FME HighEFF

Centre for an Energy Efficient and Competitive Industry for the Future

Deliverable 5.1_2020.14

Centre innovation coordination. Journal Paper II.

Developing and (not) implementing radical energy efficiency innovations: A case study of R&D projects in the Norwegian manufacturing industry

Delivery date: 2020-12-14

Organisation name of lead partner for this deliverable:
NTNU Samfunnsforskning

HighEFF- Centre for an Energy Efficient and Competitive Industry for the Future is one of Norway's Centre for Environment-friendly Energy Research (FME). Project co-funded by the Research Council of Norway and Industry partners. Host institution is SINTEF Energi AS.		
Dissemination Level		
PU	Public	x
RE	Restricted to a group specified by the consortium	
INT	Internal (restricted to consortium partners only)	

Deliverable number:	D5.1_2020.14
ISBN number:	
Deliverable title:	Developing and (not) implementing radical energy efficiency innovations: A case study of R&D projects in the Norwegian manufacturing industry
Work package:	WP5.1
Deliverable type:	Journal Paper
Lead participant:	NTNU SR and NORD University

Quality Assurance, status of deliverable		
Action	Performed by	Date
Verified (WP leader)	Jens Røyrvik	2020-11-30
Reviewed (RA leader)	Ingrid Camilla Claussen	2020-12-14
Approved (dependent on nature of deliverable)*)		

*) *The quality assurance and approval of HighEFF deliverables and publications have to follow the established procedure. The procedure can be found in the HighEFF eRoom in the folder "Administrative > Procedures".*

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Abstract

The prospect of enabling more sustainable industries through energy efficiency innovations is receiving increased attention in policy and research. However, studies have shown that the novelty and complexity of such technologies can make their adoption difficult. Yet, few have explored the innovation processes and dynamics of implementing radical energy efficiency innovations qualitatively. We address this gap by investigating the development and implementation of novel technologies (two high-temperature heat pumps and one heat recovery concept) in three R&D projects in the Norwegian manufacturing industry. Building on the literature on the adoption of energy efficiency technologies, we identify factors influencing implementation and provide a novel analytical model. By analyzing the intersection between innovation characteristics and a firm's motivation, ability, and opportunity, we find different *implementation paradoxes*, dynamics that both promote and inhibit adoption. While the novelty of innovations partly explains why they are difficult to implement, novelty is also a motivator for firms' technology development strategies and a requirement for attracting government funding. Furthermore, radical innovations often require alignment with other changes to organizations and technical systems. We conceptualize such temporary openings as implementation windows. We find that while implementation windows positively affect firms' motivation, ability, and opportunity to develop and adopt innovations, these situations introduce time constraints, putting pressure on less mature technical solutions and R&D processes. We argue that these implementation paradoxes of novelty, complexity, and opportunity show the need to account for interrelations between influencing factors and the characteristics of energy efficiency innovations in different industry situations.

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Keywords: industrial energy efficiency, radical innovation, implementation, system approach, R&D projects

1. Introduction

Improved industrial energy efficiency is pivotal in strategy and policy on climate change mitigation and the transition to more sustainable production. The prospect of reducing energy consumption through the adoption of energy efficiency measures has been widely recognized (Sorrell et al., 2011). While many studies focus on incremental improvements, often called "low-hanging fruits," more attention is being paid to technologies with high potential for energy reductions, such as industrial heat pumps and energy recovery systems (Kosmadakis, 2019; Papapetrou et al., 2018). However, these technologies, at the component level, have larger implications for industrial plants, making them difficult to implement (they are "high-hanging," to complete the fruit metaphor).

Such technologies are increasingly being conceptualized as *energy efficiency innovations* (EEIs) (Solnørdal and Thyholdt, 2019; Trianni et al., 2013). This not only contains a semantical difference to that of *measures*[1], but also directs attention to the degree of novelty for the firms involved (Rennings et al., 2013) and the

[1] While there is significant overlap in how studies conceptualize energy efficiency *measures* and *innovations*, we apply the latter from here on to highlight the novelty of the technologies for the firms involved.

complexity of implementing cleaner technologies (e.g., Dieperink et al., 2004; Fleiter et al., 2012). Distinctions are often made between incremental innovations (continuous improvements of existing technological systems) and radical innovations (discontinuous processes) (Rennings et al., 2013). Implementing radical innovations often depends on other changes to organizations or production systems (Fleiter et al., 2012). Thus, expert knowledge and innovation processes are necessary in order to develop and align EEIs with industrial production systems (Svensson and Paramonova, 2017).

This paper draws on the literature on barriers to and drivers of the adoption of energy efficiency technologies and, particularly, studies on *innovation characteristics* and *system frameworks*, to provide insights into how EEIs are developed and implemented in firms. Several studies have investigated the impact of characteristics, such as novelty, required knowledge, complexity, distance from core production technologies, and system-wide consequences (Dieperink et al., 2004; Fleiter et al., 2012). In cases where EEIs entail significant organizational and technical changes for the firms involved, system frameworks are suitable for investigating their adoption. These frameworks are dynamic in the sense that they describe interactions between *factors*, which can both promote or inhibit implementation, rather than formulating them as either barriers or drivers per se (Chai and Yeo, 2012; Svensson and Paramonova, 2017; Thollander and Palm, 2012). However, there is a need for more in-depth case studies to explain the dynamics that occur in companies when deciding whether to adopt EEIs and the factors affecting this (Chai and Baudelaire, 2015). By employing these perspectives, this study investigates the following research question: "*How does the interrelation between characteristics and influencing factors affect the implementation of EEIs?*"

We conducted a qualitative study of three R&D projects in Norwegian industry, which aim to develop and implement EEIs within firms. The cases include two planned processing plants in the food and beverage industry and one existing metallurgical plant. The projects focus on internal utilization of surplus heat, which involves applying waste heat recovery technologies to reduce the consumption of primary energy (e.g., Huang et al., 2017). More specifically, the EEIs under development are two high-temperature heat pumps and a heat recovery and transfer concept. Through an empirical investigation of these innovation processes, involving firm representatives and technical researchers, we studied the EEI characteristics and influencing factors that affect whether the projects lead to implementation.

By adding to the in-depth studies on EEIs, we contribute to the literature in two distinct ways. First, we develop an analytical model to investigate the interrelations between EEI characteristics and influencing factors. Second, we show how analyzing the intersection between these dimensions highlights different implementation paradoxes, dynamics that actualize both prohibiting and enabling factors of adoption. Essential to this is how industry situations, such as available implementation windows (e.g. new industry plants, retrofit projects), can actualize influencing factors, as well as their direction.

