UiT The Arctic University of Norway

School of Business and Economics

# Firm internal drivers for eco-process innovation

A multi-method analysis of energy efficiency in Norwegian manufacturing firms

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# Abstract

This thesis aims to explore the nature and role of manufacturing firms' internal drivers in stimulating eco-process innovation. The study is motivated by the need to increase the environmental performance of the manufacturing sector. The high energy intensity of this sector places it at the centre of all greenhouse gas emission abatement programmes. Its transition to a sustainable sector would depend on the willingness and ability of manufacturing firms to pursue eco-process innovation. Despite the growing awareness about internal drivers, most of the knowledge in this research field is related to eco-product innovation and external drivers. Thus, knowledge about the range and role of firms' internal drivers that might affect their eco-process innovation and environmental performance is limited. Therefore, the overall aim of this thesis is to answer the following question:

*What is the relationship between manufacturing firms' internal organisational drivers and eco-process innovation?*

To answer this research question, I use an explorative research design and explore the phenomenon in three interdependent empirical studies appended as Paper 1–3. These studies are empirically informed by research on energy efficiency (EE) in manufacturing firms, mainly located in Norway. Hence, in this study, I treat EE as an empirical phenomenon and use it to examine the more theoretical conceptualisation of internal drivers for eco-process innovation. Furthermore, the studies draw on different theoretical, epistemological, and methodological approaches.

*Paper 1* is a systematic literature review (SLR) synthesising the current body of the literature on drivers for EE in manufacturing firms. The SLR provides several valuable insights for the work of the thesis. In short, the study reveals the importance of managerial and organisational drivers for EE in manufacturing firms and points to the limited use of rigorous theoretical frameworks in empirical research. Building on this knowledge, the research design of Papers 2 and 3 was developed with the aim of enhancing the current understanding of firms' internal drivers for EE innovation. *Paper 2* uses the theory of absorptive capacity to quantitatively

analyse the effect of knowledge and competencies at various organisational levels for EE investment in manufacturing firms. This paper suggests that knowledge and competencies at both the individual and organisational levels affect such investments, and indicates a positive interaction effect between them. Accordingly the study indicates that internal knowledge and competencies are essential for the effective assimilation of external knowledge. From the results, the absorptive capacity of manufacturing firms is positively related to their investment in EE. *Paper 3* uses translation theory to explore the emergence of new energy management practices. This qualitative case study provides insights on how firms can implement an environmental programme into local practices. With focus on the translation processes at the micro level, the study also provides information on the internal key stakeholders at various organisational levels, management competencies, and reasons for the translation itself. The study results indicate the relevance of translation competence as a driver for eco-process innovation, in that it increases the probability of success in environmental programme implementation and firms' environmental performance. In addition, they point to the implementation process dynamics over time and relevance of managerial endurance.

The thesis builds on the integrated findings of the three empirical studies. The abductive research approach, the mixed method and the triangulation of the empirical data across the three studies contribute to extending our knowledge on internal drivers and increase the reliability of the results. In particular, the thesis proposes a new typology of internal organisational drivers for eco-process innovation: environmental leadership, absorptive capacity, organisational structure and routines, and translation competence. Furthermore, the results point to the micro foundations of each driver and suggest an interrelation between the four drivers. This interrelation is discussed in a conceptual model. The thesis further contributes to the field by providing more knowledge on the impact and role of internal stakeholders at various organisational levels. By considering EE as an empirical phenomenon, the study is also of theoretical relevance to the EE literature. Finally, I discuss the relationship between the origin of the eco-innovation literature, underlying assumptions in the field, and the value of alternating between theoretical and empirical approaches in the further development of eco-innovation theory. From my observations, the gap in the literature with regard to internal drivers is due to limited academic attention, 'redundancy' in theory development, and lack of theoretical framing and clarity in the definition of key concepts. Therefore, I suggest that, further research

would benefit from a larger degree of problematisation of existing assumptions when designing research questions, and that researchers build on alternative theoretical frameworks more actively, and are more explicit when defining key concepts. Thus, the further development of eco-innovation theory can extend our knowledge on the firm internal factors and mechanisms affecting the environmental transition of manufacturing firms. The thesis results also provide valuable insights for managers and policymakers as well as avenues for future research.

Keywords: Drivers, eco-process innovation, energy efficiency

## Table of Contents

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## List of appended papers

**Papers:**
The following papers are included in the PhD thesis:

I: Solnørdal, M. T., and Foss, L. (2018). Closing the energy efficiency gap—a systematic review of empirical articles on drivers to energy efficiency in manufacturing firms. *Energies*, 11(3), 518. doi:https://doi.org/10.3390/en11030518

II: Solnørdal, M. T., and Thyholdt, S. B. (2019). Absorptive capacity and energy efficiency in manufacturing firms – An empirical analysis in Norway. *Energy Policy*, 132, 978-990. doi:https://doi.org/10.1016/j.enpol.2019.06.069

III: Solnørdal, M. T. (2020). Translating a corporate environmental idea into energy management practices: A case study the implementation of energy management in a pharmaceutical company. Draft submitted to *Sustainability* (ISSN 2071-1050).

**Contributions:**

Table 1 depicts the contributions of co-authors and supervisors to the appended papers. Signed co-author statements with more detailed information about their contributions to the papers can be found in Appendix 1

*Table 1: Contributions form co-authors and supervisors*

| **Development phase** | **Paper I** | **Paper II** | **Paper III** |
|---|---|---|---|
| Concept and idea | MTS | MTS | MTS |
| Study design and methods | MTS | MTS, SBT | MTS |
| Data collection | MTS | MTS* | MTS |
| Data analysis | MTS | SBT | MTS |
| Interpretation of results | MTS | MTS, SBT | MTS, EAN |
| Manuscript editing | MTS | MTS, SBT | MTS |
| Critical revision of the intellectual content | MTS, LF, LC | MTS, SBT, LF, LC | MTS, EAN, LF |

* Dataset from Statistics Norway

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MTS = Mette Talseth Solnørdal
SBT = Sverre Braathen Thyholdt
LF = Lene Foss

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LF = Lene Foss
EAN = Elin Anita Nilsen
LC = Lars Coenen

# PART 1

# COVER PAPER OF THE THESIS

# 1. Introduction

This thesis focuses on the internal drivers for eco-process innovation in manufacturing firms. The empirical scope of the thesis is thus the firms classified under the economic area of manufacturing (code C in the EU NACE rev. 2). When referring to this economic area, this thesis uses the terms 'industrial sector' and 'manufacturing' interchangeably. In this introductory section, I state the research objective and the practical and academic relevance and background of the thesis. I also present the empirical focus and positioning of the appended papers in answering the research question. The overall structure of the thesis is then outlined.

## 1.1. Practical relevance of the thesis

Increasing economic and social challenges due to environmental degradation and disasters has placed global warming and climate change among the most pressing issues of the twenty-first century. The relationship between increased atmospheric $CO_2$ and global warming was officially confirmed by Swedish scientist Svante Arrhenius in 1896 (Arrhenius, 1896). However, it took over 100 years through dispute and disbelief for the research community to finally accept the reality of global warming and its link with human activity (e.g. IPCC, 2014). Today, climate change mitigation and sustainable development are at the political agenda worldwide, asserting the importance of meeting the present-day needs without compromising on the ability of future generations to meet their own needs (Brundtland, 1987). Political imperatives to limit the increase in global temperature to below 2℃ and obligations to reduce $CO_2$ emissions are expressed in several conventions such as the Paris Agreement (UNFCCC, 2015) and the European 2030 framework for climate and energy (EU, 2014). By ratifying such agreements, several nations have committed to reduce their greenhouse gas (GHG) emissions by at least 40% below the 1990 level by 2030. In 2016, the manufacturing sector accounted for 37% of total final energy consumption (TFC) globally (IEA, 2018). Energy demand showed an accelerating trend line between 1971 and 2016, when the TFC grew by a factor of 2.25 (IEA, 2018). Economic development, increased access to marketed energy, and population growth (EIA, 2017) would increase the energy demand still further if no abatement measures are urgently taken. Traditionally, fossil fuel has been the most important energy product used in the manufacturing sector. Hence, the energy intensity and GHG emissions of manufacturing firms place the sector at the centre of all GHG emission abatement programmes. Although the industrial sector has a large negative environmental impact, it ironically holds the key to economic prosperity, social equality, and poverty eradication (World Bank, 2015). Hence, abolishing industrial activity cannot be an option, but the sector needs to transition away from fossil fuel use towards renewable energy use, accelerate the development of carbon capture and storage technologies, and last but not the least use energy more efficiently.

Global GHG emissions abatement holds also a central place in Norwegian debates. Norway has the most decarbonised power sector in Europe, with around 94% (141 TWh in a normal year) of their electricity production coming from hydropower and about 3% coming from wind power. The country’s renewable power resources are used both nationally and are an important part of the Nordic power market, helping it to balance the supply and demand for domestic industry and across the region. The power consumption of mainland Norway in 2018 was 235 TWh (NVE, 2019a), with the manufacturing sector accounting for about one-third of the final energy consumption; the sector used 69 TWh energy, of which about two-third was from electricity (46 TWh) and 18 TWh came from fossil fuel such as coal, gas, and oil (NVE, 2019a). Although, the manufacturing sector includes a wide variety of industries with differing energy needs, the energy use of the sector as a whole generally reflects Norway’s extensive use of electricity. For a comparison, the industrial energy consumption of other Nordic countries in 2015 was as follows: Sweden 53 TWh, Finland 40 TWh, Denmark 10 TWh, (NVE, 2019b). The Norwegian industry is thus a relatively large energy consumer and substantial GHG emitter compared with other Nordic countries. Enova (2019) shows that a large part of the Norwegian industry's total emissions can be cut through the use of other available and profitable technology resources. Thus, the manufacturing sector can bring about extensive environmental improvement by becoming more energy efficient.

In addition to these environmental objectives, Norway faces a peculiar situation in that it is a significant exporter of fossil fuels. In 2019, around 46. 8% of Norway’s total income came from crude oil and natural gas exports (SSB, 2020). An accelerated global energy transition will have a deep impact on the future demand for fossil fuels, with severe implications for the Norwegian economy. Norway has accordingly both an extended moral responsibility to develop eco-innovation technologies and models that reduce GHG emissions, and meet the urgent need to prepare the national economy for a future with less dependencies on oil and gas exports. Thus, Norway has to develop an efficient manufacturing sector that can be internationally competitive despite being located a high cost country. Indeed, eco-innovation development and scaling and production process refinement are essential for any country aiming to enhance productivity and efficiency. For the sustainable development of the manufacturing sector in terms of both environmental and economic objectives, business managers must be well informed and policies must be well crafted to effectively stimulate and support industrial endeavours. Research can contribute by identifying and addressing key factors at the firm level that are essential and thus help managers and policymakers make well-informed decisions.

### 1.2. Problem statement and research question

Eco-innovation includes all innovation activities, such as process, product, and organisational innovations that better reduce environmental impacts compared to relevant alternatives (Kemp and Pearson, 2007). Eco-process innovations are recognised as technological solutions that enhance the environmental performance of production processes (OECD, 2009) normally through more efficient use of resources (García-Granero et al., 2018), and thus contribute to better financial performance and competitiveness of manufacturing firms (Porter and Vanderlinde, 1995). However, theory points out several barriers to the development and implementation of eco-process innovations. The first is the 'double externality problem' (Rennings, 2000), which shows how a firm investing in eco-innovation typically creates benefits for others but incurs all the costs itself. Since firms have limited incentives to invest in environmental technologies (Popp et al., 2010), general market forces make the diffusion of eco-innovation lower than the socially optimal level (Jaffe and Stavins, 1994). Furthermore, technological eco-innovations are generally applied along with other technologies, thus leading to different compatibility requirements with respect to existing technologies, technological systems, and institutional settings (Hansen and Coenen, 2017; Geels, 2012). These economic, technological, and social barriers to eco-innovation (del Río et al., 2010) hamper the implementation of available and economically feasible eco-innovations in manufacturing firms (Abdelaziz et al., 2011). As an outcome the sector holds large unexploited potential for improved environmental performance (Cui and Li, 2015; Lin and Tan, 2016). Thus, to improve the environmental performance of firms there is a need for theoretical knowledge about the drivers for eco-innovation.

Prior studies show that a wide array of external and internal drivers that positively stimulates eco-innovation in manufacturing firms (Bossle et al., 2016; Díaz-García et al., 2015; Hazarika and Zhang, 2019). Depending on the theoretical perspective of the researcher, the drivers are operationalised in many factors, such as determinants (Pacheco et al., 2017; Horbach et al., 2012), antecedents (Salim et al., 2019), success factors (De Medeiros et al., 2014), and motivation (Bossle et al., 2016). Even though several of these drivers are similar to the general innovation drivers (del Río et al., 2016), the distinctive barriers to eco-innovation call for policy interference to stimulate the adoption of eco-innovation in firms (Gillingham and Palmer, 2014). Thus, research on external drivers in terms of environmental regulation has dominated and affected the theoretical development of the field (del Río et al., 2016). However, recent research has questioned the stimulating effect of environmental legislation for eco-process innovation (Horbach et al., 2013; Cheng and Shiu, 2012; Triguero et al., 2013; García-Granero et al., 2018). Furthermore, there is growing awareness that firms need to go beyond mere regulatory compliance (Chen et al., 2012; Aragón-Correa et al., 2008) to reach the objective of sustainable development. In other words, firms need to proactively find the best technological solutions and advance their standards for environmental performance (Venmans, 2014; Sharma, 2000). In this regard, the academic community is increasingly exploring the nature and role of internal drivers for eco-innovation (Pham et al., 2019; Salim et al., 2019; De Marchi, 2012; De Marchi and Grandinetti, 2013). Arguably, the research on internal drivers of eco-innovation is still in its infancy (Schiederig et al., 2012), with several scholars highlighting a gap in the literature on comprehensive and inclusive studies that investigates the impact of organisational factors explaining the eco-innovation of firms (Díaz-García et al., 2015; He et al., 2018). In particular, a need has arisen for more knowledge and empirical research on the internal resources and competencies of firms (Díaz-García et al., 2015; del Río et al., 2017) that stimulate eco-process innovation. From a review of eco-innovation models, Xavier et al. (2017) also indicate a gap in the current research on the strategic and structural factors of a company (specific skills, environmental capacity, culture, and leadership). In view of this gap in knowledge about the role and impact of internal drivers for eco-process innovation in manufacturing firms, I have framed the overall research question of the thesis as follows:

*What is the relationship between manufacturing firms' internal organisational drivers and eco-process innovation?*

To answer this question, I use different theoretical perspectives and methods, in three interdependent studies, in exploring the role of internal organisational drivers for eco-process innovation. The three studies are appended as Papers 1–3. All papers are based on empirical studies on EE innovation. Before discussing how the three studies answer the research question, I present the theoretical positioning and empirical focus of the thesis in the following sections.

## 1.3. Theoretical positioning and empirical focus

With neutral general innovation in terms of the direction of changes (OECD, 2005), eco-innovation contributes to improve the environmental performance of firms and is categorized as process, product, and organisational innovation (Kemp and Pearson, 2007). EE is defined as the innovative steps taken by manufacturing firms to reduce their energy per unit of output (Costa-Campi et al., 2015). Thus, EE innovation reduces the harmful environmental impacts of firms by creating more goods and services with fewer resources and thus generating less pollution (Carrillo-Hermosilla et al., 2010). EE innovation is accordingly a type of eco-process innovation. In addition, from the categorical hierarchy between EE and eco-innovation, one can assert that the research field of eco-innovation is more expansive and elaborate. Therefore, this thesis treats EE as an empirical phenomenon and use it for more theoretical conceptualisation of the internal drivers for eco-process innovation. Thus, the findings of this thesis provide a wider analytical framework and contribute to theory development on process-based eco-innovation. Furthermore, the results of this thesis are useful to theorise the efforts and activities of firms to improve their EE. Figure 1 illustrates the theoretical positioning of the thesis.

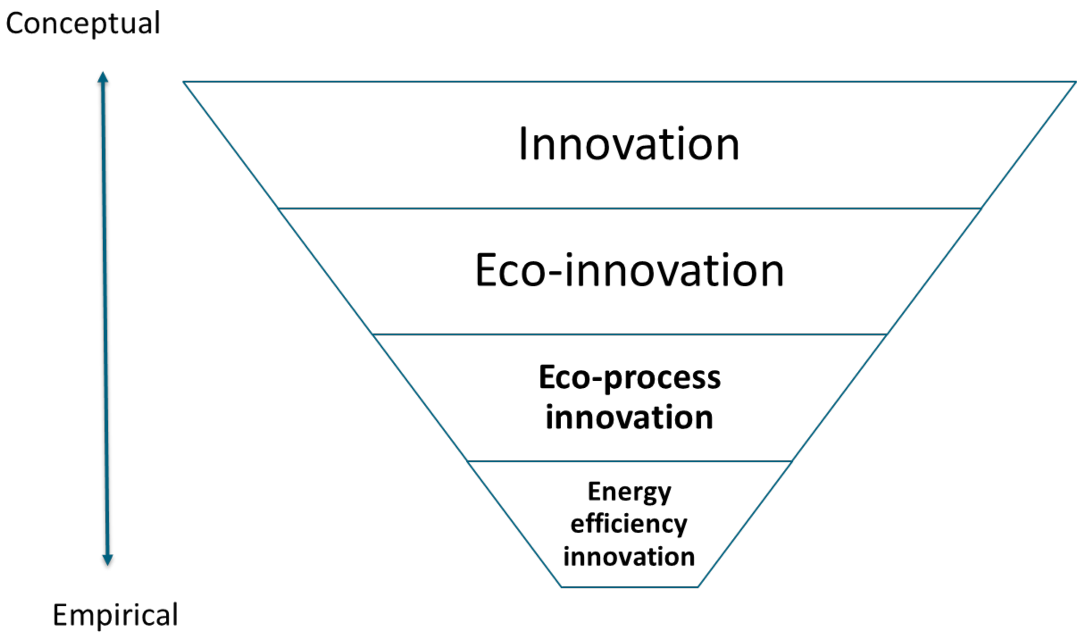


*Figure 1: Theoretical positioning of the thesis in the field of innovation*

Figure 1 depicts a conceptual empirical hierarchy in innovation theory and empirical EE innovation research. Thus, the figure visualises eco-innovation theory as a sub-category of innovation theory. Furthermore, the figure illustrates that the empirical focus is on EE innovation, which is a type of eco-process innovation. Also, note that Eco-innovation is a multidisciplinary concept, with most research conducted in business and management, environmental studies, engineering, and social sciences (García-Granero et al., 2018; Shi and Lai, 2013; Díaz-García et al., 2015). Nonetheless, by focusing on the factors that stimulate eco-innovation in manufacturing firms, this thesis relates to the theoretical field of business and innovation.

### 1.4. Positioning of Papers 1–3 in answering the research question

To answer this question, three interdependent papers are employed to investigate the phenomenon. For an overview of the current body of studies in the field, Paper 1 systematically reviews the empirical literature on drivers for EE in manufacturing firms. The SLR provided several valuable insights that affected the proceeding work of the thesis. It revealed the importance of managerial and organisational drivers as well as a limited use of theory to understand and explain the role of these drivers. Building on these insights, I developed the research design of Paper 2 and 3. These studies were motivated to better understand the nature, role and interrelation between organisational and managerial drivers, and EE. For better analysing these relationships I have based the work in Paper 2 and 3 on established theoretical frameworks. In Paper 2, we quantitatively analysed the effect of organisational absorptive capacity on firms ’ propensity to pursue EE innovations, while I in Paper 3 qualitatively explored the emergence of energy management practices by studying the implementation of an environmental programme from the perspective of translation theory.

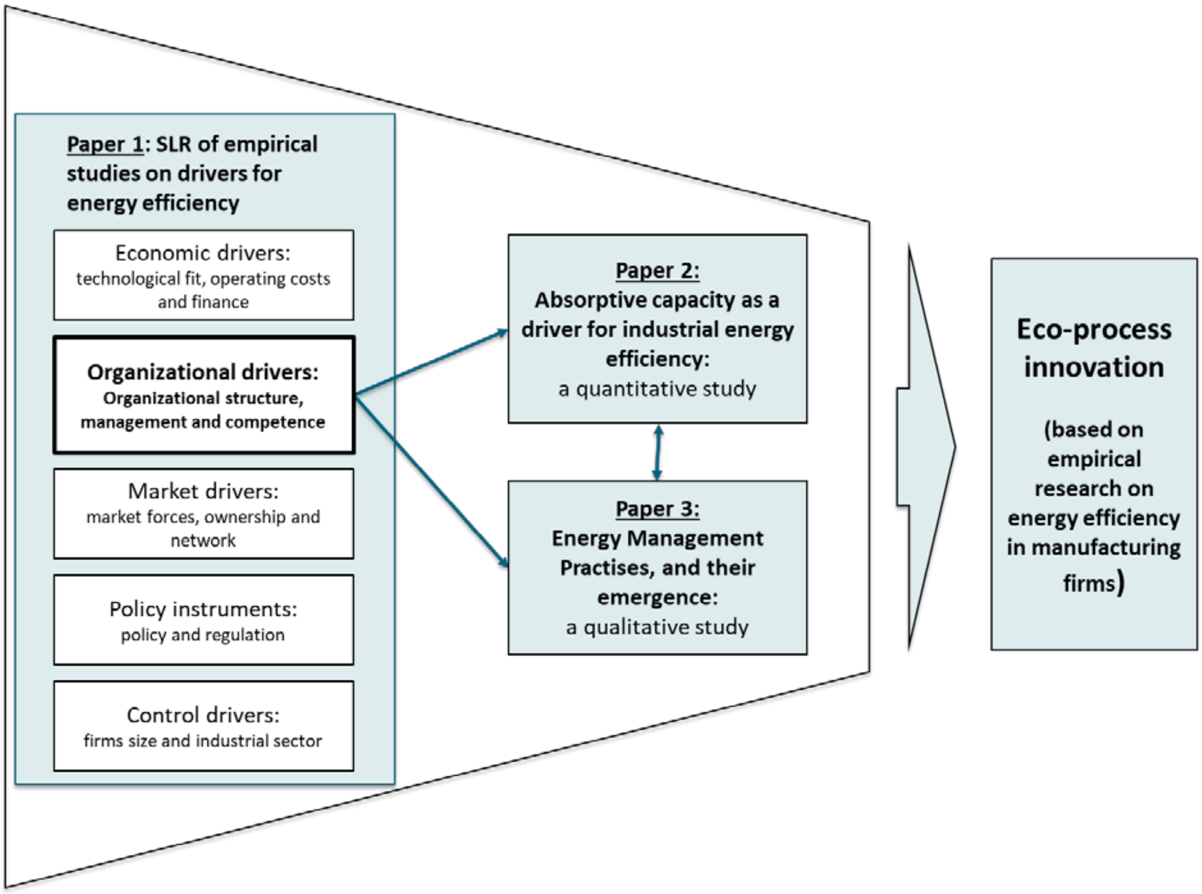


*Figure 2: Positioning of Papers 1–3 in answering the research question of the thesis*

Figure 2 illustrates the emergence and interrelation of the appended papers. The three studies contribute to answering the overall research question from different empirical, theoretical, and epistemological perspectives, and thus provide new empirical knowledge on internal organisational drivers for eco-process innovation. This thesis adds to theory development by addressing the gap in the knowledge of internal organisational drivers for eco-process innovations and demonstrates the value of theoretical and methodological triangulation. Furthermore, it provides new knowledge on internal drivers relevant to succeed with the transition towards more sustainable and energy efficient production processes that are relevant and valuable for managers and policymakers in their endeavours to improve the environmental performance and competitiveness of manufacturing firms and the manufacturing sector

### 1.5. Structure of the thesis

This thesis is structured in two parts. Part I includes a cover paper with an overall presentation of the individual papers' scientific results and an in-depth assembling in a theoretical discussion. Part II comprises the three individual publications. In Part I, the introduction section presents an overview of the thesis and outlines its relevance, problem statement, research objective, and empirical focus. Section 2 outlines the historical development and theoretical aspects of eco-innovation, with specific focus on the drivers for eco-innovation. Section 3 discusses the methodological approach of the thesis. Section 4 summarises the appended papers with a synthesis of the main findings. The results are discussed in Section 5. Section 6 presents the theoretical contributions as well as implications of the thesis for practice, with suggestions for further research. Finally, Part II presents full-length versions of the three appended papers.

## 2. Theoretical background and literature review

The thesis is positioned theoretically in the field of eco-innovation, with specific focus on drivers for eco-innovation. This section outlines the eco-innovation theory and literature on drivers for eco-innovation. Section 2.1 describes the relationship between sustainable development and the development of eco-innovation theory, while section 2.2 provides a definition of eco-innovation. Then, section, 2.3 presents some of the barriers for eco-innovation and asserts the relevance of the research on drivers for eco-innovation. The literature on drivers is presented in section 2.4. Finally, in section 2.5 I summarise and discuss the current knowledge of the literature on drivers to eco-innovation and highlighting a set of shortcomings which is addressed in this thesis.

### 2.1. Sustainable development at the core of eco-innovation theory

Historically, the industrial revolution and fossil fuel use generated extensive economic growth, with rise in consumption and material well-being. The upsurge of the industrial sector had profound impact on the entire structure of societies and the development of political and economic theories. *The Wealth of Nations* by Adam Smith appeared on the eve of the Industrial Revolution. This 'modern' paradigm was recognised by the ideology that under the preconditions of freedom, competition, and justice, the pursuit of one's self-interest would lead to the optimal distribution and exploitation of resources. Thus, the self-interest of millions of individuals ('the invisible hand') was expected to create 'natural harmony' in a stable and self-regulating prosperous society, rendering state directions or regulations unnecessary. In retrospect, these economic models have been increasingly acknowledged as having caused the industrial and financial systems to over-exploit the natural resources. A key publication that highlighted this concern was the *Limits to Growth* by Meadows et al. (1972), in which environmental economists asserted the limitations of environmental externalities. They argued that the natural global system would not support the present economic and population growth rates despite the advanced technologies, pointing to the tension between economic growth and environmental concerns.

In contrast, economic development and growth are closely related to equity and social justice issues and vital to lift the developing countries out of poverty (World Bank, 2015), and comprise a source for transformation. Economic growth can thus be viewed as both the ultimate driver of sustainability and a precondition for social well-being. In this regard, ecological economists argue that technological progress along with capital accumulation and increased productivity can offset the natural environmental limitations (Solow, 1973; Cole, 1973). That is an ecological economy assumes a positive relationship between economic development and natural conservation. The sustainable development agenda set out by the United Nations (UN) World Commission on Environment and Development in *Our Common Future* (1987) is based on this ecological economic theory. This report defines sustainable development as the 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (p 41), while also emphasising that 'sustainable development involves a progressive transformation of [the] economic and society'. Today, the proponents of economic growth form the majority (Banister et al., 2019), with their goals of efficiency and economic growth constituting the main pillars of modern politics (Gough, 2019). Thus, policymakers, managers, and academics worldwide are interested in understanding more on the drivers that stimulate the development of economically and environmentally feasible eco-innovations. Thus, while sustainable development is the ultimate social goal, eco-innovation is the key to achieve this goal.

## 2.2. Defining eco-innovation

Over the 30 years following the publication of *Our Common Future* (1987) the institutional status of sustainability has changed quite drastically. The academic definition of eco-innovation has also evolved over the period. In 2000, Rennings defined eco-innovation as ‘innovation processes toward sustainable development’ (p 319), while addressing the relevance of technological, organisational, social, and institutional innovation. Rennings also emphasised the importance of both the environmental outcome and motive behind an innovation. A few years later, Kemp and Pearson (2007) offered a conceptual clarification of eco-innovation based on a study commissioned by the European Commission. They concluded that ‘it is not the aim that is of interest, but whether there are positive environmental effects related to its use’ (p 5). Hence, they defined eco-innovation as ‘the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organisation (developing or adopting it) and which results, throughout its life cycle, in reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives’ (p 7). Kemp and Pearson also endorsed the ecological dimension of eco-innovation by asserting the risk of ignoring significant environmental innovations, with too strong focus on the social aspect. The research community embraced this more stringent definition of eco-innovation compared to that of Rennings (2000), and the Organisation for Economic Co-operation and Development (OECD; 2009) recognised that eco-innovation entails the ‘reduction of environmental impact, whether such an effect is intended or not’ (p 13). Moreover, Oltra and Saint Jean (2009) endorsed the environmental objectives of eco-innovation while defining them as ‘innovations that consist of new or modified processes, practices, systems and products which benefit the environment and hence contribute to environmental sustainability’. The ecological perspective still predominates the research in the field (Bossle et al., 2016; García-Granero et al., 2018). In this thesis, eco-innovation is understood according to the environmental effect and outcome of the innovation. Thus, this thesis follows the definition of Carrillo-Hermosilla et al. (2010), who define eco-innovation as the ‘innovation that improves environmental performance’. (p 1075). By not including the environmental aim as a distinguishing feature, this thesis does not risk overlooking the innovations that are not environmentally motivated but have environmental benefits. Furthermore, this definition of eco-innovation allows for the inclusion of ‘environmental motive’ as an explanatory variable (Costa-Campi et al., 2015). Also, note that several different terms are used in the literature for the innovation that improves the firms' environmental performance, of which the most common terms are green, environmental, and eco-innovation. After cross-analysing the definitions, Schiederig et al. (2012) conclude that these terms are similar in that they consider the economic and ecological aspects of innovation; these terms are also used as synonyms (Díaz-García et al., 2015; Pham et al., 2019; Bossle et al., 2016). Historically, the term 'environmental innovation' has been most popular. The term eco-innovation witnessed an upsurge in usage in 2005 (Pham et al., 2019), to predominate the literature by 2010 (Díaz-García et al., 2015). Therefore, the term eco-innovation is used in this thesis without differentiating between the three terms.

Similar to the categorisation of general innovations (OECD, 2005, p 46), eco-innovation are recognised as process, product, and organisational innovations. *Eco-process innovations* gain recognition by improving the environmental impact of manufacturing processes. Thus, it is important to differentiate between eco-process innovation and eco-innovation processes. While the former relates to the production processes (OECD, 1997), the latter refers to the process of developing eco-innovation, such as models for piloting eco-innovation and research and development (R&D) processes (Díaz-García et al., 2015). Eco-process innovations are often categorised as either 'end-of-pipe' or cleaner production technologies (Hammar and Löfgren, 2010). Cleaner technologies differ from end-of-pipe solutions in that they use completely new equipment and processes and thus change the production process itself (Popp et al., 2010) and are often more radical (Carrillo-Hermosilla et al., 2010). Since cleaner technologies increase the efficiency in input use and production without increasing emissions, they are also referred to as eco-efficiency innovations (Carrillo-Hermosilla et al., 2010; Fernández-Viñé et al., 2010). The outcome of these innovations can be measured by their waste production and recycling, water quality and use, air pollution, noise, raw material and EE use, and so on (Tariq et al., 2017; García-Granero et al., 2018). Arguably, EE is an eco-process innovation model contributing significantly to improvement in energy consumption of manufacturing firms.

*Eco-product innovations* are recognised by their technological improvement in existing goods/products or development of new goods/products. The environmental footprint of products can be optimised by using appropriate inputs, reducing the number of components, and increasing their durability and possibility for recycling (García-Granero et al., 2018). Eco-product innovations can be used as incremental components in production processes to improve the local air and water quality (end-of-pipe). Examples of such technologies are the scrubber used in industrial smokestacks or catalytic converters used for automobiles. However, the challenge with these incremental end-of-pipe technologies is that they do not change the main processes and hence do not solve the problem. In contrast, eco-product innovation can be radical, such as renewable energy technologies that completely replace the current systems based on fossil fuel. Despite the increased focus on radical systemic changes, these technologies do not blend with the existing industrial ecosystem and lead to discontinuous changes at several levels (Christensen et al., 1998; Geels, 2012). Such socio-technical transition processes are complex, costly, and lengthy (Farla et al., 2012), while the increasing environmental challenges calls for immediate action.

*Eco-organisational innovations* are conceptualised as the introduction of organisational methods and management systems to deal with environmental issues in production processes and products (Kemp and Pearson, 2007). Furthermore, the OECD (2009) points to the role of organisational or institutional changes in the development of technological eco-innovation. It describes eco-organisational innovation as the reorganisation of routines and structures within firms and new forms of management where all ‘deal primarily with people and the organisation of work’ (OECD, 2005, p 55). Eco-organisational innovation is considered to have an indirect effect on firms’ environmental performance by complementing and supporting technological eco-products as well as eco-process innovation. Eco-organisational innovation can include formalised environmental management systems (EMS) (Rennings et al., 2006; del Río et al., 2016), green human resources, pollution prevention plans, environmental audits (García-Granero et al., 2018), and supply chain management (Marchi and Zanoni, 2017). However, the concept in empirical works is mostly operationalised and measured as EMS certification. Accordingly, Klewitz and Hansen (2014) point to a gap in our understanding of eco-organisational innovation and the relationship between the different eco-innovation types.

This section has described the relationship between sustainable development and eco-innovation theory. The theoretical development of eco-innovation has been affected by the strong focus on the determinants of environmental technological innovation and economic feasibility from the ecological economic perspective. Although eco-innovation is defined as product, process, and organisational innovation, most research in the field has been biased towards eco-product innovation (Klewitz and Hansen, 2014; Díaz-García et al., 2015). Thus, a gap exists in the academic knowledge of eco-process and eco-organisational innovation that results in the research field disregarding important knowledge relevant to managers and policymakers in the quest for sustainable development of the industrial sector.

### 2.3. Barriers to eco-innovation: the double externality problem

Despite societal pressure for sustained development of the industrial sector, several barriers related to external environment, internal conditions, and technological characteristics prevent the environmental transition at firm level (del Río et al., 2010; Farla et al., 2012). Nonetheless, the barriers related to the double externality problem (Rennings, 2000) seem to dominate the field. In economics, externality is the cost or benefit affecting a third party who does not choose to incur that cost or benefit (Buchanan and Stubblebine, 1962). Externalities often occur when the production or consumption of a product or service involves a private price that does not reflect the true costs or benefits of the product or service for the society as a whole. Externalities can be either positive or negative. A typical example of negative externalities is the manufacturing activities causing air pollution and imposing health and clean-up costs on the whole society. In such cases, the manufacturer may choose to produce more of the product than normally would be produced if they were required to incur all the associated environmental costs. In contrast, positive externalities occurs when the consumption or production of a good causes a benefit to a third party without paying. When external benefits exist, such as in public safety matters, less goods may be produced than would normally be the case if the producer were to receive payment for external benefits provided to others. Rennings (2000) asserts that eco-innovation is characterised by double externality because it reduces the production of negative environmental externalities and leads to positive knowledge externalities. Indeed, the knowledge featured in these innovations for the firms that are developing and/or adopting them might spill over and benefit other firms. To overcome this externality problem, governments and institutions can make use of economic incentives such as taxes or subsidies. This special characteristic of eco-innovation is the core reason why ‘drivers’ – with particular emphasis on economic stimuli – have been the most dominant and recurrent theme in the eco-innovation literature.

### 2.4. The research field of drivers for eco-innovation

This section defines the concept of drivers for eco-innovation and outline the relevance of the research on drivers with regard to the double externality problem. Furthermore, I present an overview of the literature on drivers for eco-innovation as well as a critical overview of the body of knowledge and describe the most popular theoretical frameworks used to underpin this research. The section finally addresses certain important gaps in the literature.

#### 2.4.1. Defining drivers for eco-innovation

The empirical concept of drivers has been conceptualised in several ways. Concepts that can be considered similar to drivers in the literature include determinants (Pacheco et al., 2017; del Río et al., 2016; Horbach et al., 2012), success factors (De Medeiros et al., 2014), underpins (Shi and Lai, 2013), and antecedents (Salim et al., 2019). Furthermore, Díaz-García et al. (2015) describe the eco-innovation antecedents at different levels, emphasising the motivation behind the adoption, development, and implementation of these innovations. Similarly, Bossle et al. (2016) relate drivers to something that motivates the adoption of eco-innovation. They also use notions of stimuli and triggers to describe the role of drivers. Pham et al. (2019) provide a more precise definition by defining drivers as the triggering and activating factors internal/external to organisational boundaries. Furthermore, Hojnik and Ruzzier (2016b) define drivers as eco-innovation stimuli that act as a motivating (e.g. regulatory pressure, expected implementation benefit, company profile as environment friendly, competitive pressure, and customer demand) or facilitating (e.g. EMS, financial resources, technological capabilities) factor. Sroufe (2017) considers drivers as internal and external forces, leadership, sustainable growth, environmental and social opportunities, and stakeholders, and describes the enablers as teams, goals, capital (financial, natural, and social), or EMS. This thesis takes a broader approach by considering all firm internal factors that motivate, stimulate, and facilitate the manufacturing firms' eco-process innovation adoption, development, or implementation as drivers.

#### 2.4.2. Descriptive analysis of literature development

The last few years have seen a substantial growth in research on drivers for eco-innovation, with several SLRs conducted and published in synthesising this growing body of the literature. An SLR is recognised by the strict methodology it uses to ensure a systematic, transparent, and replicable selection of the literature (Denyer and Tranfield, 2009; Tranfield et al., 2003). Table 2 lists a collection of SLRs that focus particularly on the factors stimulating eco-innovation in manufacturing firms. SLRs are sampled by searching for 'drivers', 'eco-innovation', and 'reviews' in Scopus and cross-referencing. This list is not comprehensive. However, although the scope and search criteria of the SLRs show some variation, their findings are quite consistent. Table 2 indicates the development and status of the literature on the research topic, and the publication trends, outlets, and focus by eco-innovation type.

*Table 2: Collection of SLRs on drivers for eco-innovation in firms*

| **Author** | **Topic** | **Journal** | **Publication period** | **Number of publications** | **Eco-innovation type*[1]** |
|---|---|---|---|---|---|
| Shi and Lai (2013) | Identifying the underpin of green and low carbon technology innovation research | Technological Forecasting and Social Change | 1994-2010 | 106 | no |
| De Medeiros et al. (2014) | Success factors for environmentally sustainable product innovation | JCP | -2011 | 68 | no |
| Díaz-García et al. (2015) | Providing an overview of the existing body of the literature on eco-innovation | Innovation | -2013 | 384 | no |
| del Río et al. (2016) | Econometric analyses of firm-level determinants to eco-innovation | JCP | -2014 | 29 | no |
| Bossle et al. (2016) | The drivers for adoption of eco-innovation | JCP | 1992-2013 | 35 | no |
| (Pacheco et al., 2017) | Eco-innovation determinants in manufacturing SMEs | JCP | 1990-2014 | 12 | no |
| Tariq et al. (2017) | Drivers and consequences of green product and process innovation | Technology in Society | 1990-2016 | 195 | no |

| | | | | | |
|---|---|---|---|---|---|
| Salim et al. (2019) | Internal capabilities for eco-innovation in manufacturing firms | JCP | -2018 | 55 | no |
| Pham et al. (2019) | Firms' environmental innovativeness: A knowledge-based resource view | JCP | 2000-2017 | 40 | no |

** [1]: Differentiating between product, process, and organisation eco-innovation in the analysis*

As Table 2 shows, publications on drivers for eco-innovation started to emerge by the beginning of the 1990s, closely following *Our Common Future* (1987). Several SLRs report that the research in this domain experienced a remarkable increase in recent years, with a notable upsurge in publications around 2007–2009. García-Granero et al. (2018) report that the number of publications increased about four-fold since 2007, while Tariq et al. (2017) show that about 43% of the articles considered were published between 2012 and 2016.

As regards the publication outlets, the table depicts the leading position of the Journal of Cleaner Production (JCP), which is also the most important publication outlet for the articles included in the SLRs (García-Granero et al., 2018; Salim et al., 2019; Pham et al., 2019; Bossle et al., 2016; Tariq et al., 2017; del Río et al., 2016; Díaz-García et al., 2015). Research on this topic has also been published in various other journals, such as the *Journal of Business Ethics, Sustainability*, *Business Strategy and Environment*, *Ecological Economics*, *Research Policy, Academy of Management Journal*, *Sustainable Development,* and *Energy Policy*.

