unit in 2014
N	Valid	145	145
	Missing	0	0
Mean		3,8172	3,8552
Std. Deviation		,95527	1,25266
Skewness		-,222	-,044
Std. Error of Skewness		,201	,201
Kurtosis		,851	-,272
Std. Error of Kurtosis		,400	,400
Minimum		1,00	1,00
Maximum		7,00	7,00

The mean of the variable ‘firm size’ (Table 9) shows that the companies in the response set on average have between 20 to 99 employees. Another conclusion that can be derived from Table 9, is that not many companies have implemented lots of technologies, since the highest score a respondent could get was 19 and the mean of this variable is 4.06 implemented technologies. An explanation for this might be that implementing a new technology is often a large investment. The respondents implemented relatively more other managerial and organizational practices. The maximum score was 15 and, on average, the respondents implemented 7.39 other practices.

Table 9: Statistics control variables

		Industry	Firm size	Other_tech	Other_org
N	Valid	145	145	145	145
	Missing	0	0	0	0
Mean		3,8897	2,2966	4,0552	7,3931
Std. Deviation		2,0754	,9798	2,7202	3,4183
Skewness		-,016	,541	,970	-,025
Std. Error of Skewness		,201	,201	,201	,201
Kurtosis		-1,357	-,116	1,069	-,689
Std. Error of Kurtosis		,400	,400	,400	,400
Minimum		1,00	1,00	,00	,00
Maximum		7,00	5,00	14,00	15,00

4.5 Bivariate Analysis

To test whether the different variables in the model correlate with each other, a bivariate analysis was conducted. These correlations are shown in Table 10. The first thing that stands out, is that the dependent variable 'development of production costs' does not correlate significantly with any of the independent variables nor with the mediator. It can therefore be assumed that there is no mediating effect of energy consumption between the independent variables and the dependent variable. This means that this bivariate analysis does not provide support for hypotheses 1, 2 or 3, which assumed that implementation of (a combination of) sustainable technologies and/or sustainable managerial and organizational practices would lead to lower production costs. The only variable that correlates significantly with the dependent variable is 'other managerial and organizational practices', which implies that implementing those could lead to lower production costs.

However, Table 10 does show that the relationship between 'Impact and performance measurements of social and environmental corporate activities' and development of energy consumption ($r = -.227$; $p < .01$) is significant. This means that if performance measurements on environmental and social activities are implemented, energy consumption decreases. Next to that, the relationship between sustainable technologies and development of energy consumption ($r = -.167$; $p < .05$) is significant. This implies that implementation of more sustainable technologies causes a decline in energy consumption.

Even though the independent variables do not correlate with certain variables as expected, some of them do correlate significantly with certain control variables. For example, 'Chemical' correlates with 'Instruments for product life cycle analysis' ($r = .196$; $p < .05$), which means that the type of industry influences the implementation of instruments for life cycle assessment. Furthermore, 'Firm size' correlates with sustainable technologies, other technologies and other organizational practices ($r = .398$ and $r = .375$; $p < .001$). This suggests that the larger the firm, the more sustainable technologies and other technologies and more other managerial and organizational practices are implemented.

Notable is, that 'other managerial and organizational practices' and 'other technologies' also significantly correlate with many other variables, such as investments in instruments for life cycle assessment, in impact and performance measurements for social and environmental activities, and in sustainable technologies. Perhaps, this is because companies that invest in sustainability, often also invest in other innovations (for example organizational or technological innovations).

Furthermore, implementation of more other technologies and/or organizational practices could cause energy consumption to decrease. These two variables also highly correlate with each other (r = .526; p < .001). This means it is a large effect, since it is higher than .50 (Field, 2013). It is the only large effect of importance in this analysis.

Table 10: Correlations between variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) Certified EMS	1									
(2) Instruments PLC assess.	,116	1								
(3) Performance measurements env. & social	,071	,171*	1							
(4) Sustainable technologies	,038	,127	,304**	1						
(5) Energy consumption	-,017	-,113	-,227**	-,167*	1					
(6) % change in production costs	-,020	,003	-,109	,075	-,025	1				
(7) Chemical industry	-,079	,196*	,048	,063	,087	-,093	1			
(8) Firm size	,081	,059	,141	,431*	-,072	,007	-,004	1		
(9) Other technologies	,095	,152	,271**	,428**	-,245**	,053	-,136	,398**	1	
(10) Other man. & org. practices	,141	,200*	,467**	,364**	-,233**	-,176*	,065	,375**	,526**	1

**p < .05; ** p < .01*

4.6 Multivariate Regression Analysis

4.6.1 Testing assumptions

Before a regression analysis can be conducted, it has to be checked whether the data meets the assumptions composed by Field (2013): (1) normality, (2) metric variables, (3) linearity between independent variables and dependent variable, (4) homogeneity, (5) no multicollinearity between independent variables and (6) independent errors.