We structure the paper as follows. In Chapter 2, we elaborate on barriers to and drivers for energy efficiency, EEI characteristics, and system frameworks. Chapter 3 describes our methodological and analytical approach. Chapter 4 provides a case overview, narrative descriptions of the cases, and a crosscutting analysis to provide an analytical model. Chapter 5 identifies three implementation paradoxes and discusses the implications of our findings. Chapter 6 provides a conclusion and proposes areas for further research.

2. Literature background

Previous studies on EEI implementation often conceptualize the barriers and drivers affecting adoption. The premise for this strand of research is that the implementation rate is considerably lower than the potential for utilizing available cost-effective technologies (Sorrell et al., 2011). This apparent *energy efficiency gap* (Hirst and Brown, 1990) has puzzled researchers and policymakers for decades since money is presumably "left on the floor" (Sorrell et al., 2004, p. 6). Attempts to address this paradox have evolved into a vast research program to identify *non-technical barriers* (Weber, 1997), each defined as a "postulated mechanism that inhibits a decision or behavior that appears to be both energy efficient and economically efficient" (Sorrell et al., 2004, p. 4). For example, several studies draw upon orthodox, transaction costs and behavioral economics to articulate barriers, including risk, imperfect information, hidden costs, access to capital, split incentives, and bounded rationality, which hinder the adoption of technologies (Sorrell et al., 2011). The objective of these studies is to formulate policy responses to effectively overcome these barriers (Cagno et al., 2013). Other studies have focused on *drivers* of adoption, defined as "factors facilitating the adoption of energy efficient technologies and practices, thus going beyond the view of investments and including the promotion of an energy efficient culture and awareness" (Cagno and Trianni, 2013, p. 277). Here, the focus is on firms' motivation, ability, and absorptive capacity to develop and implement technologies (Solnørdal and Thyholdt, 2019).

This literature on barriers to and drivers of industrial energy efficiency is vast, and several excellent reviews proposing theoretical frameworks and taxonomies have already been conducted (e.g., Cagno et al., 2013; Johansson and Thollander, 2018; Solnørdal and Foss, 2018; Sorrell et al., 2011; Trianni et al., 2017). Studies within this literature draw on different research strands grounded in diverse and even competing assumptions of human behavior and rationality (Sorrell et al., 2011). As such, we limit our focus to studies of EEI characteristics and system frameworks to understand the factors influencing adoption.

2.1 Characteristics of energy efficiency innovations

The energy efficiency literature has tended to treat EEIs homogeneously, by classifying technologies by their energy end-use (e.g., lighting, space heating) or on a more aggregated level (e.g., motor systems, thermal systems) (Fleiter et al., 2012). Such a conceptualization does not account for how different characteristics of technologies affect implementation. Fleiter et al. (2012) provide a framework to categorize EEIs according to three dimensions: *relative advantage*, *technical context*, and *information context*. Relative advantage includes characteristics such as the internal rate of return, payback period, initial expenditure, and non-energy benefits. The technical context of EEIs includes the distance to core processes (close, distant), type of modification (technology substitution, add-on, or organizational measures), scope of impact (system-wide effects vs. local effects), and lifetime for replacement. Finally, Fleiter et al. (2012) conceptualize the information context of EEIs as transaction costs, knowledge required for planning and implementation, diffusion progress, and sectoral applicability. Here, diffusion progress relates to the maturity of the EEI, while the last dimension concerns whether the technology is process-related or has a wider sectoral applicability for other firms.

An important insight from classifications of EEIs is how characteristics, such as complexity, affect their prospects for being implemented (Fleiter et al., 2012; Trianni et al., 2014). Prior studies have found that expensive and complex technologies tend to diffuse more slowly (Kemp and Volpi, 2008) as they require more know-how and skills and are associated with higher risks (Fleiter et al., 2012). For example, Fleiter et al. (2012) found that EEIs close to core processes with system-wide effects are less likely to be adopted than those applied to ancillary processes. The difficulty of adopting innovations in general is related to whether integration with the production process, and the resulting adjustment of the same, is required (Dieperink et al., 2004, p. 778). Similarly, research on energy intensive industries finds that the risks and costs of production disruption are a significant barrier (Thollander and Ottosson, 2008). While these studies highlight the different characteristics of EEIs, there is still a need to analyze their interrelations with other factors affecting adoption.

2.2 System perspectives on EEI implementation

To study the underlying dynamics that influence the implementation of EEIs, we draw on system perspectives. System frameworks highlight that barriers to and drivers of energy efficiency cannot be properly understood by looking at them in isolation (Chai and Baudelaire, 2015). Here, organizations are viewed as social systems influenced by objectives, routines, and structures with different power relations (Thollander and Palm, 2012). For example, Svensson and Paramonova (2017) studied implementation complexity, by addressing the relationship between an EEI and the wider organizational system. This line of thought represents a shift from viewing complexity as a characteristic of technology to observing the emerging connections with the organizational system it is implemented within. Similarly, Chai and Baudelaire (2015) draw on system theory to conceptualize a framework, including motivation, ability, and opportunity, for adopting EEIs (Table 1). The MOA framework allows the assessment of the interrelations between influencing factors and the study of their impact in specific industry situations (Chai and Baudelaire, 2015).

	MOA components	Definition
Motivation	Cost-driven motivation	The extent to which energy cost reduction motivates energy efficiency implementation
	CSR objectives	The firm's commitment to building a better society
	Legal compliance	The extent to which law and regulation pressures motivate energy efficiency implementation
Ability	Know-what	The extent of firms' understanding of energy efficiency-related matters
	Know-how	The extent of firms' technical skills and proficiencies for implementing energy efficiency
Opportunity	Internal buy-in	The extent of firms' production and quality departments' commitment to energy efficiency projects
	Ease of energy efficiency implementation	The extent to which energy efficiency can be easily implemented

Table 1 MOA framework (Chai and Baudelaire, 2015, p. 225)

The *motivation* dimension includes cost-driven motivation, corporate social responsibility (CSR) objectives, and legal compliance. In addition, other studies have shown that energy efficiency can entail "multiple" or "non-energy" benefits (IEA, 2014), such as improved work environments and production systems (e.g., productivity, quality, process control) and reduced production costs, waste, and emissions (Rasmussen, 2017). Nehler and Rasmussen (2016) observed that despite high levels of awareness of non-energy benefits, such as improved maintenance and work environments, profitability and payback periods are still the most critical factors regarding whether or not an energy efficiency investment will be adopted.