When analysing the development of SLRs, we find indications of SLRs evolving from a rather broad approach of identifying all the underpinning and success factors of eco-innovation (Shi and Lai, 2013; De Medeiros et al., 2014) to a more focused approach of considering the firms' internal capabilities and environmental innovativeness (Salim et al., 2019; Pham et al., 2019). The articles included in the latter two SLRs emerged around 2010. This indicates the increasing acknowledgement of the important role of internal drivers and the need to understand them better.

Finally, Table 2 indicates that, as with the eco-innovation literature in general, research on the drivers for eco-innovation does not seem to indicate much relevance to differentiation by innovation type (eco-process, eco-product, or eco-organisational). Indeed, none of the SLRs differentiate by eco-innovation type in their analysis of drivers for eco-innovation. Even though Pacheco et al. (2017) describe the different eco-innovation types and del Río et al. (2016) list the drivers by eco-innovation type, they do not differentiate innovations by type in their analysis. Thus, research in the field might ignore important insights on how the determinants affect the different eco-innovation types.

### 2.4.3. Review of literature on drivers for eco-innovation

While the descriptive analysis of the literature provides a general overview of the development of the research field, this section describes the body of knowledge in the literature on drivers for eco-innovation. This review is based on the SLR presented in Table 2, the seminal and frequently cited publications in the field, and other relevant publications. Arguably, because most publications do not distinguish between eco-innovations by type, this literature review does not consider only those studies that focus on eco-process innovation. Furthermore, because of the interdisciplinary and wide array of 'drivers', scholars in the field have developed various conceptual and analytical frameworks. The framework used in Rennings (2000) depicts the technology push, market pull, and regulatory push/pull effects of drivers, and indicates the forces that sustain eco-innovations for greater adoption and diffusion. This framework has been used in several influential empirical studies such as Horbach (2008), Horbach et al. (2012), and De Marchi (2012). Taking a different approach, Díaz-García et al. (2015) propose a multilevel framework, classifying the drivers by three levels: micro, meso, and macro. In contrast, Bossle et al. (2016) distinguish the drivers by external factors, internal factors, and control variables. However, considering the purpose of this thesis, the following analysis categorises the drivers as external drivers, internal drivers, and the industrial sector. In the following presentation of drivers, I also outline popular theoretical perspectives in the literature.

#### 2.4.3.1. External drivers

The external drivers most considered in the literature are the environmental policy and regulations, external cooperation and networks, technological innovation systems, and market dynamics. Considering the double externality problem (Rennings, 2000) (Section 2.3), researchers have given most attention to environmental policy and regulatory pressures (del Río et al., 2016; Shi and Lai, 2013; Pacheco et al., 2017; Bossle et al., 2016), which dominate the academic discourse in the field. In this regard, the Porter Hypothesis (1995) strongly influences the development of the literature (Ambec et al., 2013). The hypothesis asserts that well-crafted and well-enforced regulations benefit both the environment and competitiveness of firms, and that 'properly designed environmental standards can trigger innovation that may partially or more than fully offset the costs of complying with them'. This research approach concludes (on balance) that a positive relationship exists between regulation and eco-innovation, although the strength of the link could vary (Ambec et al., 2013; Rubashkina et al., 2015). In particular, environmental legislation seems to be a less important driver for eco-process innovation (del Río et al., 2010).

Although regulations have dominated the research field, the relevance of other external drivers have also been acknowledged (Bossle et al., 2016; Chen et al., 2012). Innovation diffusion is a relevant theory for analysing how, why, and at what rate new ideas and technology spread (Rogers, 2003). While several studies in the field use the term 'diffusion of eco-innovation', the linkage with the Rogers theory of diffusion is very limited (Karakaya et al., 2014). However, empirical frameworks are frequently cited, for example Rennings (2000). This framework depicts the technology push, market pull, and regulatory push/pull effects and denotes the forces that sustain eco-innovation for greater adoption and diffusion. Several significant studies using this framework (Horbach, 2008; Horbach et al., 2012; De Marchi, 2012) have identified the relevance of external cooperation in driving eco-innovation. Furthermore, empirical research has found that eco-innovation requires more cooperation and knowledge inflows than general innovation (De Marchi, 2012; De Marchi and Grandinetti, 2013; Horbach et al., 2013; del Río et al., 2015). This suggests that eco-innovation is more complex and challenging than general innovation. It also implies that eco-innovation requires knowledge from outside the firms' core business (Sathitbun-anan et al., 2015) that do not form part of its core competence (Teece et al., 1997). The strength of the diffusion theory lies in its comprehensive approach to innovation diffusion. However, the diffusion theory does not provide much explanation for the empirical findings because of the limited linkage between the theory and emerging research.

A few scholars have also approached the subject from an institutional perspective (Hazarika and Zhang, 2019), exploring how surrounding institutional set-ups and institutional isomorphic processes (coercive, mimetic, and normative) influence eco-innovation in firms (DiMaggio and Powell, 1983). From this perspective, scholars identify the impact of normative pressure on the proactive environmental strategies and propensity of firms to engage in environmental innovation (Daddi et al., 2016; Berrone et al., 2013). The strength of the theory is that it explains the homogeneity and stability in organisational structures and thus has a strong explanatory power relating to the role and relevance of the external pressure surrounding the firm. The main criticism of the theory is that it is weak in analysing the internal dynamics of environmental change. Indeed, while the institutional theory focuses on explaining why an inertia exists, it does not explain how organisations can change faster and adapt to environmental conditions and demands.

A third popular perspective to investigate how external stakeholders affect eco-innovation is the stakeholder theory (Hazarika and Zhang, 2019; Bossle et al., 2016; del Río et al., 2016). This theory explores the firms' relationships with stakeholders and the consequences of such relationships (Freeman, 2010). Broadly, 'a stakeholder is any group or individual who can affect, or is affected by, the achievement of a corporation's purpose' (Freeman, 2010, p 9). From the stakeholder perspective, research emphasises the relevance of cooperation with universities, consultants, and research institutions (Cainelli et al., 2012; De Marchi and Grandinetti, 2013), suppliers (De Marchi, 2012), and distributors (Buttol et al., 2012). The relevance of external stakeholders has led to increased academic focus on supply chain management (Marchi and Zanoni, 2017; Vachon, 2007) and open innovation processes (Cagno et al., 2015; Ghisetti et al., 2015). Nonetheless, there has been insufficient research on the role of internal stakeholders. Note also that external stakeholders drive eco-innovation through cooperation and knowledge inflow and exert normative pressure on the firms' eco-innovation adoption. The role of knowledge sourcing, cooperation, and normative pressure discussed in this section points to a more complex picture than just the consideration of economic drivers for eco-innovation.

#### 2.4.3.2. Internal drivers

The increased academic interest in internal drivers for eco-innovation (Bossle et al., 2016; Salim et al., 2019; Pham et al., 2019) has enhanced the understanding of why firms follow different strategies and diverge in environmental performance, and some firms are more proactive than others (Chen et al., 2012; Aragón-Correa et al., 2008). In contrast to external drivers, firms can manage and control internal drivers to a larger extent. The internal drivers considered in eco-innovation research are strategy, resources, and capabilities (Díaz-García et al., 2015; Bossle et al., 2016); environmental leadership and culture (Chen et al., 2012); and organisational structure (Pacheco et al., 2017). These drivers coincide with familiar concepts from the resource-based view (RBV) of a firm which is also the most commonly applied perspective for studies on internal drivers (Tariq et al., 2017; Hazarika and Zhang, 2019). The RBV holds that firms with better, unique, and non-imitable resources and capabilities are likely to perform better and maintain a sustainable competitive advantage (Barney, 1991). Thus, firms with higher environmental capabilities are relatively more likely to excel in environmental performance.

Capabilities are the internal and external organisational skills, resources, and functional competencies of firms developed to match the requirements of a changing and dynamic environment (Teece et al., 1997; Eisenhardt and Martin, 2000). Environmental capabilities consist of bundles of skills and resources brought to bear on particular value-added tasks (Hart, 1995). Physical, financial, and human resources are relevant in this regard (del Río et al., 2016). Environmental capabilities can account for the diverging strategies of firms since they shape the firms' ability to respond to the opportunities it faces (Sharma, 2000). Capabilities cannot be easily acquired since they are tacit, socially complex, and rare (Barney, 1991). They must be built over time from the skills and resources the firms have at their disposal (Sharma, 2000; Teece et al., 1997). Moreover, del Río et al. (2016) describe capabilities as resources which result from activities performed repetitively and are underpinned by organisational processes or routines. Research on drivers for eco-innovation points to the relevance of technological, organisational, and managerial capabilities (Kesidou and Demirel, 2012; Horbach, 2008; Triguero et al., 2013).

**Technological capabilities:** Technological capabilities can be described as the availability and accumulation of human capital and knowledge stock (Díaz-García et al., 2015; Pacheco et al., 2017). Innovation theory recognises knowledge (both tacit and explicit) as a key resource for firms to drive technology development and innovation (Kogut and Zander, 1992; Spender, 1996). Firms pursuing eco-innovation have higher internal technological capabilities than general innovators (Rennings et al., 2006; del Río et al., 2015; De Marchi, 2012). Eco-innovations are considered to be even more knowledge demanding than general innovation (De Marchi and Grandinetti, 2013). This is particularly so for eco-innovations beyond the incremental 'end-of-pipe solutions' (De Marchi and Grandinetti, 2013), which often require knowledge that the firms do not have in-house (De Marchi, 2012). Thus, a firm's technological capabilities are based on both its internal and external knowledge resources (Peng and Liu, 2016). Internal knowledge resources are most commonly operationalised and measured as internal R&D (Rennings et al., 2006) or prior experience with innovation (Gerstlberger et al., 2016). Nonetheless, empirical research does not provide conclusive results on the positive link between internal R&D and eco-innovation (Horbach et al., 2012; De Marchi and Grandinetti, 2013). These inconclusive results underline the argument that different types of eco-innovation are driven by different capabilities (del Río et al., 2017; Peng and Liu, 2016; Triguero et al., 2013). Empirical research also finds that eco-innovative firms rely on external cooperation to a larger extent than do other innovative firms (De Marchi, 2012). This illustrates that eco-innovation could require knowledge resources that firms do not have in-house. In this regard, a firm's relations with external stakeholders (Pacheco et al., 2017) and ability to recognise, assimilate, and apply new external information become critical (Albort-Morant et al., 2018; Chen et al., 2014). In other words, one needs to understand the relationship between extant knowledge resources and the integration and development of new knowledge for eco-innovation. This capability is also described as the absorptive capacity of a firm (Cohen and Levinthal, 1990). Despite the critical role of technological capabilities as a driver for eco-innovation, the topic has been given little attention in empirical research (Triguero et al., 2013; Tariq et al., 2017).

**Organisational capabilities:** Pacheco et al. (2017) emphasise the role of the organisational structure of innovation methods, management support, external relations, and R&D while considering organisational capabilities. Some studies have identified the role of dynamic capabilities in stimulating eco-innovation (Amui et al., 2017; Mousavi and Bossink, 2017). Dynamic capabilities are described as the capacities of an organisation to create, extend, and modify its resource base and address rapidly changing environments (Helfat et al., 2007; Teece et al., 1997). Accordingly, organisational capabilities for eco-innovation include a set of specific and identifiable processes such as product development, strategic decision making, and alliancing.

EMS are the most frequently studied internal driver for eco-innovation (He et al., 2018; del Río et al., 2016). The two most cited EMS are the international standard ISO 14001 and the European Eco-Management and Audit Scheme (EMAS) (Testa et al., 2014). EMS specify the requirements for establishing, implementing, maintaining, and improving the management system. They support firms to continuously improve their corporate environmental performance and exceed the existing government environmental regulations (ISO, 2016). Hence, the adoption of EMS in empirical research is commonly considered as synonymous to gaining organisational capabilities for eco-innovation (Kesidou and Demirel, 2012; Peng and Liu, 2016). Despite the strong emphasis on EMS adoption in research, there exists an open debate on the validity of this measure (Lawrence et al., 2019; Thollander and Ottosson, 2010). While some studies find that EMS adoption has a clear positive effect on the environmental performance of firms (Testa et al., 2014), others do not find any such impact (Ziegler and Rennings, 2004). Furthermore, it is also noted that even EMS certified firms do not necessarily practice environmental management (Ates and Durakbasa, 2012). This implies that firms might use EMS certification for 'window dressing' without filling it with content (Ziegler and Rennings, 2004) and points to the problem of using EMS adoption as an organisational capability measure for eco-innovation.

**Management capabilities:** Management capabilities are the management resources and practices that stimulate and facilitate the development and implementation of environmental strategies and culture. Managerial environmental concern is among the most important drivers for eco-innovation development and implementation (Hojnik and Ruzzier, 2016a). From a management perspective, research has mainly focused on the motives for investing in eco-innovation, namely ecological (Robertson and Barling, 2017) and economic (Peng and Liu, 2016; Díaz-García et al., 2015) motives. The relevance of economic drivers elaborated earlier in this section has been shown in several empirical studies (Pacheco et al., 2017; Triguero et al., 2013; Peng and Liu, 2016; Kesidou and Demirel, 2012). As regards the environmental motives, Bansal and Roth (2000) find that managers' ecological responsibility, as well as competitiveness and legitimation, is the most important motive for firms' environmental activity. Similarly, Zhang et al. (2013) find a significant positive effect of managerial attitude on the willingness of firms to adopt and develop eco-innovation. Peng and Liu (2016) argue that managerial cognition and environmental awareness influence the managers' interpretation of environment and attention allocation and hence their strategic response to external environmental pressure. Likewise, Sharma (2000) shows that the managerial interpretation of environmental issues significantly affects corporate environmental strategies. In addition to the study motive, some newer works have addressed other relevant aspects of management such as environmental strategies (Pham et al., 2019), the development of an environmental culture within firms (Chen et al., 2012; Salim et al., 2019), and the impact of human resource management on employee involvement in environmental activities (Renwick et al., 2013).

This review of internal drivers for eco-innovation points to various firm internal factors that affect the ability and willingness of firms to adopt eco-innovation. Nonetheless, most empirical research in the field is either biased towards eco-product innovation (Hojnik and Ruzzier, 2016a; Díaz-García et al., 2015; del Río et al., 2016) or does not differentiate between eco-innovation types (Díaz-García et al., 2015). A few notable studies (e.g. Rehfeld et al., 2007; Rennings et al., 2006; De Marchi, 2012; De Marchi and Grandinetti, 2013; del Río et al., 2017; Triguero et al., 2013; Hojnik and Ruzzier, 2016a; Triguero et al., 2014) suggest that eco-product and eco-process innovation seem to be motivated by different drivers. In general, eco-product innovation seems to be more driven by demand factors, market opportunities, and social pressure, and requires greater external knowledge and R&D. In contrast, eco-process innovation seems to be primarily undertaken for cost reduction, and depends on EMS and internal technological capability.

#### 2.4.3.3. Industrial sector

Technological innovation is generally required in connection with other technologies internal and external to the firm that lead to different types of compatibility issues for new technologies with respect to existing technologies. Furthermore, existing technologies are generally deeply embedded in wider technological, social, and institutional systems affecting the eco-innovation adoption of firms (Palm and Thollander, 2010; Delmas, 2002; Coenen and Díaz López, 2010). Hence, in research on eco-innovation, the industrial sector is often used as a control variable, where the technological innovation system and sector can serve both as driver for and barrier to eco-innovation. Several studies suggest that firms are more inclined to adopt eco-innovation in high-emission sectors than in other sectors (Berrone et al., 2013; De Marchi, 2012; Horbach, 2008). However, del Río et al. (2016) point to a large variation in research on sectorial impact.

Similarly, Horbach et al. (2013) detect remarkable similarities in the determinants for eco-innovation between firms in France and Germany, despite differences in national innovation systems. Moreover, the technological regimes and demand conditions of a sector can also lead to technological inertia (Oltra and Saint Jean, 2009; Palm and Thollander, 2010). These findings point to the complexity of technological innovation transition and assert the relevance of research taking a more systemic approach. As regards firm size, there seems to be a consensus in research on the positive relationship between the control variable and eco-innovation (del Río et al., 2016; Bossle et al., 2016). Nonetheless, while large companies tend to increasingly develop and adopt eco-innovation, SME can play a key role in its diffusion. For example, Hockerts and Wüstenhagen (2010) illustrate the relation between firm size and eco-innovation diffusion, theorising the interplay between incumbents and new entrants.

## 2.5. Summary of the literature review and research purpose of this thesis

In this section, I describe the development of eco-innovation theory as well as its embeddedness in the sustainable development trajectory and ecological economic approach. The eco-innovation theory asserts a positive belief in technology innovation and economic growth. The theory's origin explains its focus on the double externality problem, why environmental policies and regulations have been the most recurrent theme in research on drivers for eco-innovation, and the dominating use of quantitative research methodologies (del Río et al., 2016). In contrast, the increasing need and social pressure for the industrial sector to adopt a more environmentally proactive approach have led to increasing focus on firms' internal aspects that affect their eco-innovation. Thus, an academic awareness has emerged on the need to move away from a rigid economic cost–benefit analysis, to a more holistic 'eco-innovative firm' approach.

However, research on internal organisational drivers requires theoretical frameworks to substitute the economic perspective. Although RBV is the most popular framework (Hazarika and Zhang, 2019), most empirical studies do not use such theoretical framing (del Río et al., 2016; Hazarika and Zhang, 2019). Moreover, since technology does not function in isolation, contextual consideration requires more research attention. The strong traditions of quantitative research in the literature also impact the theoretical development of the field. In fact, internal drivers have mainly been operationalised with higher-level constructs such as organisational capabilities (measured as EMS) and technological competencies (measured as R&D

investment). The use of such higher-level constructs has been criticised for ignoring lower-level considerations, such as the role of individuals (Foss and Pedersen, 2016) and the distinct skills, processes, procedures, organisational structures, and decision rules that enable a firm to adapt to the changing dynamic environment (Teece, 2007). Thus, the need for more knowledge on the nature and origin of internal drivers calls for more qualitative research. The difference in drivers by eco-innovation type also underlines the need for more research specifically targeting internal drivers for eco-process innovation. In view of these arguments, different approaches and methods are used for the three appended papers in exploring the internal drivers for eco-process innovation.

# 3. Research method

The following subsections discuss the methodological choices as well as validity, reliability, and ethics of this thesis.

## 3.1. An exploratory research design

Research methods are commonly classified as exploratory, descriptive, and explanatory (Saunders et al., 2019). This thesis aims to explore the role and clarify the understanding of internal organisational drivers for eco-process innovation, and thus requires a research design that is flexible and adaptable to change as new results and insights occur. Thus, an exploratory research approach was chosen for this thesis. Arguably, the flexibility inherent in exploratory research does not mean absence of direction (Saunders et al., 2019), but rather an initial broad focus gradually narrowing as the study progresses.

## 3.2. Ontological and epistemological assumptions

Research on internal drivers for eco-process innovation is much about the firms' ability to undertake and succeed in environmental change processes. A fundamental issue influencing the researchers' view on change is whether they consider organisations as consisting of things or processes (Langley et al., 2013; Tsoukas and Chia, 2002). When organisations consist of things, the organization is always something in a particular state or phase of a process; that is there is always something there. From this perspective, change is seen as something that occurs to fixed identifiable organisational entities (Klarner and Raisch, 2013), such as identity, structure, routine, and culture. In contrast, one can view firms and organisations as consisting of processes. In this view, entities (such as organisations and structures) are no more that temporary instances of ongoing processes, continually in a state of becoming (Tsoukas and Chia, 2002). A change in this ontological view is not something that occurs to things, but how a reality is brought into being. In this thesis and all the three appended papers, organisations and firms are – from an ontological perspective – a noun and real thing. This perspective lies at the foundation of much of the literature on organisational change (Langley et al., 2013). This thesis thus focuses on how and why firms' internal drivers (measured as strategies, routines, structures, knowledge, etc.) affect their ability to change in the environmental paradigm under eco-process innovation.

Furthermore, scholars hold different epistemological assumptions about knowledge, such as what constitutes acceptable, valid, and legitimate knowledge and how to communicate knowledge to others (Saunders et al., 2019). The multidisciplinary nature of innovation studies indicates that different types of knowledge can be legitimate. Organisational innovation is usually viewed as either (1) an observed difference over time or across organisational entities or (2) a narrative describing a sequence of events on how development and change unfold (Van de Ven and Poole, 2005). Depending on the researcher's view on innovation, the phenomenon is normally studied using either variance (Blass et al., 2014; Mohr, 1982) or process (Langley et al., 2013; Mousavi and Bossink, 2017) methods. While the variance method seeks explanations for innovation by analysing the covariation dependent and independent variables, process research empirically focuses on the temporal progression of activities as elements of explanation and understanding. The variance and process methods thus represent different epistemological approaches to studying organisational change and innovation. This thesis applies both epistemologies. Papers 1 and 2 analyse how the independent variables (drivers) affect the firms pursuing eco-process innovation. Paper 3 explores the process by which organisational energy management practices emergence over time. The different epistemologies focus on different questions and provide different understandings on drivers for eco-process innovation. The two approaches can thus be considered complementary (Van de Ven and Poole, 2005). The strength of variance studies lies in their objectivity and generalisability. However, they cannot account for the complexity of organisational realities and differences in individual contexts. The process approach, however, incorporates several different types of effects when explaining the emergence of energy management practices, such as critical events and turnings points, contextual influences, and key actors that give overall direction to the process. Hence, by combining the two epistemologies, the thesis yields a more holistic account of the internal organisational drivers for eco-process innovation in manufacturing firms.

### 3.3. An abductive research approach

The extent to which a research is related to theory testing or theory building raises an important question on the research approach – often portrayed as the two contrasting approaches of deductive and inductive research (Saunders et al., 2019). A third alternative – abductive research – is an approach where the researcher moves back and forth between theory and data, combining the deduction and induction methods (Alvesson and Sköldberg, 2009; Bergene, 2007; Saunders et al., 2019). Saunders et al. (2019) argue that the abductive process starts with empirics and is then used to generate a new theory or modify an existing one. In contrast, Bergene (2007) claims that abductive research starts from a general theory as source of inspiration and then draws on insights from the empirical data to explain why particular patterns are observed.

This thesis adopts the abductive research approach. The exploratory work starts quite broadly with the intent to enhance the understanding of drivers for eco-process innovation in manufacturing firms. The literature on eco-innovation is first reviewed. The literature includes the theoretical perspectives, knowledge, and views of the academic community in the field. The literature review shows that the empirical studies mainly focused on eco-product innovation, with less attention given to eco-process innovation, even though the latter is considered the key to reduce manufacturing GHG emissions. Thus, a gap occurs in the literature on drivers for eco-process innovation. The review then suggests that the issue of externalities and role of regulation to overcome these economic barriers traditionally have been central in the theoretical development of the field. In contrast to this emphasis on external drivers for eco-innovation, recent empirical studies address the relevance of firm internal drivers. These empirical observations justify the research approach calling for modification of the existing theory. Furthermore, the review indicates a close link between the empirical domain and development of eco-innovation theory (Rennings, 2000; Horbach et al., 2012). Under these circumstances, the theoretical perspectives and empirics risk of overlapping (Alvesson and Sandberg, 2013) causes the underlying assumptions of the literature to hamper the further development of theory (Alvesson and Sandberg, 2011). Thus, when setting out to explore internal organisational drivers for eco-process innovation, the existing theoretical frameworks in the field are not considered suitable. Hence, even though the work is embedded in the field of eco-innovation, the thesis evolves through continuous alternation and cross-referencing between alternative theories and empirics.

The abductive research of the thesis is illustrated in Figure 3. The X-axis illustrates the timeline, with the y-axis depicting the empirical-theoretical inspiration/contribution sliding scale that positions the various theoretical frameworks by their theoretical foundation. While the eco-innovation theory and EE literature are more empirically informed, the absorptive capacity and translation theories are considered more theoretically founded and thus having a stronger explanatory power. The solid lines illustrate the process of knowledge development from theory and empirical data, while the dotted lines show how the individual papers contribute to answering the overall research question.

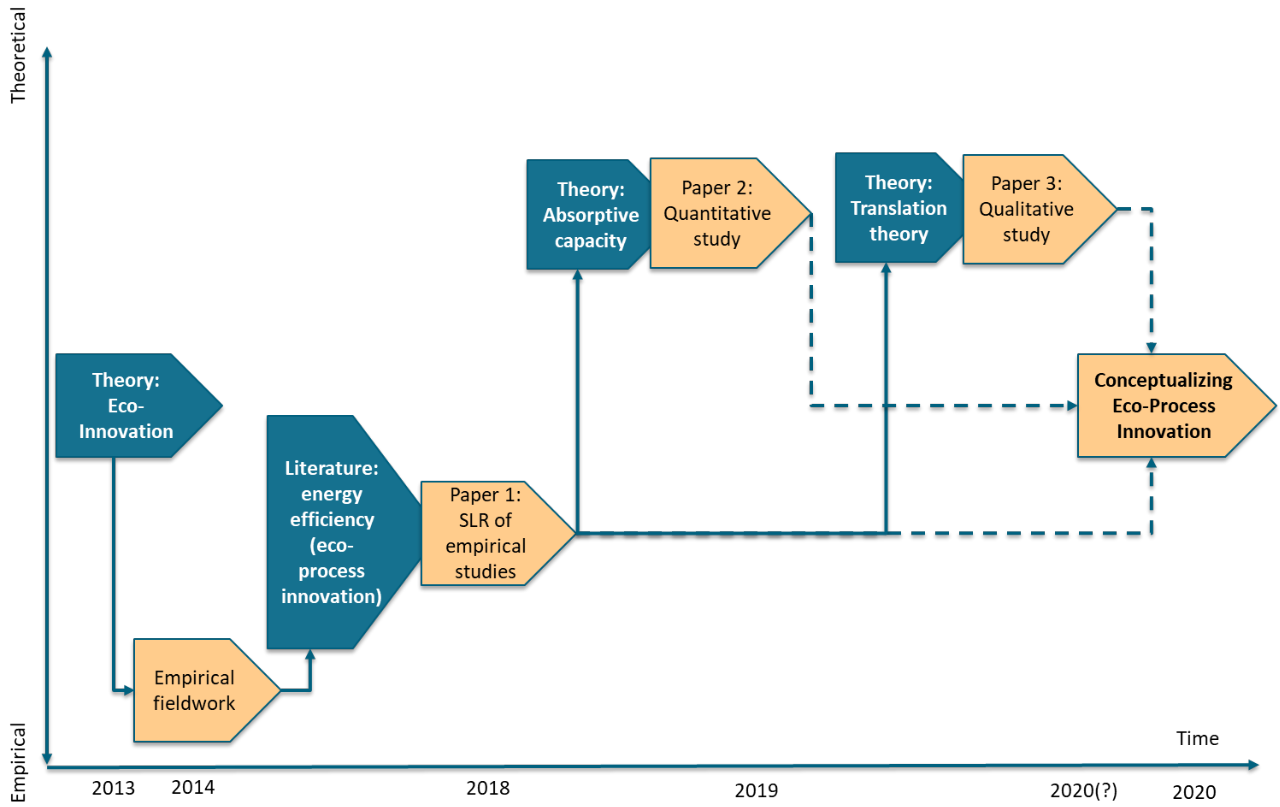


*Figure 3: Illustration of the abductive research journey*

Figure 3 illustrates how the PhD journey started out, with a review of the body of knowledge on eco-innovation. The review suggests several gaps in the knowledge on internal organisational drivers for eco-process innovation. Empirical fieldwork and expert interviews make it clear that industrial eco-process innovations are much about EE. The EE literature is then investigated, to result in an SLR on drivers for EE in manufacturing firms (Paper 1). The SLR reveals the prominence of organisational drivers, with emphasis on knowledge, competence, and management. However, the SLR does not provide much explanation on why and how these internal drivers impact the firms' pursuit of eco-process innovation. The lack of such knowledge can, to a large extent, be explained by the dominating quantitative research and limited use of theoretical framework in the included publications. To further explore the role of organisational drivers, Paper 2 quantitatively analyses the impact of knowledge and competence on stimulating industrial EE. After considering several theoretical frameworks, the absorptive capacity theory is considered relevant and adequate for the purpose. Moreover, in exploring the role of management, Paper 3 qualitatively analyses the emergence of environmental management practices in a manufacturing firm. Here, the translation theory is applied as a theoretical framework. In other words, the theoretical frameworks used in Papers 1–3 are not applied purposefully as an inspiration for the discovery of patterns for better understanding. The figure finally illustrates how the new insights from this abductive approach are integrated into the overall conceptual framework explaining the organisational drivers for eco-process innovation and contribute to eco-innovation theory development. The alternation between theory and empirical data can be considered a strength to answer the research question of the thesis.

### 3.4. Mixed method

Research methods are normally categorised as either quantitative (numerical) or qualitative (non-numerical), and multiple research strategies are employed in qualitative and/or quantitative research. Considering the research question, exploratory research design, and epistemological perspectives described in the previous sections, I apply a mixed-method research strategy in this thesis. Mixed-method research is the general term used when both quantitative and qualitative methods are used in the research design (Bryman, 2006; Saunders et al. 2019). In this thesis, I combine an SLR (Paper 1), a quantitative survey (Paper 2), and a qualitative case study (Paper 3) to answer the research question. The first two studies are based on a variance approach, while Paper 3 is based on a process approach, to study the internal organisational drivers for eco-process innovation. In the following text, I describe the advantages of the mixed method by explaining the strength and weaknesses of the different research strategies and how these strategies complement one another.

In Paper 1, the SLR is motivated by the objective to synthesise the empirical literature on drivers for EE in manufacturing firms and detect the most important drivers. To identify these drivers, the qualitative data obtained from the collected articles are converted into numerical codes for quantitative analysis. This research method is described as a mixed model (Saunders et al. 2019). The paper is considered an empirical contribution because the review included only empirical studies. The SLR methodology minimises the risk of subjective bias in article selection and establishes a replication logic by its systematic and transparent nature (Tranfield et al., 2003). The risk of subjectivity bias is also reduced by converting the qualitative data into numerical codes and analysing them statistically. The Paper 1 results give a strong feel about the importance of internal organisational drivers for eco-process innovation. Nonetheless, with regard to the validity of qualitative data, the selection of journals and search terms is always a source of error. Restraints on included journals and search terms will necessarily lead to the exclusion of others and ultimately affect the final study results. Another relevant question and point for criticism of this methodology is that attention can be confused with prominence, and lack of importance may just as well suggest an under-researched area. Hence, making inferences on importance based on frequency in empirical papers could be problematic.

To gain more rigour and confidence on the relationship between organisational drivers (in terms of knowledge) and eco-process innovation, Paper 2 chooses a quantitative survey strategy. The paper then uses a deductive research approach to test a set of hypotheses that proceeded from Paper 1, the theory of absorptive capacity, and the research on drivers for EE. The findings in Paper 2 are consolidated in a model suggesting a positive relationship between knowledge and the manufacturing firms' propensity to pursue EE. The advantage of this survey study is that it allows for the collection and analysis of a large amount of standardised data in a highly economical manner. The quantitative regression analysis also provides objective and statistically significant results with a high level of validity. Thus, quantitative survey strategies are commonly perceived as authoritative and are comparatively easy to both explain and understand (Saunders et al., 2019). However, some limitations are inherently related to the research strategy. First, the survey data provide limited possibilities for analysing and understanding contextual factors, and a cross-sectional study can convey only a screenshot of a particular phenomenon at a particular time. Furthermore, the deductive approach has the risk of conveying the 'truth' that already exists in the theoretical framework. Although it provides rigour and confidence on significance and the relationship between the dependent and independent variables, this research strategy does not lead to much new knowledge, which is the objective of the exploratory research design.

Paper 3 is a qualitative process study to explore the organisational drivers for eco-process innovation in depth and how these drivers unfold over time. We collected data from a single case study using various techniques such as interviews, observations, and documentary analyses. The case study strategy is of particular interest when the research objective is to gain a rich understanding of the context of the research and the processes enacted (Yin, 1994), while process studies are suitable to examine the organisational change and development over time (Langley et al., 2013; Langley, 1999). While quantitative research seeks generalisability, qualitative research seeks transferability, or whether the results can be transferred to other contexts or settings. To provide more rigour and transparency, the data are triangulated and analysed through the theoretical lenses of translation theory. The translation theory does not target specific elements of an organisation, and thus allows for a more integrated approach to study the organisation. Moreover, the context and analysis are comprehensively described to enable the readers judge the fit of the findings in contexts beyond the study. Moreover, Saunders et al. (2019) argue that the case study strategy enables the researcher to explore and potentially challenge existing theory and provide a source for new research questions.

The different research strategies employed in Papers 1–3 are illustrated in Table 3. In answering the overall research question, the thesis builds on the integrated findings of the three empirical studies. The studies' findings are thus the data used to answer the research question, and are referred to as 'data' in the following text. By jointly using the three described research strategies for the collection of empirical data, the thesis applies a mixed method.

*Table 3: Overview of the methodology used in Papers 1–3*

| | **Paper 1** | **Paper 2** | **Paper 3** |
|---|---|---|---|
| **Research question or aim** | Critical analysis and synthesis of the empirical literature on drivers for energy efficiency in manufacturing firms and identifying the main drivers | What is the relationship between manufacturing firms' absorptive capacity and EE innovation? | How is a corporate environmental programme translated into EnM practices in a manufacturing firm? |
| **Theoretical underpinning(s)** | | Absorptive capacity | Translation theory |
| **Research strategy** | SLR<br><br>Mixed-model; converting qualitative data into numerical codes for quantitative analysis | Quantitative | Qualitative |
| **Data collection** | Empirical articles on drivers for energy efficiency in manufacturing firms | Survey data from the Norwegian CIS and Business Enterprise R&D surveys for the period 2010-2014 | Single case |
| **Description of dataset** | 58 articles | Panel dataset of 226 observations from 128 firms reporting EE innovation in one or more years in the study period. | Nine key informants.<br><br>Two informants, considered particularly knowledgeable, were interviewed more than once. Hence, during the period, eight interviews, individually or in groups, were conducted, each lasting 1–2.5 hours. All interviews were fully transcribed. |
| **Analysis technique** | Descriptive and thematic analysis.<br><br>Constant comparison technique, with coding in NVivo. | Logit regression in Stata | Chronological analysis and thematic analysis building on a theoretical framework, coding in NVivo |

| | | | |
|---|---|---|---|
| | Converting qualitative data into numerical codes, and statistical analysis. | | |
| **Research choice** | Mixed model | Mono model | Mono model |
| **Validity, reliability, and model robustness check** | The SLR methodology aims to ensure a systematic, transparent, and replicable selection and analysis of the literature.<br><br>Basing the review on original works (empirical articles), rather than reviews and conceptual publications. | Using established measures developed by CIS<br><br>Data collected by Statistics Norway (SSB). High response rate (>95%), eliminating concerns of non-response bias.<br><br>Controlling for possible selection bias (when selecting innovative firms) by applying a two-stage logit model. | Purposeful sampling of the case company<br>data triangulation<br>Underpinned by a theory-based analytical framework. |

## 3.5. Validity – measuring eco-process innovation

The operationalisation of eco-process innovation and its measuring are key issues with regard to the validity of a study. Eco-process innovation is defined as improving firms' environmental performance, and numerous methods are available to operationalise the concept (García-Granero et al., 2018). Note that operationalisation of the variable affects the quality and results of the study (Arundel and Kemp, 2009; Kemp and Pearson, 2007). Well-defined and consistent eco-innovation indicators help researchers to understand the environmental issues surrounding production systems, express specific objectives, and monitor the progress towards sustainable production (Arundel and Kemp, 2009). However, firms might not be able to provide accurate answers as the researcher would require. By demanding too much or too rich information from the interviewees, researchers risk obtaining inaccurate (or none) responses and biased results. Thus, Kemp and Pearson (2007) argue that it sometimes can be better to measure eco-process innovation in a binary manner.

This thesis conceptualises eco-process innovation as EE innovation. However, EE innovation is commonly measured as energy consumption, innovation investment, and innovation implementation (see Paper 1). As described in the previous paragraph, operationalisation has variable impact on the results of the study. Hence, by focusing only on one of these measures, the thesis can be biased owing to the data sampling strategy. In addition, although some measures are relatively better than others, no single measure or indicator is ideal for accurate reflection of the reality of the firm. It can only provide a limited idea of the firm's level of EE innovation in the firm. Hence, the empirical work of this thesis uses all the three measures for EE, 'to see the whole elephant instead of just a part' (Kemp and Pearson, 2007, p 103). Paper 1 includes all the three EE measures, Paper 2 measures EE by a binary variable related firm investment, while Paper 3 considers the energy management practices as the dependent variable. By triangulating the data from the studies, it is argued here that the different measures complement one another, provide a more complete picture, and increase the overall validity of the thesis.

## 3.6. Reliability through theoretical underpinning and triangulation

Reliability refers to the extent to which data collection techniques or analysis procedures yield consistent findings. In this thesis, I consider the empirical findings of the individual studies as data for answering the overall research question. I apply two strategies to ensure reliability of the thesis results. The first relates to using theoretical frameworks to support the empirical studies. The second relates to using the mixed method and triangulation of the empirical data to obtain a sense of relative importance (Bryman, 2006). The eco-innovation literature is yet not able to provide a comprehensive framework for the study of drivers (del Río et al., 2017), and so several theoretical perspectives are applicable (Hazarika and Zhang, 2019). The use of theory allows researchers to offer more refined and accurate definitions of the key constructs, analyse underlying theoretical mechanisms, refine the discussion, and articulate theoretical contributions (Shaw, 2017). The use of theory is thus relevant to enhancing the empirical analysis and validity and reliability of the results.

The research questions of Papers 2 and 3 were inspired by Paper 1. The most prominent drivers in the SLR (Paper 1) were identified from their frequency. This methodology has a limitation in that attention can be confused with prominence, and so lack of importance can just as well suggest an under-researched area. In acknowledgement of this issue and to gain increased rigour, the two subsequent articles (Papers 2 and 3) are underpinned by two other established theoretical frameworks that are purposely selected. While the quantitative Paper 2 builds on the theory of 'absorptive capacity', the qualitative Paper 3 uses the theory of 'translation of management ideas' to analyse the empirical data. By building on these theories, both the validity and reliability of the studies are increased. Furthermore, combining multiple methods (mixed method) across the three independent empirical studies provides a wealth of data. When triangulating the data, the emphasis is on the data that can be considered representative across the papers rather than deviant observations. Thus, the triangulation process contributes to consistent and increased reliability of the thesis results.

### 3.7. Ethical consideration

In recent years, researchers are increasingly expected to reflect on and exert ethical considerations in their research. In Norway, the National Committee for Research Ethics in the Social Sciences and the Humanities (NESH) is responsible for issuing guidelines on research ethics in social sciences, humanities, law, and theology. These guidelines are based on recognised norms for research ethics. They contribute to regulate research by providing ethical norms linked to both the research community as well as relationship between research and society. With regard to the NESH (2016) guidelines, this section discusses the ethical considerations on my work as researcher in relation to the research community and the ethical issues related to the collection and use of empirical data.

Regarding my work as researcher, it is important to report that the funding of the project came from a scholarship from the UiT The Arctic University of Norway. The research is accordingly not in any way commissioned, and therefore this thesis has enjoyed a large degree of academic freedom, with neither constrains nor pressure from either commercial agendas or interests of other researchers. Indeed, through engagement with the literature, empirics, participation in PhD courses and research conferences, and cooperation with my supervisors this PhD project has developed and progressed. This original research has been conducted with integrity, handling the sources with honesty and following good situational practices. The topic has been selected based on personal interests under the conviction that it is of relevance to both the research community and larger society. I have thus made efforts to make the knowledge created during this project publicly available. The empirical data in Papers 2 and 3 were collected from

Statistics Norway (SSB) and a case study, respectively. As regards my sources and to disseminate the research outside the research community, the manuscripts were shared with and accepted by the institutions prior to and after publication. Furthermore, to reach a broader audience, I presented my work at conferences and opted for open access solutions as publication outlets. The publication charges for the articles have been met by a grant from the publication fund of UiT - The Arctic University of Norway. Research funding needs to be transparent, which makes it easier to ensure freedom and independence of the research. The published articles therefore include statements on the funding of the research.