The first assumption requires the variables to be normally distributed. Since the variables regarding sustainable managerial and organizational practices are dichotomous the distribution will always be skewed. However, the sample is large enough and the P-plots in Figure 3 (*Appendix 2*) are adequate, so this will not be a problem (Field, 2013). As said before, the values for skewness and kurtosis of the variable 'sustainable technologies' were sufficiently low and the P-plots (Figure 3, *Appendix 2*) are also fine, so it can be assumed that this variable is normally distributed.

The second assumption requires variables to be metric, because the distance between the different response categories has to be the same (Field, 2013). This assumption was met, since a seven-point Likert scale was used for the items measuring ‘development of energy consumption’ and ‘development of production costs’ and the others are dummies.

The third assumption is linearity, which means that the relationships between all of the independent variables and the dependent variable must be linear. The scatterplot in Figure 2 (*Appendix 2*) shows that the dots can be connected in a straight line and that there is no curve in the data and therefore, the assumption is met (Field, 2013).

Next to that, the forth assumption requires homogeneity of variance. The scatterplot in Figure 2 (Appendix 2) show that the values are more or less evenly spread out and that there is no pattern. Furthermore, Levene’s test of equality of error variance was not significant: $F(27, 117) = 1.38$, $p = .122$. This means that the null hypothesis that the error variance of the dependent variable is equal across groups cannot be rejected. Therefore, it can be concluded that the assumption of homogeneity is met (Field, 2013).

The fifth assumption is that the independent variables cannot correlate highly with each other (no multicollinearity) (Field, 2013). Table 11 shows that all VIF values are less than 10 and all tolerance levels are higher than .2, so it can be assumed that there is no multicollinearity and the last assumption is met (Field, 2013).

Table 11: VIF values and tolerance levels of the independent and mediating variables

	Collinearity Statistics	
Variable	**Tolerance**	**VIF**
Certified EMS	,984	1,017
Instruments life cycle assessment	,949	1,053
Impact & performance measurem. social & environm. activities	,860	1,163
Sustainable technologies	,893	1,120
Energy consumption	,933	1,071

a. Dependent Variable: production costs

The last assumption calls for uncorrelated residual terms for any two observations, which can be tested by the Durbin-Watson test. The closer to 2 the value is, the better (Field, 2013). For this data, the value is 2.29, which is quite close to 2, so it is assumed that this assumption has been met.

4.6.2 Model Statistics

In order to see what the main effects of the sustainable technologies and organizational practices are, what the effects of the interaction between them is on the dependent variable, and what role energy consumption plays, six different regression analysis were conducted (Four with 'production costs' as the dependent variable and two with 'energy consumption' as the dependent variable). The results of these analyses are presented in Table 12 and 13.

Before looking at the results of the analyses, the R^2 and Adjusted R^2 always need to be assessed. R^2 represents the amount of variance in the dependent variable explained by the model, which increases when more variables are added to the analysis. Adjusted R^2 takes the complexity of the model into account (Field, 2013). Table 12 shows that the models with 'development of production costs' as the dependent variable, only explain a small part of the variance. Only the models with 'development of energy consumption' as the dependent variable have higher values for R^2.

To test whether the models are useful to predict the dependent variable, the F-test of overall significance is performed. The null hypothesis in this test is: The model is not able to predict the dependent variable. Merely the models where 'development of energy consumption' was the dependent variable, the F-test was significant ($p < .05$). This means that only those two models can be used to successfully predict the dependent variable 'development of energy consumption'. In the models with 'development of production costs' as the dependent variable, the F-values are quite low, which means that probably, the improvement in prediction of the model is low and/or the difference between the model and the observed data is rather large (Field, 2013).

4.6.3 Hypothesis testing I: environmental and economic advantages of sustainable technologies and sustainable managerial and organizational practices separately

Table 12 shows the results of the regression analyses of the hypotheses regarding the main effects. The independent variables are placed in the rows of the table and the dependent variables in the columns. From the seven industrial subsectors, only the chemical sector is included in the analyses as a control variable, since this one varies the most from all sectors (Table 6, *Appendix 1*). This was done to reduce the number of variables and the number of observations per variable. The mediator 'development of energy consumption' (Table 12, row 5) operates in some analyses as the dependent variable and in some as an explanatory variable (cf. Figure 1). Therefore, this variable is included in the rows as well as the columns.