The *ability* dimension relates to "know-what," the firm's understanding and specification of EEIs, and "know-how," the technical skills and proficiencies required to implement them (Chai and Baudelaire, 2015). As such, Walton et al. (2020) argue the importance of developing firm-level competencies and intangible resources in order to implement eco-innovations, such as energy efficiency. Chai and Baudelaire (2015) emphasize that the ability of firms to implement EEIs also depends on external knowledge flows. Consequently, a combination of internal R&D and external knowledge flows has lower perceived barriers to efficiency improvements and increases firms' ability to adopt available technologies (Cagno et al., 2015). Similarly, Solnørdal and Thyholdt (2019) find a positive relationship between firms' absorptive capacity and their adoption of EEIs. These insights have directed attention towards the importance of transdisciplinary (Miah et al., 2015, p. 623) and inter-organizational projects (Thollander et al., 2007) and industrial energy efficiency networks (Backman, 2018) for increasing external knowledge flows. However, such endeavors are, at the same time, prone to collaboration barriers, such as communication issues (Ankrah and Al-Tabbaa, 2015), and rely on informal networks, trust, and mutual understanding to be effective (Al-Tabbaa and Ankrah, 2016, Steinmo and Rasmussen, 2018). Thus, the ability dimension pays attention to how firms apprehend the problem at hand and combine internal and external knowledge and the dynamics of these R&D processes.

The *opportunity* dimension includes internal commitment from the firm and the ease of energy efficiency implementation. Studies have pointed out that a lack of managerial commitment is a barrier to adoption (Johansson and Thollander, 2018). Furthermore, Chai and Baudelaire (2015, p. 227) found that easy-to-stop systems in firms and the absence of physical constraints result in easier technical implementation. Conversely, Chai and Yeo (2012, p. 468) contend that due to interrelations between technological and organizational barriers in product operations, firms will be reluctant to provide a "window" to implement energy efficiency improvements for fear of disrupting firms' production. However, changes in technical systems, such as retrofit projects or equipment changes, can create a window for implementing EEIs (Chai and Yeo, 2012). Worrell and Biermans (2005) also note that there may be periods of more intense equipment retirement and investment, and whether efficient equipment options are available and affordable during that window of opportunity is important for the implementation of energy efficiency improvements. Without such implementation windows, firms are less likely to pursue energy efficiency (Chai and Baudelaire, 2015, p. 227).

Perspectives incorporating system theory, such as the MOA framework, are useful for assessing how different industry situations actualize influencing factors. Building on these insights, this study aims to contribute with knowledge on the interrelations between EEI characteristics and influencing factors that affect firms' decisions to implement EEIs.

3. Methods

To achieve an in-depth understanding on innovation processes to develop and implement EEIs, this study has adopted a qualitative multiple case study design (Yin, 2009). This allows for studying the diverse nature of energy efficiency projects while also contributing generalizable and robust results.

3.1 Context and case selection

While this paper focuses on three specific cases of EEI implementation in Norwegian industry, an understanding of the context is useful to situate findings and enable comparisons. A study conducted by the Norwegian energy efficiency agency, covering more than 95% (76 TWh) of the energy used by shore-based industry, identified technical potentials of a 12 TWh reduction in direct energy use and a 10 TWh utilization of surplus heat (Enova, 2009). Strategies to unleash this energy potential include government incentive programs (Enova, 2020), regulations, and voluntary agreements for energy intensive industries (Cornelis, 2019), and importantly, university-industry research centers, with the objectives of increasing knowledge and innovation diffusion. This study resides within one of these research centers on industrial energy efficiency. The center includes firms (user-partners and technology developers), universities, and research institutes. While most activities focus on basic and fundamental research, one area concentrates on applied research and technologies defined as "close-to-implementation." Here, researchers and firm partners collaborate on smaller *firm projects* to develop EEIs. The objective of these projects is to contribute to firms' innovativeness, achieve funding from the national agency for energy efficiency (Enova), and ultimately, obtain implementation within the firms. These projects provide a valuable opportunity for investigating attempts at implementing EEIs.

We selected three firm projects, involving different firms and research partners (Table 2). The selection was based on theoretical sampling (Corbin and Strauss, 1990), with the purpose of exploring the varied conditions of firm implementation. All the projects shared a similar technological focus, namely the "internal utilization of surplus heat." The projects had been completed, and decisions had been taken on whether to implement the EEIs. The projects included different industry sectors and specific technologies for surplus heat utilization, which provided contextual variety (Yin, 2009). Thus, it was possible to conduct a systematic qualitative comparison of the innovation processes (Eisenhardt, 1989).

	Case I	**Case II**	**Case III**
Industry sector	Food and beverage	Metal and processing	Food and beverage
Energy intensive	No	Yes	No
EEI	Novel heat pumps utilizing internal surplus heat	Pre-heating of input factors by utilizing internal surplus heat	Novel heat pumps utilizing internal surplus heat for steam production
Implemented	Yes	No, but project considered a success and an option in the future	No, alternative EEIs were implemented in the same period
Data collection	2018–2019	2018–2019	2019

Table 2 Overview of case studies

3.2 Data collection and analysis

The data material consisted of primary and secondary data sources, such as interviews, documents, and workshops (see Appendix). The primary data for this study included 14 (16) in-depth interviews with firm and research partners who were involved in the three cases[2]. Semi-structured interviews with an open interview guide were conducted face-to-face and over the phone during 2018 and 2019. The purpose was to achieve a case narrative and identify the trajectory regarding the implementation of EEIs. We avoided using analytical terms, such as "barriers and drivers," to ensure that the informants were not steered towards a specific theoretical perspective. The interviews were transcribed verbatim shortly after they occurred.

We also drew on a significant base of secondary data. Our study is a result of a long-term multifaceted collaborative engagement in the research center, which began in 2017. In order to ensure a contextual understanding of the cases, we complemented the primary data with 29 additional interviews with research center management, research area managers, and firm partners, and with contextual interviews for Case III. Furthermore, our project group arranged three workshops with researchers, firm partners, and policymakers to discuss the topic of surplus heat utilization. We also drew on documents, such as project descriptions, reports, and presentations, as well as research notes from discussions in joint industry-research workshops. Lastly, as a research partner in the center, our experience in this multi-organizational field over time provided an ethnographic account, contributing to our contextual understanding. This methodological triangulation with primary and secondary data (Yin, 2009) gave us a more comprehensive understanding of the innovation processes leading up to (non-) implementation.