As for the collection and use of empirical data, several ethical reflections need to be made, particularly relating to humanities and social sciences, where involvement and interpretation are often integral to the research process. I have therefore tried to be honest in documentation, consistent in argumentation, and transparent on uncertainties. The literature review in Paper 1 follows a systematic methodology, with clear descripts of the data collection and analysis processes. Paper 2 is based on survey data collected through SSB using validated questionnaires and anonymised datasets. Furthermore, only the authors had access to the dataset, which was deleted after the article was published. Paper 3 is based on qualitative interviews in a single case study, and this requires more profound ethical reflections on my role as research, encounter with informants, and processing and storing of empirical data. Hence, when collecting data, the participants were informed about the project and intended research purpose. The subject and research question did not require any private information of sensitive character. However, since the data were related to identifiable individuals, they were anonymised when stored. The informants were also anonymised in the article, and the firm had to approve the manuscript before it disseminated was to others or submitted to a journal for publication. Furthermore, on request from the firm, the case study company was also anonymised. Anonymisation of the firm can to a certain extent contradict the premise of transparency. However, in this case, I do not consider transparency with regard to the case study company to be a premise for validity and value of the results of the study. Hence, I choose to respect the request of the firm.

# 4. Presentation of papers

## 4.1. Paper 1:

Solnørdal, M. and Foss, L. (2018). Closing the energy efficiency gap—a systematic review of empirical articles on drivers to energy efficiency in manufacturing firms. *Energies*, 11(3), 518. doi:10.3390/en11030518

**Summary**

The manufacturing sector accounts for a substantial part of global energy consumption and GHG emissions and also has a significant potential for increased EE. Increased EE is achieved through technological eco-process innovation. This study aims to provide a critical review of the empirical literature on drivers for EE in manufacturing firms and assess the most vital drivers. The SLR is based on peer-reviewed empirical articles published between 1998 and 2016. The study selects the three most significant drivers from each article. Using a constant comparison technique, the study shows five main categories: the economy, organisation and management, market, policy, and control drivers. On the basis of the frequency, the SLR reveals that, from the firms' perspective, organisational and management drivers are the most prominent stimuli for EE, although policy instruments are surprisingly given the least prominence.

The SLR points to several key organisational elements affecting the manufacturing firms' EE, such as management, competence, and organisational structure. As regards management, the top managers' personal environmental engagement, awareness, and commitment are essential. Further, the environmental objectives need to be endorsed in the image, strategies, and management practices of the firm. Thus, the appointment of a dedicated environmental manager is essential to follow up on the internal processes. Furthermore, the SLR underlines the important role of competence as a driver for innovation practices and EE to make the firm more capable of sharing, assessing, and absorbing external information. Employees are the main carriers of internal competence of an organisation, with their importance emphasised in the SLR. The relevant competence to affect the firms' EE can be acquired through education, training programmes at the workplace, accumulation of experience, and collaboration with R&D institutions. In fact, increased knowledge and skills of employees influence the development of energy-efficient solutions as well as their motivation and engagement to facilitate the implementation process. Finally, the SLR also addresses how organisational structure impacts the firms' EE. Thus, the energy manager's position in the organisational hierarchy influences his or her impact on the firms' environmental management practices. In addition to the prominent role of internal drivers in EE, it is interesting to note the relatively low importance assigned to policy and regulation. This observation might imply a potential mismatch between the energy policymakers' and firm managers' understanding of the factors most important for stimulating EE in manufacturing firms. It also addresses the need for more knowledge on which and how internal resources, organisational capabilities, and management practices impact EE in manufacturing firms.

## 4.2. Paper 2:

Solnørdal, M. T., and Thyholdt, S. B. (2019). Absorptive capacity and energy efficiency in manufacturing firms – An empirical analysis in Norway. *Energy Policy*, 132, 978-990. doi:10.1016/j.enpol.2019.06.069

**Summary**

Departing from the theory of absorptive capacity and the current EE literature, this paper tries to gain more knowledge on the impact of competence at individual and organisational levels by analysing the relationship between firms' absorptive capacity and EE innovation. This analysis is based on logit regressions using a Norwegian panel dataset for the period 2010-2014. The results show that manufacturing firms' absorptive capacity affects their pursuit of EE. The study also finds that human resources in terms of higher education, knowledge development in terms of R&D capacity, and external cooperation with knowledge institutions and competitors positively affect the firms' pursuit of EE. Hence, the study supports the importance of external knowledge sourcing for the pursuit of eco-process innovation. The study thus endorses that knowledge resources and competencies at both the individual and organisational levels affect the firms' engagement with environmental issues. Furthermore, the results indicate a positive interaction effect between higher education and university collaboration, meaning that internal knowledge resources and competencies are essential for effective external knowledge sourcing. The results further emphasise the importance of working simultaneously with both at the individual and organisational levels for the stimulation of eco-innovativeness in firms. From these results, the authors conclude that firms' absorptive capacity affect their ability to assimilate and exploit information about environmental issues and technological solutions. Thus, firms' absorptive capacity is an essential issue that must be considered and stimulated in environmental policies.

## 4.3. Paper 3:

Solnørdal, M. T., (2020). Translating a corporate environmental idea into energy management practices: A case study the implementation of energy management in a pharmaceutical company. Draft submitted to *Sustainability*.

**Summary**

A promising method to stimulate industrial EE is to adopt energy management (EnM) practices. However, the literature has limited knowledge on the development of EnM practices in manufacturing firms. Paper 3 tries to fill this research gap by exploring the implementation of a corporate environmental programme in an incumbent firm and the ensuing emergence of EnM practices. The study is based on a single case study considering the implementation process retrospectively over the period 2004-2014. Translation theory and the 'travel of management ideas' are used as the theoretical lens. In short, the theory asserts that management ideas are successful models providing solutions to pressing problems (Sahlin-Andersson, 1996). However, when ideas 'travel' between contexts (time, space, and location), they can be perceived as intangible accounts (Czarniawska-Joerges and Sevón, 1996; Wæraas and Sataøen, 2014; Sahlin-Andersson, 1996). Thus, when an idea is implemented in a new setting (e.g. organisation), local editors must translate it. The outcome of this translation process is materialisation of the idea in terms of, for example practices, routines, organisational structures, and mind-set of individuals (Wæraas and Nielsen, 2016; Wæraas and Sataøen, 2014). By applying the translation theory and the editing rule of Sahlin-Andersson (1996) as an analytical framework on a longitudinal case study, the thesis provides new knowledge on the origin and emergence of routines that drive eco-process innovation. Furthermore, from a review and synthesis of prior studies, the study develops the best EnM practices and uses them as a threshold to describe the EnM practices of the case study firm. Building on this premise, the study contributes to the EnM literature by outlining the relevance of the regulative and technological context, firm internal resources, and competencies of key editors. Furthermore, the study points to the implementation process dynamics over time and the relevance of managerial involvement and endurance at various organisational levels. Managerial and policy implications as well as avenues for further research are provided from the study results.

*Table 4: Overview of appended papers and their contribution in answering the research question*

| Paper | Objective of paper | Contributions towards answering the main research question | Theoretical perspective | Type of study |
|---|---|---|---|---|
| **1** | Analyse and synthesise the empirical literature on drivers for energy efficiency in manufacturing firms and identify the main drivers at the firm level. | - Identifying internal organisational drivers as the most significant drivers for EE in manufacturing firms.<br>- Identifying the importance of organisational structure, environmental leadership and motives, and knowledge in driving EE.<br>- Pointing to relevant organisational routines facilitating EE innovation. | **-** | **SLR** |
| **2** | Analyse the relationship between manufacturing firms' absorptive capacity and EE innovation. | - Firms' absorptive capacity is positively related to firms' pursuit of EE innovation.<br>- Formal education at the individual level and innovation capabilities at the organisational level are positively related to EE innovation.<br>- External cooperation with competitors and knowledge institutions are positively related to firms' EE innovation.<br>- There is a positive interaction effect between individual competences and external cooperation.<br>- Environmental motive positively affects EE. | **Absorptive capacity** | **Quantitative study** |
| **3** | Explore the emergence of energy management practices (EnM) in a manufacturing firm. | - Identifying organisational structures and environmental routines facilitating EE behaviour in a firm.<br>- Identifying processes at the origin of the development of environmental routines.<br>- Identifying the role of internal stakeholders in driving these processes.<br>- Identifying how the emergence of environmental routines is a product of contextual factors, inherent organisational logic, and key stakeholder championing the idea. | **Translation of management ideas** | **Qualitative case study** |

# 5. Overall results

In answering the overall research question, the thesis builds on the integrated data obtained from the three empirical studies Papers 1–3. Since the objective of this thesis is to know more about the role and nature of internal drivers for eco-process innovation, the focus is on data that can be considered representative rather than deviant across the studies. However, owing to the different perspectives of the studies, some data have been identified in only one of the studies. The complementarity and interrelation of the three studies are illustrated in Figures 2 and 3.

This section analyses, triangulates, and synthesises the data across the three studies. The explorative research design of the thesis influences the analysis process. Paper 1 proposes a typology of significant drivers for EE. The study also underlines the essential role of internal organisational drivers, with the sub-categories of (1) human knowledge and competence, (2) management, and (3) organisational structure. The typology and sub-categories are depicted in Figure 1. The research questions and objectives of Papers 2 and 3 were inspired by the findings of Paper 1. These papers further researched the role and relevance of internal organisational drivers (sub-categories 1–3). Therefore, when analysing the data across Papers 1 to 3, sub-categories 1–3 were used as points of departure.

Through a constant comparison of the data and framework (Glaser and Strauss, 2009), new elements were added to extend the content of each category. With the integration of new elements, the categories had to be further adjusted. Moreover, when analysing the data, some additional elements that were not addressed in the initial analytical framework were identified, leading to the creation of a fourth category, 'translation competence'. The outcome of this analytical process is described as resulting from the thesis. The thesis results are summarised under four internal driver types for eco-process innovation, (1) environmental leadership, (2) absorptive capacity, (3) organisational capabilities, and (4) translation competence. The content of each of these internal drivers is described and discussed in Section 5.1 to 5.4 below. The new internal driver types for eco-process innovation are depicted in Table 5 in Section 5.5. Furthermore, the interrelation between these internal drivers is discussed and illustrated in a conceptual model in Section 5.6.

## 5.1. Environmental leadership

The empirical results underline the management and environmental leadership role as driver for eco-process innovation. In particular, the results point to the relevance of both economic and environmental objectives in investment decision making. Indeed, both Papers 1 and 3 emphasise the imperatives of economic criteria such as cost savings, risk of increasing energy tariffs, and short payback time when evaluating new technological solutions. In other words, investment decisions are seemingly strictly based on financial estimates and calculations, with no environmental considerations. This finding coincides with the underlying economic assumptions embedded in eco-innovation theory. Nonetheless, the results also suggest that the environmental awareness and objectives of managers have a strong impact on manufacturing firms' environmental performance. Indeed, the large volatility in energy prices challenges the accuracy of financial estimates based on eco-innovations. Thus, the financial inducement to invest in eco-process innovation is partly based on the managers' *assumptions and 'guesstimates'* of future costs and benefits associated with the investment, rather than strictly objective figures. In such situations, managers' environmental ambitions are likely to affect the financial figures and thus impact the investment decisions. This argument is supported by Peng and Liu (2016), who assert that managerial cognition and environmental morals influence the managers' attention to and interpretation of the environment and thus their response to external environmental pressure. The driving effect of the environmental and economic objectives of managers for eco-process innovation has also been addressed by Costa-Campi et al. (2015) and Hojnik and Ruzzier (2016a). However, the environmental and economic motives of these quantitative studies were analysed separately as two dichotomous variables. In contrast to this dichotomy perspective, the qualitative approach in Paper 3 points to the two objectives' interaction effect and how they reinforce one another. Indeed, while Paper 3 emphasises the imperative of economic feasibility, the results point to the importance of environmental motivation when searching for and developing economically feasible technological solutions. Undeniably, the best long-term technological solutions agree with both the economic and environmental objectives.

Furthermore, the results suggest that the ability of firms to identify eco-process innovations that comply with both economic and environmental objectives is driven not only by environmental motives, but also by environmental management practices (Ates and Durakbasa, 2012; Lawrence et al., 2019; Thollander and Ottosson, 2010). Environmental management practices are both about organisational structures and routines (discussed in more details in section 5.3.)

and managerial actions generating environmental awareness in the organisation and putting environmental issues at the strategic agenda. In this regard, the results indicate that the top managers must be supportive and committed to the environmental agenda and formulate the firm's long-term environmental strategies, goals, and profile. The top managers' strategic commitment will accordingly percolate down to the individual members of the organisation and contribute to developing a culture and willingness for environmental change (Salim et al., 2019). Arguably, the results show that the successful implementation of environmental strategies depends on employee support and engagement. Thus, managers need to focus on employee involvement and motivation. This result agrees with Hansen and Coenen (2017), who assert the relevance of specific environmental absorptive capacity of management affecting the managers' ability to mobilise human (and financial) resources and enhance the firm's environmental performance. In this regard, the results point to the important role of the environmental manager in mobilising human resources. While top managers play a significant role in setting long-term environmental strategies, the environmental manager is found to be a vital player for internal operationalisation of these strategies. Middle managers are increasing acknowledged for their strategic role in organisational change processes (Rouleau and Balogun, 2011). Indeed, energy managers are often middle managers who lack the hierarchical authority of top managers and immediate operational knowledge of operations personnel (Blass, 2014; Radaelli and Sitton-Kent, 2016). However, the results suggest that environmental managers play a key role in translating and communicating strategies, concerns, objectives, and needs vertically between the executive and operational levels in the organisation and horizontally between departments.

The results presented in this section suggest that in manufacturing firms, managers drive eco-process innovation through their personal environmental cognition and objectives. However, they also depend on the support and engagement from the operational level to succeed in environmental transformation of the production processes. This requires the implementation of environmental management practices, strategies, and culture. Hence, the thesis finds that the role of managers has several similarities with the notion of transformational and environmental leadership (Robertson and Barling, 2017) entailing the encouragement of ethical behaviour, motivation, stimulation, and negotiation for individual needs. Chen et al. (2012) describe environmental leadership as a dynamic process in which one individual influences others to contribute to the achievement of environmental management and environmental innovations. Furthermore, Robertson and Barling (2017) assert that environmental leadership generates a supportive and motivating environment, where leaders encourage their subordinates to engage in workplace pro-environmental behaviours. Accordingly, I propose that environmental leadership is a significant driver for eco-process innovation.

## 5.2. Absorptive capacity

Environmental transition of the manufacturing sector represents the external pressure and fast-paced regulatory and technological changes that firms need to handle. While the previous section focused on environmental leadership, this section points to the role of knowledge and absorptive capacity (Cohen and Levinthal, 1990) in driving eco-process innovation. Knowledge creation and application are critical to firms' environmental innovativeness (Albort-Morant et al., 2018). Moreover, absorptive capacity has been defined as the ability of a firm to recognise the value of new information, assimilate it, and apply it to commercial ends (Cohen and Levinthal, 1990; Zahra and George, 2002). In other words, absorptive capacity can be described as a measure for organisational learning and is largely a function of related prior knowledge.

Prior research in the field has most commonly considered the knowledge resources of firms as firm-level technological capabilities for eco-innovation and measured as R&D (Díaz-García et al., 2015; Pacheco et al., 2017; Horbach et al., 2012; De Marchi, 2012). Despite the extensive use of the R&D measure, the thesis results (Paper 2) only partly support the relationship between R&D and eco-process innovation. Thus, the results add to the growing literature that questions the driving effect of internal R&D on eco-process innovation (Rennings et al., 2006; Horbach et al., 2012; De Marchi and Grandinetti, 2013). In any case, the results emphasise that cooperation with universities has a significant positive effect on manufacturing firms' eco-innovativeness. In addition, the results suggest the relevance of organisational knowledge and accumulation of prior experience with innovation (Gerstlberger et al., 2016). Hence, overall, the results suggest that knowledge and knowledge development at the firm level are essential drivers for eco-process innovation.

Furthermore, management scholars have lately asserted the relevance of understanding the role of human resources at the individual level when advising managers on how to promote organisational capabilities linked to firm-level performance (Foss and Pedersen, 2016). Indeed, both Papers 1 and 2 underline a positive relationship between employees' formal education and training, and eco-process innovation. In fact, the papers indicate that a higher-educated work force seems to affect the firms' environmental awareness and ability to overcome barriers, and that such firms seem more prone to invest in eco-process innovation than do other innovative firms. Training programmes are also found to increase the employees' environmental awareness and knowledge about available technologies. Furthermore, Paper 3 emphasises the importance of prior experience and the key employees' detailed knowledge about the firm's internal contextual conditions. The thesis also suggests a positive relationship between knowledge and skills at the individual level and the development and implementation of eco-process innovation at the firm level.

In addition, the thesis suggests that eco-process innovation is likely to be relatively higher in firms with highly educated employees *and* where the firm cooperates with competitors or knowledge institutions. Paper 3 finds that the need for detailed knowledge about the in-house production processes makes it hard to include external stakeholders in innovation processes. However, in such cases, industrial networks are found to be important inspirational sources for the development of technological solutions. Some of the variation in results could be related to the distinction between the 'science, technology and innovation' (STI) and 'learning by doing, using and interacting' (DUI) modes of innovation (Parrilli and Alcalde Heras, 2016) and/or analytic and synthetic knowledge bases (Asheim and Coenen, 2005). However, the overall results emphasise the interrelation between prior and new knowledge at both the individual and organisational levels. Consequently, from the results of the thesis, I argue that absorptive capacity is an important driver for eco-process innovation.

### 5.3. Organisational structures and routines

The results of the thesis suggest that organisational structures and routines are important for eco-process innovation in manufacturing firms. Organisational structure is related to the introduction of environmental departments, teams, or cross-functional units and committees (Klewitz and Hansen, 2014), whereas organisational routines can be described as complicated, detailed, analytic processes that rely on existing knowledge to produce predictable outcomes (Eisenhardt and Martin, 2000). Routines can thus be conceptualised as properties coordinating and directing human action (Aggarwal et al., 2017). As for environmental structures, the results point to the relevance of strategic positioning for the environmental manager in the organisational hierarchy. In fact, the energy manager should preferably be positioned close to the decision makers in the top management team and the operation personnel. When it comes to routine, the thesis points to the relevance of environmental (energy) management practices (Lawrence et al., 2019; Thollander and Ottosson, 2010; Ates and Durakbasa, 2012). Indeed, the investment decision process can be considered a key routine in the allocation of resources for environmental improvement. This includes the routines of earmarking financial resources to environmental projects and inclusion of environmental objectives as an investment criterion. Anyhow, the results endorse that the most sustainable technological solutions comply with both the environmental and economic objectives. Thus, organisational practices and routines that drive the development of good technological solutions are of core interest. Such practices include the use of performance measurement and monitoring systems, information assimilation and distribution, delegation of environmental responsibility, and routines stimulating employee engagement.

Indeed, performance measurement systems and routines related to the operation and use of these systems are essential to monitoring, controlling, and benchmarking environmental performance with environmental targets. Energy audit and metering systems are examples of drivers providing fact-based information, better follow-up activities, transparency, understandable calculations, and shared course of action in strategic energy planning. As described in Sections 5.1 and 5.2, employee motivation and knowledge are vital for eco-process innovation. Hence, structures and routines that ensure employee involvement and competence-enhancing activities need to be set up. The relevant routines in this regard could be the assimilation of ideas for technological solution, recognition of good ideas, and employee involvement in environmental strategy processes. Furthermore, since prior experiences with environmental and general innovation processes are positively related to eco-process innovation, one can argue that innovation processes in themselves are routines that build organisational capability for eco-process innovation (Gerstlberger et al., 2016). Environmental delegation by implementing key performance indicators (KPI) can further enhance the environmental awareness of employees. However, KPI systems can also have the risk of drawing attention towards business performance at the expense of environment performance. Arguably, the mere existence of a KPI system cannot by itself increase the firm's environmental performance. It is rather the routines related to analysing the KPI along with some form of consequence management that can improve the firm's environmental performance.

The results presented in this section illustrate several organisational structures and routines found to have a positive impact on manufacturing firms' environmental performance. In the eco-innovation literature, researchers have tended to measure organisational capabilities for eco-innovation as EMS certification. In contrast, this thesis describes some micro foundations of this capability in terms of organisational structure and routines. By describing these micro foundations in detail, the thesis provides a better understanding of the concept of organisational capabilities for eco-process innovation. Furthermore, from the results, I assert that the relevant organisational structures and routines are drivers for eco-process innovation.

### 5.4. Translation competence

As argued in previous sections, the internal factors of several firms, such as their resources, structures, and routines, affect their ability and willingness for eco-process innovation. These results coincide to a large extent with prior observations in the literature. Nonetheless, most of these studies analyse the relationship between the dependent and independent variables from a variance perspective, namely eco-innovation and internal drivers. Hence, the dependent and independent variables in these studies are treated as given entities without questioning how and why the variables have emerged and developed over time. Indeed, while for example routines coordinate and direct the practices of individuals, they also emanate from structured relations and interactions between individuals (Aggarwal et al., 2017). Hence, the emergence of new routines driving the environmental performance of firms requires that the firms go through a process where the organisation members at all levels have understood, accepted, and adopted the environmental agenda. These processes that lead to the emergence of new routines and other drivers have received limited attention in the eco-innovation literature (Lawrence et al., 2019). The results presented in this section are mainly based on the qualitative study Paper 3.

The study takes a process approach to analyse the implementation of a corporate environmental programme in manufacturing. This approach contrasts and complements the variance approach taken in the two other papers. Furthermore, the translation theory is used as an analytical framework (Czarniawska-Joerges and Sevón, 1996; Røvik, 2016; Wæraas and Nielsen, 2016; Sahlin-Andersson, 1996). Translation theorists focus on the 'travel' of intangible management ideas across contexts, with the factors affecting the materialisation of ideas in a new setting (Czarniawska-Joerges and Sevón, 1996) often identified from the emergence of new practices, routines, organisational structures, and mind-set of individuals (Wæraas and Nielsen, 2016; Wæraas and Sataøen, 2014). In other words, the theory describes the relationship between the translation process and translation outcome (Røvik, 2016). Translation competence is accordingly described as the ability of editors to translate ideas and programmes between organisational contexts in ways that increase the probability of achieving the desired organisational ends (Nilsen and Sandaunet, 2020; Røvik, 2016). The results suggest that environmental programmes can be considered as intangible accounts that need to be translated when implemented in a firm, and introduce translation competence as a new driver for eco-process innovation.

The results further show that the editors can have quite large freedom to interpret, change, and form their own version of the environmental idea. The thesis addresses several external and internal contextual conditions affecting the local implementation of the environmental idea. Such conditions can include the sectorial acts that regulate and complicate commercialisation of new products and thus make eco-product innovations less attractive. However, environmental regulations such as emission permits make eco-process innovations more attractive because increases in production volume depend on the firm's ability to retain environmentally harmful emissions. External non-environmental issues, such as increased competition and financial crises, can also increase the search for solutions that enhance efficiency. As for internal conditions, the thesis holds that financial aspects such as capital binding in existing production equipment and facilities and access to investment capital provide incentives to search for environmental solutions where firms can capitalise on existing infrastructure and machinery. Furthermore, high production complexity provides incentives to search for solutions with minimal operational risks. These conditions are commonly described as barriers to eco-innovation (Hansen and Coenen, 2017). In contrast, the thesis results indicate that they can also be considered as contextual conditions impacting and directing the local translation of the environmental programme towards EE and eco-process innovation. However, such local changes in the environmental programme to fit the local setting depend on the abstraction level of the programme (Lilliank, 1995) and the local editors' understanding of the environmental programme and knowledge of the local context.

Organisational routines are the aggregation of individual practices (Aggarwal et al., 2017). The emergence of new environmental routines for eco-process innovation (or other desired ends) would depend on the organisational members' acceptance of and engagement with the environmental programme. The results indicate the relevance of formulating and labelling the idea to make it easy to communicate and deemed appropriate in the organisation. Furthermore, the results underline the effectiveness of building on familiar rhetoric and concepts to enhance one's understanding and gain legitimacy and support for the idea. This underlines the relevance of being process oriented for successful implementation of a new environmental programme in an organisation. Furthermore, the results suggest that the internal labelling of environmental ideas affects the organisational response direction. As with a self-fulfilling prophecy, by labelling the idea as efficient, the development of technological solutions is geared towards eco-process innovations. All members of an organisation will have their individual perspectives and agenda that affect their perception of the environmental programme (Helin and Babri, 2015). Thus, for successful implementation of the environmental programme at the firm level, the members' individual perceptions and interests must to some extent be united. To this end, the results assert the effectiveness of aligning the environmental agenda with the predominating rationale and rules of logic within the organisation (Sahlin-Andersson, 1996). Such rationales can be related to cost reduction, competition, and long-term survival. Furthermore, during the process of aligning the environmental programme with the dominating economic rationale, the editors must work proactively to continuously sell the environmental programme, mediate others' versions, and align their goals and agendas. These are lengthy processes and underscore the need for long-term environmental strategies and managerial endurance.

The thesis further suggests that before new environmental practices successfully emergence in a firm, the environmental programme has to be thoughtfully contextualised, rhetorically fitted, and rationalised to the local firm setting. Although these steps coincide with the editing rules of Sahlin-Andersson (1996), editors might follow the rules blindly, rather than deliberately choose them (Røvik, 2016). During this translation process, all those affected by or affecting the materialisation of the firm's internal environmental programme can be perceived as editors. Nonetheless, some editors could seem to be playing a more significant role than others. In particular, the results point to the top managers' role in contextualising the environmental programme during the first steps, while the energy manager (middle manager) plays the more significant role of aligning the environmental programme with the extant organisational rationale. The changes in role and involvement of various editors during the translation process can possibly be explained by their formal mandate, competence, and detailed knowledge of the contextual conditions.

This section examines how the translation process of an environmental programme can impact the manufacturing firms' pursuit of eco-process innovation by raising the question of whether translation competence can be considered a driver for eco-process innovation. An important prerequisite for translation competence is the editors' knowledge about the source of the original idea, local recipient context, and translation rules (Røvik, 2016). The thesis results denote that implementation of the environmental programme requires the firm to have relevant knowledge about the contextual conditions and good understanding of the programme, in addition to the ability to master the lengthy process of selling the environmental idea to the organisation. These results coincide with the description of translation competence (Nilsen and Sandaunet, 2020; Røvik, 2016). Therefore, I propose translation competence as a driver for eco-process innovation, in that it increases the probability of successful implementation of environmental programmes and thus the firm's environmental performance.

## 5.5. Typology of internal drivers for eco-process innovation

*Table 5: Framework of internal organisational drivers for eco-process innovation*

| | **Internal drivers** | **Micro foundations of the drivers** | **Paper 1** | **Paper 2** | **Paper 3** |
|---|---|---|---|---|---|
| **1** | Environmental leadership | - Environmental motives | **X** | **X** | **X** |
| | | - Economic cost-benefit motives | **X** | | **X** |
| | | - Top managers' cognitive environmental awareness | **X** | | **X** |
| | | - Environmental mangers **(**middle managers) | **X** | | **X** |
| | | - Long-term environmental commitment | **X** | | **X** |
| | | - Long-term environmental strategies | **X** | | **X** |
| | | - Employee involvement and engagement | | | |
| **2** | Absorptive capacity | - Education and training of employees | **X** | **X** | **X** |
| | | - Professional experience and expert knowledge of environmental manager | **X** | | **X** |
| | | - Firm internal R&D | **(X)** | **(X)** | |
| | | - Cooperation with knowledge institutions | **X** | **X** | |
| | | - Prior innovation experiences | **X** | | **X** |
| **3** | Organisational structures and routines | - Routines for employee engagement | **X** | | **X** |
| | | - Strategic positioning of the environmental manager in the organisational hierarchy | **X** | | **X** |
| | | - Cross-sectional environmental teams | **X** | | **X** |
| | | - Investment decision processes – routines for including environmental objectives | **X** | | **X** |
| | | - Environmental performance measurement systems and routines (e.g. energy audits) | **X** | | **X** |
| | | - Information assimilation and dissemination routines (reporting and communication) | **X** | | **X** |
| **4** | Translation competence | - Contextualisation and adjusting the environmental programme according to contextual conditions | | | **X** |

| | | |
|---|---|---|
| | - Familiarising the programme to the organisation | **X** |
| | - Rationalising the programme to the members of the organisation | **X** |

*'X' indicate observations and data that support the result. +'(X)' indicate observations and data that partly support the result.

Table 5 synthesises the thesis results in a new typology of internal organisational drivers for eco-process innovation. The typology includes the following drivers: (1) environmental leadership, (2) absorptive capacity, (3) organisational capabilities, and (4) translation competence. The table illustrates (with 'X') from where the data that substantiate the results are collected. Thus, the thesis results build on empirical data representative across the tree studies. Furthermore, the table illustrates that the fourth driver 'translation competence' builds mainly on the empirical data from Paper 3. Although this driver is a known theoretical construct in translation (Nilsen and Sandaunet, 2020; Røvik, 2016), it has not been proposed so far as a driver for eco-innovation. Hence, the introduction of this driver provides a new theoretical perspective on internal drivers for eco-process innovation. Moreover, by approaching the subject from three different perspectives and mixed methods, the findings provide some detailed knowledge on the role and origin of these constructs at individual and organisational levels.

### 5.6. Conceptual model of internal drivers for eco-process innovation

From the thesis results, I develop a new typology of internal organisational drivers for eco-process innovation, arguing the importance of (1) environmental leadership, (2) absorptive capacity, (3) organisational capabilities, and (4) translation competence. The typology as presented in Table 5 depicts the four drivers as independently having positive stimulating effect on manufacturing firms' eco-process innovation. However, the results presented in Section 5.1 to 5.4 suggest overlaps and interrelations between the drivers. For example, translation competence affects how an environmental programme is contextualised, understood, and operationalised locally in firms. Moreover, how the translation process unfolds is strongly affected by the managers' environmental cognition, employee support, and knowledge about contextual conditions. Furthermore, the managers' knowledge about contextual conditions forms the contingent organisational structures and routines that allow the collection of relevant information and transparency. Myriad of such examples in the text show the interrelation between the drivers as well as their interdependence in enhancing the manufacturing firms' environmental performance. The interrelation between internal drivers are illustrated in Figure

4. The figure also depicts (as a rebounding arrow) how the drivers' prior experience with eco-process innovation help driving new eco-process innovation.

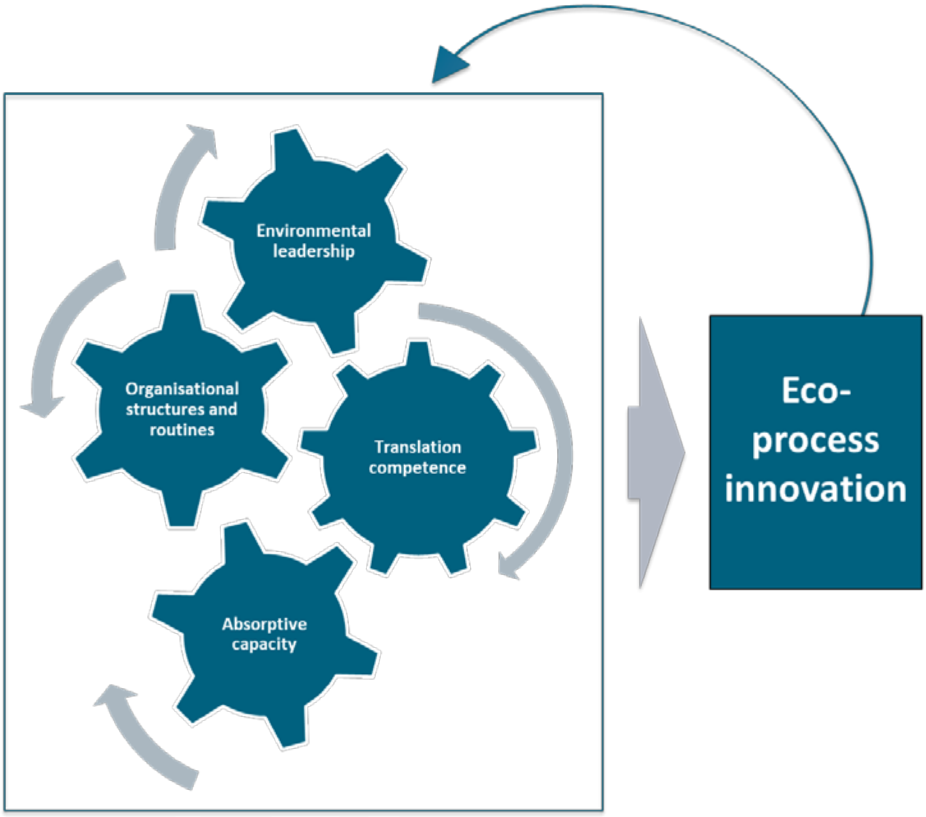


*Figure 4: Conceptual model of internal organisational drivers for eco-process innovation*

Eco-innovation is an empirical research field with different relevant theoretical approaches to analyse the internal drivers and underlying organisational mechanisms. Thus, the interrelation between drivers can be discussed from a theoretical perspective. As regards the four proposed drivers' traits, they seem to reflect the perspectives of notable theoretical schools. The notion of driver and absorptive capacity (Cohen and Levinthal, 1990) emanates from the RBV (Barney, 1991; Hart, 1995). The theory holds that firms with better, unique, and non-imitable resources and capabilities are likely to perform better and maintain a sustainable competitive advantage. Hence, this theoretical stance provides explanatory power to examine how and why organisational resources impact the firms' ability to undergo environmental changes. Furthermore, organisational structures and routines are drivers that coincide with the dynamic capability theory approaches (Teece et al., 1997; Eisenhardt and Martin, 2000). This theory endorses the importance of organisational routines for creating, extending, and modifying the resource base by adjusting to changing dynamic environments (Helfat et al., 2007; Teece et al., 1997). Environmental leadership is a driver reflecting the theoretical perspectives of strategic decision making (Mintzberg et al., 1976), human resource management (Renwick et al., 2013), and innovation management (Adams et al., 2006). Finally, translation competence and translation theory (Nilsen and Sandaunet, 2020; Røvik, 2016) originate from Scandinavian institutionalism (Czarniawska-Joerges, 1996). This theoretical perspective emphasises the translation processes at the micro level, and includes the involvement of internal stakeholders, the competencies they manage, and the reasons for the translation itself. The different theoretical approaches on drivers provide differing explanations to the relationship between the drivers and innovative behaviour of the firm. Indeed, by considering the drivers from different theoretical perspectives, the conceptual pluralism 'drivers' becomes a boundary concept that helps the different theoretical perspectives to relate to one another. Arguably, in addition to addressing the individual drivers' direct effects on eco-process innovation, the thesis results also corroborate that the drivers complement one another and should be considered as a whole. Furthermore, the analytical focus could move with advantage from the 'drivers for eco-innovation' to a more systemic 'eco-innovative firm' perspective.

# 6. Contribution, implications, and avenues for future research

Research on the drivers (and barriers) for eco-innovation started to emerge in the early 1990s, and the literature has expanded extensively since then. From its origin, the literature has mainly been underpinned by the ecological economic theory. This perspective emphasises economic considerations, and assumes a positive relationship between technological progress and natural conservation. Alvesson and Sandberg (2013) show that theoretical and empirical perspectives could overlap when theory development is closely linked to the empirical domain. Similarly, the eco-innovation theory evolves to show tendencies of redundancy and a 'lock-in' situation, where the theoretical development is closely linked to quantitative research mainly focusing on external economic drivers. Thus, eco-innovation theory has mainly supported and reinforced the underlying economic assumptions and 'truths' in the literature since its origin. In contract, by applying a multi-method analysis of the internal drivers for EE in Norwegian manufacturing firms, the thesis results emphasise environmental leadership, absorptive capacity, organisational structures and routines, and translation competence as important drivers for eco-process innovation. As the thesis extends the knowledge about the nature, impact, and interrelation of these drivers, it also opens up theoretical reflections on internal drivers for eco-innovation, provide policy and management implications, and illuminate avenues for future research.

## 6.1. Theoretical contributions

Currently, eco-innovation theory does not provide a comprehensive framework for research on drivers (del Río et al., 2017). However, several theoretical approaches are relevant to research in this field, but most publications lack in a clear theoretical approach to the phenomenon (del Río et al., 2016; Hazarika and Zhang, 2019). Theory is essential for the development of accurate definitions for key constructs and analysis of the underlying theoretical mechanisms (Shaw, 2017). The thesis results endorse the value of using established theories abductively to enhance the validity and reliability of research results and the empirical analysis and knowledge on internal organisational drivers for eco-process innovation. Indeed, a wealth of theories focus on, for example organisational change processes, strategic and transformational leadership, and innovation, from which researches can derive analytical frameworks and theoretical understanding. However, some theories account for what is observed better than others and thus are more relevant for research on internal drivers. Arguably, this thesis contributes theoretically to eco-innovation by introducing and demonstrating the applicability of absorptive capacity and translation theory for research on internal organisational drivers for eco-process innovation.

Translation theory can be used to analyse the implementation of an environmental programme in a manufacturing firm and indeed provide results with theoretical implications. Prior studies have mainly addressed the impact of external contextual factors (Palm and Thollander, 2010; Soepardi et al., 2018), technological systems, and institutional settings in which the firm is embedded (Hansen and Coenen, 2017; Geels, 2012). However, this thesis illuminates the active role that the firm itself plays in developing the local understanding of an environmental programme and impact of the firms' internal rationale. Hence, as opposed to considering the environmental agenda as 'given', the thesis depicts the environmental programme as something intangible, flexible, and negotiable. Furthermore, the thesis suggests that the firm's translation competence (Nilsen and Sandaunet, 2020; Røvik, 2016) supports its implementation of environmental programmes and environmental performance. Hence, the results support the argument by Banister et al. (2019) that transition for sustainable development do not solely dependent on technological innovation, but rather the engagement of individuals and institutions at all levels. Moreover, the results make reference to two different conceptualisation of competence – 'knowledge' and 'knowing'. The 'knowledge' signifies the rationalistic perspective that treats knowledge as an independent, factual object, whereas the 'knowing' conveys a performative conception and treats human expertise as being inseparably intertwined with social practices (Ibert, 2007). Hence, the introduction of the translation theory and concept of translation competence suggests a new perspective to internal drivers and thus contributes to extend the theoretical debate on drivers for eco-process innovation.

In the literature, the drivers for eco-process innovation are most commonly measured at the firm level. Examples of such measures are R&D investment (e.g. Díaz-García et al., 2015) or EMS adoption (Kesidou and Demirel, 2012; Peng and Liu, 2016). However, the accuracy and validity of this measure have been questioned (De Marchi and Grandinetti, 2013; Lawrence et al., 2019; Ziegler and Rennings, 2004). Arguably, to better understand the relationship between firm-level constructs and eco-process innovation, one needs to understand the micro foundations of these constructs. The micro foundations of organisational (dynamic) capabilities include the distinct skills, processes, procedures, organisational structures, and decision rules that allow the firm to adapt to a changing environment (Teece, 2007). With more knowledge on the micro foundations of drivers, the thesis results build on the representative data derived from the three empirical studies. The mixed method and differing perspectives applied to the studies allow for greater richness and complementarity of the collected data, to result in a new typology of internal organisational drivers (Table 5). Initially, from the SLR of Paper 1, the analytical framework included three drivers. However, after triangulation of the data across the three studies, the micro foundation of each driver was elaborated and reinforced. Furthermore, a fourth driver was identified, 'translation competence', along with the relevance of the time dimension in environmental transition processes. Arguably, the thesis contributes to the field with increased knowledge on the micro foundation of drivers for eco-process innovation and presents the advantages and strengths of the mixed method for illuminating and yielding more comprehensive knowledge on the phenomenon.