The effect of sustainable technologies

Hypothesis 1 argued that *The larger an organization's investment in sustainable technologies, the larger the saving on energy consumption and by extension the lower the production costs.* Column A of Table 12 shows that the direction of the relationship between sustainable technologies and energy consumption is as expected (the more sustainable technologies are implemented, the stronger the decrease of energy consumption). However, this effect is not significant. This means that the available data do not provide support for the first hypothesis. In column B was tested whether there is a significant effect between the development of energy consumption and the development of production costs per unit. This effect was not significant either, so this part of hypothesis 1 could neither be confirmed. Column C examines whether there is a direct effect of sustainable technologies on production costs. In other words: can implementing sustainable technologies deliver economic benefits (in terms of reduced production costs) regardless of whether there are environmental benefits (in terms of reduced energy consumption)? In this model, regarding the relationship between introducing new sustainable technologies and the development of production costs, is controlled for the development of energy consumption. This effect is to a small extent positive, but not statistically significant ($p > .10$).

According to the data, no statistically significant effect can be confirmed between the development in energy consumption and the development of production costs in 2014. Therefore, it can be concluded in advance that the other hypotheses cannot be fully supported, since all three hypotheses state that reduction in energy consumption would lead to reduction in production costs.

The effect of sustainable practices

It was not statistically justified to merge the three sustainable practices measuring the effect in hypothesis 2 into one variable (see section 4.3.1). Therefore those three practices were taken into the analysis as three separate variables (Table 12, row 6 to 8). Column A indicates that implementing 'Certified energy management systems' (row 6), 'Instruments of PLC analysis' (row 7), or 'Performance measurements of social and environmental activities' (row 8) does not significantly decrease energy consumption. Column C examined whether the three sustainable practices have a direct effect on production costs, controlled for the development of energy consumption. These effect are not significant either ($p > .10$), which means that the second hypothesis, *The larger an organization's investment in sustainable managerial and organizational practices, the larger the saving on energy consumption and by extension the lower the production costs,* is not supported by the data either.

Table 12: Regression analyses regarding hypotheses 1 and 2

	Development of energy consumption	Development of production costs	
	A	B	C
Control variables	**b (SE)**	**b (SE)**	**b (SE)**
1. Chemical Industry	,33 (,27)	-,11 (,57)	-,28 (,37)
2. Other technologies	-,05 (,04)	,08 (,05)	,06 (,05)
3. Other managerial & organizational practices	-,03 (,03)	-,11 (,04)	-,10 (,04)**
4. Firm size	,07 (,09)	,06 (,12)	,01 (,12)
Explanatory variables			
5. Sustainable Technologies	-,04 (,06)		,11 (,08)
6. Certified EMS	,14 (,35)		-,03 (,46)
7. Instruments of PLC analysis	-,22 (,27)		,17 (,36)
8. Performance measurements social & env. activities	-,26 (,19)		-,18 (,25)
Mediator Variable			
9. Energy consumption		-,06 (,11)	-.05 (,12)
Model information			
F-value	2,05**	1,92	1,32
R^2	,11	,07	,08
Adjusted R^2	,06	,03	,02
N	145	145	145

Other findings

As said before, column C of Table 12 tested whether the sustainable technologies and practices reduce the production costs directly, regardless of their effect on the development of energy consumption. This does not seem to be the case. Implementing sustainable technologies as well as sustainable practices do not have a direct effect on the development of production costs. However, important to state here, is that that was also not what was expected, since a mediation was hypothesized.

An interesting result is that ‘other managerial and organizational practices’ significantly reduces the production costs per unit (row 3), while ‘other technologies’ does not (row 2). This is in line with the findings of Vaessen et al. (2014).

Overall, it can be concluded from Table 12 that the development of energy consumption (over 2014) can be merely explained to a very limited extent by the indicators in these analyses. One methodological explanation for this might be that the explanatory variables are not operationalized adequately. For example, only the fact whether a technology or practices was implemented in a company or not was taken into the analysis. The extent to which the potential of the technology or practice was implemented or used was not examined. Another methodological explanation might be, that the amount of time the technology or practice had already been implemented, was not taken into the analysis. Technologies or practices could have been implemented a long time ago, which would mean that their effect on the development of energy consumption is not visible anymore. Moreover, they could have been implemented so recently, that the economic benefits of these investments had not appeared yet.