To achieve an in-depth understanding of the interrelations between EEI characteristics and influencing factors, we conducted two initial analysis sessions, discussing the main findings to lay the basis for further analysis. In this phase, we noted that the prominent crosscutting themes were different implementation paradoxes. Next, we utilized NVivo to code the data, applying an analytical approach inspired by Gioia et al. (2013). Here, we identified 36 empirical first order codes. At this point, we revisited the literature on energy efficiency and narrowed our focus to innovation and system theory perspectives. Then we coded the empirical constructs into second order codes according to the MOA framework (Chai and Baudelaire, 2015),

[2] We interviewed two of the key informants twice at different stages in the process.

expanding its initial categories to include multiple benefits, R&D process, and implementation windows (Figure 1).

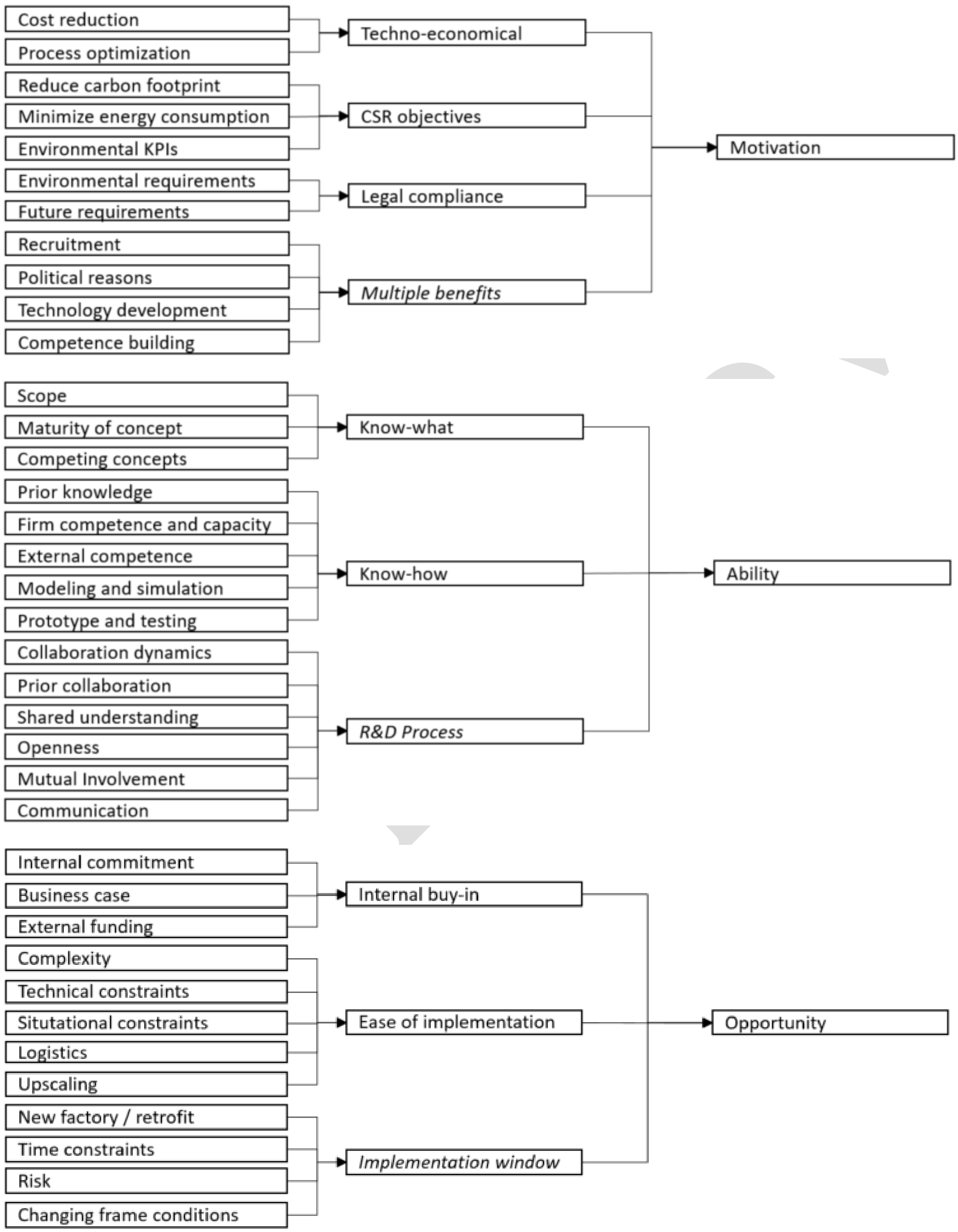

Figure 1 First order and second order coding of empirical data organized in the MOA framework (Chai and Baudelaire, 2015)

Furthermore, we systematically reviewed the data in order to reconstruct the case narratives. In this way, we sought to avoid missing the forest (main issues and implementation paradoxes in cases) for trees (empirical constructs). After analyzing the cases, we structured the EEIs according to Fleiter et al. (2012) framework of EEI characteristics. Lastly, we developed an analytical model encompassing the interrelations between EEI characteristics and influencing factors. This further expanded our understanding of the empirical constructs through viewing their interrelations from a system perspective. Thus, while our analytical point of departure was inspired by a grounded theory approach (Glaser and Strauss, 1968), we relied on and sought to expand the understanding of existing analytical concepts.

4. Findings

We present the cases as empirical narratives to provide an overview of their development, R&D processes, and results. Then, we analyze the EEI characteristics and provide a crosscutting analytical model, highlighting the interrelations between characteristics and influencing factors affecting implementation.