Furthermore, the thesis contributes to the field by providing more knowledge on the impact on and role of internal stakeholders (Freeman, 2010) at different levels in the organisation. Prior studies have mainly considered the external stakeholders such as cooperation partners and suppliers (e.g. (De Marchi, 2012; De Marchi and Grandinetti, 2013). The results of this thesis complement these studies by pointing to the role of internal stakeholders at various levels in the organisation and how they affect the environmental achievements of manufacturing firms. The results also support the view that operational personnel have an important role in the implementation of eco-process innovation (Lawrence et al., 2019). Hence, enhanced environmental performance is largely about skilfully managing employees and the choice of suitable management techniques. In particular, the results indicate the importance of top managers in generating environmental awareness in the organisation and including environmental issues in the strategic agenda and initiating the adoption of environmental management practices. Furthermore, the results suggest that environmental managers (middle managers) play a significant role in the implementation of such environmental management practices. Accordingly, the results add to the growing literature on the impact and role of middle managers in environmental and organisational change processes (Blass, 2014; Radaelli and Sitton-Kent, 2016; Rouleau and Balogun, 2011). Increased knowledge on the individuals' role in and impact on firm-level performance is not only essential for theory development but also vital for informing managers.

The thesis results emphasise and conceptualise four internal organisational drivers for eco-process innovation and the interrelation between them. Prior research on the interconnection between drivers has been limited (Chai and Baudelaire, 2015; Cagno and Trianni, 2013), and so this relationship has not been well understood. Although several models have been proposed to conceptualise the dynamics of eco-innovation, there has not been much research on the organisational models considering eco-innovation at the firm's strategic level (Xavier et al., 2017). Hence, by conceptualising the drivers in relation to one another as a whole (Iñigo and Albareda, 2016), this thesis contributes theoretically to the eco-innovation literature from a systems perspective.

In this thesis, I consider EE as an empirical phenomenon and use it to examine the more theoretical conceptualisation of internal drivers for eco-process innovation. I chose this approach because of the limited prior research on the phenomenon. Thus, the results are also of theoretical relevance for the EE literature by conceptualising the internal drivers enhancing manufacturing firms' EE. Furthermore, the thesis results allow for discussing the relationship between the origin of the eco-innovation literature, the underlying assumptions and the theoretical development of the field. Thus, my observations suggest that the prior gap in the literature with regard to internal drivers is not only due to the lack of attention from researchers, but also the result of the 'self-confirmation' and overlapping of theoretical and empirical perspectives. Hence, the thesis suggests that further development of eco-innovation theory would benefit from a larger degree of 'problematisation' methodology when researchers generate research questions (Alvesson and Sandberg, 2011). Thus, by challenging the prevailing assumptions in the field, future research can lead to new and influential theoretical perspectives on eco-innovation.

## 6.2. Limitations and future research

This thesis has certain limitations that should be considered when interpreting its contributions and implications. The specific limitations of the three empirical studies are discussed in the appended papers. Furthermore, the validity and reliability of the results have been discussed in Subsections 3.4.2 and 2.4.3, respectively. In this section, I discuss the limitations of the results in terms of generalisability.

The previous section outlined the theoretical contributions of the thesis. Note that these contributions are based on an exploratory research design, and provide directions for interesting and relevant avenues for future research. However, additional research would be required for further development of eco-innovation theory. In this regard, several theoretical challenges can be found in terms of lack of clarity in the definition of key concepts. With rapid expansion of the literature, empirical key concepts could be diluted and the theoretical lenses could become blurred (Alvesson and Einola, 2019). The thesis results endorse the need for a more systemic approach relevant to the internal organisational drivers for eco-process innovation. These results initiate a theoretical discussion on the complementarity and potential overlap between the concepts of internal drivers and eco-organisational innovation. Eco-organisational innovation is an eco-innovation type (Kemp and Pearson, 2007) described as the reorganisation of routines and structures in the firm and a new management form (OECD, 2009) (see also Section 2.2.). The literature also suggests a positive relationship between eco-organisational and eco-process innovation (Cheng and Shiu, 2012), although Klewitz and Hansen (2014) point to gaps in the understanding of these relationships. Hence, several similarities and potential overlaps seem to exist between the conceptualisation of internal drivers in this thesis (Figure 5) and the definition of eco-organisational innovation. Hence, future research needs to address some of the current vagueness with the definitions of key concepts in the field. Scholars need to be more explicit about the operationalisation of both drivers and eco-innovation to start the process of reaching a consensus on the academic understanding of drivers for eco-innovation. Such an approach is necessary for the literature to serve its purpose, namely contributing to sustainable development of the manufacturing sector.

Furthermore, the results suggest a mixture of several internal organisational drivers affecting eco-process innovation and the environmental change processes in manufacturing firms. To better understand the interrelation between these drivers, an interesting avenue would be for future research to explore the phenomenon using multi-dimensional theoretical frameworks. Indeed, the need for integrative conceptual frameworks and theoretical triangulation to further energy social science research has recently been emphasised in the agenda-setting paper by Sovacool et al. (2020). One example of a theoretical framework with long traditions in conceptualising organisational change processes is the theory of organisational change capacity (OCC) (Judge et al., 2009; Soparnot, 2011). This framework integrates context, processes, and learning dimensions when conceptualising the organisational ability to efficiently plan, design, and implement change. The OCC framework can thus help researchers better understand the combination of managerial and organisational factors that allows for firms to adapt more effectively to the environmental paradigm and succeed in environmental transition. Another interesting avenue for future research on drivers for eco-process innovation adheres to the theoretical field of technological innovation systems (TIS). This research field has become increasingly preoccupied with the micro-level in recent years (Farla et al., 2012) and the linkages between micro- (firm/organisational) and meso-level (system/institutional) analyses of eco-innovation (Markard and Truffer, 2008). By adhering to the TIS theory, researchers can gain more knowledge on the relation between institutional structures at various levels and the manufacturing firms' pursuit of eco-process innovation.

Context dependency is also an essential question pertaining to the limitation in terms of generalisation. The thesis results do not differentiate by manufacturing sector. Considerable research has analysed the role of the manufacturing sector, with particular emphasis on the impact of energy-intensive versus non-energy-intensive sectors (e.g. Gerstlberger et al., 2016; Horbach, 2008; Thollander and Ottosson, 2010). Although several arguments support sectorial impact, the literature provides ambiguous results (Paper 1). Therefore, an interesting avenue for future research is to analyse the impact of internal organisational drivers across manufacturing sectors. Furthermore, with respect to geographical diversity the studies build on empirical data from Western European firms (Paper 1) and with emphasis on Norway (Papers 2 and 3). The strong focus on a single empirical setting risk to limit the generalisability of the findings. Although, the results should be applied cautiously to other national contexts I argue that the results have a broader geographical outreach. Indeed, sustainable development of the manufacturing sector is of global urgency. As the international community strives to reduce

GHG emissions, all governments and industries need to prepare for innovative and competitive solutions with reduced dependence on fossil fuels (UNFCCC, 2015). Moreover, the results build on the triangulation of data across the three appended studies with focus on representativeness. The multi-national data from Paper 1 does accordingly serve as a threshold to assure the representativeness of the results beyond the Norwegian context. In addition, one of the few studies applying cross-country analysis detects remarkable similarities in drivers despite differences in the national innovation systems (Horbach et al., 2013). Nonetheless, the geographical unevenness of environmental transition processes call for more knowledge about place-specific impacts on sustainability transitions (Coenen, et al., 2012). Hence, further research needs to verify whether the thesis results hold for firms in different geographical contexts. Given that the future increase in energy demand is expected to come from Asia owing to its strong economic growth, increased access to marketed energy, and quickly growing populations, increased focus should be given to the Asian context. Finally, note that the concept of sustainable development (Brundtland, 1987) is defined in terms of the future generations' needs. As the future generations' needs progress along with the emerging future challenges, the pressure exerted by internal or external stakeholders will be affected by the current scenario of sustainable development. Moreover, this dynamic definition of sustainable development emphasises that the thesis results must be considered in terms of its time context, with the need for a continuous and updated research to verify the generalisability in the time context.

### 6.3. Policy implications

Policymakers all over the world are struggling to reach their national and the Paris agreements' ambitious goals of a carbon-neutral society, stimulating the development of an economic and environmentally sustainable manufacturing sector. Even though the world is transitioning away from fossil fuel towards renewable energy, the speed and depth of this transition is uncertain and controversial. Hence, policymakers need to continuously focus on eco-innovation and refinement of the manufacturing processes to optimise the use of resources and minimise GHG emissions. In this regard, the results of this thesis suggest a policy approach with increased emphasis on internal organisational drivers for eco-process innovation.

Considering the positive relationship between education**,** absorptive capacity, and eco-process innovation, policymakers can make an impact by focusing on and supporting the integration of sustainability topics in education programmes at all levels. Education enhances technological and scientific skills and contributes to enhanced environmental awareness and a common knowledge platform and language that facilitate communication and cooperation across different fields of science (Smith et al., 2005). The results also draw attention to the prominent role of universities in providing manufacturing firms with expertise in terms of higher education and R&D collaboration. Since institutional barriers could undermine university-industry cooperation (Bruneel et al., 2010), it is advisable to develop policy programmes that facilitate learning networks and encourage the development of university-industry cooperation platforms. Furthermore, education welfare systems that stimulate people to enter higher education need to be developed.

Prior studies have pointed to the challenge of designing environmental policies from the various contextual perspectives that impact their effect (Palm and Thollander, 2010; Soepardi et al., 2018). This suggests that contextual conditions as well as the framing of environmental programmes impact the firms' environmental response. Environmental policy programmes have similarities with environmental management programmes in that both can be treated as intangible accounts providing norms and guidance to socially pressing issues. Thus, the complexity and abstraction level of environmental policy programmes affect the firms' understanding of the programmes and how they are implemented locally (Lillrank, 1995). Hence, policymakers must ensure that the policy programmes contain all relevant information required to explain and understand them at the firm level. Furthermore, the programmes have to be flexible enough for the firms to fit them into the local setting. Therefore, in addition to economic regulations, policymakers should make extended use of more advanced policy programmes such as voluntary agreement programmes (VAPs) and long-term agreements (LTAs) (Cagno et al., 2015; Rietbergen et al., 2002). Such programmes can effectively overcome the traditional constraints of implementing top-down policies at the local level (Eichhorst and Bongardt, 2009) and allow each firm to identify the solutions that are deemed most fit for the local setting.

It is also relevant to discuss the thesis results in relation to the Norwegian environmental policy instruments. As asserted in the introduction section, the energy consumption of the manufacturing sector is rather heavy in Norway compared to in other Nordic countries. The Norwegian economy also shows an imperative to diversify away from depending on fossil fuel exports and towards a low emission society. Hence, Norway needs to cut their emissions and Norwegian businesses need to create new value. In their GHG emissions abatement efforts, the Norwegian governments have historically emphasised the need for and applied extensive effort and investment in R&D on carbon capture and storage (CCS) technologies (Norby et al., 2019; OED, 2016). However, several of these technologies are yet to be tested or have not succeeded at a large scale (Norby et al., 2019). Furthermore, these solutions can be considered as 'end-of-the-pipeline' solutions that impact neither the efficiency nor competitiveness of the manufacturing sector. To this end, Enova, on assignment from the Norwegian Ministry of Climate and Environmental, manages the Climate an Energy Fund. The purpose of Enova is to contribute to technology development for the reduction in GHG emissions in the long run under a central Norwegian policy for the development of a low-emission manufacturing sector (OED, 2016). Enova provides advisory services and financial support for businesses to take up technological eco-innovation. Their annual investments are more than NOK 2 billion of public resources (Enova, 2019). Studies commissioned by Enova show that a majority of the industry's total emissions can be cut through the use of available and profitable technology, with 40% contingent on new technology. Furthermore, from experience, Enova shows that energy consumption can be reduced by a projected 10% through energy management (Enova, 2019). The positive effect of energy management coincides with the results of this thesis. Nonetheless, Enova mainly adopts the two main lines of technology development and market development. Hence, less attention is given to supporting and enhancing the manufacturing firms' willingness and ability to adopt these technological changes. The downgrading of firms' internal matters is further illustrated by Enova's decision not to support the introduction of energy management by the end of 2018 (Enova, 2019). This decision was made despite their good experiences in establishing energy management in more than 700 Norwegian businesses since 2012. With regard to the energy savings potential related to energy management and the thesis results, I would advise continued support for introducing energy management in manufacturing firms in Norway.

## 6.4. Managerial implications

The new environmental paradigm and demand for environmental transition requires the manufacturing firms to take up new objectives and coordinate new activities. By pointing to the significance of internal drivers for eco-process innovation that the firms can control, the results of the thesis also provide management implications. Indeed, the economic feasibility of eco-process innovation suggests that manufacturing firms need to go beyond mere compliance with regulations and reap the competitive advantage by adhering to internal drivers such as environmental leadership, absorptive capacity, organisational structures and routines, and translation competence.

The results indicate that firms are not passive receivers of environmental programmes but play an active role in editing and reshaping the programmes when fitting them to the local setting. Hence, managers need to take an active role in supporting the firms' internal environmental transition. Indeed, the managers can by personal commitment, ambition, and environmental awareness impact the decision process and firm culture. Furthermore, managers can stimulate the environmental performance of firms by implementing environmental management practices, such as through long-term environmental strategies and targets, promoting an environmental company profile, and establishing relevant organisational structures and routines. However, the implementation of such organisational practices is a lengthy process and would therefore require the managers to be dedicated and exert endurance and long-term commitment.

Note that environmental objectives are not necessarily in conflict with the economic rationale of business. In contrast, with the right competence and organisational structures and routines, firms can develop technological solutions that comply with both environmental and economic objectives. To attain both objectives, managers must interpret the environmental issues proactively and view them as opportunities rather than threats. In this regard, efforts are particularly needed for a common understanding of the environmental objectives and to accelerate knowledge sharing across different organisational functions. During this process, environmental middle managers can play an important role. It is therefore important to formally appoint strategically positioned environmental managers in the organisational hierarchy

This thesis has demonstrated that individual and organisational competencies are important drivers for eco-process innovation. Managers with environmental ambitions should thus employ highly educated and experienced personnel, organise internal training programmes, and encourage the continued environmental education of executives and employees. Education is important for enhancing the firms' internal knowledge resources as well as affecting the firms' absorptive capacity and ability to adapt to new environmental demands. Access to relevant and trustworthy information is essential for enhancing the environmental performance of manufacturing firms. In this regard, cooperation with universities is a strong driver for eco-process innovation. Managers are therefore required to work strategically and enter into strategic partnerships with universities and research institutions.

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# PART 2

# APPENDED PAPERS

# Paper 1: Publication in Energies

Solnørdal, M. T., and Foss, L. (2018). Closing the energy efficiency gap—a systematic review of empirical articles on drivers to energy efficiency in manufacturing firms. *Energies*, 11(3), 518. doi:10.3390/en11030518 *energies*

*Review*

# Closing the Energy Efficiency Gap—A Systematic Review of Empirical Articles on Drivers to Energy Efficiency in Manufacturing Firms

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**Abstract:** Research has identified an extensive potential for energy efficiency within the manufacturing sector, which is responsible for a substantial share of global energy consumption and greenhouse gas emissions. The purpose of this study is to enhance the knowledge of vital drivers for energy efficiency in this sector by providing a critical and systematic review of the empirical literature on drivers to energy efficiency in manufacturing firms at the firm level. The systematic literature review (SLR) is based on peer-reviewed articles published between 1998 and 2016. The findings reveal that organizational and economic drivers are, from the firms' perspective, the most prominent stimulus for energy efficiency and that they consider policy instruments and market drivers to be less important. Secondly, firm size has a positive effect on the firms' energy efficiency, while the literature is inconclusive considering sectorial impact. Third, the studies are mainly conducted in the US and Western European countries, despite the fact that future increase in energy demand is expected outside these regions. These findings imply a potential mismatch between energy policy-makers' and firm mangers' understanding of which factors are most important for achieving increased energy efficiency in manufacturing firms. Energy policies should target the stimulation of management, competence, and organizational structure in addition to the provision of economic incentives. Further understanding about which and how internal resources, organizational capabilities, and management practices impact energy efficiency in manufacturing firms is needed. Future energy efficiency scholars should advance our theoretical understanding of the relationship between energy efficiency improvements in firms, the related change processes, and the drivers that affect these processes.

**Keywords:** energy efficiency; drivers; manufacturing sector; systematic literature review; firm-level analysis

## 1. Introduction

Climate change is one of the most imperative topics of the 21st century. It challenges the very structure of our global society, and encompasses issues such as economics, politics, business management, and individual choice of lifestyle. The commonly acknowledged relationship between energy consumption, emissions of greenhouses gases (GHG), and climate change [1] has brought energy efficiency into political agendas worldwide [2,3]. Energy efficiency is the use of technologies that require less energy to perform the same function [4]. The manufacturing sector accounts for about 50% of the world's energy use [1]. Industrial energy efficiency is thus a key factor for mitigating climate change. Moreover, reduced energy costs are crucial for industrial companies in maintaining a competitive advantage [5,6]. Increased energy efficiency can arrive from technological improvements [7], improved supply chain management [8], and the implementation of environmental management systems (EMS) [9], environmental regulation [10], and economic motives [6].

Despite the increased energy efficiency in the manufacturing sector over the last decades [11,12], there remains significant potential for further improvements [13]. The gap between the theoretical potential and current level of energy efficiency is referred to as the energy efficiency gap [14]. Firms' decision to decline the adoption of energy-efficient technologies, even though they are economically and environmentally attractive and easy to implement [15–17], is considered a paradox from an economic perspective [18]. The major model used to explain the discrepancy between the optimal and current level of energy efficiency is the barrier model [19–21]. Barriers are "postulated mechanisms that inhibit investment in technologies that are both energy efficient and economically efficient" [20] (p. 295). The stream of research has been motivated by the objective of providing knowledge of how to most effectively overcome these barriers.

To advance our understanding of how to close the energy efficiency gap, there is an emerging literature arguing the need to understand the drivers that motivate and enable firms to become more energy efficient [20,22,23]. Instead of considering drivers as the opposite of barriers [24], this new literature has generated a broader understanding of the concept [23], and defines drivers as "factors that positively affect a firm's intentions for innovation and therefore assist innovation activities" [25] (p. 291), as well as "factors facilitating the adoption of both energy-efficient technologies and practices, thus going beyond the view of investments and including the promotion of an energy-efficient culture and awareness" [26] (p. 277). Moreover, the process of overcoming barriers can include the removal, reduction, or avoidance of barriers [27], which are fundamentally different processes motivated by different drivers.

The literature has identified various factors that stimulate industrial energy efficiency, namely; economical and financial drivers, organizational and behavioral factors, market-related driving forces, energy policies and regulation, information and networking, management, training and education, technology, and firm characteristics [26,28–31]. However, the main reasons why firms improve their energy efficiency are still unclear. The most effective way to answer this question is to take the perspective of the firm [23] and summarize the extant knowledge on the topic [20]. As previous reviews have been limited in sectorial scope and analytical profoundness, e.g., [23,32–34], a comprehensive and critical review of the literature seems warranted. The objective of this systematic literature review (SLR) is therefore to critically assess and synthesize the empirical literature on drivers to energy efficiency in manufacturing firms, as well as identify the main drivers at the firm level.

We aim to provide crucial lessons for policy-makers and practitioners, and propose key avenues for further research. The paper is structured as follows: Section 2 describes the method and analytical framework employed in this SLR. Section 3 presents a descriptive analysis of the literature. In Section 4, the main results are described. Finally, in Section 5, we draw conclusions and highlight implications and avenues for future research.

## 2. Review Methodology

The review is conducted in accordance with the SLR methodology, outlined by Tranfield et al. [35] for the field of management and organizational science. This evidence-based review methodology builds on methods developed in medical science by the Cochrane Collaboration (www.cochrane.org). As traditional narrative reviews in management studies have been criticized for lacking rigor due to the use of a personal, subjective, and biased methodology [36,37], the SLR methodology requires authors to locate, select, evaluate, analyze, and synthesize data in a way that is transparent, inclusive, explanatory, and heuristic [35,38]. Moreover, the methodology demands the results to be reported in a manner that allows reasonably clear conclusions to be reached [39]. This SLR is conducted according to the five steps proposed by Denyer and Tranfield [39]: Question formulation, locating studies, study selection and evaluation, analysis and synthesis, and reporting and using results.

To locate studies, we searched for articles in the following scholarly databases: ScienceDirect, Web of Science, and Scopus. Factors that stimulate energy efficiency in manufacturing firms are most commonly named drivers [23] and driving forces [29], but are also referred to as triggers [31], measures [40], and determinants [41]. Thus, to locate relevant publications, we applied two separate search strings. The first search string contained the search words "driv*" in the title, and "energy efficiency" in the title-abstract. The second search string searched for "energy efficiency" in the title and "industr*" and "manufacturing" in the title-abstract. We selected journals in the domains of business, management and accounting, economics, energy, environmental science, and social sciences, in which eligible articles have appeared. The functionality of the databases used differed slightly (see search string in Table A1 in Appendix A). Higher ranked journals are often considered to provide higher quality research [42]. The exclusion of journals based on quality rating is thus considered as a means to assure the research quality of the sample articles. However, due to the heterogeneity of studies in the field of organization and management, it can be challenging to appraise the quality of information sources based on the rating of journals [39]. Moreover, the inclusion of a wider range of studies, research types, and data forms promotes a more comprehensive understanding of the phenomenon of interest [39]. In this review, following the advice of Denyer and Tranfield [39], we did not exclude journals on the basis of quality rating. Nevertheless, to assure the quality of the studies we excluded conference proceedings, periodicals, working papers, books, and contributions to edited volumes, as such publications generally go through a less rigorous review process [42].

We chose 1979 as the starting point of our review since this year represents the start of the second global oil crisis and the end of cheap oil [43]. The increased oil price marks a turning point regarding awareness of global energy consumption and, accordingly, sets a starting point for increased focus on industrial energy efficiency. Following the argument of Fink [36], the best way to guarantee quality and accuracy is to base the SLR on original works rather than on interpretations of findings. Therefore, our SLR only includes empirical articles, and excludes reviews and theoretical and conceptual studies. As opposed to meta-analysis, SLR does not impose any guidelines on the methodology used in included articles [35], and both qualitative and quantitative studies at the firm level are included in the review. Studies concerning industrial energy efficiency on a micro level (e.g., technical solutions or energy measuring systems) or on a macro level (e.g., sectoral or national energy consumption or energy efficiency potential) are beyond our scope. Further, the field of interest is the manufacturing sector, thus other sectors such as service, transportation, and construction are excluded from the study. The included studies have to treat energy efficiency as the dependent variable. Consequently, articles considering energy efficiency as an independent variable are not included. If an article includes several studies or models, e.g., [32,44], only the analysis corresponding to the inclusion criteria are considered in the SLR. Table 1 describes our study selection and evaluation criteria.

**Table 1.** Selection criteria of the systematic literature review.

| Issue | Inclusion Criterion |
|---|---|
| Publication type | Peer-reviewed academic journal |
| Language | English |
| Availability | Available online as full text |
| Research discipline | Business, management and accounting, energy, environmental science, and social sciences |
| Research methodology | Empirical |
| Time period | 1978–2016 (The search was performed in January 2017) |
| Sector | Manufacturing industry |
| Level of analysis | Firm level |
| Relevance | Article addresses factors promoting (drivers) implementation of industrial energy efficiency at an organizational level of analysis |

The first electronic database search, after the removal of duplicates, resulted in 835 articles. We reviewed the title and abstract of the articles, and excluded the articles that did not fit the inclusion criteria presented in Table 1. This process led to the exclusion of 766 articles. A high discard rate of articles after the initiating literature search is not unique for this review [45–47]. The main causes for exclusion in this paper were that the articles focused on other sectors (such as service, transport, and construction), treated energy efficiency as an independent variable (explaining e.g., firm performance), considered other levels of analysis (such as national or industry levels), or were conceptual in design. Afterwards, we manually analyzed the full-text of the remaining 69 articles, and examined their eligibility according to the inclusion criteria depicted in Table 1. In addition, we searched for relevant studies through manual screening of cross-references, and through this process identify an additional 16 publications. When assessing the eligibility of the remaining 85 articles we analyzed the full-text carefully, making sure that they corresponded to the inclusion criteria. This process led to the final inclusion of 58 articles eligible for our SLR. The review protocol is illustrated in Figure 1, and the literature search process is depicted in Table A1, Appendix A.

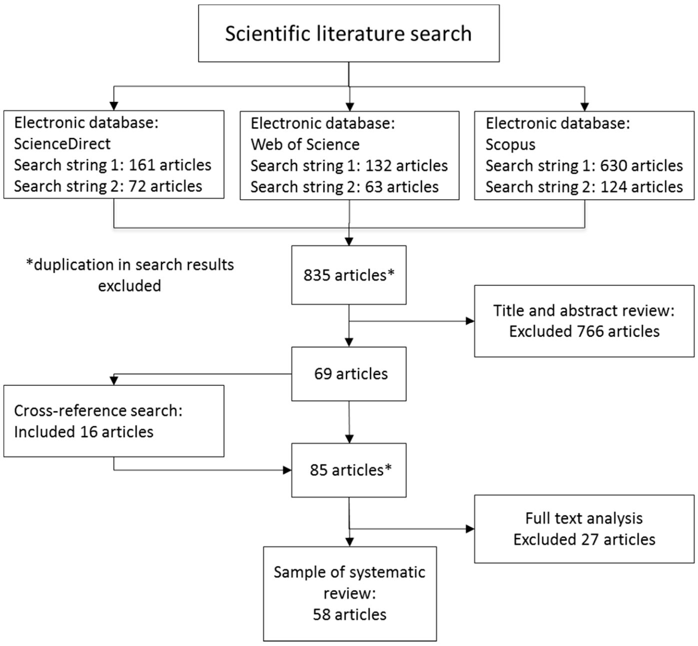


**Figure 1.** Flow diagram illustrating the review process.

After identifying the eligible articles, we designed a data extraction form. The data was extracted with the support of the software NVivo (11.4.1.1064 (64-bit), QSR International, Melbourne, Australia), simplifying the process of coding, storing, and structuring the data we needed for the analysis of the sample articles. The articles were first coded according to bibliographic, methodological, and contextual characteristics. Secondly, in accordance with the objective of this review, we extracted the three (some studies reported less than three prominent drivers) drivers in each article found to have the strongest impact on the energy efficiency behavior of the firms. The coding process followed a methodology applied in prior reviews [19,32,34]. In quantitative studies applying inferential statistics we selected the most significant drivers, while in studies using descriptive statistics we selected the highest rated drivers. In qualitative studies, given the nature of qualitative methodology, the relative importance of identified drivers was not identified. Consequently, the process of selecting the most important drivers in these studies involved some judgement from the authors. However, to assure full transparency of the selection process, Table A3 in Appendix C contains a list of all included articles and the selected drivers. The analysis also considers size and sector as control drivers, e.g., [48]. The final analysis of the data was done manually or with the help of Microsoft Excel (Excel 2016, Microsoft Corporation, Redmond, WA, USA).

## 3. Descriptive Analysis of the Literature

As part of the critical review of the literature, we assessed publication trends, journals, geographical and sectorial distribution of the empirical data, and methods applied in the empirical studies. Our observations are presented in the following.

*3.1. Publication Trend; Year, Journals, and Authors*

The number of annual publications on drivers for energy efficiency has increased considerably over the last two decades. The publication trend is illustrated in Figure 2. During the period of 1998–2006 only one or two articles were published annually. Since 2006 the number of studies has increased remarkably; in the period of 2013–2016 up to nine studies were published annually. The increased interest reflects greater political focus and a pressing need for knowledge about factors that can contribute to the mitigation of climate change challenges.


**Figure 2.** Number of annual publications.

Note that the review covers the period of 1978–2016, expecting that the start of the oil crisis in 1979 [43] would generate academic interest in the field. Surprisingly, the first eligible article was not published before 1998. Explanations for this time gap might be that firms first prioritized the "low hanging fruits" [41], and focused on energy-saving activities rather than energy efficiency. Another cause might be that research on energy efficiency started out with the identification of the energy efficiency gap [14] and the barriers hampering the implementation of energy-efficient technologies [49]. It was after recognizing that knowledge about barriers was not enough to stimulate energy efficiency sufficiently that politicians and researchers started to focus on the stimulating drivers.

The journals that have published most frequently on the topic include the Journal of Cleaner Production, Energy Policy, and Energy Efficiency (Table 2). Relevant articles have been published in 24 different journals, and only eight journals have published more than one eligible study. The relatively large number of journals, as well as the multidisciplinary scope of the journals, reflects the high interest for and multidisciplinary nature of the topic.

**Table 2.** Top publishing journals on drivers to energy efficiency.

| Journal | Number of Articles | Percentage |
|---|---|---|
| Journal of Cleaner Production | 12 | 21% |
| Energy Policy | 11 | 19% |
| Energy Efficiency | 7 | 12% |
| Energy | 4 | 7% |
| Applied Energy | 3 | 5% |
| Energy Economics | 2 | 3% |
| Journal of Engineering and Technology Management | 2 | 3% |
| Journal of Environmental Economics and Management | 2 | 3% |
| Others | 15 | 26% |

Of the 58 articles, as many as 46 scholars have been first authors and 114 scholars have contributed as authors. Eleven scholars have authored two or more publications as first and/or co-author, and the most pronounced authors include: Enrico Cagno, (Politecnico di Milano, 11 publications), Andrea Trianni (Politecnico di Milano, 11 publications), and Patrik Thollander (Linköping University, eight publications).

### 3.2. Empirical Data; Geographical and Sectoral Distribution

Figure 3 illustrates the regional distribution of the studies, and shows that even though empirical data are collected globally, data from Western Europe predominate. This is despite the fact that most of the increase in energy demand is expected to take place in other world regions, where strong economic growth, increased access to marketed energy, and quickly growing populations lead to rising demand for energy [1]. However, a preliminary analysis of the spatial distribution of the articles over time (Table A2, Appendix B) indicated a tendency of increased interest in the topic in Asia and Africa, while the interest seems to diminish in North America.

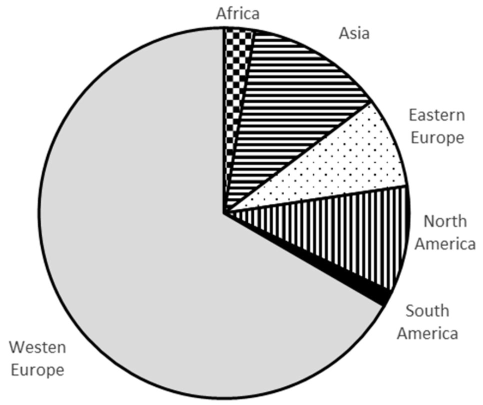


**Figure 3.** Regional distribution of empirical data.

A more detailed illustration (Figure 4) shows that empirical data are collected from 27 countries, of which Sweden, Italy, and the US predominate. Most of the studies are based on single-country analysis; only four studies conduct cross-country comparisons [25,29,50,51], focusing exclusively on Western European countries.

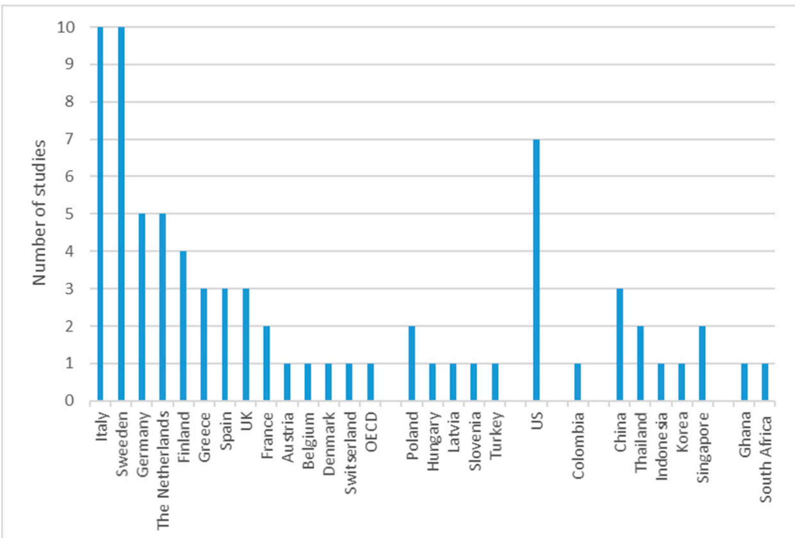


**Figure 4.** Distribution of empirical data by countries.

The review reveals that the literature covers a broad variety of industrial sectors (Table 3). Several studies apply a multisectoral approach, allowing to control for sectorial differences. Among the included articles, 59% consider energy-intensive industries and 26% non-energy-intensive sectors, while 15% of the studies do not report an industrial focus. In accordance with definitions in previous studies, we consider the following sectors as energy-intensive: chemical and petrochemical, basic metals, non-metallic minerals, paper and print, and food and tobacco [22,52–55]. A preliminary temporal analysis of the sectorial distribution of the empirical data (Table A2) indicated a relatively stable coverage of the sectors.

**Table 3.** Distribution of empirical studies by manufacturing sector.

| Energy-Intensive Sectors | Nr. Studies | Non-Energy-Intensive Sectors | Nr. Studies | Not Defined | Nr. Studies |
|---|---|---|---|---|---|
| Basic metals (e.g., iron and steel) | 17 | Textiles | 6 | Small and medium enterprises (SME) | 11 |
| Food, beverage, and tobacco | 15 | Machinery | 6 | | |
| Chemicals and petrochemicals | 13 | Electrical equipment | 5 | Not defined | 8 |
| Wood, paper, and printing | 11 | Plastic products | 4 | | |
| Non-metallic minerals (e.g., cement and ceramics) | 10 | Vehicles and transport equipment | 3 | | |
| Foundry | 5 | Computer and electronics | 3 | | |
| Energy-intensive | 3 | Pharmaceuticals | 3 | | |
| | | Non-energy-intensive | 3 | | |

### 3.3. Energy Efficiency—Definitions and Measures of the Dependent Variable

Energy efficiency is a widely used term across numerous scientific disciplines and, consequently, operationalized in many ways. In general terms, energy efficiency can be understood as the ratio between service outputs (result) and the energy input required to provide it [56]. In this paper, we follow the definition from the U.S. Energy Information Administration (EIA) [4], which states that energy efficiency is “to use technology that requires less energy to perform the same function”. Thus, energy efficiency in manufacturing firms contributes to reduce their relative consumption of energy, and should not be confused with energy conservation (or saving) that involves the use of less energy caused by behavioral changes.

Although the definition of energy efficiency is relatively simple, numerous indicators and proxies are used to identify and measure the concept. Among the articles in our sample, the three most commonly used proxies are: energy consumption, investment, and implementation. The frequency of the proxies is illustrated in Figure 5. We also notice that scholars used the concepts interchangeably, and that there are inaccuracies between the claimed and applied measures, e.g., authors might claim that they study the implementation of energy efficiency, while the empirical data measure investment. A preliminary temporal analysis of the use of the three proxies shows a relatively stable distribution over the period in question (Table A2).

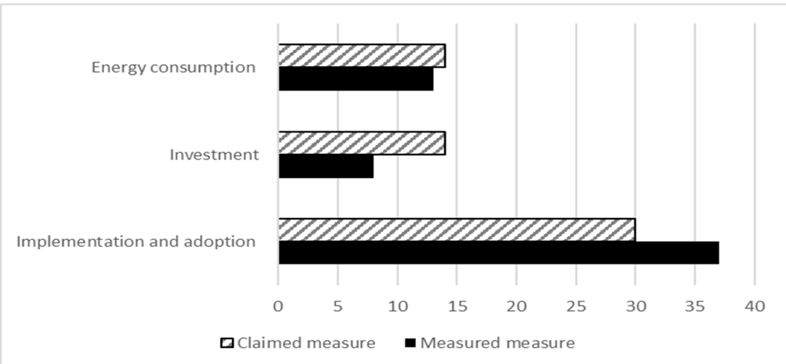


**Figure 5.** Distribution of the dependent variable, energy efficiency, according to measurement.

In the literature, implementations are measured objectively as the implementation rate of external energy efficiency recommendations, e.g., [41,57,58], or as the participation rate in voluntary energy programs, e.g., [18,59]. Implementation is also expressed subjectively as a binary variable (yes or no) in firm surveys [50] or interviews [32,60]. The advantage of implementation as a measure is that it intercepts real technological change. However, it does not capture unsuccessful efficiency projects, which impede the possibilities of a comparative analysis of implementation success and failure.

Energy consumption is measured as energy cost [61], total energy expenditure [62], production output per energy input [63], or as energy intensity [64]. In the studies reviewed here, service output is generally considered constant, and a reduction in energy consumption or energy costs are viewed as increased energy efficiency. The advantage with this measure is that it is based on "hard facts", while the disadvantage is the inability to identify whether the observed changes are related to energy efficiency (technological changes) or energy savings (behavioral changes).

The investment proxy is based on the assumption that technological changes require investments [41,65]. The measure is objective and allows researchers to trace most of the energy efficiency projects in the firm. The shortcoming with this measure is its inability to capture the fact that, ultimately, not all investments end in the successful implementation of new energy-efficient technologies. Thus, by measuring investments in aborted projects, the investment proxy can over-estimate energy efficiency. Further, not all energy efficiency projects require investments, but rather are incremental improvements [41,65]. In such cases measuring energy efficiency by investment will underestimate the efforts taken by the companies.

When analyzing the empirical data, the most frequently used methodologies are quantitative methods (71%). However, several of the articles apply descriptive statistics, rating the drivers according to each other, as opposed to inferential statistical methods such as econometrics, logit and probit, ordinary least square, Fisher's test, and factor analysis. Qualitative studies (22%) use more inductive methodologies and are based on case studies and in-depth interviews.

## 4. Analysis of Drivers to Energy Efficiency

### *4.1. Categorization of Drivers*

A majority of the articles in our sample take the perspective of practitioners and apply multidisciplinary frameworks and taxonomies to guide their research, e.g., [23,24,26,28,29,31]. The taxonomies provide valuable insights about the magnitude and complexity of drivers that stimulate the energy efficiency of manufacturing firms. However, even though the taxonomies are similar, we observed inconsistencies in which drivers are considered, and how these drivers are classified. Thus, to synthesize the evidence base from articles we applied the constant comparison technique [66]. First, we grouped the empirical drivers having the same meaning (e.g., competence, education, training) and/or the same outcome (e.g., cost reduction for lower energy use and increased energy prices). We also considered the origin of the driver—internal or external. Internal drivers refer to forces within a company that stimulate energy efficiency, while external drivers are external stakeholders and forces influencing the firm's decisions. This inductive procedure allowed us to identify 10 sub-categories of drivers. In addition, we categorized firm size and industrial sector as control drivers. In the next step, we followed the same inductive procedure; e.g., from a production perspective, energy efficiency technologies deal with productivity, which eventually impact the economic outcome [67], thus the sub-categories technology, operating costs, and finance are grouped together as economic drivers. This process enabled us to identify four main categories of drivers, namely; economic, organizational, market forces, and policy instruments. The classification of drivers forms the framework illustrated in Figure 6, and provides a basis for the following results section.

### *4.2. Drivers for Energy Efficiency in Manufacturing Firms*

In this section, we synthesize the results of the sample articles and present our findings. Following the methodology described in Section 2, we collected 155 drivers from the literature. When classifying the drivers according to the framework in Figure 6 and assessing their frequency, we were able to evaluate the relative prominence of various drivers (Figure 7).