Next to the fact that the development of energy consumption can only be explained deficiently by the independent variables (the first part of the hypotheses), the development of energy consumption does not seem to have a significant effect on the development of the production costs per unit either (the second part of the hypotheses). A possible explanation might be derived from the results of a study from Hart and Ahuja (1996) about the relationship between emission reduction and financial performance in organizations. They found that companies with high emissions, financially benefit higher from emission reduction than companies that have relatively little emissions. This might also be the case in the effect of the development of energy consumption on the development of the production costs. Further analysis showed that for most of the companies in the dataset (80 percent) energy costs are merely five percent of the revenues at most and for 94 percent, at most 10 percent. This might indicate that the development of energy consumption only has a small effect on the development of production costs, compared to other costs, such as labour and purchasing goods and machines.

4.6.4 Hypothesis testing II: environmental and economic advantages of *combining* sustainable technologies and organizational practices

Hypothesis 3 argued that *The more extensively an organization combines sustainable managerial and organizational practices with sustainable technologies, the larger its additional savings on energy consumption and by extension the lower the production costs.* Column A (Table 13) shows that only the direction of the second interaction variable is negative, as expected. This means that implementing sustainable technologies as well as instruments for PLC assessment, leads to reduced energy consumption. However, this effect is not significant ($p > .10$). The direction of the other two interaction variables is positive, which is not in line with the expectations. It implies that implementing sustainable technologies combined with certified energy management systems or with performance measurements for social and environmental activities and sustainable technologies, leads to higher levels of energy consumption. This means that the results of this analysis do not provide support for the third hypothesis.

In column B of Table 13 was tested whether there is a direct effect of the interaction variables on production costs. This means: can simultaneous implementation of sustainable technologies combined with sustainable practices deliver economic benefits in terms of reduced production costs regardless of whether there are environmental benefits, in terms of reduced energy consumption? Hereby was controlled for the development of energy consumption. These effects were not statistically significant either ($p > .10$), so the third hypothesis is not supported by the available data. Thus, implementing Certified energy management systems as well as sustainable technologies simultaneously, nor combining Instruments for life cycle assessment and sustainable technologies, nor Performance measurements for social and environmental activities combined with sustainable technologies, has a significant effect on the development of production costs nor energy consumption.

Table 13: Regression analyses regarding hypothesis 3

	Development of energy consumption	Development of production costs
	A	B
Control variables	**b (SE)**	**b (SE)**
1. Chemical Industry	,28 (,29)	-,26 (,40)
2. Other technologies	-,03 (,04)	,05 (,05)
3. Other managerial & organizational practices	-,03 (,03)	-,10 (,04)**
4. Firm size	,07 (,09)	-,00 (,13)
Explanatory variables		
5. Sustainable Technologies	-,12 (,08)	,21 (,11)
6. Certified EMS	-,42 (,50)	,41 (,68)
7. Instruments of PLC analysis	,05 (,49)	-,06 (,66)
8. Perform. measurements social & environmental activities	-,50 (,29)	,17 (,39)
9. Certified EMS combined with sustainable technologies	,37 (,23)	,16 (,28)
10. Instruments PLC analysis combined with sust. technol.	-,19 (,21)	-,19 (,16)
11. Performance measurements social & environmental activities combined with sustainable technologies	,14 (,12)	-,02 (,12)
Mediator Variable		
12. Energy consumption		-,30 (,31)
Model information		
F-value	1,91**	1,20
R^2	,14	,10
Adjusted R^2	,07	,02
N	145	145

* *p < ,1;* ** *p < ,05;* *** *p < ,01*

From these regression analyses can be concluded, that only the control variable ‘other managerial and organizational practices’ has a significant influence on the development of production costs. The unstandardized betas of all four analyses in which ‘other org.’ is significant, show that when a (not sustainable) managerial or organizational practice is implemented, the production costs reduce with 0,1 percent.

4.7 Summary of the findings

The bivariate analysis as well as the regression analyses do not provide support for hypotheses 1, 2 or 3, which assumed that implementation of (a combination of) sustainable technologies and/or sustainable managerial and organizational practices would reduce production costs. The regression analyses showed that the explanatory variables cannot be used to predict the development of production costs. Furthermore, both analyses showed that there is no mediating effect of development of energy consumption between the independent variables and the dependent variable. Next to that, the bivariate analysis showed that implementation of sustainable technologies or in impact and performance measurements of social and environmental corporate activities could lead to a reduction in energy consumption.

5. Conclusion and Discussion

5.1 Introduction

In this chapter, a short summary of the study and its results are presented. The main question will be answered and a conclusion is drawn. Thereafter, the theoretical and managerial implications of this study are described. Lastly, the limitations of this research will be discussed and recommendations for future research are given.