4.1 Case narratives

Case I - Implementing integrated heat pumps in a food and beverage company

Case I includes a large firm that produces food and beverages sold in stores around the country. The firm has a strategic long-term objective: "*to become carbon neutral within 2025 and 2030 for production" (FP1)*. To ensure carbon neutral production, the firm engages in long-term collaborations with universities in order to develop technologies for more efficient energy use. The firm and research partner had collaborated over time to develop and demonstrate the viability of an integrated high-temperature heat pump for the firm's production process: "*We developed that technology a lot in the last five-six years before the [center] started. Therefore, we had a head start, which paved the way for us to offer customers a solution that is already close to industry implementation" (RP1)*. Hence, the firm's motivation was to further investigate and develop use cases for specific heat-pump technology. While "*cost is a big part of it*," as argued by the firm informant, the objective was also to optimize its production process and to "*retrieve as much [surplus heat] as possible" (FP1)*. In addition, the firm was in the process of planning a new factory in Norway, which provided an opportunity, as well as a necessity, for implementing novel technologies: "*One of the reasons that we wanted in was to have a case where we studied a specific solution with high-temperature heat pumps […] then the new factory presented an excellent opportunity for testing it" (FP1).*

The decision to build the industry plant also put pressure on the research partners by introducing time constraints, as one of the researchers explained: *"A decision is made centrally, it happens quickly, and then, you have to deliver quickly too" (RP1)*. This meant that the firm and researchers needed to establish a project quickly. They established a project to evaluate novel heat-pump solutions for implementation in the new factory and to answer the question: "*How do we make this the most energy efficient?" (FP1).* The principle idea was to reuse surplus heat from the internal sub-processes at the factory and raise it to the required temperature levels using heat pumps. The research partner evaluated different heat-pump solutions for minimizing energy consumption at the industrial plant. Hence, the collaboration between the researchers and the firm revolved around searching for the best possible solution concerning thermodynamic, technical, and economic aspects.

The firm partner experienced that the prior collaboration was important for scoping out and developing the project: *"In a way, they have the background knowledge. They understand how our processes work" (FP1)*. During the project, the firm partner contributed with knowledge about the industry processes and operational requirements: "*We discussed a bit, back and forth, the practical feasibility of some of their cases. Mainly, they studied what was the optimal solution, and then our job was to 'reality check'" (FP1)*. The strong mutual involvement aided the research partner in assessing which of the solutions were the most technical and economically feasible: "*We received input along the way of 'we do not want this,' 'this is more relevant,' and discussed a bit, for all cases, have approximately the same [results]" (RP1).*

This resulted in the evaluation and modeling of five heat-pump technologies. Consequently, the firm decided to move forward with one of the solutions. Rather than just replacing a traditional steam boiler with heat pumps, the EEI entailed a fully integrated system close to the core production at the plant. As argued by the firm partner: "*The complexity of heat pumps is significantly higher [than conventional technologies] in that respect" (FP1)*. Thus, the proposed EEI meant system-wide implications for the other processes at the plant. This also induced risks since "*The systems cannot stop. So we have back-up systems in order to contain the risk" (FP1)*. Implementing the EEI also depended on achieving government funding to cover the additional costs compared to conventional technologies. With the help of its research partner, the firm developed an application for funding grants from Enova for a full-scale pilot:

> One of the principles was that it had to be innovative, moving beyond the best-available technology. Therefore, we had to describe how the chosen technology was better, or more innovative, than other available technologies (FP1)

Demonstrating the *novelty* of the EEI was essential in order to achieve funding from the agency, which made its implementation economically viable. Based on the assessment from the researchers and technology developers, the firm decided to implement the heat-pump concept.

Case II - Assessing the viability of pre-heating metal with surplus heat

Case II includes a Norwegian metal and processing plant, which is part of a large multinational company. The plant produces metal that goes into different products and has significant energy consumption. The firm has an explicit objective: *"reduce our carbon footprint and energy consumption. All of these things lie in our strategic values and goals" (FP3).*

The firm had an established strategy of continuously searching for incremental energy efficiency improvements since energy consumption is one of the largest expense items: "*We do it in order to strengthen our company in the long term either in the form of a new product or improved processes; all these things increase our earnings" (FP3)*. Moreover, representing an industry characterized as energy intensive, the firm must comply with and position itself regarding existing and future environmental requirements: "*We get stricter and stricter requirements and expectations" (FP2)*. Engaging with research institutions and universities in energy efficiency projects is key to the firm's strategy of attaining these objectives and provides other multiple benefits, such as "*increased competence, recruitment, public relations, or corporate relations, which improve our standing in the local community*" (*FP3*). Thus, the firm aimed to initiate projects to address its significant energy consumption: "*We need projects that are relevant for our energy efficiency potential, which is obviously huge but not so easy to grasp. If it was, we would have done it a long time ago" (FP2).*

The partners formed a project with the principle of pre-heating raw materials, to reduce the time required before initiating metal production. In the original production process, raw materials with ambient temperatures are inserted into a fully heated oven. This discrepancy in temperatures delays the start of metal production. The firm had earlier hypothesized that production could be initiated faster by pre-heating the material before inserting it into the oven, but it did not have the capacity to test it, as stated by several informants: "*We have had some wild ideas over the years*" (*FP2*). "*I have the impression that employees there have had similar thoughts before, and they think it is fun to finally test them" (RP4)*. To systematically investigate possible solutions and establish a proof of concept, the firm engaged a student from the research center. The aim was to verify the viability of pre-heating: "*The results will confirm whether it works or not. If it doesn't, then at least we know*" (*FP2*).

With help from management and process operators in the firm, the research partner became familiar with the firm's production process by joining work shifts. During this time, the idea matured into utilizing the surplus heat from materials removed from the oven to pre-heat the new materials before inserting them: "*We actually had a different idea on how to do the pre-heating. Then we thought, 'why not just place them next to each other?'"(RP7)*. The set-up for testing was based on a "*do-it-yourself solution,*" using existing metal boxes to place the old and new materials next to each other and covering them to optimize heat transfer. As a firm representative stated: "*That is how we do it here. We call it a Reodor Felgen crash test method*[3]*. If we have something similar available, then we use it" (FP2)*. The firm provided access to an oven with testing equipment to assess the energy-saving potential. The researchers designed a research concept, simulations, and test procedures to verify the results of the EEI in practice.

The results from the project showed significant improvements when inserting pre-heated materials compared to materials with ambient temperatures: "*The results are surprisingly good. We did not think the difference would be zero, but not that it would be this good either" (FP2)*. In addition, pre-heating raw materials optimized other parts of the production process. However, the partners identified several factors that hindered implementation. Upscaling the concept to the full plant would involve significant complexity to fit the interdependencies and internal logistics, as explained by the manager: "*There are technical barriers […] we do not have sufficient automation to control them. It will be a lot of extra work, and it is difficult to achieve the gains" (FP2)*. As such, "*There is no apparent way towards innovation. Because the biggest challenge is not energy, but logistics" (FP2)*. Changing internal logistics implies a significant retrofit project. However, the manager argued that implementing EEI could be viable at a later stage: "*There might be other reasons that force us to change [equipment]: when it is expired or if we need to improve how we handle emissions. So, other factors can push us in a direction where this could be viable" (FP2)*. While the implementation of the EEI is on hold until it can be aligned with larger changes at the plant, both the researchers and firm partner agreed that the study was a satisfactory proof of concept and regarded the project as having been successful.