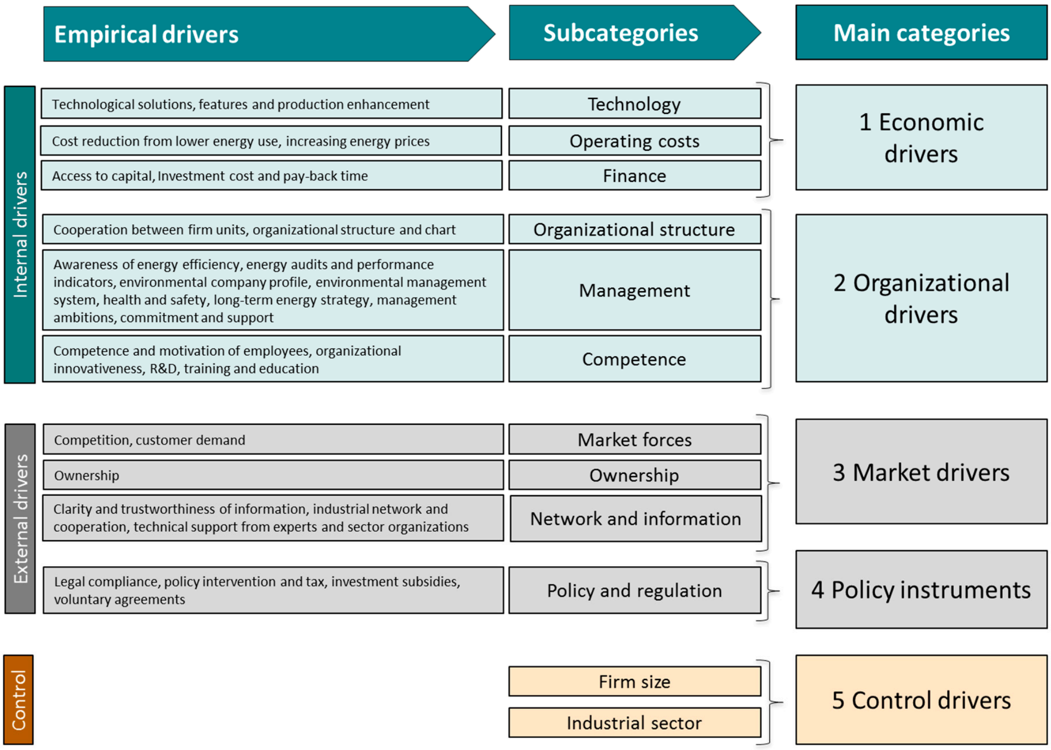


**Figure 6.** Categorization of drivers to energy efficiency.

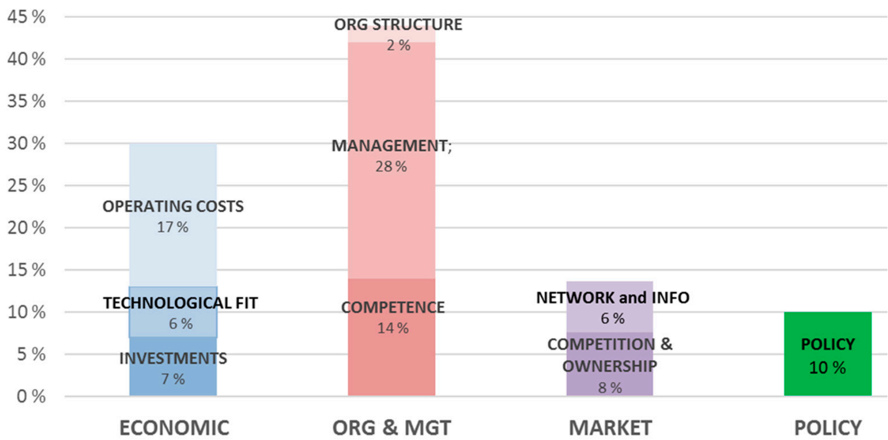


**Figure 7.** Presentation of the distribution of the most important drivers by category.

Figure 7 clearly illustrates the vital role of organizational (ORG) and management (MGT) drivers. Forty-five percent of the sampled drivers belong to this category. The second most considered category of drivers is economic drivers, to which 30% of the sampled drivers belong. Both these categories are defined as internal drivers. The external drivers, policy instruments (10%) and market forces (15%), are given less prominence. In the following we discuss in more detail which of the drivers and how the drivers affect energy efficiency in manufacturing firms.

### 4.2.1. Organizational Drivers for Energy Efficiency

The review reveals the vital role of organizational drivers from a firm-level perspective. Here, organizational drivers consist of three sub-categories: management (28%), competence (14%), and organizational structure (2%). This finding is supported by an emerging literature on energy management [46,68,69], and shows that both managers' personal engagement and management practices affect firms' energy efficiency. This includes managers' awareness and sensitivity to environmental issues [40,70], their ambitions, e.g., [24,71], and commitment, e.g., [32,72]. It is also vital that top managers are involved in energy efficiency projects [73], because without such personal involvement managers might perceive energy efficiency improvements as secondary to other investments.

Research also shows that a clear energy strategy stimulates energy efficiency in firms, e.g., [31,32,74]. A green image and environmental company profile, e.g., [22,75,76], has the same positive effect. Management practices also impact the energy efficiency of manufacturing firms [61,77,78]. Studies from the UK show that both generic management practices [77] and climate-friendly management practices [61] have a positive impact on energy efficiency. More specifically, it is found that the mere existence of performance indicators or of lean manufacturing is not sufficient to generate significant energy efficiency; rather, it is the use and analysis of these performance indicators accompanied by some form of consequence management that leads firms to be less energy intensive [77]. Moreover, it is possible that firms with a dedicated environmental manager will be more likely to participate in voluntary environmental agreements, adopt energy targets, and monitor their energy usage compared to firms without an environmental manager [61].

Energy audit is another management practice identified as an important driver, e.g., [53,79,80]. Energy audits provide access to correct information, better follow-up activities, transparency, and understandable calculations [53]. In addition, energy audits can aid in overcoming internal barriers to industrial energy efficiency [72]. When assessing the effect of energy audits, Anderson and Newell [81] found that approximately half of the projects recommended by energy assessment teams were adopted by plants receiving these recommendations. However, the authors emphasize that in the absence of energy audits it is impossible to say how many of these projects might have been adopted.

Competence is the second sub-category of organizational drivers. Competence and know-how are directly linked with firms' willingness and ability to be innovative and energy efficient [79]. Studies focusing on innovation find that both product and process innovation [50], as well as the innovativeness of the market in which firms operate [82], are positively related to the firm's energy efficiency. It is suggested that the positive effect of innovation is related to the organizational capability of innovation practices [83], and innovative firms' ability to share information and consider the competitive potential of energy efficiency interventions [57]. Innovative firms are also more likely to increase their energy efficiency if they consider the reduction of environmental impact to be an important objective for innovation [22]. Relevant competences can be acquired through the accumulation of experience. The propensity for innovative companies to adopt new energy efficiency technologies increases with both the introduction of organizational innovations [22] and previous experience with energy efficiency technologies [22,48,50]. These findings indicate the relevance of organizational competences as drivers for energy efficiency.

The importance of employees is also emphasized in several studies. Firms with more educated employees are found to be less sensitive to barriers, and more prone to invest in energy efficiency [52,54]. The employment of individuals with specific education and competences in energy efficiency also affect firms' energy performance significantly [80]. Training at the workplace is another way of increasing the competence of individuals. Training programs contribute to both increased knowledge about available energy-efficient technologies and awareness about the importance of improving energy efficiency [26,72]. Vocational training programs can be facilitated with the help of external resources such as Energy Service Companies (ESCOs) [30] or Industrial Assessment Centers (IAC) [80], or collaboration with research institutions [84]. Increased knowledge and skills among employees not only influences the development of energy-efficient solutions, but also facilitates the implementation process [85]. However, in addition to having the necessary competences, employees also need to be engaged and motivated [40] in order to produce solutions and facilitate implementation.

Organizational structure is the third sub-category. First, the presence of an energy manager has a positive impact on the firm's energy efficiency. Moreover, the impact increases the closer the energy manager is to the top management within the organizational structure. In fact, environmental practices improve as the energy manager moves up the hierarchy, yet practices become worse again if the CEO assumes the responsibilities of energy management [61]. Moreover, Kounetas and Tsekouras [28] argue that flexible and effective organizational structures allow firms to cope with a wide range of barriers such as human capital, information gathering and accumulated knowledge, process flexibility, and financial constraints.

#### 4.2.2. Economic Drivers

Economic factors (30%) are also identified as critical motivational drivers for energy efficiency in manufacturing firms. The economic drivers are divided into three sub-categories: operating costs (17%), financial considerations (6%), and technological fit (6%). Both energy use and energy tariffs impact the operating costs. Thus, reduced energy use, e.g., [29,73,74], and/or increasing energy tariffs, e.g., [29,73,74], are found to increase energy efficiency in firms. The motive of lower energy use is, however, more frequent than increased energy tariffs. This implies that firms use energy efficiency not only as a means to encounter increased energy tariffs, but also as a strategy to produce more efficiently and become more competitive.

Technological fit refers to additional non-energy-related advantages following the implementation of the energy-efficient technology that also drive the investment and implementation of such technologies [72]. Examples of such advantages are: replacement of outdated production facilities [28] and increased productivity [22,64] and safety considerations [63]. A study by Ren [25] further found that external limitations through a tight supply of energy (gas feedstock) served as an important driver for the implementation of energy-efficient technologies. In this case, the implementation of energy-efficient technologies was used as a means to reduce the risk of production limitations due to resource scarcity. These findings show that energy efficiency technologies have additional positive implications that improve firms' competitiveness.

Firms' investments in energy efficiency are driven by internal financial resources [33,75], the historical rate of growth of industry earnings, and expected future earnings growth [18], as well as positive external economic prospects [86]. Nevertheless, the most important financial drivers include investment costs and payback time [41]. Moreover, Anderson, De Dreu, and Nijstad [58] revealed that firms are about 40% more responsive to investment costs than to energy savings (operating costs). In fact, energy efficiency investments have a larger probability of being realized if the payback time is shorter than 2–3 years [72,86,87]. Thus, we identified contradicting research results considering the economic rationale that drives energy efficiency. In studies where managers were interviewed about motives for energy efficiency investments, they considered reduced energy costs to be the most important, e.g., [29,73]. However, studies assessing investment decisions in retrospect found that payback time and investment costs are given higher significance, e.g., [41,58]. This paradox is a thought-provoking observation that calls for future investigation.

The strong importance of economic drivers emphasizes the economic potential of energy efficiency technologies. The energy benefits are often obvious; nevertheless, non-energy benefits are also found to provide economic gain. Hence, energy efficiency technologies contribute various ways to sustained competitive advantage. Accordingly, our review supports the argument by Bunse et al. [88], stating that energy efficiency contributes to the "triple bottom line"; attending economic, environmental, and social considerations.

#### 4.2.3. Market Drivers

Drivers that originate external to the firm, apart from policy instruments, are classified as market drivers (15%). These are further divided into the sub-categories of network and information (6%), competition (6%), and ownership (3%). Networking and cooperation between companies are shown to be valuable drivers for energy efficiency. Through knowledge and information sharing, the companies cooperate in finding ideas and inspiration for energy efficiency projects [34,82,83].

Access to trustworthy information is found to be critical during the decision process [53,74,89]. By sharing information firms can explore and exploit energy efficiency synergies [22]. Relevant cooperation partners include, for example, consultancy services from ESCOs [53,75], technology suppliers and installers [30], governmental energy efficiency programs [80], academia [84], and other members of multinational companies (MNCs) [33]. Cooperation is found to be particularly important in small and medium enterprises (SMEs), who often suffer from internal resources scarcity [82].

Other market drivers that affect energy efficiency include competition and international ownership. Firms facing tough international competition and substantial energy costs are often more motivated to reduce production costs to a minimum and thus become more energy efficient [33,52,70]. This includes the growth ambitions of the firm [70]. Furthermore, competitive organizations are more solution-oriented and more likely to find the use of energy-efficient technologies across various engineering domains [90]. Thus, increased innovations significantly reduce the firms' perception of barriers to energy efficiency [82]. These findings imply that competition drives firms to become more cost-driven and solution-oriented, given that they have the resources necessary to implement new energy efficiency strategies. However, the findings are ambiguous. First, in Reference [44] we found that companies with competitive advantage and high bargaining power have the resources necessary to implement environmental strategies [44]. Second, Trianni, Cagno, Thollander, and Backlund [51] found that companies lacking competitiveness might aim towards energy efficiency, considering it as a path for their survival. Hence, the competitive environment can affect the firms' energy efficiency strategies in various ways. Demands from the owner are a strong driver for energy efficiency [91]. Particularly, studies conducted in countries with less developed economies show that the presence of foreign ownership [33,63] and foreign investments [64] has a statistically significant and positive impact on energy efficiency.

#### 4.2.4. Policy Instruments

We find that policy instruments (10%) are the category of drivers considered to have the least impact. Policy instruments can be prescriptive, economic, or supportive [92], and these three categories are applied in the energy policy mix [28,74]. The review finds that economic policy instruments are considered most important. They stimulate energy efficiency through increasing energy taxes [52,91] and emission fees [26], or by providing investment subsidies [26,28,76,89,90]. Considering that firms are more responsive to initial costs than annual savings [41,58], one may assume that subsidies may be more effective at promoting energy-efficient technologies than energy price increases. Legal compliance [59,73,93] is dictated by prescriptive policies that compel specific actions by companies. Complying with legal requirements is a precondition for conducting business activities. Thus, one could expect this driver to be more prominent. The lack of such prominence might imply a lack of appropriate policy frameworks [73], or that policies are not sufficiently ambitious to have a driving effect on energy efficiency in manufacturing firms.

Voluntary agreements [31,93,94] and government energy efficiency programs such as IAC programs [80] are examples of supportive policy tools. Voluntary agreements are based on cooperation, and have the potential to overcome traditional constraints of implementing top-down policies at the local level [59]. In the US, the Industrial Assessment Center (IAC) Program was associated with significant change in firms' energy efficiency within a relatively short period of time [80]. Moreover, between one quarter and one half of the energy savings in the Dutch manufacturing industry can be attributed to such agreements [94]. Given the striking results from voluntary agreements and the positive impact of policies on eco-innovations [45,47], it seems like a paradox that policy instruments are given less significance as a driver in the energy efficiency literature. This result can be explained by several factors. Firstly, there is an identified lack of common understanding between governmental and industrial organizations of the most prominent drivers and barriers [74]. Hence, energy policies might not be fully designed according to the needs of the industry. Secondly, policy instruments often have an indirect effect on energy efficiency, e.g., economic policies impact energy tariffs and thus mediate the effect of economic drivers. Thirdly, we see that voluntary agreements are indirect policy instruments designed to identify opportunities for energy efficiency, cooperative measures, capacity building, and information policies [92]. Consequently, the indirect effect of several energy policies makes it hard to properly capture their effect as drivers for energy efficiency.

### *4.3. Control Variables*

We define firm size and industrial sector as control drivers. In the reviewed studies, these drivers were used as control variables of energy efficiency and proxies enabling comparative analysis (e.g., comparing SMEs with larger enterprises). Accordingly, these drivers have a mediating effect on the other drivers. The effects of the control drivers on energy efficiency in manufacturing firms are presented in the following section.

#### 4.3.1. Firm Size

Firm size is a commonly used control variable in innovation studies [95], and is frequently used as a control in the studies included in the review. Size is mainly measured as the number of employees, but also as the firm's revenue [70] and market share [33]. The majority of the studies state a positive relationship between size and energy efficiency, e.g., [33,63,70]. It is argued that the positive relationship is caused by larger firms' advantageous access to internal and external resources such as information about available energy-efficient technologies [52]; technical and financial means [75,96]; concern about energy costs [96]; and their concerns about compliance with legal restrictions and green image [89]. Several studies have compared how larger and smaller firms consider the impact and importance of various drivers and barriers for energy efficiency. The research results show that firm size affects factors such as: information and evaluation criteria [57,97], time or priorities [51], competence and implementation [48,51,57], energy efficiency awareness [48,89], operating costs [51,89], and access to capital [98]. Studies on perceived and real barriers to energy efficiency [96], and the step-by-step decision process [30], further confirm the positive effect of firm size during all phases of the decision process. Based on the reviewed studies, one can argue that larger organizations' access to resources seems to make them more apt to take on new challenges and environmental considerations, and strive towards energy efficiency.

There are, however, some studies providing contradicting results. Kounetas, Skuras, and Tsekouras [97] discovered that the effect of size is reduced when firms are engaged in activities demanding a high quality of human capital resources. They thereby argue that size advantage is contextually dependent. Some informational barriers are also perceived to be more pronounced in larger rather than smaller enterprises [30,82,96], and larger companies also seem to suffer from stricter formal investment criteria and implementation challenges [60,96]. Furthermore, smaller firms tend to perceive technology either as more adequate or available than larger companies do, and they tend to trust their information sources, thus perceiving the available information as sufficient. This finding could be related to a lower complexity of production in smaller companies [82], or a stronger relationship with their technology suppliers and installers [30]. The research results show that a firm's size, in general, has an impact on energy efficiency behavior and is, consequently, an important control variable. In most cases the size effect is positively related to energy efficiency, but under certain circumstances size might have a negative effect.

#### 4.3.2. Manufacturing Sector

Differences in the energy intensity of various industries makes the industry sector a pronounced control variable. The effects of the industry sector have been studied either by comparing the energy efficiency behavior of firms between various sectors [18,48,52], or by comparing energy-intensive and non-energy-intensive sectors [22,30,64,89,99].

From an economic perspective, we can assume that energy-intensive firms are more attentive to energy efficiency, as energy expenditure denotes a larger share of the firms' operating costs. Several studies support this assumption in finding that energy-intensive firms consider energy reduction to be very important [22], they are more considerate of energy efficiency [89], good management practices have a larger impact on energy efficiency [78], they are more adaptive to energy efficiency behavior [78], and they are less sensitive to technology and organizational barriers [30]. Comparative analyses across several industries have also discovered evidence of sectoral differences [18,54].

However, other studies have contradicting results, making it harder to reach conclusive findings about the impact of sectors. Hasanbeigi, Menke, and du Pont [99] compared drivers to energy efficiency in the cement (energy-intensive) and textile industries (non-energy-intensive) in Thailand, finding that both industries rate the same drivers as most important, namely: reducing final product cost by reducing energy cost, improving staff health and safety, and improving products' quality. Martínez [64] assessed the main determinants for energy efficiency performance in energy-intensive and non-energy-intensive sectors in Colombia. Likewise, she found that both sectors considered the same drivers to be most important, namely; energy prices and foreign investments. The only sectoral difference was that investments in machinery and equipment also had an impact on energy efficiency performance in less energy-intensive sectors. Furthermore, a study from the Netherlands found few systematic differences in energy efficiency between various industrial sectors [52]. The only two sectors that stood out were horticulture and the basic metals industry. In a comparative study in Northern Italy, Trianni and Cagno [48] only found sectorial specificities for the textile industry. The authors relate this finding to a deep crisis and structural changes in the national textile industry over the last two decades. Hence, they argue that the differences were not directly related to features of the industry itself, but rather to external contextual circumstances.

## 5. Conclusions

### *5.1. Synthesis of Findings*

The most obvious observation that emerges from our analysis of the literature on drivers to energy efficiency is that the evidence base is highly heterogeneous. The academic debate takes place in numerous journals, many of which are multidisciplinary in scope with energy and/or sustainability as their common denominator. The multidisciplinary nature of the field is also reflected in the publications included in this review.

The majority of articles take practitioners' perspectives and apply multidisciplinary taxonomies as frameworks supporting their empirical research, e.g., [23,24,26,28,29,31]. Even though varying to which extent they focus on economic factors [41,81], management issues [77,78], organizational features [40,79], or policy instruments [59,97], all the articles study the impact of drivers from several fields. This approach offers valuable knowledge about the magnitude and complexity of drivers that motivate energy efficiency in firms. However, due to the heterogeneity of the literature, scant consensus has been reached about key questions or overarching analytical frameworks, or about the underlying mechanisms leading firms to increased energy efficiency and the interrelations between the drivers.

This SLR investigated, from a firm's perspective, which drivers are considered critical when improving their energy efficiency. Our review identified four main categories of drivers, namely economic drivers, management and organizational drivers, market drivers, and governmental policy (Figure 6). In addition, we identified a category of control drivers, firm size and industrial sector, that have a mediating effect on the other drivers.

The first and most significant finding of this study is the vital role of internal drivers, i.e., organizational, management, and economic drivers. Our results coincide with prior research arguing the vital role of energy management [69,100], and finding that managerial and organizational factors have the greatest direct effects on energy efficiency improvements [21]. The results also coincide with a recent review on drivers for the adoption of eco-innovations [45] that also points to the importance of internal factors. Moreover, our finding corresponds to research on barriers to energy efficiency, arguing the impact of bounded rationality, organizational, and institutional barriers [19,69,100]. The review also reveals that competence is frequently considered as a vital driver for energy efficiency, and that the most prominent knowledge sources are competitors, knowledge institutions, and employees.

The paper also finds that firms less frequently emphasize external factors, such as governmental policy, as significant drivers for energy efficiency. In other words, firms designate less importance to policy and regulation as important driving factors for energy efficiency. This finding contradicts previous arguments that technology-push and market-pull factors do not provide sufficient incentives for firms to develop environmental innovations [101], and that regulatory frameworks are thus necessary to stimulate such innovations [101,102].

Our results can be explained by more recent research on energy efficiency, finding that firms and governmental and industrial organizations lack of a common understanding of the factors, actors, and mechanisms affecting the energy efficiency behavior of firms [74]. Moreover, this might imply that some environmental policies are not designed appropriately for simulating increased energy efficiency in firms, or that such policies might be lacking [73].

The significance given to management and organizational drivers imply that policy instruments should to a larger extent aim to stimulate internal drivers such as environmental awareness and competence-enhancing initiatives. In other words, government policy is most efficient when mediated by organizational and management factors [103]. Examples of policy programs that also involve energy management are voluntary agreement programs (VAP) and long-term agreements (LTA) [59,94,98].

The impact of contextual factors on energy efficiency is argued in the literature, particularly the influence of the industrial sector [49,100]. Nevertheless, our review found that the evidence base of such a sectorial impact is ambiguous. While some of the sample articles found that the industry sector has a significant mediating effect on energy efficiency, other articles did not find supporting evidence of this effect. However, when controlling for firm size, the literature provides more conclusive results, finding that, with a few exceptions, firm size is positively related to energy efficiency.

### *5.2. Limitations*

This study followed the same methodology as prior reviews [19,32,34]. When identifying the most important drivers in the empirical articles, we extracted the three drivers found to be most important in each study. To identify the drivers most frequently emphasized by the firms we coded the drivers according to the categories depicted in Figure 6, and summarized their frequency. A relevant critique to this method is that attention can be confused with prominence, so that lack of importance may suggest an under-researched area. Accordingly, it may appear problematic to make inferences on importance based on frequency in empirical papers. Moreover, the sampled articles are based on firm-level data that is mainly collected through firm surveys and interviews. One of the main limitations of such data is the risk of respondent biases [104], which is the respondents' tendency to provide answers despite having limited knowledge about the subject. The firm-level data also presents a risk of influencing the results through circular argument, i.e., what firms do is what they consider as important. Acknowledging these limitations, we nevertheless argue that the data and the methods applied in the sample articles justify our analytical approach. Firstly, the multidisciplinary scope of the majority of the articles assures a broad and relatively equal distribution of attention to various drivers. Secondly, several of the articles rate the drivers using a Likert scale and descriptive statistics. It is therefore relatively easy to select and rate the three most important drivers. Third, the objective of the review is to provide insights about how firms perceive the importance of various drivers, and gain knowledge about which drivers have the strongest motivating effect on firm managers who are expected to make the changes in their firms.

### 5.3. Avenues for Future Research

Viewing the literature as a body of knowledge about drivers to energy efficiency in manufacturing firms, we find shortcomings and gaps in the literature that future research should address.

First, future research should address our limited knowledge about drivers to energy efficiency in firms located in non-OECD countries. The literature is mainly based on empirical data from American and Western European firms, despite the fact that the industrial energy efficiency performance varies across countries [7] and regions [10]. This is a severe shortcoming in the current literature, given that most of the increase in energy demand is expected to come from Asia, where strong economic growth, increased access to marketed energy, and quickly growing populations lead to rising demand for energy.

Second, the contextual impact of industrial sector on the energy efficiency behavior of firms is not well understood, as the literature provides ambiguous results. While some articles find that the industry sector has a significant mediating effect on a firm's energy efficiency, other studies do not find any evidence for this effect. Thus, much work remains to clarify potential causes for how and when the industrial sector affects firms' energy efficiency.

Third, knowledge about the interconnection and mediating effect of drivers to energy efficiency is limited. The review shows that, with the exception of industry sector and firm size, the current literature and frameworks on drivers to energy efficiency focus solely on the type and importance of each driver.

Some studies investigated the effect drivers have on barriers [74,75,89], while research on the interconnection of drivers is rare. The scarce exceptions [26,79] provided evidence that drivers interconnect; however, this relationship is not well understood and there is a need for conceptual and empirical models that better explain this relationship.

Fourth, to better understand the interconnection of drivers and underlying mechanisms that enable the firms to succeed with energy efficiency improvements, more qualitative research is needed. A majority of the studies are based on quantitative research, and almost half of the studies apply Likert scales when collecting data. However, as opposed to inferential statistical methods, several of the articles are analyses of the empirical data using descriptive statistics. This methodology allows the indication of drivers that are found to be important motivational factors, but does not allow any conclusions to be drawn about the significance of the drivers. Moreover, even though the quantitative methodology allows identification of important drivers, there remains a lack of knowledge about the underlying mechanisms that motivate and drive energy efficiency in firms. To obtain such in-depth understanding there is a need for more qualitative research addressing this issue. Due to the limited number of studies applying qualitative and inductive methodologies, much work remains to be done in conceptualizing and describing different participants, relationships, activities, and resources.

Fifth, future research could profit from the inclusion of theoretical frameworks derived from related fields of science. The identification and recognition of the vital role of management, competence, and organizational structure on energy efficiency outcome enable us to advance theoretically and open several interesting avenues for future research. First, future research could, to a larger extent, integrate insights derived from organizational and managerial perspectives on innovation, which address firm-level internal matters that can stimulate energy efficiency. Thus, this perspective can provide a useful theoretical lens for advancing our knowledge of how and which resources, capabilities, and management practices affect energy efficiency in manufacturing firms.

Sixth, the literature lacks a common understanding of how to define and measure energy efficiency. As opposed to medical science, where the dependent and independent variables are clearly defined, this is often not the case in social sciences. The review reveals that the dependent variable, energy efficiency, is operationalized in several ways in the literature. The three most common proxies are investment, implementation, and energy consumption. In some studies, the concepts are used interchangeably, but even though the concepts are related the usage of them as substitutes can lead to inaccuracy and potential misunderstandings. Moreover, different indicators are used when measuring energy efficiency, e.g., binary variables (yes/no), amount (of investments or energy consumption) or rate (of implemented energy efficiency recommendations). It can be problematic to say something about magnitude, as it involves comparing something that might be similar, but also might not be. Thus, this variation makes it harder to analyze energy trends and monitor achievements of past and present energy policies.

### 5.4. Policy and Managerial Implications

In addition to contributing to academic discourse about drivers to energy efficiency, the results of this review suggest some implications for managers and policy-makers. For managers, the findings of this paper contribute to created awareness about the active role managers can and need to take in order to succeed in achieving increased energy efficiency. The review points out the significance of internal factors that firms can control to increase energy efficiency. Thus, while firms have minimum control of external factors, they can go beyond the mere compliance with regulations when adhering to internal factors, such as environmental capabilities and managerial awareness, energy strategies, human resources, and organizational structure. Firstly, managers' can, through personal commitment, ambitions, and environmental awareness, affect a decision process favoring energy efficiency behavior. Secondly, mangers can advocate environmental awareness through the firm culture, strategies, and company profile, and put energy efficiency on the agenda in the entire organization. Third, as cooperation and interaction between all units of the firm contribute to spur on energy-efficient solutions, managers should be proactive to maintain a flexible organizational structure. Forth, the review demonstrates that individual and organizational competencies are important drivers to energy efficiency. To spur on these drivers, managers should employ qualified and experienced personnel, facilitate internal training programs, and encourage environmental empowerment of both executives and employees. Finally, our study suggests that access to relevant and trustworthy information is prominent for increased energy efficiency. The most relevant sources of information include industrial networks, competitors, technical experts and consultants, and foreign investors. Managers should therefore develop a strategy for monitoring and cooperating with relevant partners.

In suggesting policy implications, we recognize the challenge of designing energy policies, as their effect can be mediated by contextual factors and other drivers [21,100]. When suggesting policy implications it is essential to consider both the policy mix and the total spectrum of drivers. Despite this complexity, we advocate increased political attention towards the vital role of awareness, competence, and knowledge exchange in the pursuit of increased energy efficiency in manufacturing firms. Academia and knowledge institutions play a significant role as both partners in projects and providers of education to employees. In addition, the review reveals a positive impact of market forces such as competition and internationalization on the energy efficiency behavior in firms. Thus, policies favoring market flexibility, preventing monopoly situations, and supporting foreign investments and international expansion may have an indirect positive effect on firms' energy efficiency. Moreover, policy-makers should make extended use of more advanced policy programs, also involving energy management, such as voluntary agreement programs (VAPs) and long-term agreements (LTAs) [59,94]. However, as drivers to energy efficiency are multifaceted, diverse, and often specific to individual technologies and sectors, there is no universal approach to implement energy management practices [100]. We therefore suggest that new policy design also take into account cultural and structural consideration in order to be efficient.

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**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

**Table A1.** Search strings applied in the databases (the search was conducted on 25 January 2017).

| Database | Search String | Search Result |
|---|---|---|
| Science Direct Search String 1: | pub-date > 1977 and TITLE (driv*) and TITLE-ABSTR-KEY ("energy efficiency") [All Sources (Business, Management and Accounting, Economics, Econometrics and Finance, Energy, Environmental Science, Social Sciences)]. | 161 articles |
| Science Direct Search String 2: | pub-date > 1977 and TITLE ("energy efficiency") and TITLE-ABSTR-KEY (industr* and manufacturing) [All Sources (Business, Management and Accounting, Economics, Econometrics and Finance, Energy, Environmental Science, Social Sciences)]. | 72 articles |
| Web of Science Search String 1 | driv* (TITLE) AND "energy efficiency" (TOPIC) AND YEAR = 1978–2016 AND DOCUMENT TYPE = (PEER-REVIEWED JOURNAL) ARTICLE. | 132 articles |
| Web of Science Search String 2 | "energy efficiency" (TITLE) AND (industr* and "manufacturing" (TOPIC) AND YEAR = 1978–2016 AND DOCUMENT TYPE = (PEER REVIEWED JOURNAL) ARTICLE. | 63 articles |
| Scopus Search String 1 | TITLE (driv*) AND TITLE-ABS-KEY ("energy efficiency") AND PUBYEAR > 1978 AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "ip")) AND (LIMIT-TO (SUBJAREA, "ENER") OR LIMIT-TO (SUBJAREA, "ENVI") OR LIMIT-TO (SUBJAREA, "SOCI") OR LIMIT-TO (SUBJAREA, "ECON") OR LIMIT-TO (SUBJAREA, "BUSI") OR LIMIT-TO (SUBJAREA, "DECI")). | 632 articles |
| Scopus Search String 2 | TITLE ("energy efficiency") AND TITLE-ABS-KEY (industr* AND manufacturing) AND PUBYEAR > 1978 AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "ip")) AND (LIMIT-TO (SUBJAREA, "ENER") OR LIMIT-TO (SUBJAREA, "ENVI") OR LIMIT-TO (SUBJAREA, "BUSI") OR LIMIT-TO (SUBJAREA, "ECON") OR LIMIT-TO (SUBJAREA, "SOCI") OR LIMIT-TO (SUBJAREA, "DECI")). | 124 articles |

## Appendix B

**Table A2.** Temporal evolvement of the literature.

| Period | 1998–2002 (5 Years) | | 2003–2007 (5 Years) | | 2008–2012 (5 Years) | | 2013–2016 (4 Years) | |
|---|---|---|---|---|---|---|---|---|
| Observations | 5 | | 7 | | 13 | | 33 | |
| **Methodological distribution by dependent variable** | | | | | | | | |
| Energy efficiency outcome | 2 | 40% | 0 | 0% | 4 | 31% | 7 | 21% |
| Investment | 2 | 40% | 2 | 29% | 4 | 31% | 7 | 21% |
| Implementation and adoption | 1 | 20% | 5 | 71% | 5 | 38% | 19 | 58% |
| Sum | 5 | 100% | 7 | 100% | 13 | 100% | 33 | 100% |
| **Spatial distribution by region** | | | | | | | | |
| Western Europe | 3 | 60% | 5 | 71% | 8 | 62% | 19 | 58% |
| Eastern Europe | 0 | 0% | 1 | 14% | 0 | 0% | 2 | 6% |
| North America | 2 | 40% | 1 | 14% | 1 | 8% | 3 | 9% |
| South America | 0 | 0% | 0 | 0% | 1 | 8% | 0 | 0% |
| Asia | 0 | 0% | 0 | 0% | 3 | 23% | 7 | 21% |
| Africa | 0 | 0% | 0 | 0% | 0 | 0% | 2 | 6% |
| Sum | 5 | 100% | 7 | 100% | 13 | 100% | 33 | 100% |
| **Sectorial distribution by energy intensity** | | | | | | | | |
| Multisector | 3 | 60% | 3 | 43% | 8 | 62% | 14 | 42% |
| Non-energy-intensive | 0 | 0% | 1 | 14% | 2 | 15% | 2 | 6% |
| Energy-intensive | 2 | 40% | 3 | 43% | 3 | 23% | 17 | 52% |
| Sum | 5 | 100% | 7 | 100% | 13 | 100% | 33 | 100% |

## Appendix C

**Table A3.** Articles included in the systematic literature review (SLR).

| ID | Study | Energy Efficiency; Proxy | Measuring Energy Efficiency | Type of STUDY (DS = Descriptive Statistics and IS = Inferential Statistics) | Geographic Focus (Country Codes According to ISO 3166) | Sector | Most Significant Drivers |
|---|---|---|---|---|---|---|---|
| [41] | Abadie et al. (2012) | Implementation | Binary; yes/no | Quant (IS) | US | SME multisector | Investment costs and payback time<br>Primary resource stream |
| [81] | Anderson and Newell (2004) | Implementation | Binary; yes/no | Quant (IS) | US | SME multisector | Energy audits<br>Investment costs and payback time<br>Cost reduction lowered energy use |
| [73] | Apeaning and Thollander (2013) | Implementation | Binary; yes/no | Quant (DS) | GH | Energy-intensive | Cost reduction lowered energy use<br>Increasing energy prices<br>Requirements by government |
| [86] | Arens et al. (2016) | Implementation | Binary; yes/no | Mixed | DE | Basic metals | Payback time<br>Attitude towards new technologies<br>Access to capital |
| [87] | Blass et al. (2014) | Implementation | Binary; yes/no | Quant (IS) | US | SME multisector | Involvement of operational manager<br>Investment costs and payback time<br>Position of management |
| [77] | Bloom et al. (2010) | Energy consumption | Energy intensiy | Quant (IS) | UK | Multisector | Key performance indicators of production<br>People management<br>Skilled labor |
| [78] | Boyd and Curtis (2014) | Energy consumption | Energy intensiy | Quant (IS) | US | SME multisector | Effective monitoring<br>Incentive structures of employees<br>Lean manufacturing operations |
| [32] | Brunke et al. (2014) | Implementation | - | Mixed | SE | Basic metals | Commitment from top management/energy management<br>Cost reduction lowered energy use<br>Long-term energy strategy |
| [26] | Cagno and Trianni (2013) | Implementation | - | Quant (DS) | IT | SME multisector | Allowances or public financing<br>Competition<br>Increasing energy prices |

**Table A3.** *Cont.*

| ID | Study | Energy Efficiency; Proxy | Measuring Energy Efficiency | Type of STUDY (DS = Descriptive Statistics and IS = Inferential Statistics) | Geographic Focus (Country Codes According to ISO 3166) | Sector | Most Significant Drivers |
|---|---|---|---|---|---|---|---|
| [57] | Cagno and Trianni (2014) | Implementation | Binary; yes/no | Quant (DS) | IT | Non-energy-intensive | Technological complexity |
| | | | | | | | Innovativeness |
| [83] | Cagno et al. (2015a) | Energy consumption | Energy intensity | Quant (DS) | NE | Basic metals | Internal R&D |
| | | | | | | | Training of personnel |
| | | | | | | | Acquiring advanced machinery |
| [74] | Cagno et al. (2015b) | Implementation | - | Quant (DS) | IT | Foundry | Cost reduction lowered energy use |
| | | | | | | | Long-term energy strategy |
| | | | | | | | Clarity of information |
| [89] | Cagno et al. (2016) | Implementation | Number of EEM8F (Energy Efficiency Measures) implemented | Quant (DS) | IT | SME multisector | Information about real costs |
| | | | | | | | Clarity and trustworthiness of information |
| | | | | | | | Public investment subsidies |
| [75] | Chai and Yeo (2012) | Implementation | - | Qual | SG | Multisector | Reduction of operating costs |
| | | | | | | | Corporate social responsibility |
| | | | | | | | Resources and competencies |
| [79] | Chai and Baudelaire (2015) | Energy consumption | Energy consumption | Quant (IS) | SG | Multisector | Cost motivation |
| | | | | | | | Know-how |
| | | | | | | | Monitoring ability |
| [72] | Chiaroni et al. (2016) | Implementation | - | Qual | US | Electrical equipment | Energy audit process |
| | | | | | | | Commitment from top management |
| | | | | | | | Energy saving and cost |
| [105] | Conrad (2000) | Energy consumption | Energy consumption | Quant (IS) | DE | Chemicals | R&D investment |
| | | | | | | | Increased energy prices |
| [22] | Costa-Campi et al. (2015) | Implementation | Binary; yes/no | Quant (IS) | ES | Multisector | Reduce environmental impact |
| | | | | | | | Innovativeness |
| | | | | | | | Meet regulatory requirements |
| [18] | DeCanio (1998) | Participation in a voluntary energy program | Binary; yes/no | Quant (IS) | US | Multisector | Access to capital |
| | | | | | | | Ownership |
| | | | | | | | Voluntary agreements |

**Table A3.** *Cont.*

| ID | Study | Energy Efficiency; Proxy | Measuring Energy Efficiency | Type of STUDY (DS = Descriptive Statistics and IS = Inferential Statistics) | Geographic Focus (Country Codes According to ISO 3166) | Sector | Most Significant Drivers |
|---|---|---|---|---|---|---|---|
| [59] | Eichhorst and Bongardt (2009) | Participation in a voluntary energy program | - | Qual | CN | Non-metallic minerals | Compliance with requirements |
| | | | | | | | Voluntary agreements |
| | | | | | | | Support from technical expertise |
| [50] | Gerstlberger et al. (2016) | Implementation | Binary; yes/no | Quant (IS) | Europe | Multisector | Innovativeness |
| | | | | | | | Environmental management systems |
| | | | | | | | Previous implementation of technologies |
| [52] | Groot et al. (2001) | Investment | - | Quant (IS) | NE | Energy-intensive | Cost reduction from lower energy use |
| | | | | | | | Fiscal arrangements |
| | | | | | | | Green image of corporation |
| [99] | Hasanbeigi et al. (2010) | Implementation | - | Qual | TH | Textiles and non-metallic minerals | Reducing energy costs |
| | | | | | | | Health and safety |
| | | | | | | | Improving product quality |
| [33] | Hrovatin et al. (2016) | Investment | Binary; yes/no | Quant (IS) | SI | Multisector | Energy cost relative to total production cost |
| | | | | | | | Improving safety at work |
| | | | | | | | Favorable expectations about demand |
| [106] | Hämäläinen and Hilmola (2016) | Energy consumption | Energy consumption | Qual | FI | Paper | Lower production costs |
| [34] | Johansson (2015) | Implementation | - | Qual | SE | Basic metals | Networking and cooperation |
| | | | | | | | Senior management prioritizes energy issues |
| | | | | | | | Cost reduction from lowered energy use |
| [70] | Kostka et al. (2013) | Implementation | Binary; yes/no | Quant (IS) | CN | SME multisector | Access to energy finance |
| | | | | | | | Familiar with energy-efficient practices/equipment |
| | | | | | | | Energy cost relative to total production cost |
| [28] | Kounetas and Tsekouras (2008) | Implementation | Binary; yes/no | Quant (IS) | GR | Multisector | Public capital subsidy |
| | | | | | | | Access to capital |
| | | | | | | | Increased fixed capital vintage |