5.2 Summary and conclusions

People are starting to realize that we have to become more sustainable (Thomas, 2017). In order to achieve this, it is essential that the manufacturing industry will make a large contribution, since they are seen as one of the primary polluters and consumers of energy (Dessus & Bussolo, 1998; IEA, 2007). However, many companies still believe that investing in sustainable technologies or practices will only cost them money (Nidumolu et al., 2009). To encourage them to become more sustainable, the aim of this study was to demonstrate to what extent investments in sustainable technologies and sustainable managerial and organizational practices reduce energy consumption (improve environmental performance) while also decreasing production costs (improve economic performance).
To achieve this, the main research question to be answered was:

To what extent do investments in sustainable managerial and organizational practices as well as in sustainable technologies reduce energy consumption as well as total production costs per unit?

To be able to answer this research question, three hypotheses were tested, which are shortly described below.

Research has shown that energy-saving technologies lead to enhanced energy-efficiency and reduction of energy consumption and negative impacts on the environment (IEA, 2007; Pons et al., 2013; Shrivastava, 1995; Zhang & Wang, 2008). Furthermore, for example, a study of Zhang and Wang (2008) also showed that sustainable technologies can lead to enhanced productivity and lower production costs. Therefore, the first hypothesis stated:

H1: The larger an organization's investment in sustainable technologies, the larger the saving on energy consumption and by extension the lower the production costs.

Next to that, researchers have found that sustainable managerial and organizational practices can enhance efficiency, reduce energy consumption and diminish manufacturing costs (Gordić et al., 2010; Ngai et al., 2013). For this reason, the second hypothesis was:

H2: The larger an organization's investment in sustainable managerial and organizational practices, the larger the saving on energy consumption and by extension the lower the production costs.

Additionally, some literature argues that simultaneous implementation of technologies and managerial and organizational practices, could even lead to synergetic effects on energy consumption and production costs (Armbruster et al., 2006; Ligthart et al., 2018). Since this might also be the case for sustainable technologies and practices, the third hypothesis was formulated as follows:

H3: The more extensively an organization combines sustainable managerial and organizational practices with sustainable technologies, the larger its additional savings on energy consumption and by extension the lower the production costs.

To test these hypotheses, a quantitative study was conducted, based on the data regarding 177 Dutch manufacturing companies collected by the European Manufacturing Survey of 2015. First, a bivariate analysis was done, which examined the correlations between the main variables. The results showed that sustainable technologies and some sustainable managerial and organizational practices, in this case 'Impact and performance measurements of social and environmental corporate activities', can have a reducing effect on energy consumption.

Surprisingly, none of the independent variables nor the mediating variable 'development of energy consumption' correlated significantly with the dependent variable 'the development of production costs'. This means that the results of this bivariate analysis did not provide support for any of the three hypotheses. This was unexpected, since many empirical evidence has indicated that environmental and economic performance go hand-in-hand (Al-Tuwaijri et al., 2004; Schaltegger & Synnestvedt, 2002) and that it pays off to be green (Hart & Ahuja, 1996). According to many researchers, good environmental performance, for example through sustainability in supply chains and technological innovation, leads to improved resource productivity, higher (energy) efficiency, reduced costs and enhanced economic performance (Despeisse et al., 2012; Fujii et al., 2013; Klassen & McLaughlin, 1996; Porter & Van der Linde, 1995; Rao & Holt, 2005). It would be interesting for researchers to further examine what could be possible explanations for these results.

Another remarkable result from the bivariate analysis is that ‘other technologies’ and ‘other managerial and organizational practices’ correlate significantly with all independent variables and also highly correlate with each other. This suggests that implementing other technologies or practices could lead to more implementation of sustainable technologies and practices and to lower levels of energy consumption. Furthermore, implementation of other organizational practices could even decrease production costs. This is in line with previous research (Hayes & Jaikumar, 1988; IEA, 2007; Schmidt & Rammer, 2007; Tassey, 2007; Vaessen et al., 2014), but it goes against the assumption made when drawing up the hypotheses, that sustainable technologies and practices might have the same effect. The outcome of the bivariate analysis that ‘other technologies’ reduce energy consumption is not very surprising, since many technologies are designed to improve efficiency and, in general, technological improvements can often diminish manufacturing costs (Lange, 2001).