Case III - Novel energy efficiency solutions in a food-processing plant

Case III involves another large firm from the food and beverage industry. Similar to Case I, the firm was about to build a new food-processing factory when it became engaged with the research center. Accordingly, its motivation was to develop and implement EEIs to construct the "*most environmentally friendly food-processing plant in the world" (FP6)*, operationalized in indicators, such as "*kilowatt hours divided by produced [products]*" *(FP4)*. While the firm representatives agreed that this objective was ambitious, they argued that this was useful "*as a management tool"* to guide the choice of technologies: "*If we are to become the best in the world, can we do it like this?" (FP4)*. Furthermore, management and project leaders at the firm were open to new technologies to reach their ambitious sustainability targets.

The firm partner proposed a project to identify novel heating and cooling solutions for the factory. However, the plant's specification and location were not decided at this time. Therefore, the project entailed an open-ended approach to assessing solutions for minimizing energy consumption. As noted by one of the research partners, this proved difficult to align with the otherwise strict timelines imposed by the parallel planning

[3] A reference meaning a "creative inventor," which became common in the Norwegian language after the stop-motion animated feature film "The Pinchcliffe Grand Prix" from 1975, where a bicycle repairman "Reodor Felgen" builds a racing car, using only available spare parts from the mountain where he resides.

of the new factory: *"We were contacted at short notice, and the case was not clearly defined"* and *"It was not possible to work in peace and provide a thorough concept" (RP1)*. The firm also acknowledged the difficulties of aligning the R&D process with these time constraints: *"It is not so easy to develop concrete ideas according to cost guidelines within the time period we have" (FP4)*. Another researcher also recognized challenges imposed by cost constraints: "*When you meet the firm, you have to 'calculate it home' from day one, and [the solution] should be economically viable without external funding from Enova" (RP6).*

The researchers proposed investigating a novel integrated high-temperature heat-pump concept that utilized surplus heat to produce steam. While they argued this concept could fit the firm's techno-economic demands, it also introduced complexity: *"You have high temperatures, you are producing steam with heat pumps; that is completely new, […] and if everything is to be integrated, it is quite difficult" (RP6)*. The concept was "*sort of groundbreaking*" *(RP6)* since no similar concepts were in operation, making its implementation a challenge for first adopters: "*If you are number four, it is a completely different story than if you are number one" (RP6)*.

Furthermore, the proposed EEI was not a commercial off-the-shelf solution and required more development, which further complicated the collaboration: *"There was a mismatch between what was industrially available and what was actually under development. That also created expectations" (RP1)*. The lack of shared understanding was arguably due to "*a lot of actors involved with different agendas,*" as well as communication barriers: *"When it came to the technology readiness level, we spoke two different languages" (RP1)*. A firm representative also pointed out these communication issues: "*The information we first got was that this existed and that we could do it. When we started to investigate, things were not ready*" *(FP6)*. Thus, the project experienced multiple challenges, essentially due to the low maturity of the EEI, which were intensified by scoping issues and a lack of shared understanding in the R&D process.

Furthermore, the frame conditions changed along the way when the firm decided on the final location for the industrial plant: *"The decision to move there and become part of a future industry cluster probably led to a drift in the choice of technology*" *(RP6)*. At this point, competing concepts for utilizing available external heat sources emerged: *"After a while, it became clear that there were other parallel projects with neighboring firms that investigated a 'cluster alternative'" (RP6)*. According to a firm representative, the technology focus drifted while the overall ambition was maintained:

> In the beginning, we had an overarching concept that we thought we would go for, but it has changed. Eventually, we sat down and asked 'What are we actually going to have?' and then it evolved. But, the overall idea of phasing out fossil fuel [is intact]" (FP4)

As another firm representative argued, the new solution, which eventually became district heating, would integrate better with the regional energy system: *"The story is best if we do it like this; it will also be the best option from a wider socio-economic perspective" (FP6)*. The initial researchers agreed that "*When you eventually calculate emissions and energy efficiency, it will be positive when you consider the frame conditions, energy system, neighbors, and connections. I think it is ok" (RP6)*. As such, the partners agreed to end the heat-pump case, and the firm continued with the district heating solution.

4.2 Analysis of EEI characteristics

Based on our findings, we can analyze the EEIs according to their different characteristics (Table 3). Cases I and III entail a medium internal rate of return and payback period, since the EEIs require large initial investments. In Case II, the project was not implemented (at this stage) and therefore was not assessed. The initial expenditure is high in all the cases. Non-energy benefits are difficult to assess by looking at the EEI in isolation, but the informants argue that the EEIs substantiate firms' CSR objectives and offer multiple benefits, such as technology and competence development, recruitment, and political anchoring.

	Case I	**Case II**	**Case III**
Relative advantage			
Internal rate of return	*Medium*	*N/A*	*Medium*
Payback period	*Medium*	*N/A*	*Medium*
Initial expenditure	*High*	*High*	*High*
Non-energy benefits	*Medium*	*Medium*	*Medium*
Technical context			
Distance from core processes	Close (Core process)	Distant (Ancillary process)	Close (Core process)
Type of modification	New technology	Technology add-on/organizational measure	New technology
Scope of impact	System-wide	System-wide	System-wide
Lifetime	Long	Long	Long
Information context			
Transaction costs	*N/A*	*N/A*	*N/A*
Knowledge of planning and implementation	Technology expert	Technology expert	Technology expert
Diffusion progress	Take-off	Incubation	Incubation
Sectoral applicability	Crosscutting	Process related	Crosscutting

Table 3 EEI characteristics of cases based on Fleiter et al. (2012)

The technical context of the EEIs in Cases I and III can be characterized as being close to the core processes as the proposed heat pumps entail energy systems that provide heating and cooling. Case II, on the other hand, is distant as it does not require changes to the core technology (ovens). However, the scope of impact is system-wide in all cases as the EEIs affect the new plant specifications or require the retrofitting of plant logistics. Since Cases I and III involve new industrial plants, the type of modification is essentially introducing a new technology. In Case II, the EEI entails a technology add-on and organizational measures to handle plant logistics. The expected lifetimes of the EEIs are high in all cases.