**Table A3.** *Cont.*

| ID | Study | Energy Efficiency; Proxy | Measuring Energy Efficiency | Type of STUDY (DS = Descriptive Statistics and IS = Inferential Statistics) | Geographic Focus (Country Codes According to ISO 3166) | Sector | Most Significant Drivers |
|---|---|---|---|---|---|---|---|
| [97] | Kounetas et al. (2011) | Implementation | Binary; yes/no | Quant (IS) | GR | Multisector | Cooperating with external energy efficiency experts |
| | | | | | | | Introduction of innovative procedures |
| | | | | | | | Exportation to foreign markets |
| [91] | Lee (2015) | Implementation | - | Quant (DS) | KR | Basic metals | Cost savings from lowered energy use |
| | | | | | | | Demand from owner |
| | | | | | | | Energy tax |
| [61] | Martin et al. (2012) | Energy consumption | Energy consumption | Quant (IS) | UK | Multisector | Environmental management |
| | | | | | | | Management practices |
| | | | | | | | Organizational structure |
| [64] | Martínez (2010) | Energy consumption | Energy consumption | Quant (IS) | CO | Multisector | Energy prices |
| | | | | | | | Machinery and equipment investments |
| | | | | | | | Foreign investments |
| [93] | Masurel (2007) | Investment | Binary; yes/no | Quant (IS) | NE | Printing | Working conditions |
| | | | | | | | Legislation |
| | | | | | | | Moral duty |
| [84] | Miah et al. (2015) | Energy consumption | Energy consumption | Qual | UK | Food | Cooperation with academia |
| | | | | | | | Technological support from experts |
| | | | | | | | Trustworthiness of information |
| [107] | Ozoliņa and Roša (2013) | Implementation | - | Qual | LV | Food | No drivers identified |
| [62] | Ramstetter and Narjoko (2014) | Energy consumption | Energy consumption | Quant (IS) | ID | Multisector | No drivers identified |
| [25] | Ren (2009) | Implementation | - | Qual | OECD | Chemicals | Cost savings |
| | | | | | | | Tight supply of gas feedstock |
| | | | | | | | Personal commitment of individuals |
| [94] | Rietbergen et al. (2002) | Energy consumption | Energy consumption | Mixed | NE | Multisector | Long-term agreements on energy efficiency |

**Table A3.** *Cont.*

| ID | Study | Energy Efficiency; Proxy | Measuring Energy Efficiency | Type of STUDY (DS = Descriptive Statistics and IS = Inferential Statistics) | Geographic Focus (Country Codes According to ISO 3166) | Sector | Most Significant Drivers |
|---|---|---|---|---|---|---|---|
| [60] | Rohdin and Thollander (2006) | Implementation | - | Quant (DS) | SE | Non-energy-intensive | Long-term energy strategy<br>Increasing energy prices<br>People with real ambition |
| [71] | Rohdin et al. (2007) | Implementation | - | Quant (DS) | SE | Foundry | Long-term strategy<br>People with real ambition<br>Environmental company profile |
| [63] | Ru and Si (2015) | Energy consumption | Energy consumption | Quant (IS) | CN | Food | Production safety<br>Private ownership<br>Technical progress |
| [53] | Sandberg and Söderström (2003) | Investment | - | Qual | SE | Multisector | Follow-up activities and transparency<br>Access to correct information<br>Environmental management |
| [54] | Sardianou (2008) | Implementation | - | Quant (IS) | GR | Multisector | Qualified employees<br>Highly educated employees |
| [76] | Sathitbun-anan et al. (2015) | Implementation | - | Quant (DS) | TH | Food | Potential to reduce energy costs<br>Creating a green image of the firm<br>Subsidies on investment in energy efficiency technologies |
| [90] | Singh and Lalk (2016) | Implementation | - | Quant (IS) | ZA | Multisector | Competitive organizations<br>Public finance mechanisms<br>Increase in energy costs |
| [85] | Svensson and Paramonova (2017) | Implementation | - | Qual | SE | Multisector | Cooperation between firm units<br>Employee involvement<br>"Train the trainer" |
| [98] | Thollander et al. (2007) | Implementation | Binary; yes/no | Qual | SE | SME multisector sector | Long-term strategy<br>People with real ambition<br>Environmental company profile and/or environmental management system |
| [24] | Thollander and Ottosson (2008) | Implementation | - | Quant (DS) | SE | Paper | Cost reductions from lower energy use<br>People with real ambition<br>Long-term energy strategy |

**Table A3.** *Cont.*

| ID | Study | Energy Efficiency; Proxy | Measuring Energy Efficiency | Type of STUDY (DS = Descriptive Statistics and IS = Inferential Statistics) | Geographic Focus (Country Codes According to ISO 3166) | Sector | Most Significant Drivers |
|---|---|---|---|---|---|---|---|
| [29] | Thollander et al. (2013) | Implementation | - | Quant (DS) | Europe | Foundry | Cost reductions resulting from lowered energy use<br>Threat of rising energy prices<br>Commitment from top management |
| [80] | Tonn and Martin (2000) | Implementation | Binary; yes/no | Quant (DS) | US | SME multisector | Energy assessments and audits<br>Staff qualification<br>Voluntary agreement |
| [48] | Trianni and Cagno (2012) | Implementation | - | Quant (DS) | IT | Non-energy-intensive | Previous experience with energy efficiency |
| [51] | Trianni et al. (2013a) | Investment | - | Quant (DS) | IT | SME multisector | Competition from emerging economies<br>Complex production processes |
| [96] | Trianni et al. (2013c) | Investment | - | Quant (DS) | IT | Basic metals | Complexity of production<br>Demand variability<br>Strength of competitors |
| [82] | Trianni et al. (2013b) | Implementation | - | Quant (DS) | IT | SME multisector | Innovativeness<br>Local network of knowledge<br>Competition |
| [30] | Trianni et al. (2016a) | Investment | - | Quant (DS) | Europe | Foundry | Management support<br>Public investment subsidies<br>Private financing |
| [44] | Ulubeyli (2013) | Energy consumption | Binary; yes/no | Quant (IS) | TR | Non-metallic minerals | Competition |
| [31] | Venmans (2014) | Investment | - | Mixed | BE | Non-metallic minerals | Increasing energy prices<br>Commitment by management to an environmental policy<br>Environmental image building towards clients |
| [40] | Zilahy (2004) | Implementation | - | Qual | HU | Energy-intensive | Environmental awareness<br>Rewards and other incentives<br>Performance and competence motivation |

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# Paper 2: Publication in Energy Policy

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# Absorptive capacity and energy efficiency in manufacturing firms – An empirical analysis in Norway

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ABSTRACT

Increased energy efficiency (EE) in manufacturing firms is important for confronting climate challenges. However, the information barrier is considered a major restriction on EE innovation. Building on the theory of absorptive capacity and the current EE literature, we argue that this barrier relates to firms' ability to assimilate and exploit information. Thus, this study's objective is to analyse firms' knowledge characteristics as determinants of EE innovation. We perform logit regressions using a Norwegian panel dataset for the period 2010–2014. The results are based on statistical correlations between data points that have potential uncertainties. Still, the main implications from our study are that prior knowledge, in terms of higher educated workforce, knowledge development, in terms of R&D capacity, and external knowledge cooperation, such as cooperation with universities and competitors, increase firms' pursuit of EE innovation. Further, the results also imply that there is an interaction effect between higher educated workforce and collaboration with universities. These results suggest that policy makers should consider firms' ability to assimilate and exploit information. This can be done by providing information according to firms' needs and absorptive capacity, and offering possibilities for firms to increase this capacity.

## 1. Introduction

Global energy consumption and the emission of greenhouse gases (GHG) are causing climate challenges worldwide. Between 1971 and 2016, the global total final consumption (TFC) of energy grew by a factor of 2.25 (IEA, 2018); if no actions are taken, energy demands are expected to continue rising precipitously, due to economic development, increased access to marketed energy, and population growth (EIA, 2017). Political responses to the urgent need for climate change mitigation and energy efficiency (EE) include, for example, the Paris Agreement (UNFCCC, 2015) and the European 2030 framework for climate and energy (EU, 2014). Since industry is the largest energy-consuming sector globally, accounting for 37% of TFC in 2016 (IEA, 2018), increased industrial EE is considered vital to achieving environmental commitments and ensuring a safe and affordable transition to a sustainable energy system.

EE can be understood as “action taken by firms that has the objective of reducing the amount of energy per unit output” (Costa-Campi et al., 2015 p. 230). Although EE is positively related to manufacturing firms' performance (Fan et al., 2017; Martin et al., 2012; Martínez, 2010; Worrell et al., 2009) and compliance with both social pressure and stricter environmental regulations (Apeaning and Thollander, 2013; Masurel, 2007), firms tend to avoid adopting energy-efficient technologies that are economically and environmentally attractive (Abadie et al., 2012; Anderson and Newell, 2004). Economists refer to this discrepancy between the theoretically optimal and the current level of EE as ‘the EE gap’ (Jaffe and Stavins, 1994). It is considered a paradox (DeCanio, 1998) that might be explained by market failures, including environmental externalities, lack of information, principal-agent issues, and systematic behavioural biases (Gillingham et al., 2009; Sorrell et al., 2011). Accordingly, energy policies and programmes have been designed to address these market failures (Gillingham and Palmer, 2014; Tanaka, 2011). However, prevailing evidence of the significant unexploited potential for improved industrial EE (Cui and Li, 2015; Lin and Tan, 2016) has raised a call for increased research into the link between EE and innovation. In particular the call address the need for more research regarding which firm characteristics influence EE innovation by innovative firms (Costa-Campi et al., 2015; De Marchi, 2012; Horbach et al., 2012; Hrovatin et al., 2016; Rennings and Rammer, 2009; Trianni et al., 2013b).

The theory of absorptive capacity posits that a firm's innovative performance is influenced by its prior knowledge and its ability to develop new knowledge, through either internal knowledge creation or the inflow of external knowledge (Cohen and Levinthal, 1990;

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Lichtenthaler, 2009; Sagar and van der Zwaan, 2006; Smith et al., 2005). Newer research, have started to reveal how absorptive capacity, knowledge accumulation capabilities, and cooperation strategies also affect firms' environmental innovativeness (Albort-Morant et al., 2018; Costa-Campi et al., 2017; De Marchi, 2012; De Marchi and Grandinetti, 2013; Horbach et al., 2012, 2013). However, these studies focus on eco-innovations in general, which are rather broadly defined (e.g. Kemp and Pearson, 2007; OECD, 2009). Thus, scholars have argued the need for further classifying various types of eco-innovations (De Marchi, 2012), in order to identify their specific characteristics (Carrillo-Hermosilla et al., 2010; Kemp and Pearson, 2007) and analyse their determinants (Hammar and Löfgren, 2010; Horbach et al., 2012). Following the proposed definition by Costa-Campi et al. (2015 p. 230), we therefore argue that EE innovation is a type of eco-innovation requiring specific academic attention. Indeed, the EE literature indicates that EE innovation in manufacturing firms are positively related to the firms' human resources (Chai and Baudelaire, 2015; Sardianou, 2008), innovativeness (Cagno et al., 2015a; Gerstlberger et al., 2016; Trianni et al., 2013b), and external cooperation (Cagno et al., 2017; Miah et al., 2015; Trianni et al., 2016b). However, these factors have not previously been studied in relation to one another, in terms of their significance, relative importance, and interaction effect. Thus, in this study we aim to fill this gap, using absorptive capacity as a theoretical framework, asking: *What is the relationship between manufacturing firms' absorptive capacity and EE innovation?*

For this analysis, we perform a logit regression using firm-level data from a sample of innovative manufacturing firms in Norway. The self-reported data were collected through the Norwegian Community Innovation Survey (CIS) and the Business Enterprise R&D survey (BERD) for the period 2010–2014. We use R&D investments in EE as a measure of EE innovation. The Norwegian economy is highly dependent on the oil and gas industry (IEA, 2017). As the world looks to diminish reliance on fossil fuels, the government needs to prepare for a future with less dependency on this sector. In this transition, the importance of an innovative and competitive manufacturing industry becomes more pronounced. Concurrently, having ratified the Paris Agreement, Norway faces challenges in seeking to reduce GHG emissions by at least 40% below the 1990 level by 2030 (UNFCCC, 2015). In attaining both objectives increased industrial EE innovation is considered as vital (MPE, 2016), and which requires both governmental and firm-level efforts to maximise the sector's EE potential (IEA, 2017). Given that Norway invests above average and is on par with the EU vision in the knowledge economy (RCN, 2017), we argue that Norway, like other Nordic countries, could be seen as inspirational with respect to how innovation should support competitiveness and green growth; therefore, it is a suitable context to examine our research question.

The paper is structured as follows. Section 2 provides the theoretical background, analytical framework, and hypotheses. Section 3 describes the data, variables, and analysis. Section 4 then presents and discusses the results. In Section 5, we conclude and outline policy implications, the study's limitations, and suggestions for future research.

## 2. Conceptual framework and hypotheses

### 2.1. Background

Manufacturing firms face increasing pressure to play an active role in mitigating climate challenges. EE innovation is one of the main mechanisms that firms can adopt to pursue this objective and both gain and sustain competitive advantage (Porter and Vanderlinde, 1995; Trianni et al., 2013a). However, research has identified numerous economic, organisational, and behavioural barriers to EE innovation in manufacturing firms (Backlund et al., 2012; Cagno et al., 2013; Sorrell et al., 2011). Furthermore, economists recognise several market failures (Gillingham et al., 2009; Rennings, 2000; Sorrell et al., 2011), causing the diffusion of energy-efficient products to be slower than socially optimal (Jaffe and Stavins, 1994). In particular, the significance of information, and the lack of such, before making EE innovation investments decisions is theoretically well documented (Cooremans, 2011; Gillingham and Palmer, 2014; Sorrell et al., 2011) and empirically demonstrated (Cagno et al., 2017; Kounetas et al., 2011; Wohlfarth et al., 2017). These barriers and market failures imply that technology and market factors insufficiently incentivise EE innovation (Gillingham et al., 2009; Rennings, 2000; Sorrell et al., 2011), and highlight the need for energy policies and regulation to achieve social optimal EE innovation. This has driven governments worldwide to implement numerous policies and measures (Abdelaziz et al., 2011; Tanaka, 2011). Voluntary programmes are particularly abundant, with energy information provision and audit consultancies playing a central role (Abadie et al., 2012; Johansson and Thollander, 2018; Kounetas et al., 2011).

Although the need for external information is acknowledged, firms seem to encounter difficulties in assimilating and fully exploiting such information (Apeaning and Thollander, 2013; Johansson and Thollander, 2018; Trianni et al., 2013a). In fact, when studying industrial energy audit programmes, Anderson and Newell (2004) found that firms adopted only about half of audit recommendations. Scholars have also identified a lack of common understanding between governmental and industrial organisations about the most prominent drivers of and barriers to EE (Cagno et al., 2015b), and that policies tend to ignore firms' needs and capabilities (Kounetas et al., 2011). Consequently, this suggest than energy programmes might not be properly designed according to firms' competence levels and needs and address a need for better understanding how firm characteristics influence EE innovations.

### 2.2. Absorptive capacity and EE innovation in manufacturing firms

In the innovation literature, it is widely recognised that a firm's innovation performance is closely tied to its knowledge accumulation capabilities (Forés and Camisón, 2016; Lööf and Heshmati, 2002; Vinding, 2006). A comprehensive contribution in this regard is the concept of absorptive capacity (Cohen and Levinthal, 1990; Zahra and George, 2002), which concerns the importance of external knowledge for innovation, and posits the ability to evaluate and utilise external knowledge as largely a function of the level of prior related knowledge. Indeed, firms with relevant prior knowledge are likely to better understand information about novel technologies for generating new products, services, and processes (Tsai, 2001), which is relevant for the adoption of EE technologies (Gerstlberger et al., 2016). In addition, a firm can accumulate its knowledge through internal knowledge creation and externally available information (Cohen and Levinthal, 1990; Forés and Camisón, 2016).

Thus, a firm's innovative performance depends on both internal and external knowledge sources (De Marchi and Grandinetti, 2013; Forés and Camisón, 2016). The firm's internal knowledge is embedded within the human capital of individuals and the organisational capital of the business. Human capital comprises the knowledge, skills and abilities residing in and utilised by individuals, whereas organisational capital is the institutionalised knowledge and codified experience residing in and utilised through databases, patents, manuals, structures, systems, and processes (Stefania and Christian, 2015; Subramaniam and Youndt, 2005; Vinding, 2006). Examples of external knowledge can be accessed through different market transactions (Palm and Thollander, 2010). However, the more tacit the knowledge (Leonard and Sensiper, 1998), the greater the need for closer external relationships to transfer the information (Vinding, 2006). In this regard, a firm's absorptive capacity also depends on cooperation strategies and how the knowledge is transferred across organisations (Stefania and Christian, 2015; Subramaniam and Youndt, 2005). Thus, to better understand how to overcome the information barrier and improve energy policies, this paper builds on the theory of absorptive capacity and by analysing firm knowledge characteristics relevant to EE innovation.

### 2.2.1. Prior knowledge and EE innovation

A firm's prior knowledge base is strongly related to its employees and their individual skills (Subramaniam and Youndt, 2005; Vinding, 2006), the latter referring to their level of education, training, and experience (Vega-Jurado et al., 2008). Higher-educated staff seem more receptive to assimilating and transforming available knowledge, leading to greater innovations (Smith et al., 2005; Vinding, 2006) and higher productivity (Haltiwanger et al., 1999). Studies indicate that industries with highly educated employees are less sensitive to barriers to EE investment (Sardianou, 2008), and that competence-enhancing activities positively influence such investments (Cagno et al., 2015a; Svensson and Paramonova, 2017; Trianni et al., 2016a). In other words, companies with highly educated and trained employees seem to have higher levels of absorptive capacity and innovative capabilities, and we predict:

**H1.** Prior knowledge is positively related to manufacturing firms' EE innovation.

### 2.2.2. Internal knowledge development and EE innovation

Internal knowledge creation is commonly measured through R&D activities (Arundel and Kemp, 2009; Cohen and Levinthal, 1990), and has traditionally been considered a determinant of absorptive capacity (Vinding, 2006). Internal R&D is an organisational process in which firms access and utilise the knowledge of individual members. These activities not only generate new knowledge but also contribute to developing the firm's innovative capabilities (Grant, 1996; Horbach, 2008).

However, research is inconclusive on the link between internal R&D and EE innovation. Studies in Colombia (Martínez, 2010), Spain (Costa-Campi et al., 2015), and Germany (Horbach et al., 2012), do not provide statistically significant evidence that internal R&D impacts manufacturing firms' investments in EE. However, higher investments in R&D relative to sales (Rennings and Rammer, 2009), strong participation of R&D departments (Rennings et al., 2006), and continuous internal R&D activities (De Marchi, 2012) have all been found to be positively associated with EE. Cagno et al. (2015a) find that firms combining internal R&D with purposive knowledge inflows have lower perceived barriers to efficiency improvements, increase their adoption of available technologies, and improve their EE. Congruently, Martin et al. (2012) contend that firms which have already picked the 'low-hanging fruit' must invest in R&D to further improve their EE. In the light of these research findings, we propose the following hypothesis:

**H2.** Internal knowledge development is positively related to manufacturing firms' EE innovation.

### 2.2.3. External knowledge cooperation and EE innovation

Several studies suggest that firms do not consider EE innovation as a part of their core business (Harris et al., 2000; Rudberg et al., 2013; Sardianou, 2008; Sathitbun-anan et al., 2015), and thus not among their core competences (Teece et al., 1997). Consequently, EE is overlooked by management (Harris et al., 2000), employees focus their attention on daily production issues (Sardianou, 2008), and energy-related revenues are neglected (Rudberg et al., 2013; Sathitbun-anan et al., 2015). This findings suggest that firms' are dependent on inflow of external knowledge, and openness to external knowledge sources in order to stimulate their EE innovativeness (Cagno et al., 2015a).

External knowledge can be accessed through written sources such as journals and magazines, conferences, consultants, and cooperation (Palm and Thollander, 2010). However, introducing new innovations might require knowledge that is firm-specific, tacit, and not easily exchanged through market transactions (Grant, 1996; Kogut and Zander, 1992). Under such circumstance, it is found to be more efficient to develop closer relationships and strengthen the information channels (Vinding, 2006). As such, learning networks and strategic alliances provide opportunities to access, and facilitate the transfer of knowledge embedded in other firms (Inkpen and Tsang, 2005; Powell et al., 1996; Sampson, 2007). EE innovative firms are found to jointly develop new projects, and both explore and exploit synergies by using networks (Costa-Campi et al., 2015; Johansson, 2015; Trianni et al., 2013b). Moreover, cooperation may reduce a firm's need for internal R&D (De Marchi, 2012), and lower its transaction costs and risks (Kounetas and Tsekouras, 2008; Venmans, 2014), as well as compensate for internal resource limitations (Trianni et al., 2013b). In light of this research, we propose the following hypothesis:

**H3.** External knowledge cooperation is positively related to firms' EE innovation.

### 2.2.4. Interaction effect of knowledge sources of EE innovation

The firm's ability to link internal knowledge to that generated outside the organisation is considered one of the conditions for realising innovation activity (Albort-Morant et al., 2018; Vinding, 2006), and a premise of the notion of absorptive capacity (Cohen and Levinthal, 1990). It is argued that the impact of absorptive capacity on innovation performance is higher in contexts characterised by high market uncertainties and technological turbulence (Lichtenthaler, 2009). The market and technological uncertainties that characterise many EE technologies (Venmans, 2014) suggest that complementarities between internal knowledge and external cooperation are essential for EE innovations. Several contributions to the general innovation literature support this complementarity argument (Cassiman and Veugelers, 2006; Forés and Camisón, 2016; Subramaniam and Youndt, 2005). Prior research in EE innovation supports the criticality of prior knowledge (section 2.2.1.) and external knowledge cooperation (section 2.2.4). However, besides a few studies indicating an interrelation effect between these variables (Cagno and Trianni, 2013; Chai and Yeo, 2012), empirical evidence of this phenomenon is scarce in the EE literature. Nevertheless, building on insights from the innovation literature, we here hypothesise:

**H4.** The interaction-effect of knowledge sources is positively related to firms' EE innovation.

### 2.2.5. Control variables: motivational factors and firm size

Research on the drivers of EE innovation in manufacturing firms indicates the relevance of various motivational factors, firm size, and sector characteristics (May et al., 2017; Solnørdal and Foss, 2018). Empirical studies show that firms are sensitive to increased energy prices, which might affect their competitiveness (Conrad, 2000; Thollander et al., 2013; Venmans, 2014). Hence, the reduction of energy use and related energy costs are strong motives for increased EE (e.g.: Anderson et al., 2004; Brunke et al., 2014; Cagno et al., 2015b; Thollander et al., 2013). The literature also implies that industrial EE is strongly motivated by environmental objectives (Costa-Campi et al., 2015). Relatedly, proactive energy-efficient firms are recognised by long-term environmental strategies (Brunke et al., 2014), managers' awareness of environmental issues (Kostka et al., 2013; Zilahy, 2004), and their involvement in EE projects (Apeaning and Thollander, 2013). Finally, the EE literature has identified a positive relationship between firm size and EE (Costa-Campi et al., 2015; Kounetas et al., 2011; Trianni et al., 2016b). The significance of size may be attributable to larger firms' exposure to higher energy costs (Ru and Si, 2015) and better access to the resources necessary to engage in EE projects, such as competences, organisational slack, networks and capital (DeCanio, 1998; Kounetas et al., 2011; Trianni and Cagno, 2012; Trianni et al., 2013a). Hence, this study controls for cost-savings objective, public subsidies, environmental objectives, and firm size.

Research on the determinants of EE innovation also points to the impact of sectorial differences (Palm and Thollander, 2010). Sector characteristics are in this paper accounted for using industry-specific dummies in Model 1a. Moreover, since it is assumed that energy-intensive firms are more willing and able to pursue EE innovation than non-energy intensive firms (Boyd and Curtis, 2014; Cagno et al., 2017; Costa-Campi et al., 2015; Trianni et al., 2016a), the model is analysed separately for energy-intensive and non-energy-intensive sectors, as respectively presented in Models 1b and 1c. The classification follows the Norwegian Water Resources and Energy Directorate report (NVE, 2013), which shows that, over several years, sectors 17, 20, 23, and 24 have consistently been considerably more energy intensive than other sectors. Energy intensity is calculated as energy consumption in kWh divided by net sales of production.

Fig. 1 illustrates the proposed models for analysing the relations between absorptive capacity and EE innovation in manufacturing firms. Model 1 analyses the direct relationship between the explanatory variables and EE innovation, while Model 2 includes the interaction effect of different knowledge sources.

## 3. Methodology

The data used in this analysis were collated from the Norwegian CIS and the Business Enterprise R&D surveys for the period 2010–2014. All data were collected by Statistics Norway (SSB), and every Norwegian firm with more than 50 employees, as well as a representative sample of firms with less than 50 employees, participated in the surveys. As the Norwegian Statistics Act stipulate firms' obligation to provide information in SSB surveys, the response rate was high (> 95%), thus eliminating concerns of non-response bias. The panel dataset consists of manufacturing firms (sectors 10–32[1]).

The dataset comprises of 6,021 observations from 2,933 firms, and consists of both innovative and non-innovative firms. In the analysis, we only consider innovative firms. To control for possible selection bias occurring from the exclusion of non-innovative firms, we apply a two-stage logit model (De Marchi, 2012; Vega-Jurado et al., 2009). In the first stage, the probability of a firm becoming an innovator (*PrINNOVATION*) is estimated by regressing the variable *INNOVATION*, a dichotomous variable indicating if the firm introduced any product or process innovation in the period of 2010–2014, on several variables measuring exogenous obstacles to innovation for both innovative and non-innovative firms. The variables measuring obstacles to innovation are lack of external financial sources (*HFOUT*), if it was hard to find cooperation partners for innovation (*HPAR*), and if there was lack of demand for innovation (*HMAR*). In addition, number of employees (*SIZE)*, and industrial sector dummies are included as explanatory variables. The results from the first-stage logit regression are presented in table A1, Appendix A. After the non-innovative firms are removed from the dataset, the dataset comprises 5,336 observations from 2,340 firms. Our sample comprises of 226 observations from 128 firms reporting EE innovation in one or more years in the study period.

The sectoral distribution of innovative firms is presented in Table 1. The four most prominent innovative sectors are sector 10–12 (20%); sectors 30–32 (13%); sector 28 (11%); and sector 25 (8%). However, those most prominent in pursuing EE innovation are sectors 27 (13%), sector 28 (13%), sector 24 (13%), and sector 19–21 (13%). This suggests that high innovative behaviour in a sector does not necessarily signify high engagement in EE innovation.

The dependent variable in our analysis is EE innovation, represented by $IE_{it}$. It is generated based on the questionnaire item about R&D investments in 'other environmental energy: energy saving, energy efficiency, energy systems, environmentally friendly transport, etc'. $IE_{it}$ is a dichotomous variable that equals 1 if firm *i* reports such investments at time *t*, and 0 otherwise. R&D investment is commonly used as a measure for innovation (Jaffe and Palmer, 1997). By considering investments in EE R&D, we can identify the characteristics of firms that have actually invested in EE, thereby avoiding the partial observability cases discussed by (Poirier, 1980). Our explanatory variables are designed according to the hypotheses and control variables detailed in section 2.2; full definitions are presented in Table A2, Appendix A.

Table 2 reports descriptive statistics for the explanatory variables. It shows that when comparing firms pursuing EE innovation with other innovative firms, there are significant differences at the 5% level for all explanatory variables except *RDPROD*. This implies that, on average, there is a significant difference in the characteristics of firms that pursue in EE innovation compared to other innovative firms.

Since the dependent variable is dichotomous, a logit regression model was used to estimate Equation (1) in Stata version 15:

$$\begin{aligned} p(IE_{it}) = \Lambda(&\beta_1 + \beta_2 HDSHRE_{it} + \beta_3 DRSHRE_{it} + \beta_4 COOPCUS \\ &+ \beta_5 COOPSUP_{it} + \beta_6 COOPCOMP_{it} + \beta_7 COOPCONST_{it} \\ &+ \beta_8 COOPUNIS_{it} + \beta_9 ENVPUR_{it} + \beta_{10} MATPUR_{it} + \beta_{11} LSIZE_{it} \\ &+ \beta_{12} RDPROD_{it} + \beta_{13} SHRRD_{it} + \beta_{14} PUBLFUN_{it} + \alpha_i + \mu_{it}) \end{aligned} \tag{1}$$

$\beta_1 - \beta_{14}$ are the estimated parameters, $\alpha_i$ is an unobserved time invariant individual effect, and $\mu_{it}$ is a zero-mean residual. In the study period, most firms in our sample do not report EE innovation while some report EE innovation at every year in our study period. Thus, using a fixed-effects model would result in the loss of 2,244 firms (4,922 observations), which is around 95% of the firms in our sample. We therefore employ a random-effects model in this study. Not all firms are represented in every year of our study period, making our panel unbalanced. The logit model was used because the Akaike information criterion (AIC) and the Bayesian information criterion (BIC) indicated that it was more suitable than the probit model, and, when testing, the probit model produced similar results to those presented in the paper. To control for heteroscedasticity, the model is run with cluster-robust standard errors. We include *PrINNOVATION* from the first-stage logit regression as an explanatory variable to control for possible selection bias by including the effects of firms that did not innovate (De Marchi, 2012).

The analysis of Norwegian CIS and BERD data is useful to gain insights based on a large number of observations, however it has also some limitations. The first concerns how the dataset was sourced. Since the Norwegian CIS and BERD surveys collect self-reported data from firms, the reported investments of EE and R&D depend on the respondents' understanding of the questions and their methods for estimating the requested data. Although both EE investments and R&D are commonly used measures for innovation, with the advantage of being objective and traceable, they pose the risk of measuring biases since neither R&D nor investments are guaranteed to produce innovations. Moreover, the dataset does not permit the fine-grained analysis of the various forms of R&D expenditures. In addition, the dependent variable used is a proxy that not allows distinguishing between firms that introduced just few EE innovations from other whose entire innovative effort is devoted toward EE innovations. Given these limitations, the findings should be understood as indications of the relationship between absorptive capacity and EE innovation in manufacturing firms.

## 4. Results and discussion

### *4.1. Model 1: direct impact of absorptive capacity on EE innovation*

Equation (1) is estimated with all the sectors in the sample, presented in Model 1a (Table 3), as well as with subsamples of only energy intensive and non-energy intensive sectors, respectively presented in

[1] The EU NACE rev.2 and UN ISIC standards are basis for the Norwegian Standard Industrial Classification (SIC, 2007).

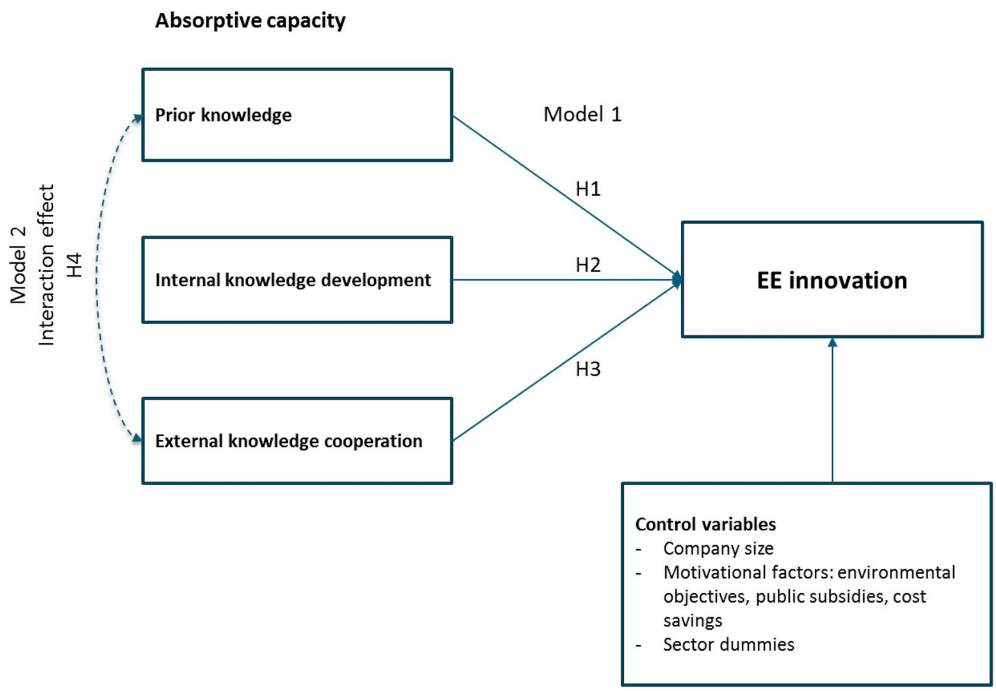


**Fig. 1.** Analytical framework and hypotheses.

**Table 1**
Manufacturing sectors and distribution of innovative firms and EE-innovators.

| Sector code+ (SN 2007) | Industrial sector | Energy-intensive | Innovative firms | | Energy efficiency innovators | |
|---|---|---|---|---|---|---|
| | | | Obs. | Percent* | Obs. | Percent* |
| 10–12 | Food, beverage, and tobacco | No | 473 (1,017) | 20% (19%) | 9 (11) | 7% (5%) |
| 13–15 | Textile, clothing, and leather | No | 118 (279) | 5% (5%) | 1 (1) | 1% (0%) |
| 16 | Wood and cork | No | 166 (351) | 7% (7%) | 9 (14) | 7% (6%) |
| 17–18 | Pulp and paper, printing | Yes | 94 (228) | 4% (4%) | 4 (5) | 3% (2%) |
| 19–21 | Coal and refined petroleum products, chemicals, and pharmaceuticals | Yes | 120 (345) | 5% (6%) | 13 (31) | 13% (14%) |
| 22 | Rubber and plastic products | No | 112 (224) | 5% (4%) | 4 (9) | 3% (4%) |
| 23 | Other non-metallic mineral products | Yes | 126 (279) | 5% (5%) | 12 (21) | 9% (9%) |
| 24 | Metallurgy | Yes | 62 (175) | 3% (3%) | 16 (33) | 13% (15%) |
| 25 | Manufacture of fabricated metal products, except machinery and equipment | No | 193 (473) | 8% (9%) | 9 (18) | 7% (8%) |
| 26 | Manufacture of computer, electronic and optical products | No | 131 (360) | 6% (7%) | 5 (8) | 4% (4%) |
| 27 | Manufacture of electrical equipment | No | 126 (259) | 5% (5%) | 16 (29) | 13% (13%) |
| 28 | Machinery and mechanical equipment | No | 246 (539) | 11% (10%) | 17 (28) | 13% (12%) |
| 29 | Motor vehicles and trailers | No | 80 (178) | 3% (3%) | 8 (12) | 6% (6%) |
| 30–32 | Production of transport equipment, furniture, and other manufacturing industries | No | 293 (629) | 13% (12%) | 5 (6) | 4% (3%) |
| | SUM | | 2,340 (5,336) | 100% | 128 (226) | 100% |

*Percentages are calculated based on total innovative firms and total EE-innovators, respectively. The obs. column is number of firms, and number of observations in parentheses.
+Some related industries have been merged due to the small number of firms. There are no firms in industry 12 (Manufacture of tobacco products).

Models 1b and 1c (Table 4). The estimated parameters, odds ratios, and marginal effects are reported in Table 3. The variance inflation factor (VIF) is below 2.5 for each variable, and the mean VIF is 1.65, confirming that there are no issues with multi-collinearity.

H1 predicts that prior knowledge is positively related to firms' EE innovation. In Model 1a, the coefficients estimated for *HDSHRE* and *DRSHRE* are significant and positive. The average marginal effect shows that a 100% increase in staff members with a master's or PhD degree in the R&D department would, on average, increase the probability of EE innovation by 4.9% or 2.6%, respectively. The odds ratios are 12.48 for *HDSHRE* and 3.78 for *DRSHRE*, indicating that an R&D department with twice as many R&D staff members with a master's degree (PhD degree) is 12.48 (3.78) times more likely to pursue EE innovation. This result supports prior studies advocating the positive effect of education and staff training on EE innovation (Cagno and Trianni, 2013; Sardianou, 2008), and suggests a positive relationship between education and EE innovation. Even though our analysis denote a statistical relationship between education and EE innovation, one must exercise caution when interpreting the causal effect of education on EE innovation. In fact, Haltiwanger et al. (1999) found that while workers' educational level was significantly related to firms' productivity, the changes in productivity could not be explained by changes in workers' education level. Thus, our result might reflect that EE innovative and high-productivity firms have more skilled workers (Sardianou, 2008), or that higher educated employees influence their firms' strategies and EE innovative behaviour (Tonn and Martin, 2000), or a combination of the two.

H2 posits that internal knowledge development is positively related

**Table 2**
Descriptive statistics.

| Explanatory variables | | Innovative firms (excl. EE) | | EE-innovators | |
|---|---|---|---|---|---|
| Variable | Variable description | Mean | SD | Mean | SD |
| *HDSHRE* | Level of individual competence in R&D department | 0.13 | 0.27 | 0.32 | 0.31 |
| *DRSHRE* | Level of individual research competence in R&D department | 010 | 0.24 | 0.21 | 0.29 |
| *RDPROD* | R&D investment per employee | 56.38 | 225.77 | 81.71 | 127.05 |
| *SHRRD* | R&D capacity | 0.06 | 0.15 | 0.10 | 0.15 |
| *COOPCUST* | Cooperation with customers | 0.17 | 0.37 | 0.41 | 0.49 |
| *COOPSUP* | Cooperation with suppliers | 0.18 | 0.39 | 0.43 | 0.50 |
| *COOPCOMP* | Cooperation with competitors | 0.06 | 0.24 | 0.19 | 0.40 |
| *COOPCONS* | Cooperation with consultants | 0.12 | 0.32 | 0.26 | 0.44 |
| *COOPUNIS* | Cooperation with universities | 0.17 | 0.38 | 0.50 | 0.50 |
| *ENVPUR* | Environmental motivation | 0.39 | 0.49 | 0.71 | 0.46 |
| *MATPUR* | Economic motivation | 0.45 | 0.50 | 0.73 | 0.44 |
| *PUBLFUN* | Public funding | 0.22 | 0.41 | 0.54 | 0.50 |
| *LSIZE* | Company size | 3.79 | 1.23 | 4.75 | 1.22 |
| *PrINNOVATION* | Probability of being an innovator | 0.76 | 0.16 | 0.87 | 0.12 |
| *HDDR* | Firms with R&D staff with master's or PhD degree | 0.34 | 0.47 | 0.83 | 0.37 |

**Table 3**
Estimated parameters, odds ratios, and average marginal effects of logit regression. Dependent variable: EE innovation.

| Hypothesis | Variables | (1a) Total | | |
|---|---|---|---|---|
| | | Coef. | Odds ratios | AME |
| H1: | HGSHRE | 2.524*** (0.000) | 12.477 *** (0.000) | 0.049*** (0.000) |
| | DRSHRE | 1.329*** (0.009) | 3.776*** (0.009) | 0.026 *** (0.008) |
| H2: | RDPROD | −0.000 (0.712) | 1.000 (0.712) | −0.000 (0.713) |
| | RDSHRE | 2.525** (0.012) | 12.490** (0.012) | 0.049** (0.013) |
| H3: | COOPCUST | −0.336 (0.408) | 0.714 (0.408) | −0.007 (0.407) |
| | COOPSUP | 0.305 (0.373) | 1.356 (0.373) | 0.006 (0.374) |
| | COOPCOMP | 0.712* (0.051) | 2.038* (0.051) | 0.014* (0.051) |
| | COOPCONS | −0.421 (0.254) | 0.657 (0.254) | −0.001 (0.254) |
| | COOPUNIS | 0.990*** (0.010) | 2.692*** (0.010) | 0.019*** (0.010) |
| Controls: | LSIZE | 0.790*** (0.000) | 2.204*** (0.000) | 0.015*** (0.000) |
| | ENVPUR | 0.841*** (0.007) | 2.320** (0.007) | 0.016** (0.007) |
| | MATPUR | 0.334 (0.325) | 1.397 (0.325) | 0.007 (0.325) |
| | PUBLFUN | 0.628* (0.052) | 1.874* (0.052) | 0.012** (0.053) |
| | PrInnovation | 1.745 (0.272) | 5.727 (0.272) | 0.034 (0.274) |
| | Constant | −14.871*** (0.000) | 0.000*** (0.000) | |
| Sector dummies | IND13-15 | −0.053 (0.971) | 0.949 (0.971) | −0.001 (0.971) |
| | IND16 | 2.911*** (0.000) | 18.379*** (0.000) | 0.056*** (0.000) |
| | IND17-18 | 1.305 (0.162) | 3.686 (0.162) | 0.025 (0.164) |
| | IND19-21 | 1.679** (0.047) | 5.361** (0.047) | 0.033** (0.047) |
| | IND22 | 1.998** (0.031) | 7.376** (0.031) | 0.039** (0.031) |
| | IND23 | 3.114*** (0.000) | 22.530*** (0.000) | 0.061*** (0.000) |
| | IND24 | 4.283*** (0.000) | 72.587*** (0.000) | 0.084*** (0.000) |
| | IND25 | 2.423*** (0.004) | 11.279*** (0.004) | 0.047*** (0.004) |
| | IND26 | −0.132 (0.896) | 0.876 (0.896) | −0.003 (0.896) |
| | IND27 | 3.807*** (0.000) | 45.028*** (0.000) | 0.074*** (0.000) |
| | IND28 | 2.116*** (0.006) | 8.299*** (0.006) | 0.041*** (0.006) |
| | IND29 | 3.180*** (0.000) | 24.050*** (0.000) | 0.062*** (0.000) |
| | IND30-32 | −0.139 (0.880) | 0.871 (0.880) | −0.003 (0.880) |
| Observations (groups) | | 5,336 (2,340) | 5,336 (2,340) | 5,336 (2,340) |

*, **, and *** indicates significance at the 10%, 5%, and 1% level, respectively. AME denotes average marginal effects. P-values in parentheses. Regression is run with cluster robust standard errors. The sector variable IND-10-12 are in the basis.

to firms' EE innovation. The result is not significant for *RDPROD* but significant for *SHRRD*. This indicates that the share of human resources allocated to R&D positively affects EE innovation, while the effect of financial resources allocated to R&D is not identified. The average marginal effects suggest that an increase of 100% in R&D employees would, on average, increase the probability of pursuing EE innovation by 4.9%. Finding that *RDPROD* is not significant contradicts our hypothesis but reflects the inconsistent results in the literature regarding this variable's impact on EE innovation. RDPROD is measured here as the sum of investments in R&D, including wages, infrastructure, and other costs, whereas other studies have considered the various investments as separate variables (Horbach et al., 2012; Martínez, 2010), assessed the continuity of R&D activities (De Marchi, 2012), or analysed the participation of the R&D department in the innovation process (Rennings et al., 2006). This heterogeneity in measuring R&D might explain why little consensus has been reached on the influence of internal R&D on EE innovation.