After the bivariate analysis, a multivariate regression analysis was conducted. The results of this analysis have shown that the models with ‘the development of production costs’ as dependent variable cannot be used to successfully predict this variable. This means that it cannot be confirmed that sustainable technologies, sustainable managerial and organizational practices or a combination of those have an effect on production costs, nor that development of energy consumption is a mediating variable. Therefore, this regression analysis has shown that none of the three hypotheses are supported by the data. A possible explanation for this might be that there are too many other variables that influence the development of production costs. Examples of different costs that also determine the production costs per unit are: fixed costs, such as labour, maintenance and overhead, and variable costs, such as the consumption and price of resources and energy (Lange, 2001). Perhaps, the fact that only the development of energy consumption was taken into account in this study, not energy costs, explains why the development of energy consumption did not have an effect on the development of production costs. It could have been the case that energy consumption decreased in many companies, but the costs of energy were really high in 2014. Then a decrease in energy consumption does not necessarily lead to lower production costs.

Furthermore, the analysis did not take the level of output into account, and whether economies of scale were accomplished by the manufacturing company. Economies of scale imply that “a small proportional increase in the levels of all input factors can lead to more than proportional increases in the levels of outputs produced” (Panzar & Willig, 1977, p. 1) This might be a large determinant of the reduction of production costs per unit (Hopkinson & Dicknes, 2003).

It was unexpected that both analyses have shown that the development of energy consumption and the independent variables do not significantly affect the development of production costs. However, this is consistent with some studies that did not confirm a significant positive relationship between environmental performance and economic benefits (Friedman, 1970; Jaggi & Freedman, 1992; Wagner et al., 2002). Perhaps, sustainable technologies and practices can deliver competitive advantages (Armbruster et al., 2006; Despeisse et al., 2012; S. L. Hart, 1995; Klassen & Whybark, 1999; Nidumolu et al., 2009), but no direct financial advantages such as a decrease in production costs. However, both analyses have shown that ‘other managerial and organizational practices’ can have an effect on the development of production costs. This might be an interesting topic for future research.

Another surprising outcome is that the interaction variables, combining sustainable technologies and sustainable managerial and organizational practices, did not have an effect on the development of energy consumption or on the development of production costs. A reason for this might be that there is a possibility that a combination of sustainable technologies and practices only works complementary when they are implemented sequentially, not simultaneously. Perhaps, because implementation of new technologies often asks for new managerial and organizational practices (Damanpour & Evan, 1984), it is important to first implement new technology to be able to accomplish a complementary effect.

The results of this study imply that investing in technologies and/or practices in general could reduce consumption of energy and perhaps even to a decrease in production costs. However, sustainable technologies and/or managerial and organizational practices do not have the same effect. The bivariate analysis showed that implementing sustainable technologies and performance measurements of environmental and social activities could lead to a reduction of energy consumption, but not to a reduction of production costs. It can therefore be concluded that, according to the data, implementing sustainable technologies and/or sustainable managerial and organizational practices does not simultaneously enhance environmental performance (energy consumption) as well as economic performance (production costs).

5.3 Theoretical Implications

There has been some research on the relationship between environmental and economic performance, but the results are often divergent and ambiguous (Pons et al., 2013). Therefore, this study was meant to contribute to finding consensus on this relationship. The results contribute to the theory by showing that a positive relationship between environmental performance (energy consumption) and economic performance (production costs) cannot be confirmed.

The analyses have shown that other managerial and organizational practices could affect the development of energy consumption and the development of production costs. Therefore, this study offered some confirmatory insights regarding the general literature on the relationship between managerial and organizational practices, energy consumption and economic performance. Unfortunately, this study has not been able to demonstrate that sustainable practices have the same effects.

The fact that the results have indicated that nor the explanatory variables, nor the development of energy consumption have a significant effect on the development of production costs, shows that there is still a gap in the sustainability literature. There is not enough knowledge to determine in what way sustainability could also enhance economic performance. In my opinion, it is crucial that more research will be conducted on this topic in the future.

5.4 Managerial implications

The results of this study indicate that investing in technologies and managerial and organizational practices in general, could lead to lower levels of energy consumption. Specifically, implementing ‘Impact and performance measurements of social and environmental corporate activities’ and the sustainable technologies named in section 3.4.2 could be a smart move for management of manufacturing companies if they want to reduce their energy use. (For example, if energy costs are a large part of their production costs.)

For companies doubting about whether to invest in sustainability, this research might help to make the decision, if the company is focused on economic outcomes of the investment. Unfortunately, this study will not give them an incentive to invest, since the results have shown that implementing sustainable technologies and practices does not necessarily lead to a decrease in production costs. However, it might be an incentive to invest in technologies and practices in general, since the results have shown that some technologies and practices could lead to lower energy consumption and perhaps even to lower production costs.