The information context is, in our cases, connected to R&D projects, which encompass transaction costs. The development, specification, and eventual implementation of the EEIs require knowledge at the technology expert level in all three cases. Moreover, the diffusion progress in Cases II and III is that of *incubation* since implementation would make them first adopters. Finally, both heat-pump concepts have a potential crosscutting sectoral applicability, while the EEI in Case II is process related since it is only applicable to similar metal processing plants.

Essentially, all the cases highlight the broader characteristics of *novelty* and *system-wide consequences*. While the EEIs have different maturity levels, their implementation would still introduce "something new" for the firms involved. Furthermore, the EEIs are radical in the sense that they all require reconfigurations of the organizations and wider technical systems.

4.4 The interrelations between EEI characteristics and influencing factors

The case narratives illustrate the interrelations between the EEI characteristics analyzed above and influencing factors affecting the development and implementation of the EEIs (see Figure 1 for an overview). Case I shows that the EEI is a radical technology for the firm, and especially for the industrial plant. The EEI, which is close to the core processes and has a system-wide impact, depends on alignment with an implementation window, which, in this case, was the planning of a new industrial plant. Here, collaboration between the partners and the technology had matured over the years, and the project group was able to align the remaining development with the time constraints of planning the new factory. This opportunity for implementation also positively affected the firm's motivation for establishing the project in the first place.

Case II, on the other hand, illustrates how an apparent incremental concept for pre-heating materials outside core production systems becomes radical if scaled up to the full industrial plant. While the EEI is techno-economically viable, implementation requires alignment with the wider industrial system and essentially a change in plant logistics. Thus, adoption depends on an implementation window where other technologies are replaced and the EEI can "tag along." In this case, such an opportunity remains several years away.

Case III shows how the novelty of the proposed EEI made it difficult to align with the planning and development of a new factory. The time constraints imposed by the new factory made it difficult for the research group to conduct open-ended research. This further actualized collaboration issues in the R&D processes, such as a lack of shared understanding regarding the maturity and specification of the solution. The open-ended approach, combined with a strict time plan for implementation, proved to be difficult to align with the slower temporal trajectory of research.

These case narratives highlight the systemic effects and interrelations between influencing factors and EEI characteristics. As such, we provide an analytical model (Figure 2) to encompass these dynamics. The framework directs attention towards dynamics visible at the intersection between dimensions and characteristics, which we discuss in the following chapter.

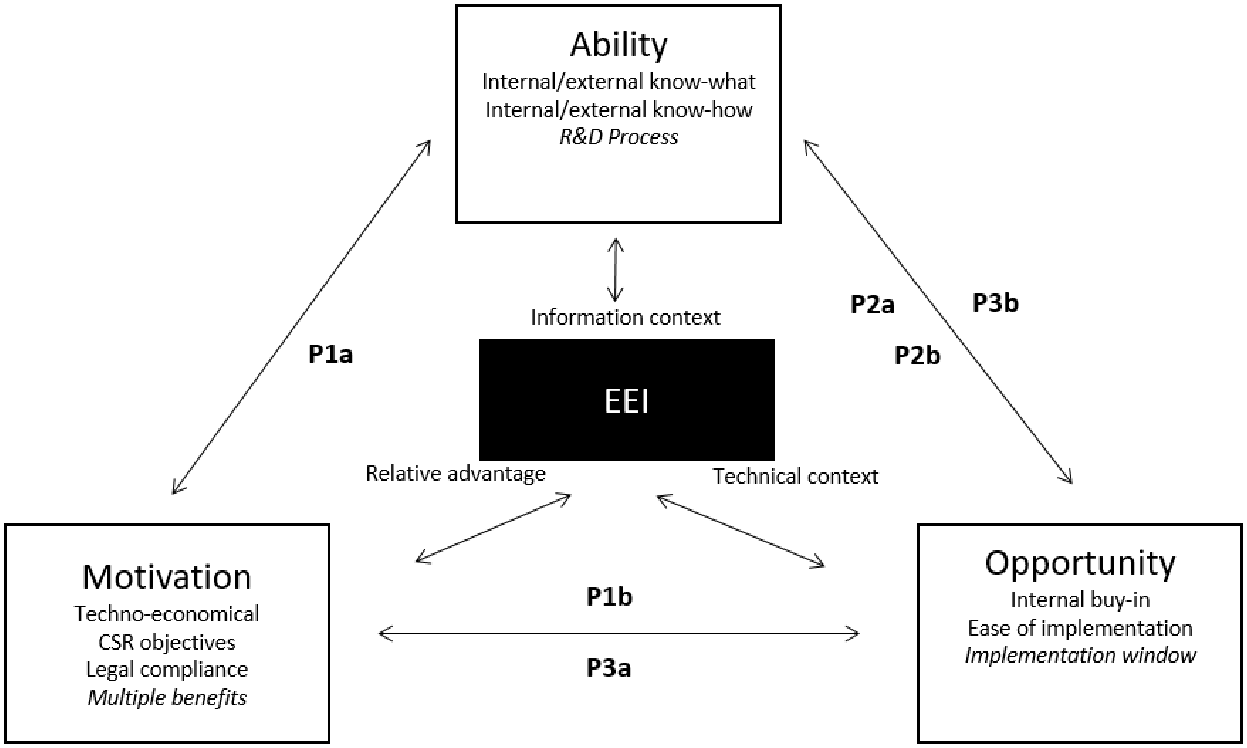

Figure 2 Analytical model based on Fleiter et al. (2012), Chai and Baudelaire (2015), and case studies

5. Discussion

The analysis above shows three examples of developing EEIs in small-scale industry-research projects. In the following, we discuss how the intersections between the characteristics and influencing factors in the MOA framework reveal important underlying dynamics, explaining the (non-) implementation of EEIs. We formulate these as *implementation paradoxes* – dynamics that articulate factors that both promote and inhibit implementation.

Prior studies have emphasized that EEI characteristics impose different consequences for organizations when implemented (Fleiter et al., 2012; Svensson and Paramonova, 2017). The novelty of EEIs, and innovations in general, is often considered to be a barrier to implementation (Kemp and Volpi, 2008). Our findings corroborate these dynamics as the novelty of EEIs actualizes implementation challenges, such as the need for mutual involvement in the R&D process, shared understanding, and the specification of the concept (know-what), as well as the need to align the development of the innovations with operational requirements (know-how). Conversely, we find that the novelty of an EEI also serves as an enabling factor. In all three cases, the informants argue that developing and implementing novel technologies are important motivators in their own right. Furthermore, in order to be eligible for public funding for energy efficiency projects, applications must demonstrate novelty beyond the state of the art. Thus, downgrading the innovation aspect will not necessarily make them easier to implement. While characteristics such as novelty partially explain the difficulty of adopting EEIs in firms (Kemp and Volpi, 2008), our findings indicate that the novelty characteristic also enables the implementation of EEIs. We formulate this as a paradox of novelty:

> P1a. The novelty of EEIs actualizes influencing factors, such as technical and collaboration challenges, making implementation more difficult.