Hypothesis H3 predicts that external knowledge cooperation is

**Table 4**
Estimated parameters, odds ratios, and average marginal effects for energy-intensive and non-energy-intensive sectors.

| Variables | (1b) Energy-intensive | | | (1c) Non-Energy-intensive | | |
|---|---|---|---|---|---|---|
| | Coef. | Odds ratios | AME | Coef. | Odds ratios | AME |
| HGSHRE | 2.881*** (0.005) | 17.826*** (0.005) | 0.094 *** (0.001) | 2.550*** (0.000) | 12.812*** (0.000) | 0.0389*** (0.000) |
| DRSHRE | 1.826* (0.089) | 6.211** (0.089) | 0.058 *** (0.048) | 1.200** (0.045) | 3.320** (0.045) | 0.018** (0.049) |
| RDPROD | −0.001 (0.563) | 0.999 (0.563) | −0.000 (0.635) | 0.000 (0.890) | 1.000 (0.890) | 0.000 (0.890) |
| RDSHRE | 6.698*** (0.001) | 811.012*** (0.001) | 0.226*** (0.009) | 1.322 (0.336) | 3.751 (0.336) | 0.020 (0.337) |
| COOPCUST | −0.468 (0.426) | 0.626 (0.426) | −0.015 (0.415) | −0.139 (0.780) | 0.871 (0.780) | −0.002 (0.780) |
| COOPSUP | 0.421 (0.481) | 1.523 (0.481) | 0.014 (0.487) | 0.009 (0.986) | 1.009 (0.986) | 0.000 (0.986) |
| COOPCOMP | 0.340 (0.542) | 1.405 (0.542) | 0.010 (0.606) | 0.885* (0.070) | 2.424* (0.070) | 0.013* (0.070) |
| COOPCONS | −0.342 (0.591) | 0.711 (0.591) | −0.011 (0.573) | −0.344 (0.468) | 0.709 (0.468) | −0.005 (0.466) |
| COOPUNIS | 1.151* (0.093) | 3.162** (0.093) | 0.038** (0.076) | 0.969** (0.048) | 2.634** (0.048) | 0.015* (0.046) |
| LSIZE | 1.734*** (0.000) | 5.663*** (0.000) | 0.056*** (0.000) | 0.462** (0.026) | 1.587** (0.026) | 0.007** (0.027) |
| ENVPUR | 0.753 (0.314) | 2.124 (0.314) | 0.025 (0.294) | 0.842** (0.032) | 2.321** (0.032) | 0.013** (0.034) |
| MATPUR | 0.221 (0.784) | 1.248 (0.784) | 0.007 (0.778) | 0.282 (0.468) | 1.326 (0.468) | 0.004 (0.467) |
| PUBLFUN | −0.982 (0.109) | 0.375 (0.109) | −0.033* (0.093) | 1.344*** (0.001) | 3.836*** (0.001) | 0.020*** (0.001) |
| Constant | −11.978*** (0.000) | 0.000*** (0.000) | | −14.656*** (0.000) | 0.000*** (0.000) | |
| IND13-15 | Omitted | Omitted | Omitted | −0.433 (0.788) | 0.649 (0.788) | −0.007 (0.788) |
| IND16 | Omitted | Omitted | Omitted | 2.854*** (0.001) | 17.362*** (0.001) | 0.043*** (0.001) |
| IND17-18 | −3.243*** (0.004) | 0.039*** (0.004) | −0.105*** (0.004) | Omitted | Omitted | Omitted |
| IND19-21 | −2.06** (0.022) | 0.127** (0.022) | −0.071** (0.022) | Omitted | Omitted | Omitted |
| IND22 | Omitted | Omitted | Omitted | 1.642 (0.108) | 5.164 (0.108) | 0.025 (0.110) |
| IND23 | −0.972 (0.182) | 0.378 (0.182) | −0.033 (0.245) | Omitted | Omitted | Omitted |
| IND25 | Omitted | Omitted | Omitted | 2.361*** (0.007) | 10.604*** (0.007) | 0.036*** (0.007) |
| IND26 | Omitted | Omitted | Omitted | −0.599 (0.584) | 0.549 (0.584) | −0.009 (0.582) |
| IND27 | Omitted | Omitted | Omitted | 3.515*** (0.000) | 33.613*** (0.000) | 0.054*** (0.000) |
| IND28 | Omitted | Omitted | Omitted | 1.909** (0.014) | 6.745** (0.014) | 0.029** (0.015) |
| IND29 | Omitted | Omitted | Omitted | 2.932*** (0.004) | 18.769*** (0.004) | 0.045*** (0.004) |
| IND30-32 | Omitted | Omitted | Omitted | −0.077 (0.934) | 0.925 (0.934) | −0.001 (0.934) |
| Observations (groups) | 1,027 (402) | 1,027 (402) | 1,027 (402) | 4,309 (1,940) | 4,309 (1,940) | 4,309 (1,940) |

*, **, and *** indicates significance at the 10%, 5%, and 1% level, respectively. AME denotes average marginal effects. P-values in parentheses. Regression is run with cluster robust standard errors. The sector variable IND 24 are in the basis for model 1b, and IND-10-12 are in the basis for model 1b.

positively related to EE innovation. Both *COOPUNIS* and *COOPCOMP* are found to be significant and positive. The average marginal effects for *COOPUNIS* show that cooperation with universities and private and public research institutions (henceforth universities) increases the probability of pursuing EE innovation by 1.9%, and the odds ratio of 2.69 indicates that the odds for pursuing EE innovation are more than two and a half times higher for firms that cooperate with universities. The positive effect of cooperation with knowledge institutions is supported by prior research (Miah et al., 2015; Tonn and Martin, 2000). The finding might also reflect that environmental innovations are knowledge-demanding (De Marchi and Grandinetti, 2013; Horbach et al., 2013), and that external cooperation can compensate for internal resource scarcity (Trianni et al., 2013b), and reduces transaction costs and risk (Kounetas and Tsekouras, 2008; Venmans, 2014). The analysis also suggest that cooperation with competitors increases the probability of pursuing EE innovation by 1.4%, with an odds ratio of 2.04 indicating that the odds of pursuing EE innovation are twice as big for firms cooperating with competitors. However, Lööf and Heshmati (2002) and Belderbos et al. (2006) found that cooperation with competitors and research institutions has a generally positive effect on innovations, and our study propose this for EE innovation.

The analysis finds no significant effects for *COOPCUST*, *COOPSUP,* or *COOPCONS*. The limited importance of customers for EE innovation is also identified in previous studies (Ozoliņa and Roša, 2013). However, the identified lack of significance for cooperation with suppliers and consultants is more intriguing. This finding contradicts prior research on the topic, which identifies the relevance of consulting energy service consultancy organisations (Chai and Yeo, 2012; Sandberg and Söderström, 2003) and cooperation with technology suppliers and installers, and other experts (e.g. Rennings and Rammer, 2009; Trianni et al., 2016a).

The control variables assess motivational factors affecting the decision to pursue EE innovation. The estimated coefficients for *LSIZE, PUBLFUN* and, *ENVPUR* are all positive and statistically significant. Larger firms appear more likely to pursue EE innovation, with a 1% increase in the number of employees associated with a 0.015% rise in the probability of pursuing EE innovation. Further, receiving public investment subsidies increases the probability of pursuing EE innovation by 1.2%. The findings also show that firms pursuing EE innovation are more motivated by environmental objectives than other innovative manufacturing firms, and if the environmental purpose is of high or medium importance, then the probability of pursuing EE innovation rises by 1.6%. However, the estimated coefficient for *MATPUR* is not significant, implying that the motive for cost savings is equally important for both innovative manufacturing firms and firms pursuing EE innovation. The sector dummies, *IND12-IND30*, reveal sectorial differences in pursuing EE innovation.

The results from Models 1b and 1c is presented in Table 4 and suggest differences between the energy-intensive and non-energy-intensive sectors. For instance, cooperation with competitors only positively influences EE innovation in non-energy-intensive firms, while the share of employees in the R&D department is only significant for energy-intensive firms. Considering the motivational factors, non-energy-intensive firms are motivated by both environmental objectives and public funding, whereas public funding negatively affects EE innovation in energy-intensive firms.

Several studies have investigated the sectorial impact on firms pursuing EE innovation, and the findings are inconclusive (Solnørdal and Foss, 2018). This paper adds to the studies that identifies sectorial differences, but several other studies find no or little evidence of sectorial impact. Therefore, further empirical work is required to identify potential causes for how and when the structural effect of industrial sector affects EE innovation.

### 4.2. Model 2: interaction effect of knowledge sources of EE innovation

Hypothesis H4 posits an interaction effect between prior knowledge and knowledge cooperation that is positively related to EE innovation. Thus, Equation (2) examines the interaction effect between the variables education level *(HDDR)* and cooperation (*COOPCOMP and COOPUNIS*), which was found to be significant in Model 1a. The following equation is estimated:

$$\begin{aligned} p(IE_{it}) = \Lambda(&\delta_1 + \delta_2 COOPCUS + \delta_3 COOPSUP_{it} + \delta_4 COOPCONS_{it} \\ &+ \delta_5 ENVPUR + \delta_6 ENVPUR_{it} + \delta_7 MATPUR_{it} + \delta_8 LSIZE_{it} \\ &+ \delta_9 RD_{it} + \delta_{10} SHRRD_{it} + \delta_{11} PUBLFUN_{it} \\ &+ \delta_{12}(HDDR_{it} \times COOPCOMP_{it}) + \delta_{13}(HDDR_{it} \times COOPUNIST_{it}) \\ &+ \alpha_i + \mu_{it}) \end{aligned} \tag{2}$$

Some studies warn against estimating interaction effects in non-linear models (Ai and Norton, 2003; Allison, 1999). However, as Kuha and Mills (2018) note, the need for caution depends on whether the model of interest is the continuous latent variable of $Y^*$ or the underlying observed binary response of *Y*. In the latter case, the group comparison problem disappears. In this study, the model of interest is whether innovative manufacturing firms are pursuing EE innovation. Since this is the binary response of *Y*, we believe that group comparison is appropriate in this context.

Table 5 depicts the coefficients and odds ratios for the estimated parameters of Model 2. The results show a significant and positive interaction effect between higher education and cooperation with both competitors and universities.

Following the procedure proposed by Buis (2010), we estimate the multiplicative and marginal effects of the interaction between *HDDR* and cooperation with competitors, as well as the interaction between *HDDR* and cooperation with universities; these results are presented in Table 6.

For firms whose R&D department employees do not have a higher education degree, cooperation with competitors or universities is not associated with more EE innovation. However, for firms whose R&D staff have a higher education degree, cooperation with competitors and universities increases the probability of pursuing EE innovation by 4.0% and 2.9%, respectively. These findings indicate that EE innovation are likely to be highest where staff have a higher education degree *and* the firm cooperates with competitors or universities.

This result reinforces a study by Subramaniam and Youndt (2005)

**Table 5**
Estimated parameters and odds ratios of Equation (2).

| Variables | Coef. | Odds ratio | P-value |
|---|---|---|---|
| *RDPROD* | 0.000 | 0.999 | 0.884 |
| *RDSHRE* | 0.501 | 7.949 | 0.648 |
| *COOPCUST* | −0.385 | 0.731 | 0.278 |
| *COOPSUP* | 0.200 | 1.060 | 0.584 |
| *COOPCONS* | −0.531 | 0.782 | 0.130 |
| *LSIZE* | 0.698*** | 2.092 | 0.000 |
| *ENVPUR* | 0.811** | 2.207 | 0.013 |
| *MATPUR* | 0.185 | 1.186 | 0.573 |
| *PUBLFUN* | 0.251 | 1.109 | 0.398 |
| | | | |
| *HDDR* | 3.647*** | 32.492 | 0.000 |
| *COOPCOMP* | −0.248 | 0.461 | 0.844 |
| *COOPUNIS* | 2.931*** | 21.284 | 0.001 |
| *HDDR x COOPCOMP* | 1.010 | 4.462 | 0.432 |
| *HDDR x COOPUNIS* | −2.038** | 0.123 | 0.024 |
| *BASELINE* | −12.517*** | 0.000 | 0.000 |

*, **, and *** indicates significance at the 10%, 5%, and 1% level, respectively. Regression is run with cluster robust standard errors.

**Table 6**
Multiplicative and marginal effects of interaction between *HDDR* and external cooperation.

| (*HDDR* × *COOPCOMP*) | Multiplicative effects | Marginal effects |
|---|---|---|
| HDDR = 0, COOPCOMP = 0 | 0.000 (0.106) | |
| HDDR = 0, COOPCOMP = 1 | 0.001 (0.358) | 0.001 (0.448) |
| HDDR = 1, COOPCOMP = 0 | 0.014*** (0.003) | |
| HDDR = 1, COOPCOMP = 1 | 0.054** (0.015) | 0.040 (0.043) |
| | | |
| HDDR = 0, COOPUNIS = 0 | 0.000 (0.119) | |
| HDDR = 0, COOPUNIS = 1 | 0.002 (0.171) | 0.002 (0.182) |
| HDDR = 1, COOPUNIS = 0 | 0.007*** (0.008) | |
| HDDR = 1, COOPUNIS = 1 | 0.036** (0.003) | 0.029*** (0.008) |

*, **, and *** indicates significance at the 10%, 5%, and 1% level, respectively. P-values in parentheses.

also identifying the positive interaction effect between organisations' human capital and cooperative abilities on innovative performance. This finding coheres with the theory of absorptive capacity, advocating the importance of prior knowledge for taking in new external knowledge and exploiting it for EE innovation.

## 5. Conclusion and policy implications

Increasing EE innovation in the manufacturing sector is essential to tackle the challenges of global warming. By applying absorptive capacity as a theoretical framework, this study has examined the relationship between knowledge characteristics and EE innovation in Norwegian manufacturing firms. The paper is motivated by the increasing importance of understanding the determinants of EE innovation in order to inform efficient energy policies. Following the theory of absorptive capacity, we adopted an analytical framework for selecting and separating the explanatory variables: prior knowledge, knowledge development, and external knowledge cooperation. The related hypotheses (H1-H4) were tested using logit random-effects models on a sample of innovative firms from the Norwegian manufacturing sector for 2010–2014. A two-stage logit model was applied to control for possible selection bias occurring from the exclusion of non-innovative firms. The direct effect of the explanatory variables is analysed in Model 1a-c (Tables 3 and 4), while their interaction effect is analysed in Model 2 (Tables 5 and 6). We also controlled for motivational factors, firm size, and sectors.

Hypotheses H1–H3 (Model 1a) are either fully or partly supported by our empirical analysis, indicating that prior knowledge, knowledge development, and external knowledge cooperation are positively related to EE innovation. The analysis also suggests that universities and competitors are particularly relevant for EE cooperation. Hypothesis H4 is also supported, suggesting that the interaction of higher education and external cooperation are leading firms to pursue EE innovation more extensively, compared to a situation characterised by either higher educated employees or external cooperation. Accordingly, the paper suggests that higher educated employees contribute to increase the firm's ability to effectively assimilate and exploit outside knowledge, and coheres with Cohen and Leventhal's (1990) assertion that individual and organisational absorptive capacities are cumulative. The suggested relevance of prior knowledge might contribute to explain why some firms (Camisón and Forés, 2011; Escribano et al., 2009) experience different levels of difficulties in exploiting external information about EE solutions (Anderson and Newell, 2004; Thollander et al., 2007; Tonn and Martin, 2000), and do not derive equal innovation performance (Camisón and Forés, 2011; Escribano et al., 2009). In this vein, the study's empirical results support the paper's initial argument that absorptive capacity is an antecedent for EE innovation in manufacturing firms.

These findings propose several interesting implications for policy, which are discussed in the following. The analysis suggest that universities play a prominent role for industrial EE innovation, as providers of both higher education and as cooperation partners. The indicated relationship between higher education and EE innovation implies that higher education programmes have a positive impact on firms' EE innovativeness. However, since the model only depict the statistical relationships, there are several plausible explanations for this finding. One can be that the innovative and high-productivity firms that consistently adopt the latest technology exhibit the most innovative workforce practices and have more skilled workers (Sardianou, 2008). Another explanation can be that employees with higher education influence the strategies and innovative behaviour of their firms (Tonn and Martin, 2000). Nonetheless, in both cases, firms targeting EE innovation seem to need a higher educated workforce. In this regard, it can be advisable that policymakers make available higher education and education welfare systems, stimulating the population to enter higher education.

In addition, universities also appear as important cooperation partners enhancing industrial EE innovation, since firms pursuing EE innovation seem to cooperate significantly more with universities than other innovative firms. There are indeed many benefits that can motivate firms to cooperate with universities for innovation (Ankrah and Al-Tabbaa, 2015; Tether, 2002). In particular, universities are important providers of technological know-how and expertise about EE solutions (Miah et al., 2015; Tonn and Martin, 2000). Prior research has also identified that differing institutional environments in academia and industry can create barriers for university-industry cooperation (Bruneel et al., 2010). Nonetheless, prior collaboration experience and breadth of interactions facilitates the transfer of knowledge between innovation partners, and can help to overcome this barrier (Bruneel et al., 2010; Inkpen and Tsang, 2005; Steinmo and Rasmussen, 2018). Thus, in order to stimulate industrial EE innovation, it can be advisable to design policy programmes facilitating learning networks and encourage the development of university-industry cooperation platforms where industry and universities can meet at regularly basis.

Furthermore, the study suggests there is an interaction between higher educated workforce and collaboration with universities that accelerate firms' pursuit of EE innovation. The literature emphasise the importance of prior experience for overcoming barriers for university-industry collaboration (Bruneel et al., 2010). However, EE innovations can represent a technological frontier on which firms are more inexperienced, and thus face the challenge of lacking prior cooperation experiences with relevant partners and experts. In such cases, employees' affiliation with universities from higher education can serve as relevant prior experiences (Steinmo and Rasmussen, 2018), creating necessary trust between the partners (Inkpen and Tsang, 2005). Moreover, the results of the analysis may reflect that higher education leads to greater EE innovation not only by improving the technical, cognitive and relational skills of employees, but also by developing a common knowledge platform (Smith et al., 2005), that permits university and industry to share more efficiently knowledge not previously common between them. In this way can higher education contribute to accelerate the effect of university-industry cooperation and increase the EE innovation output. Consequently, it can be recommendable that policies take in how firms with varying degrees of experience in cooperation with universities rely on different mechanisms to achieve successful cooperation with universities. This also imply that research cooperation should not only be evaluated in terms of their direct effect to EE innovation, but also by the development of the firms' absorptive capacity, which may form the basis for future collaborations.

The results also imply that cooperation with competitors contributes to increasing EE innovation in manufacturing firms. Cooperation with competitors is found to be suitable when they face common problems, considered as being outside the realms of competition such as e.g. the regulatory environments. It might also be motivated by firms' need for standard setting and encouragement of the market, which can be reluctant to take up a new technology when there is only one provider (Tether, 2002), and when prevailing system act as a barrier to the creation and diffusion of a new EE system. Nevertheless, Ritala and Hurmelinna-Laukkanen (2013) find that firms' engagement in cooperation with competitors depends on the firms' absorptive capacity and ability to protect its core knowledge and innovations against imitation. Given that several firms report that EE innovations is not a part of their core competence (Harris et al., 2000; Rudberg et al., 2013; Sardianou, 2008; Sathitbun-anan et al., 2015), it might thus seem like EE innovations is particularly appropriate for cooperation with competitors. This imply that firms might improve their EE innovativeness by both increasing their absorptive capacity and disregard the traditional skepticism about cooperating with competitors. To achieve this visionary coordination of policies, regulation and firm strategies are needed.

This study also controlled for firm size, industry sector, and three motivational factors: environmental objectives, public funding, and cost savings. We find that firm size generally has a positive effect on firms' willingness to pursue EE innovation, despite some sectorial variation. Furthermore, EE-innovative firms seem to be more motivated by environmental objectives than other innovative firms. The analysis also indicates that firms funded by public institutions are more willing to pursue EE innovation. However, the cost-savings motive is not found to have a significant effect, which might signal that cost-savings is equally important for all innovative firms. These findings suggests the relevance of policy programmes providing access to capital and raising environmental awareness.

The literature is inconsistent regarding the sectorial impact on industrial firms' pursue of EE innovations (Solnørdal and Foss, 2018), signalling the need for more research on the topic before conclusions can be drawn. In this study, some sectorial differences between energy-intensive and non-energy-intensive sectors (Models 1b and 1c) are observed. The results indicate that higher education, firm size, and cooperation with universities are the common factors linked to EE innovation in both sectors. Energy-intensive firms with a higher share of human resources allocated to R&D pursue EE innovation compared to other innovative firms in the same sector. On the other hand, the analysis signals that non-energy intensive firms pursuing EE innovation are encouraged by environmental motives, public funding and cooperation with competitors. This may be related to sectorial differences with respect to development: some sectors characteristically undertake in-house process development, while others depend more extensively on external knowledge (Wesseling and Edquist, 2018). These findings add to the ongoing discussion in the EE literature on sectorial differences (Boyd and Curtis, 2014; Cagno et al., 2017; Costa-Campi et al., 2015; Trianni et al., 2016a), and suggest a need for customised energy programmes at both sectorial and firm level.

The findings of the paper also points to several other interesting avenues for future research.

In fact, the dataset used here only includes Norwegian firms and covers a limited time period (2010–2014), with data collected shortly after the global financial crisis (GFC) of 2008 and during the ensuing global recession. During this period, access to external funding was probably more limited compared to circumstances of a steady-state economy. Hence, according to the OECD (2012b), the lack of accessible funding after the crisis negatively affected business innovation and R&D development in every country. Norway was also undoubtedly affected, since investments in innovation declined in 2009 compared to 2006–2008 (Filippetti and Archibugi, 2011). Given that manufacturing firms often have limited capital available for efficiency projects (Anderson and Newell, 2004), one might risk that some firms in our dataset would have pursued EE innovation in other circumstances but were restricted by reduced access to financial resources. However, the impact of the GFC and the recession was relatively shallow in Norway compared to other OECD countries (OECD, 2010), and the Norwegian economy had essentially recovered in the first half of 2011 (OECD, 2012a). Thus, there is a risk that national economic factors might bias the paper's results. Additional research is accordingly needed to verify whether the study's findings hold for firms in different economic systems, and facing other exogenous macroeconomic conditions compared to the firms studied here.

Further, the results of this paper indicate a positive relationship between firms absorptive capacity and pursue of EE innovations. However, to expand our understanding of how firms' characteristics affect their propensity for EE innovations, and the interaction effect between these variables future research may include the impact of contingent factors such as organisational structure and strategy design, and environmental factors such as location in a network, energy policies, and macroeconomic elements.

Using survey data from the Norwegian CIS and BERD questionnaires is useful to gain insights based on a large number of observations, but it also comes with some caveats. The data set is based on self-reported variables, and it does not allow to distinguish between firms according to level of involvement in EE innovation or form of R&D expenditure, as discussed in Section 3. Given these limitations, the results should be interpreted as indications of the relationship between absorptive capacity and EE innovations for manufacturing firms. In order to gain more understanding about the causal relationships underlying the results presented herein, applying qualitative methods in further research is needed. This is particularly important for better understanding the interaction effect between the explanatory variables. Bansal et al. (2018) argue that qualitative research methods are increasingly needed to unpack the complex challenges our world faces, and this includes climate challenges, to build theory inductively. Thus, a contribution that future research should attempt to provide is to focus on the causal relationships between the variables and to describe the various stakeholders, motives, activities, and resources involved in the EE innovation processes.

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## Appendix

Table A1
First-stage logit regression

| Variables | Coef. | P-value |
|---|---|---|
| *LSIZE* | 0.587 | 0.000 |
| *HPAR* | 0.366 | 0.000 |
| *HFOUT* | 0.592 | 0.000 |
| *HMAR* | −0.402 | 0.000 |
| *Sector dummies* | Included | |
| *Constant* | −1.524 | 0.000 |

Regression is run with cluster robust standard errors.

Table A2
Description of variables (the panel data indicate the activity firm *i* at time *t*).

| Variable | Description | Measure |
|---|---|---|
| $IE_{it}$ | Energy efficiency innovation | Dichotomous variable: 1 if the firm has invested in R&D in 'other environmental energy: energy saving, energy efficiency, energy systems, environmentally friendly transport, etc.'; 0 if not |
| $Innovation_{it}$ | Innovative firm | Dichotomous variable: 1 if the firm introduced a product or process innovation during 2010–2014; 0 if not. |
| $HDSHRE_{it}$ | Higher education at master's level in R&D department | Share of staff in R&D department with higher education degree at master's level or equivalent |
| $DRSHRE_{it}$ | Higher education at PhD level in R&D department | Share of staff in R&D department with a PhD degree or equivalent |
| $RDPROD_{it}$ | R&D investment | Sum of investment in R&D (wages, infrastructure investments, and other costs) per employee. |
| $SHRRD_{it}$ | R&D capacity | Share of employees in R&D department |
| $COOPCUS_{it}$ | Cooperation along the value stream | Dichotomous variable: 1 if firm cooperates with customers; 0 if not |
| $COOPCOMP_{it}$ | Cooperation with competitors | Dichotomous variable: 1 if firm cooperates with competitors; 0 if not |
| $COOPSUP_{it}$ | Cooperation with suppliers | Dichotomous variable: 1 if firm cooperates with suppliers; 0 if not |
| $COOPCONS_{it}$ | Cooperation with consultants | Dichotomous variable: 1 if firm cooperates with consultants; 0 if not |
| $COOPUNIS_{it}$ | Cooperation with universities | Dichotomous variable: 1 if firm cooperates with universities, private and public research institutions, and/or commercial laboratories; 0 if not |
| $ENVPUR_{it}$ | Environmental motivation | Dichotomous variable: 1 if reducing environmental impact is considered of medium or high importance; 0 if not |
| $MATPUR_{it}$ | Cost savings | Dichotomous variable: 1 if reducing material and energy costs is considered of medium or high importance; 0 if not |
| $PUBLFUN_{it}$ | Public funding | Dichotomous variable: 1 if firm has received funding from public institutions; 0 if not |
| $LSIZE_{it}$ | Company size | Natural logarithm of number of employees in the firm |
| $PrINNOVATION_{it}$ | Probability of being an innovator | Probability of being an innovator, estimated in the first-stage logit regression. |
| $HDDR_{it}$ | Educational level in R&D department | Dichotomous variable: 1 if firm has employees in the R&D department with a master's and/or PhD degree; 0 if not |
| $HFOUT_{it}$ | Financing obstacle for innovation | The importance of lack of external financial sources as obstacle for innovation. Factor variable: 3 if it was very important, 0 if it was not relevant |
| $HPAR_{it}$ | Cooperation obstacle for innovation | The importance of lack of cooperation partners as obstacle for innovation. Factor variable: 3 if it was very important, 0 if it was not relevant |
| $HMAR_{it}$ | Demand obstacle for innovation | The importance of lack of demand for innovations in the market as obstacle for innovation. Factor variable: 3 if it was very important, 0 if it was not relevant. |

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# Translating a corporate environmental program into energy management practices: Case study of a pharmaceutical company

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**Abstract:** A promising way to stimulate industrial energy efficiency is via energy management (EnM) practices. There is, however, limited knowledge in the literature on the evolvement of EnM practices in manufacturing firms. Aiming to fill this research gap, this study explores the implementation of a corporate environmental program in an incumbent firm and the ensuing emergence of EnM practices. Translation theory and the 'travel of management ideas' is used as a theoretical lens in this single case study when analysing the implementation process retrospectively over a period of 10 years. Furthermore, based on a review and synthesis of prior studies, best EnM practices are developed and used as a threshold when describing the EnM practices of the case firm. Building on this premise, the study contributes to the EnM literature by outlining the relevance of the regulative and technological context, firm internal resources, and the human capital of key editors. Furthermore, the study points to the dynamics of the implementation process over time and the relevance of managerial involvement and endurance at various levels in the organization. Managerial and policy implications, as well as avenues for further research, are provided based on the results.

**Keywords:** energy efficiency; energy management practices; translating management ideas; case study; internal stakeholders

## 1. Introduction

There is growing interest and awareness about the potential of energy management (EnM) to escalate industrial energy efficiency (EE) [1-5]. The industrial sector accounts for a large proportion (37%) of the world's total final energy consumption [6]. Therefore, increased industrial EE is essential to reach global sustainability targets such as the Paris Agreement [7] and the European 2030 climate and energy framework [8]. Industrial EE can be realised by new technological measures that require less energy to perform the same functions [9]. Although EE leads to reduced energy costs [10], and increased productivity [11,12] and is positively related to firms' financial performance [5,13] and competitiveness [14], the manufacturing sector holds significant unexploited potential for EE improvements [15-17]. The discrepancy between the theoretically optimal and current level of EE is referred to as the EE gap [18], leading to extensive research addressing the wide range of barriers for EE [19-21], including economic, organizational, and behavioural obstacles.

One of the most promising means of stimulating firm internal EE is through EnM [22,23]. Industrial EnM has been covered in a number of research publications, which have been comprehensively reviewed by Schulze, Nehler, Ottosson and Thollander [24] and May, Stahl, Taisch and Kiritsis [3]. There is a broad variety in the conceptual understanding of EnM, with sometimes interrelated and overlapping meanings. Lawrence, Nehler, Andersson, Karlsson and Thollander [2] describe EnM as the procedures in industrial firms addressing energy use to improve EE. EnM is also described as a system with reference to both computer-aided technical energy monitoring and measurement systems [25] and organizational systems for the continual improvement of energy performance [26]. Further, EnM is considered a tool in helping firms overcome barriers to improving industrial EE [27,28]. Agencies such as the International Organization for Standardization (ISO) denote EnM as a standard, such as the ISO 50001 [29] energy management standards, whereas Sannö, Johansson, Thollander, Wollin and Sjögren [4] describe EnM as a program. Although there is no cohesive definition of EnM in the academic literature, there seems to be a consensus that to achieve energy improvements, EnM must be integrated as practices within an organization [1-3,5,28,30]. It is, therefore, alarming that numerous studies report that manufacturing firms fail to practice EnM despite good intentions [2,10,26,31], thereby illustrating the difficulties established firms confront when attempting to implement EnM.

Prior studies on EnM practices have mainly focused on how to characterize successful EnM practices at the firm level [5,10,21,24,26,27,31,32]. With the exception of Sannö, Johansson, Thollander, Wollin and Sjögren [4], few empirical studies have analysed the adoption process and the performance of an in-house EnM program in a multinational company. Hence, the literature does not provide much knowledge on how firms adopt new EnM routines and implement adapted processes [24], and there are several calls for more research on firms' EnM practices and their alignment with core business and strategic agendas [33]. In agreement, Lawrence, Nehler, Andersson, Karlsson and Thollander [2] assert that 'while barriers to and drivers for industrial EE have been investigated for many industries, there is a lack of studies of barriers to and drivers for EnM practices'. Furthermore, scholars stress the need for more knowledge on the relationships between EnM practices and contextual factors, organizational and cultural characteristics, and human participation [3,34]. To address these calls, this study explores the implementation process of a corporate environmental program in an incumbent firm and the ensuing emergence of EnM practices by asking the question: How can a corporate environmental program be translated into EnM practices in a manufacturing firm?

The selected case company (Pharma) is a subsidiary of a multinational company (MNC) and subject to a corporate environmental program, EcoFuture. Through this program, the MNC pledged to integrate its long-term sustainability objectives into its business strategy and proposed environmental targets to this end. This study's analysis follows the implementation process retrospectively from 2004–2014. Translation theory and the 'travel of management ideas' is used as a theoretical lens in this single case study [35,36]. Sahlin-Andersson [36] defines management ideas as successful models that provide solutions to pressing problems in different contexts and at different points in time. They can further be described as social and legitimized norms for how an efficient organization should appear regarding structural arrangements, procedures, and routines [37], such as codes of ethics [38], lean management [39], reputation management [40], and balanced scorecards [41]. When ideas travel between settings (e.g. organizations), they can be understood as intangible accounts [35,36,42]. Therefore, when implementing a management idea into a new setting, the recipient organization needs to translate the idea according to the local context [43]. Local editors play a central role in reinterpreting the idea and giving it meaning in the new setting [38,44]. The outcome of a successful implementation process can be observed by the materialization of, for example, new routines and practices [40]. Hence, in contrast to the more traditional top-down view of innovation diffusion (e.g. [45]) and knowledge transfer [46], translation theory focuses on organizational change processes and their outcomes [38,47,48]. This theoretical framework is thus deemed suitable for analysing the implementation of an EnM program and the processes leading to the evolvement of EnM practices in the case company.

Building on this premise, this study contributes to the EnM literature with new knowledge about the internal processes, key editors, and contextual factors influencing the emergence of EnM practices in a manufacturing firm. In addition, the study adds to our limited knowledge of EnM adoption and implementation within MNCs. The study is also new in the sense that it explores the process longitudinally over a period of 10 years. The new information derived from this study benefits both practitioners and policymakers in their efforts to stimulate increased industrial EE. Furthermore, from a theoretical perspective, the study points to the potential of translation theory use in research on EnM.

The remainder of the paper is organized as follows. The second section presents the management idea and case company, as well as a literature review of EnM practices. The third section presents the theory of the translation of management ideas and the conceptual framework used in the empirical analysis. The research methods and data collection are outlined in section 4. Section 5 presents the results, while the discussion and conclusions section discusses several firm internal factors affecting the emergence of EnM practices in a manufacturing firm, highlights management and policy implications, and addresses avenues for future research,

## 2. Corporate environmental management program

The corporate environmental program of an MNC, here named EcoFuture, is the management idea scrutinized in this study. The MNC operates in a multitude of sectors, employing more than 300,000 people in over 180 countries. EcoFuture runs from 2004–2020 and aims to integrate long-term sustainable objectives into the core of the MNC's business strategy by: (1) increasing its investment in clean R&D (cleaner technologies); (2) increasing revenue from EcoFuture products, defined as products and services that provide significant and measurable environmental performance advantages to customers; (3) reducing greenhouse gas (GHG) emissions and their intensity, along with improving EE; and (4) informing the public. The program and its targets were globally revised in 2007, 2009, 2010, and 2014. Hence, at the corporate level, EcoFuture was mainly based on quantifiable environmental targets, without any instructions on how it should be operationalized at the local level in the subsidiaries.

The case company, Pharma, is a pharmaceutical company situated rurally in Norway with about 100 employees. The firm specializes in producing drug substances for contrast agents used in medical imaging. Hence, most of its activity is based on two products, for which it holds a significant market share. The firm's activity is thus mainly based on commodity-type products of high volume and limited variety, global markets, and high capital investments in facilities, which are typical in the broad-process industrial sector [33]. Pharma was purchased by the MNC in 2004 and became subject to the EcoFuture program; hence, the decision to adopt the program was not within the hands of the firm. To fit the program to the local setting, EcoFuture was locally translated and considered an EnM program. In this study, the emergence of EnM practices is considered indicative of the successful implementation of the corporate environmental program.

In developing a threshold used when characterising the EnM practices of Pharma, prior studies were reviewed and synthesised as 'best EnM practices'. The reviewed articles were identified by searching for 'energy management practices' in Google Scholar and through manual screening of cross-references. Empirical articles addressing EnM practices in manufacturing firms were sampled. The selection of articles in Table 1 does not represent an exhaustive list but provides an overview of the EnM practices relevant to energy improvements. Whereas prior studies have categorized EnM practices as 'minimum requirements' (e.g. [26]) and 'maturity matrixes' (e.g. [2]), this study presents the more comprehensive 'best EnM practice' based on a larger sample of empirical articles.

**Table 1.** Theoretical 'best EnM practices' based on a synthesis of scholarly articles

| Categories | Energy Management Practices (EnM practices) | Brunke, Johansson and Thollander [21] | Bloom, Genakos, Martinand Sadun [49] | Thollander and Ottosson [10] | Schulze, Nehler, Ottosson and Thollander [24] | Ates and Durakbasa [31] | Johansson and Thollander [27] | Christoffersen, Larsen and Togeby [26] | Martin, Muûls, De Preux and Wagner [5] | Gordić, Babić, Jovičić, Šušteršič, Končalović and Jelić [32] |
|---|---|---|---|---|---|---|---|---|---|---|
| **anagement and environmental leadership** | Top management support and awareness of energy issues | X | | | | X | X | X | X | |
| | Energy strategy (policy), planning, and targets | X | X | X | X | X | X | | X | X |
| | Employee involvement, motivations, and incentives | | X | | X | | X | | | X |
| **Organizational structures and routines** | Organizational structure, energy manager position, and allocation of energy costs | X | | X | X | X | X | X | | X |
| | Information systems, sub-metering, controlling, and monitoring | X | X | | X | | X | | X | X |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Competence** | | | | | | | | | | |
| | Staff awareness, education, and training | | | | X | | X | | | X |
| **Investment decision** | Investment and pay-off criteria | X | | X | X | | | | X | X |
| | Competitions and energy prices | | | | | X | | X | X | |
| **Firm characteristics** | Firm characteristics | | | | | X | | X | | |
| | Operations and production processes | | X | | | | | | | |
| | Innovation and R&D focus | | | | | | | | X | |
| **External factors** | Policies and regulations | | | | | X | | X | X | |
| | External relations | | | | | X | | X | | |

Table 1 synthesises the findings in the literature on how to characterize successful EnM practices. These theoretical 'best EnM practices' assert the need to adopt both management routines and organizational structures, in addition to competence-enhancing activities. Considering environmental leadership practices, it is essential that top managers support and are committed to the environmental agenda and formulate long-term environmental strategies and goals. Management practices should also focus on employee involvement and motivation. Furthermore, successful EnM practices depend on adapted organizational structures and routines, such as a dedicated personnel working on energy matters and a clear allocation of responsibility. Additionally, energy measurement systems and routines are essential in controlling, monitoring, and planning energy consumption against strategic targets, thus allowing for effective information assimilation and reporting to management and operations personnel. Competence is positively related to environmental awareness; hence, education and training are outlined as important ways to improve internal energy performance. Studies also assert that EnM should be reflected in a firm's investment decision processes and plans by prioritizing environmental business objectives and allocating resources to EE projects. Firm characteristics and operations, such as production processes, innovation, and R&D focus are also found to influence EnM. It is of note that although some studies include energy costs and external factors they are not organizational structures or routines and thus not here considered as EnM practices.