5.5 Limitations and recommendations for future research

One of the limitations of this research might be, that perhaps, the hypotheses were based too much on logic reasoning and assumptions derived from literature on technologies and organizational practices in general, instead of on research outcomes of studies regarding sustainable technologies and practices in particular. The existing literature is contradictory and there is not much empirical evidence supporting the hypotheses yet. This thesis therefore confirms that more research needs to be conducted on the topic of the effects of sustainable technologies and practices.

Since the urgency for sustainability keeps increasing and the manufacturing industry can play a big role in this, it is important that future research focuses on finding out how sustainability in manufacturing companies could also lead to other (economic) benefits, in order to be able to stimulate investments in sustainability.

Another flaw in the research process was, that the variable ‘sustainable organizational practices’ was not reliable, due to bad internal consistency. This meant that three dummies had to be taken into the analysis separately and three different interaction variables had to be computed.

Lastly, the extent to which a technology or practices was implemented and how long it had already been implemented were not included in the analyses, since a few items of ‘sustainable technologies’ did not measure this. However, this might have been valuable information to take into account. Therefore, the quality of the study might have been better if the EMS 2015 had asked about the extent and implementation year of all technologies and organizational practices. Perhaps, merely taking the sum of these items was not enough to give an accurate image. Next to that, it would be better to include more items measuring different sustainable technologies and managerial and organizational practices, so that as many technologies and practices as possible are covered by the survey.

For future research, it might be interesting to further examine the relationship between energy consumption and production costs. Perhaps, an explanation could be found for the results of this study, suggesting that energy consumption does not affect production costs. In order to convince companies all over the world to become more sustainable, future research should focus on finding out how investing in sustainability could also lead to economic benefits.

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Appendix 1: Variable Construction

Table 6: Linear regression on dummies of control variable 'Industry'

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	4,179	,239		17,511	,000
	vFood	-,231	,375	-,062	-,616	,539
	vTextile and packaging	-,512	,404	-,125	-1,267	,207
	vConstruction	-,262	,351	-,078	-,746	,457
	vChemical	-,679	,413	-,161	-1,642	,103
	vMachinery	-,429	,337	-,136	-1,270	,206
	vElectronic	-,414	,388	-,107	-1,066	,288
2	(Constant)	4,349	,535		8,129	,000
	vFood	-,253	,383	-,068	-,662	,509
	vTextile and packaging	-,677	,413	-,165	-1,640	,103
	vConstruction	-,369	,363	-,110	-1,016	,311
	vChemical	-,759	,430	-,180	-1,765	,080
	vMachinery	-,458	,342	-,145	-1,339	,183
	vElectronic	-,462	,389	-,119	-1,187	,237
	Certified EMS	-,098	,471	-,018	-,207	,836
	Instruments of LCA	,145	,374	,035	,388	,699
	Impact & performance measur. of social & envir. activities	-,453	,240	-,174	-1,891	,061
	Sustainable technologies	,117	,076	,140	1,541	,126
	Energy consumption	-,040	,117	-,031	-,341	,733

a. Dependent Variable: percent change in production costs per product unit in 2014

Appendix 2: Model Assumptions

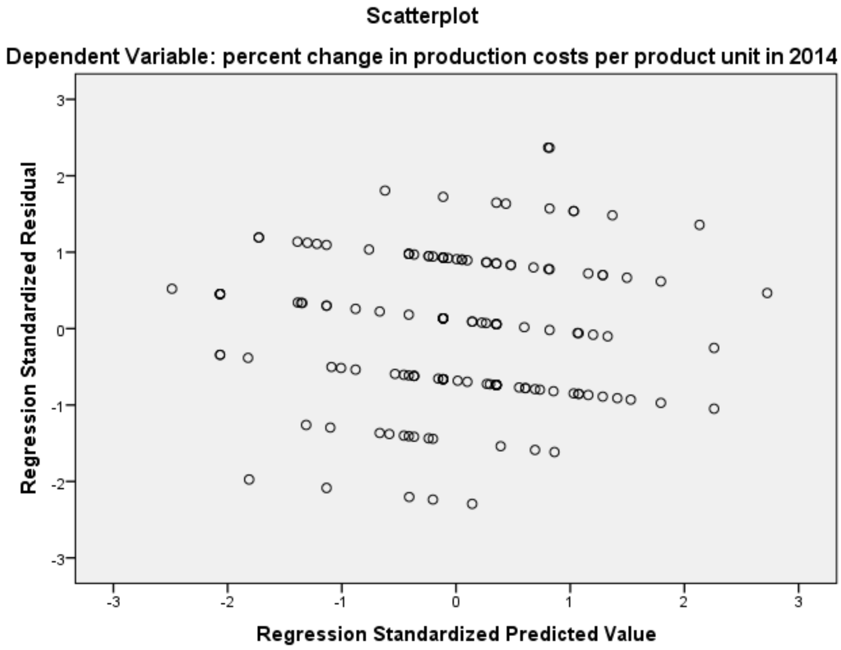

Figure 2: Scatterplot

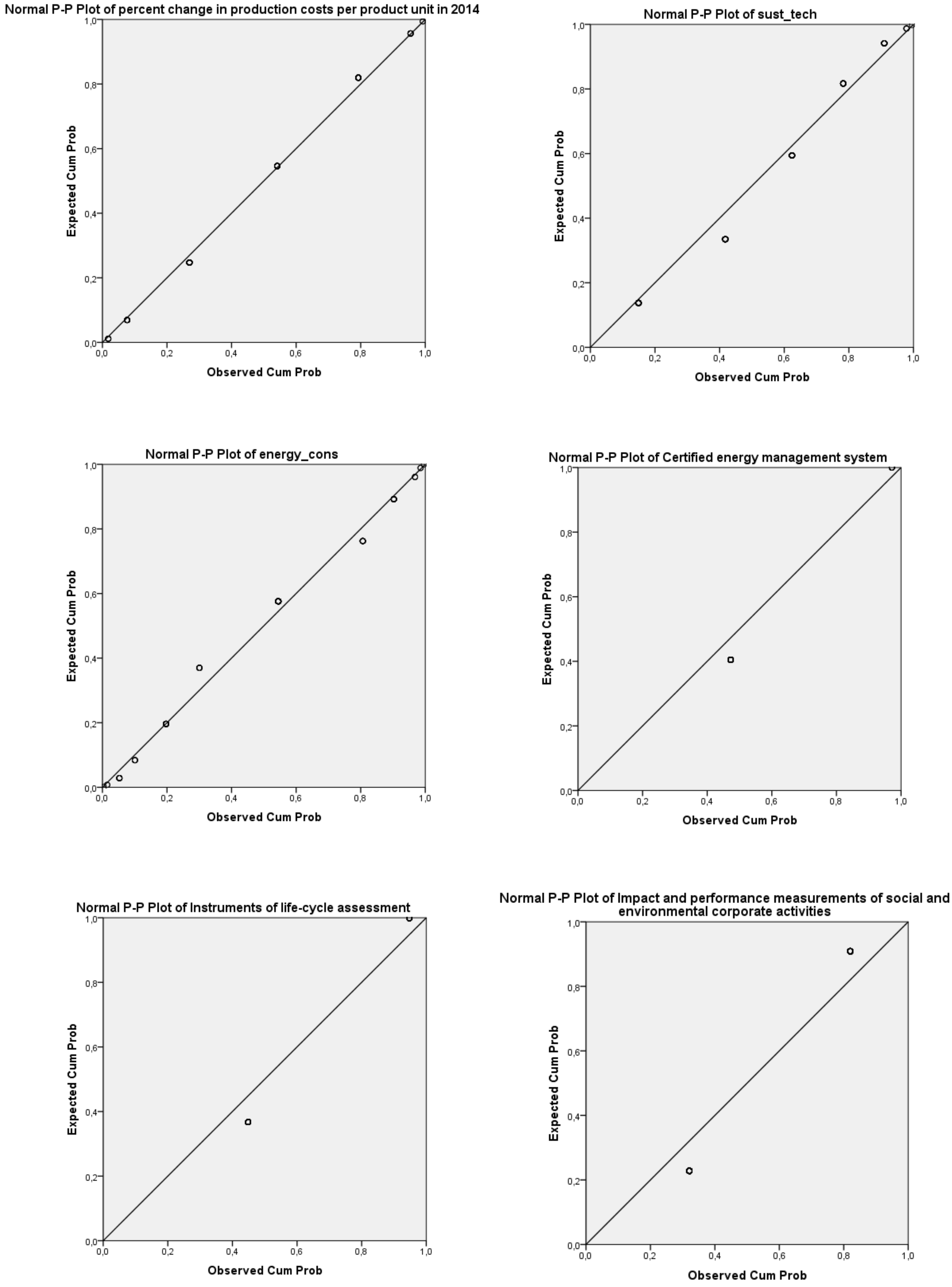

Figure 3: P-Plots of the dependent and independent variables and the mediator