## 3. Theoretical framework

In exploring the emergence of EnM practices in Pharma, this study considers EcoFuture a management idea and analyses the firm's internal translation process of the idea. When travelling between settings, ideas are conceived as immaterial accounts that are dis-embedded from their original contexts in terms of time, space, and location [36,40]. Hence, when an idea is re-embedded in a new setting, it must be translated and recontextualized [35]. This translation process is driven by people – editors – that edit the idea according to their individual perspectives and preferences. Indeed, Latour [50] states that 'each of these people may act in many different ways, letting the token drop, or modifying it, or deflecting it, or betraying it, or adding to it, or appropriating it'. Thus, each editor contributes to the idea with meaning. As the translation process may include a broad range of editors, including government personnel, managing directors, middle managers, researchers, consultants, and trainers [44,47], there are numerous ways of editing the idea. The translation process is ultimately about mediating and aligning various conceptions, interests, and objectives [51]. The outcome can be witnessed through changes in the mindset of individuals, formal documents, and the enactment of new practices [40]. This study focuses on the emergence of EnM practices specifically.

Theorists have conceptualized the translation process through, for example, translation modes and rules [40,42], abstraction levels [48,52], and translation processes [51]. The theoretical framework in this study builds mainly on editing rules, following Sahlin-Andersson [36], which are apt for analysing the steps of translating broad ideas into local workplace practices. The first editing rule concerns the context and the process by which the idea is made appropriate for the local setting. In recontextualizing the idea, organizational members add time, space, and sector-bounded features and make it relevant to the local setting. In this study, emphasis is placed on regulative and normative sector-bounded features and macroeconomic issues. The second editing rule concerns the formulation and labelling of ideas. The focus is on how the idea is formed so that it is deemed appropriate in the new context by discarding and adding elements to the idea [40]. Relabelling offers explanations for why an idea is successful and allows an idea that 'seems different but familiar' [39] and is relevant when analysing how EcoFuture was formulated, branded, and communicated to the organization at different points in time. The third rule relates to the plot of the story or the rules of logic. Sahlin-Andersson [36] describe this rule as the rationale behind the idea, in which 'explanations are given as to why a certain development has taken place'. Doorewaard Doorewaard and Van Bijsterveld [51] describe this as a power-based process in which the actors 'continuously reshape the element of this process by confronting their own ideas with those of others and with existing organizational practices'. Prior empirical studies provide different examples of how to operationalize this editing rule [39,53]. Here, the focus is on the editors' endeavours in championing EcoFuture in the organization and stimulating engagement by aligning EcoFuture with the existing organizational logic. Because the materialization of the idea is inextricably linked to the translation process, the theoretical framework is extended to also consider the emergence of local EnM practices. This is done by evaluating Pharma's EnM practices with reference to the best EnM practices described in Table 1. The theoretical framework is summarized in Figure 1.

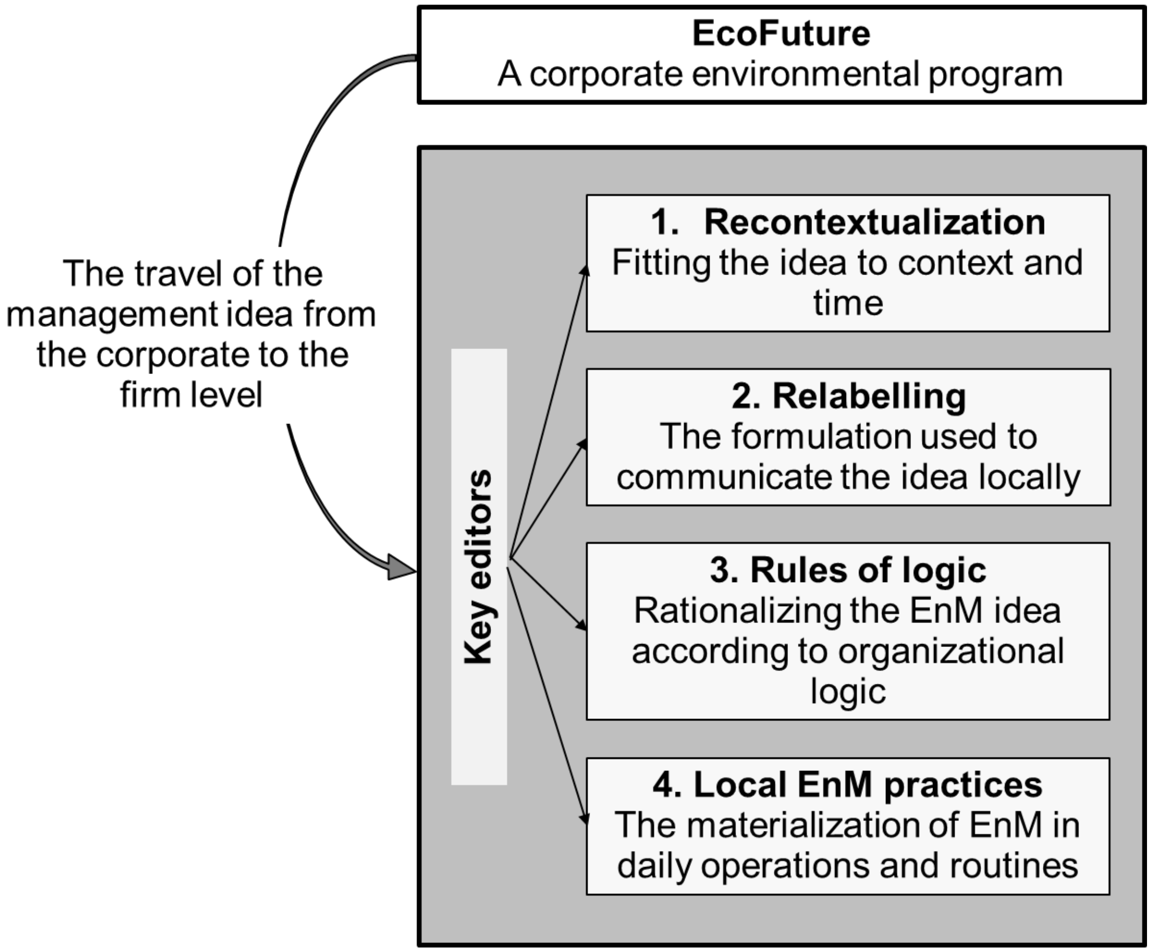


**Figure 1.** Translating EnM: From a corporate environmental program to local EnM practices

The figure depicts how the original idea travels from the corporate to the firm level and illustrates the translation steps and the involvement of key editors. It is important to notice that time is essential in the translation process, which is not captured by this model.

## 4. Materials and methods

### *4.1 Data collection*

This study explores factors affecting how and why an idea emerges as EnM practices by analysing the translation process over 10 years and using a qualitative and process methodology [54]. In this single case study [55,56], the case is selected purposefully [57] and considered information-rich and adequate to answer the research question. The empirical data were collected retrospectively through interviews, observation, manuals, and other documents during three company visits over a period of four months in 2014. It started with a meeting with the energy manager at Pharma. At this first meeting, the overall objectives of the research project were discussed. The second company visit included a guided tour of the site and observations in some of the factories, a firm presentation, and an interview with the firm's top management. Additionally, the author was given access to internal documents such as investment prospects, project descriptions, and project manuals. The author also collected secondary information from press articles, marketing brochures, conference proceedings, and annual corporate reports. This information was used to prepare for new interviews. During the third company visit, semi-structured interviews were carried out with key informants. The main purpose of the interviews was to understand informants' perceptions of the firm's operations, including production processes, R&D, technology implementation, and decision processes and practices for employee involvement and training. Additionally, they were asked about their understanding of EcoFuture and the integration of EnM into the firm's daily operations and activity. Following Eisenhardt and Graebner [58], data were collected from highly knowledgeable informants who view the focal phenomena from diverse perspectives. The energy manager helped identify key informants representing a cross-section of the organization that were engaged in and/or affected by EcoFuture, including the director of health, safety, environment (HSE), energy manager, project managers, site managers, operating personnel, R&D staff, and members of the EcoFuture team. This cross-sectional sample allowed for a comprehensive understanding of the translation process and EnM practices within Pharma. For practical reasons, some of the interviews were performed in groups of 2–3 interviewees. In total, nine key informants were interviewed. Two of the informants, considered particularly knowledgeable, were interviewed more than once. Hence, during the period, eight interviews, individually or in groups, were conducted, each lasting 1–2.5 hours. All interviews were fully transcribed.

### *4.2 Analysis*

The analysis is based on an abductive research approach [59,60], alternating between translation and EnM theory and the empirical data and successively reinterpreting one in light of the other. Such theoretical conceptualization of the empirical data is particularly suitable for case studies [56]. Furthermore, temporal bracketing was applied as an analytical strategy [55] by which the data are decomposed into successive periods. This strategy permits the composition of comparative units of analysis [61] and helps analyse how the translation of EcoFuture unfolds over time. Accordingly, this strategy mitigates the absence of the time dimension in the theoretical framework (Figure 1). The analysis started with a chronological presentation of the empirical data. The sequence of events revealed some shifts in intensity of the translation process by which the empirical data were decomposed into the following three periods: 2005–2007, 2008–2010, and 2011–2014. Then, following this chronological structure, the empirical data were analysed according to the translation steps in the theoretical framework. Using Nvivo software, the empirical data was coded along the two dimensions of time periods and translation steps. The use of both primary and secondary data sources allowed for the inclusion of both broad trends and fine-grained information and for developing an understanding of the translation process retrospectively. Triangulation of the multiple sources also helped reduce the intrinsic biases in the empirical materials. Finally, the result of the translation process was analysed by comparing the firm's EnM practices with the theoretical best EnM practices (Table 1).

## 5. Results

The presentation of results is structured according to the three chronological time periods described in section 4.2. By following the translation steps across periods, the findings illustrate how EcoFuture goes through a process of maturity before unfolding as EnM practices. The findings are summarized in Table 2 at the end of the chapter.

### *5.1 Period 1: Contextualizing EcoFuture as an EE program*

The first period is mainly recognised by the top managers' initial efforts to fit EcoFuture into the local setting. Normally, the translation process begins with the decision to adopt the idea [43] In contrast, the adoption decision was made at the corporate level, and the local managers had to find ways to fit EcoFuture at the firm level. Hence, the top management contextualized EcoFuture according to regulative and technological sector-bounded features. The results point to the impact of pharmaceutical acts regulating lengthy procedures and product certificates before commercializing new drugs, in addition to licences and emission permits by the national environmental authorities affecting the firm's production figures. Furthermore, Pharma was characterized as having a few commodity-type products, continuous production in high volumes, extensive capital binding in existing production equipment and facilities, and limited access to investment capital. The following interviewee quote illustrates how EcoFuture imposed new environmental demands on the firm without the backing of additional resources:

*[Y]ou don't get any money for doing this. The environmental investments compete on equal terms with any other investment project. They say that we have to reduce the energy consumption, but they don't say 'Here, you have money to do it'. It doesn't work that way. The environmental projects have to enter ordinary budgets. That is tough!*

These regulative and technological features prompted the managers to search for a way to implement EcoFuture without triggering significant operational changes or large investments. Subsequently, EcoFuture was edited to fit the extant portfolio of products and production processes by contextualizing it as an EE program. During this first period, Pharma had significant potential for EE improvements, which was realized via minor adjustments and 'picking the low-hanging fruit'. However, only the top managers were preoccupied with EcoFuture, with no significant efforts made to implement the program within the entire organization. Such situations in which the idea resides high in the hierarchy so it is decoupled from organizational practice are described as 'isolation' by Røvik [43] the travel of ideas and stagnating EE improvements.

*5.2 Period 2: Economic shocks, relabelling, and first evolvement of EnM practices*

This second period is recognized by external economic shocks and changes in the institutional environment that boosted the relevance of EcoFuture. Accordingly, the local translation of the program intensified, with the top managers recontextualizing and relabelling EcoFuture in an effort to implement the program within the organization. Indeed, the global financial crisis of 2008 led to reduced sales, price drops, and production overcapacity. The patent protection on Pharma's products also expired during this period, leading to increased competition from generic drug manufacturers. EcoFuture was also revised at the corporate level and the environmental targets amplified. As the firm had already taken advantage of the 'low-hanging fruit', greater organizational involvement was now needed, and it became necessary to rethink the strategy and organization of the program.

Economic considerations were prominent when top managers edited the idea. Furthermore, in translating EcoFuture into an internally understandable concept, the program was relabelled as a productivity program named 'Smart Growth', with an emphasis on EnM. The use of familiar rhetoric is an efficient means to avoid organizational resistance to an idea [38]. Productivity was a well-established concept within the organization. EcoFuture and EnM were, hence, fitted to the local setting by having productivity as a primary objective and taking advantage of the synergies between increased productivity and EE. This approach is illustrated by an interviewee stating that the 'environmental benefits are a spin-off of productivity'.

The intensification of the translation process also involved the restructuring of the organization and technical improvements. Furthermore, new EnM practices started to emerge such as energy audits, the systematic monitoring of main energy streams, and the measurement of total energy consumption, all of which are essential for attaining correct information, reporting, transparency, and constructing a shared course of action in strategic energy planning [69]. In addition, the operations personnel started to engage in EE. As illustrated by the following interviewee quote, this upscaling of the program can be considered an important premise for succeeding with energy improvements:

*[F]rom then, the program changed from being an energy-saving program that only some were engaged in to become a factory productivity program. This is one of the success criteria.*

In contrast to the stagnation described in the first period, the idea was now reactivated in response to contextual changes [43] and locally considered a productivity and EnM program. Subsequently, the initially abstract idea started now to materialize with the addition of local elements [42] and to travel further in the organization. This could be observed in both the relabelling of EcoFuture and the first emergence of EnM practices.

*5.3 Period 3: Role of the energy manager in rationalizing the idea into EnM practice*

During the first two periods, EcoFuture was edited into an EnM program after being recontextualized and relabelled primarily by the top managers. In contrast, this third period is recognized by the emergence of EnM practices. The analysis indicates that several organizational characteristics affected the editing of the idea: the technological complexity of the production processes, organizational resistance to change, organizational integration of energy issues, and the rationale of economic feasibility. Furthermore, the analysis emphasizes the energy manager's editing role and efforts in aligning EnM with these organizational characteristics and thus stimulating the emergence of accepted and legitimate EnM practices.

Pharma had developed a complex production infrastructure over decades. Any changes in the production processes, including energy improvements, required not only excellent engineering skills but also comprehensive and in-depth knowledge about the factory. External parties lack such detailed knowledge; thus, the innovation processes in Pharma depended mostly on the skills and creativity of the employees. Consequently, Pharma's EnM practices were largely determined by the employees' adoption of and motivation toward EnM. This finding coincides with prior studies underlining the role of operations personnel in process innovation and EnM [2] and the significance of employee motivation regarding EnM [25]. Nonetheless, in addition to technological complexity, the translation of a management ideas needs to deal with and is affected by organizational resistance to change [53]. Such resistance was also experienced in Pharma, with the following interviewee quote illustrating the challenge of motivating employees to work collectively toward EnM:

*[W]e have some examples [in which] we have completed projects in one area where the savings have been in another area, and then we have met a lot of resistance in the area in which the change has taken place.*

The integration of energy issues in organizational structures, or lack of such integration, also affected the translation process. Pharma had systems and routines for controlling and monitoring the largest energy flows, however the analysis indicates that energy issues was only formally integrated in selected areas of the organization. This restricted integration can be exemplified by the firm's use of key performance indicators (KPIs) KPIs are a management tool developed to motivate employees in a preferred direction, and their use is a recommended EnM practice [27]. Nonetheless, the use of KPIs can also hamper change processes and compromise EnM practices [1]. In Pharma, KPIs were customized to the main activity of each unit, and only the units with extensive energy consumption had energy use integrated into their KPIs. Consequently, this use of KPI's provided most employees with limited incentives and motivation for engaging with the firm's total energy consumption.

An additional organizational characteristic affecting the editing process and the emergence of EnM practices in Pharma was related to the prominent rationale of economic feasibility. In general, investments arise due to new technology, machinery wear-out, and changes in market demand, prices, and legal requirements. Investments are, thus, necessary to remain competitive in changing environments. The analysis indicates that the principle of 'good business' was an overarching logic in Pharma and strongly affecting the internal investment decision processes and reporting schemes . Good business is understood as investments that are economically feasible in the short term and ideally lead to long-term sustainability. Indeed, all investments were based on economic considerations within which environmental improvements were deemed positive spin-offs. This approach is exemplified in the following interviewee quote:

*We don't really think that our first priority is to save the environment. However, we include it in productivity. We will show you how we plan to become CO2 neutral … It is, however, not a target in itself for this factory, even though there are some demands for us to become CO2 neutral.*

The significance of the economic logic is also apparent in the way investment projects were evaluated and prioritized. The typical required payback time for investments was 2–3 years. Prior studies have noted that it is a challenge for energy projects to comply with such short payback demands, thus causing a significant barrier for industrial EE improvements [62,63]. Furthermore, all investment projects were categorized and rated according to compliance, health, safety and environment (HSE), maintenance, and productivity. The following interviewee quote illustrates the limited priority given to environmental objectives:

*Legislative compliance, HSE, and maintenance have priority before the green projects (because the green projects are sometimes productivity-related), and we don't get green projects through just because they are green.*

This practice contradicts with recommendations from prior studies asserting that earmarked funding for environmental investments is a significant driver for EE [70]. Moreover, Sandberg and Söderström [70] state that the priorities made during investment decision processes depend on the culture of the firm. In other words, the strong economic rationale can be considered a cultural factor affecting the translation process of EnM in Pharma. Despite these organizational characteristics, Pharma continued to improve its EE significantly. Furthermore, the findings point to several EnM practices within the firm that seem to have had a positive impact on the energy performance. Indeed, Pharma had significant long- and short-term energy targets and an elaborate system for controlling and monitoring the most important energy flows. The firm also had organizational structures and routines for assimilating information and reporting to management and the organization about energy consumption. Nonetheless, to gain support for energy-related projects during investment decision processes, energy improvements had to be argued and rationalized according to the extant economic logic and culture of the firm. Hence, arguments based on compliance, HSE, maintenance, and productivity had to be integrated and highlighted in environmental projects or vice versa. This strategy of searching for and aligning economic and environmental objectives is here considered an EnM practice.

Moreover, to stimulate and motivate employees to work collectively with EnM, Pharma provided several competence-enhancing schemes and activities such as internal training programs and education support, which are found to be significant drivers for industrial EE [23,64]. The following interviewee quote illustrates how the benefits of energy improvements at the individual level were identified and communicated to provide motivation to make energy improvements:

*The best projects are carried out when the area in which the change takes place [obtains] good benefits from the change. So, being very strategically smart, when you create projects, you have to find something that the department [in which] the change [takes place] benefits from.*

This illustrates how the process of editing EcoFuture into EnM practices involves selling a version of the idea, mediating others' versions, and aligning goals and agendas [44], thus supporting Doorewaard Doorewaard and Van Bijsterveld [51] who describe translation as a power-based process in which the involved actors 'continuously reshape the element of this process by confronting their own ideas with those of others and with existing organizational practices'. Although several human resources from different parts of the organization were allocated to work with energy issues, and thus involved in the translation process, the findings point to the prominent editing role of the energy manager

In Pharma, the energy manager had seniority and operational experience, which provided him with in-depth knowledge about the factory and production processes. He also took advantage of the established energy monitoring practices, which provided him with accurate information on energy consumption, production bottlenecks, and investment opportunities. Radaelli Radaelli and Sitton-Kent [44] describe several channels that middle managers can use in this editing process. Here, the energy manager worked proactively and used formal and informal arenas to continuously sell the EnM idea, manage conversations, and align diverging interests among organizational units and members. He also formed alliances with external stakeholders. The use of an external network is a well-known strategy for enhancing EE by exchanging knowledge and ideas [30]. Pharma was a member of an industrial network for sustainable process industry firms. This network in addition to other external stakeholders were used strategically to gain legitimacy for the idea and convey the relevance of EnM to the organization by promoting Pharma's EnM at conferences, generating editorial publicity, and inviting firms, experts, academics, non-governmental organizations, and politicians to the site.

Further, the energy manager's central position in the organization allowed him to communicate directly to top management and have close relationships with operations personnel. The energy manager's position in the organization affects EnM implementation [5,33]. Personal relationships are also known to be valuable assets in innovation processes [71]. Here, the energy manager took advantage of his position in the network to get involved in the conceptual design of projects early on. The following quote by the energy manager illustrates how such early involvement is essential for aligning the demands, interests, and rationales of other organizational members:

*Here, we have a project that is very good. However, it does not include that much energy saving. It is a project that is about reducing solvent in one area. It provides a yield increase and some energy savings… I think there is more energy to be saved! Since it includes energy saving, I have worked with the concept.*

By getting involved early in the conceptual design of new projects, the energy manager uses his expertise when strategically aligning the EnM idea with the organizational rationale, engaging allies, and inviting opponents to identify common goals and values. In this way, he helps stimulate the firm's EE. Accordingly, this study asserts that early involvement in projects and the editing process also should be considered a relevant EnM practice. In summary, the third period is characterized by the energy manager's editing efforts needed to rationalize and embed EnM in firm practices. Although top managers were predominant in the first two periods, the energy manager emerged as a key editor during this third period.

### *5.4 EnM practices in Pharma*

The result of the translation process is evaluated based on the premise of the emergence of EnM practices and with reference to the theoretical 'best EnM practices' (Table 1). The observed EnM practices in Pharma are listed in Table 2 and marked with (+) or (-) depending on their compliance with a 'best EnM practice'. The study finds that the EnM practices of Pharma to a large extent comply with the theoretical recommendations. Indeed, several EnM practices related to management, organizational routines and structures, and competences are identified. In contrast, the study also reveals that Pharma lacks EnM practices that are thought to be essential in succeeding with EE. First, for most units in Pharma, the KPIs do not include energy indicators. Hence, the use of KPIs might eventually reduce employees' motivation to improve the firm's overall energy performance. Second, the energy strategies are not integrated into the firm's investment decision processes, which is known as a considerable barrier to EE improvement [62,63]. Regardless, the firm improved its EE considerably over the analysed period, which might seem a paradox. There are several plausible explanations for this, such as the practices aligning environmental and economic objectives, early involvement, and employee motivation.

**Table 2.** Translation process of the idea according to translation concepts and period

| **Time Period** | **External factors** | **Translation concepts** | | | | |
|---|---|---|---|---|---|---|
| | **Context**<br>Contextual factors external to the firm affecting the translation of the idea | **Recontextualization**<br>Fitting the idea to the context and time | **Relabelling**<br>Formulations used in communicating the idea locally | **Rules of logic**<br>Rationalizing the idea according to the inherent organizational logic | **EnM practices**<br>Materialization of EnM in daily operations and routines | **Key editors** |
| 2005–2007 | EcoFuture is launched (2005) as a corporate environmental program<br><br>EcoFuture targets include:<br>• Increase investment in R&D of cleaner technologies<br>• Increase revenues from products and services that provide environmental performance advantages to customers<br>• Reduce GHG emissions and improve the EE of the firm's operations | The program was contextualised according to national environmental regulation, sector bounded technological and regulative features, in addition to limited access to investment capital, and translated as an energy efficiency program | - | The editors were focusing on synergies between environmental and efficiency objectives – 'picking the low-hanging fruit' | - | Top management |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2008–2010 | EcoFuture is revised (2009 and 2010) with new and increased targets<br>Global financial crisis<br>Increased global competition<br>Establishment of an industrial cluster – a network in the sustainable process industry | The program was locally contextualised as an EnM and organization development program, with focus on productivity | The program was relabelled 'Smart Growth', including emphasis on energy efficiency | Economic rationale: all EnM investments should be economically feasible | (+) Top management awareness of and support for EnM<br>(+) energy audits<br>(+) Systematic monitoring and measuring of energy consumption<br>(+) Employee involvement | Top management |
| 2010–2014 | EcoFuture is revised (2014) with new and increased targets | - | - | Economic rationale: all energy investments should be economically feasible | (+) Systems and routines for controlling and monitoring the largest energy flows<br>(+) Long- and short-term energy reduction targets<br>(+) Routines to provide information about energy consumption to management and the organization<br>(+) Allocation of resources to energy issues; two full-time employees (including the energy manager) are working with environmental reporting and energy-saving projects, with the ability to involve others when needed | Energy manager |

| | | | |
|---|---|---|---|
| | | The rationalization of the program was also affected by the technological complexity of the production processes, organizational resistance to change, and existing organizational integration of energy issues | (+) Energy manager is positioned strategically in the organization and reports directly to the top management<br>(-) Only production areas with a high consumption of energy have energy-related KPIs and are, hence, motivated to engage in energy-saving projects; other areas lack the same incentives<br>(+) Top managers are aware of and support environmental issues and the value of energy savings<br>(+) Employees have opportunities for internal and external EnM-related training and education<br>(+) Culture of employee involvement, communication, and cooperation between departments to identify good technological solutions for reducing energy consumption<br>(-) The firm has not earmarked any investment capital for EnM; EnM projects are evaluated similarly to all other projects according to compliance, HSE, maintenance, and productivity. |

| | |
|---|---|
| | (-) Investments in energy projects are assessed according to a relatively short payback time of 2–3 years<br>(+) Member of an external network for sustainable process industry firms in the region |

Note: (+) = EnM enhancing practices, (-) = EnM hampering practices

Table 2 depicts the implementation process of the idea in terms of translation and periods over several stages. The implied linearity of the translation process, as depicted in the conceptual framework, was more complex than assumed. In fact, the translation did not follow a chronological order but rather stages with several concepts in each stage.

## 6. Discussion

This study explores the implementation of a corporate environmental program in a manufacturing firm and the emergence of EnM practices, a perspective that has received limited attention in the EnM literature. The conceptual framework is built on translation theory and the EnM literature, and the empirical analysis is based on data from a single case study over the period 2004–2014. The results of the study suggest that the case company practices EnM quite extensively, and complement prior research suggesting a positive link between EnM practices and energy efficiency in manufacturing firms. Furthermore, the findings of the study indicate that several firm internal factors affect the emergence of EnM practices: (1) the dynamics of the translation process and relevance of time (2) the abstraction level of the idea, (3) the key editing role of the top management and the energy manager according to the steps of the process (4) the EnM practices of the case company and the identification of alternative EnM practices.

Regarding the dynamics of the translation process the results of this study show how the translation of the corporate environmental program passed through three time periods, which were recognised by changes in intensity and the involvement of various editors.

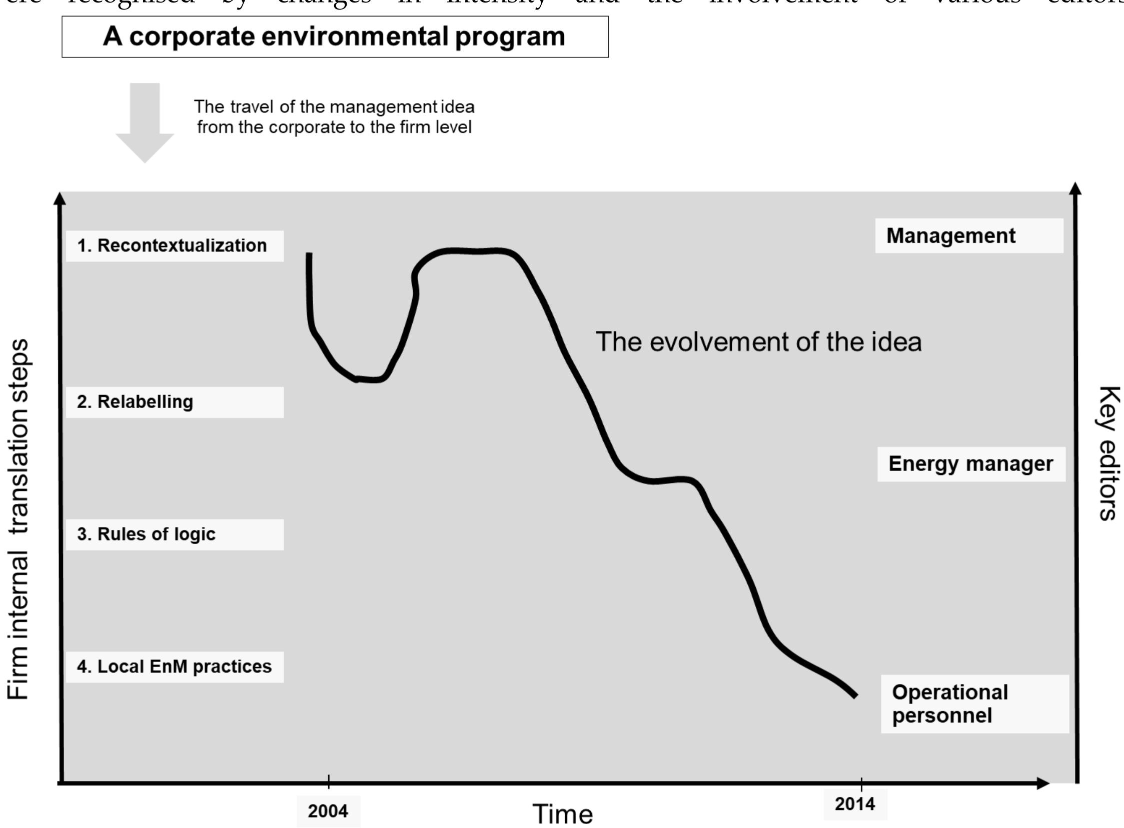


**Figure 2.** Conceptual model of the firm internal translation process from corporate program to emergence of EnM practises

Figure 2 is a conceptual model of the translation process leading to the emergence of firm-level EnM practices. The model incorporates the local translation steps, the involvement of key editors, and the time dimension. This model illustrates how the translation moved back and forth between translation steps and key editors over a decade before resulting in new local EnM practices. Hence, the implied linearity of the translation process, as depicted in the conceptual framework, was more complex in reality. This observation complements prior studies stating that ideas need to undergo several cycles of translation before being applied to a new setting [39]. The findings also correspond to Røvik's [43] remark that ideas might alternate between passive and active phases and may linger in an organization for a long time before materializing, leading to a gradual, slow-phased transformation of the idea to practice. Subsequently, the model illustrates the relevance of time, management endurance and the involvement of key editors from all levels in the organization when implementing an environmental program in a manufacturing firm.

Translation theorists hold that there are variations in the abstraction level of management ideas. The abstraction level reflects whether the idea provides detailed descriptions on how to operationalize it or gives room for the local organization to make its own interpretation of the idea [52]. Moreover, Røvik [42] argues that abstract ideas are more complex and thus harder to implement in a new context. EcoFuture was oriented around quantifiable targets without providing details on how to operationalize the program locally, and is thus here considered to hold a rather high abstraction level. The results show that the abstraction level of the environmental program allowed the editors much flexibility during the translation process, and that EcoFuture changed quite extensively when fitted to the local setting. Hence, in contrast to prior research Røvik [42], the study suggest that the high abstraction level of the program might have be a success criterion rather than a barrier for the implementation of the program and the emergence of EnM practices.

It is also important to notice how the involvement of key editors changes over time according to the steps of the process. Although the top managers played an important role, in the first stage of the process, in contextualizing and labelling the corporate environmental program for the local setting, the energy manager emerged as a key editor when rationalizing the idea into EnM practices accepted and adopted by the operational personnel. Energy managers are often middle managers that lack the hierarchical authority of top managers and the immediate operational knowledge of operations personnel [44]. Although energy managers' operational experience is found to have a positive effect on firms' EnM [63], this study addresses how an energy manager can use his or her competence, social network and position in the organization to champion the environmental agenda. Furthermore the results show how the energy manger worked actively, using formal and informal arenas, to rationalize energy improvements using logic that was deemed legitimate and agreed upon in the organization.

The results show that Pharma practiced most of the EnM practices recommended in the literature. Indeed, the study complements prior research in emphasizing the relevance of EnM practices related to environmental leadership, organizational structures and routines, and competence-enhancing activities. However, compared with the theoretical 'best EnM practices' (Table 1), there are some vital shortages in the firm's EnM practices. In particular, this relates to the investment decision processes and use of KPIs, under which environmental issues are granted limited priority. Financial limitations and firms' reluctance to prioritize EnM at a strategic level are considered substantial barriers to energy performance [10,33]. Despite this, the firm reports exemplary records of EE improvements during the analysis period. The results point to some new EnM practices absent from previous EnM studies that might provide plausible explanation for this paradox. First, editors and proponents of the environmental program worked actively to align environmental and economic objectives in projects, thereby gaining favour in the investment decision process without earmarking funding for environmental projects. A second practice is to design projects so that all operations personnel involved in or affected by the projects gain benefits and thus support the necessary changes. A third practice relates to the active role editors must take to constantly sell their version of the idea, mediate others' versions, and align goals and values. Hence, EnM was put on the strategic agenda by translating EnM according to the firm's extant economic organizational logic, and projects were conceptualized so that both economic and energy objectives were attained. In this way, the firm surmounted financial and organizational barriers and attained continuous EE improvements. This finding supports Røvik's [65] claim that management ideas' capacity to travel depends on the extent to which they are associated with rational values such as renewal, efficiency, and effectiveness. Furthermore the results indicate that the firm's translation competence, that is the ability of editors to translate ideas and programs between organisational contexts, increase the probability of achieving the desired organisational ends [42,72]**.** In addition, the results points to the flexibility related to the translation process. Indeed, what the environmental program represents becomes negotiable in each new setting, where each local translation is likely to give rise to new versions of the program, with significant variations in structures, routines, and practices. Arguably, it is impossible to create 'best EnM practices' that fit all contexts and organizational settings, and one might question the need for a best-practice example of EnM, as addressed by Schulze, Nehler, Ottosson and Thollander [24]**.** Instead, it might be more useful to have best EnM translation process that could help firms customize the environmental program to their context and organizational logic and thus succeed in translating the program into EnM practices.

This study has implications for both managers and policymakers. From the perspective of managers, the study emphasizes that organizations are not passive receivers of environmental programs but play an active role in editing and reshaping how they are operationalized as EnM practices. Commonly, the implementation of management ideas includes lengthy processes that last for years and thus require managerial endurance, support, and dedication. Furthermore, as middle managers and other employees play a prominent role during this process, managers need to encourage and educate individuals and set up organizational structures supporting the environmental change process.

This study is also relevant from a policy perspective. By advocating a positive relationship between EnM and firm EE, the study suggests that EnM is an important way to attain the EU Energy Roadmap 2050 [66] targets. To accelerate the emergence of EnM practices in manufacturing firms, there are three mechanisms that policymakers should consider: regulation, idea complexity, and education. Policies and regulations on energy consumption or emissions may require organizations to adopt a concept or maintain a certain practice, as legislative compliance is a precondition for business operation [67]. Voluntary agreements based on cooperation are also effective in overcoming the traditional constraints of implementing top-down policies at the local level [68], and allow each firm to identify the solutions that are deemed most fitted for the local setting. The study also illustrated how the abstraction levels of an idea affect how the environmental idea is implemented locally. An abstraction level that is either too high or too low might pose challenges for implementation [52]. Hence, policymakers must be observant and ensure that the policy framework contains all relevant information required to explain and understand the EnM practices and be flexible enough to fit it into the local setting. Furthermore, this study shows that the emergence of EnM practices depends on the competence of the editors and the amount of resources devoted to educating and training organizational members. This implies that energy policies should support EnM-related education and on-the-job training.

This explorative study has provided new knowledge on firm internal processes and key editors affecting the emergence of EnM practices, nonetheless there are some limitations related to the research design of this study. It is for example challenging to make causal connections between actions and results in single case studies. Furthermore, the translation occurs in a dynamic environment in which both the idea and context change over time [47]. Hence, it is difficult to determine if the EnM practices emerged as a direct result of the idea or would have emerged regardless of the adaptation. More research is thus needed to obtain better knowledge about this causal relationship. Preferably data should be collected real-time in a comparative multiple case studies.

Moreover, although this study focused on the translation process in a recipient organization, little is known about how to effectively prepare an idea for new settings. Hence, there is need for more research about the decontextualization phase of environmental programs – that is, translating the desired practices into an abstract representation (e.g. images, words, and texts) that is easy to recontextualize at the firm level. More knowledge about this process can thus give rise to valuable recommendations to policymakers on how to design environmental policy frameworks that easily travel across contexts and organizations.

Furthermore, the findings in this qualitative study show how linking to translation theory can serve as a stepping stone in the theoretical evolvement of EnM studies and suggest an interesting avenue for future research.

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# APPENDIX 1

# CO-AUTHOR STATEMENTS

## Author declaration

**Paper title:** Closing the energy efficiency gap—a systematic review of empirical articles on drivers to energy efficiency in manufacturing firms.

**Authors**: Solnørdal, M. T., & Foss, L.

**Published**: 2018, *Energies*, 11(3), 518. doi:https://doi.org/10.3390/en11030518

**Author's contributions:**

Mette Talseth Solnørdal is the first author of the paper and had primary responsibility of all developmental phases of the paper. She developed the concept and idea of the paper, the research design, conducted the systematic literature search, analysed all articles and prepared the manuscript. Lene Foss is the second author of the paper and contributed with comments and guidance of all the developmental phases of the paper and critical revision of the content of all paper drafts.

| Development phase | Mette Talseth Solnørdal | Lene Foss |
|---|---|---|
| Concept and idea | X | |
| Study design and methods | X | |
| Data collection | X | |
| Data analysis | X | |
| Interpretation of results | X | |
| Manuscript editing | X | |
| Critical revision of the intellectual content | X | X |

With my signature, I consent that the above listed articles where I am a co-author can be a part of the PhD thesis of the PhD candidate

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Signature: ---------------------------------------- ------------------------------------ Lene Foss

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Date: 28.10.2020

# Author declaration

**Paper title:** Absorptive capacity and energy efficiency in manufacturing firms – An empirical analysis in Norway

**Authors**: Solnørdal, M. T., & Thyholdt, S. B.

**Published**: 2019, *Energy Policy*, 132, 978-990. doi:https://doi.org/10.1016/j.enpol.2019.06.069

**Author's contributions:**

Mette Talseth Solnørdal is the first author of the paper and had primary responsibility of all developmental phases of the paper, except the statistical data analysis. She developed the concept and idea of the paper, the conceptual framework and research design, and was responsible for collecting the dataset from Statistics Norway. She also prepared the manuscript. Sverre Braathen Thyholdt is the second author of the paper. He contributed with the statistical analysis, the interpretation of the statistical results and manuscript editing.

| **Development phase** | **Mette Talseth Solnørdal** | **Sverre Braathen Thyholdt** |
|---|---|---|
| Concept and idea | X | |
| Study design and methods | X | X |
| Data collection | X* | |
| Data analysis | | X |
| Interpretation of results | X | X |
| Manuscript editing | X | X |
| Critical revision of the intellectual content | X | X |

*dataset from Statistics Norway

With my signature, I consent that the above listed articles where I am a co-author can be a part of the PhD thesis of the PhD candidate

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