P1b. The novelty of EEIs actualizes influencing factors, such as motivation for technology development and achieving external funding, which positively affects implementation.

Prior studies have found that EEIs close to core production technologies and with system-wide consequences are more difficult to implement than those applied to ancillary processes (Fleiter et al., 2012), since they influence the entire production process (Dieperink et al., 2004). Our study corroborates these findings in that such systemic effects entail alignment with larger changes to organizations. Therefore, complexity is not an embedded characteristic of the EEI but emerges from the relationship with the implementation context. EEIs can be radical in the sense that they provoke, or depend on, larger changes in organizations and technical systems. Thus, while some EEIs are considered *low-hanging fruits* or stand-alone technologies, our findings suggest that implementing these EEIs in tightly-coupled systems certainly requires climbing to the top of the tree. We formulate this as a paradox of complexity:

P2a. EEIs close to core production technologies actualize implementation challenges and the need for larger changes in organizations and technical systems.

P2b. EEIs that seem to be incremental can have system-wide consequences when implemented in tightly-coupled systems, actualizing technical and situational constraints.

Our study shows how building new industrial plants creates opportunities to implement EEIs. Conversely, the lack of larger changes to organizations can delay implementation. As shown, even EEIs considered to be economically viable can be put on hold until they can “tag along” with a larger retrofit project. These findings support previous research on how periods of equipment retirement and investment make it easier to implement EEIs (Worrell and Biermans, 2005). In these implementation windows, influencing factors, such as the fear of disrupting production, are minimized (Chai and Baudelaire, 2015). However, we find that implementation windows are not only “technical openings” that remove technical barriers to implementing new technologies. As explored through the MOA framework (Chai and Baudelaire, 2015), these events provide an *opportunity* to push organizations towards implementing EEIs, also affecting firms’ *motivation* and *ability*. As shown, implementation windows affect firms’ motivation for engaging with research partners to increase know-what and expertise and search for suitable EEIs. This, in turn, contributes to firms’ ability and knowledge flows concerning assessing opportunities for energy efficiency and forming applicable projects with better possibilities of implementation. Furthermore, larger investments in new industrial plants enable the incorporation of capital investments in EEIs. Thus, the impact of implementation windows transcends the phases of EEI adoption. Thus, we propose:

P3a**.** Implementation windows can increase firms’ motivation and ability regarding developing and adopting EEIs.

Implementation windows also actualize influencing factors that make adoption difficult. The most notable in our findings is how the planning of new factories imposed time constraints, which put pressure on less mature technical concepts as well as on collaboration. This illustrates a paradox of opportunity. While implementation windows provide an opening for adopting technologies, they also put increasing pressure on the R&D process since the EEIs must be ready to be implemented within the given time window:

P3b**.** Implementation windows induce time constraints, putting pressure on the R&D process, and actualize potential collaboration issues, which can make the adoption of EEIs more difficult.

6. Concluding remarks

In this study, we applied a novel analytical model to investigate the development and (non-) implementation of EEIs. The paper shows how moving from developing to implementing EEIs requires alignment between innovation processes, implementation windows, and technical and organizational systems. These results have potential implications for firms and researchers that engage in R&D collaborations to promote energy efficiency. Firms should seek to align innovation processes with implementation windows outside the project level. This could potentially increase the chances for successful implementation of radical EEIs. Thus, exploring the impact of implementation windows on the adoption of EEIs is a promising avenue for future research as well as practice. Furthermore, building informal networks and trust to enable mutual involvement in R&D processes seem imperative, both for the successful development of innovations, and for meeting time constraints once an opportunity for implementation arises. This calls for a focus on collaboration dynamics and external knowledge flows in energy efficiency projects, which can potentially increase chances of adoption.

The limitations of a case study approach apply, and there is a need for more research on the interaction effects between influencing factors and EEI characteristics in other contexts. However, empirical evidence from the Norwegian context is under-represented in the energy efficiency literature, and this paper provides a comparative contribution to this end. Another limitation relates to the qualitative approach. Future research could apply statistical methods to utilize the analytical model proposed in this paper or test the findings quantitatively. Nevertheless, we argue our results have potential theoretical implications for the literature on barriers to and drivers for energy efficiency. As discussed, there are some theoretical limitations to some of these studies due to their reliance on dichotomies, such as "implemented/not implemented" conceptualizations of EEIs and "push/pull" framings of influencing factors. We provide a complementary contribution to this end, by articulating implementation paradoxes, dynamics that can both hinder and promote the adoption of EEIs. The question remains whether these in fact are *paradoxes*, in the correct sense of the word, since we can explain their influencing direction (enabling or prohibiting) by unpacking them and investigating their impact qualitatively. However, by employing the paradox metaphor, we pinpoint the need for dynamic perspectives to reveal system dependencies and account for how different industry situations articulate influencing factors as well as their directions. This approach can yield novel insights on the implementation of radical energy efficiency innovations.

Appendix

Primary data sources					
No.	**Informant Code**	**Case I**	**Case II**	**Case III**	**Who**
1	RP1	x		x	Researcher, responsible for Cases I and III (two interviews)
2	RP2		x		Researcher
3	RP3		x		Researcher, master student
4	RP4		x		Researcher
5	RP5	x	x	x	Researcher, in charge of firm projects
6	RP6			x	Researcher, industry contact
7	RP7		x		Researcher responsible for Case II
8	FP1	x			Firm representative Project leader
9	FP2		x		Firm representative Project leader
10	FP3		x		Firm representative (Engineering)
11	FP4			x	Firm representative (Environmental Manager)
12	FP5			x	Firm representative (Energy Planning)
13	FP6			x	Firm representative Project leader (two interviews)
14	FP7			x	Firm representative (District Heating Network)
Secondary data sources					
15-31	Contextual interviews (Research center)	x	x	x	Interviews on collaboration dynamics and innovation from the research center
32-42	Contextual interviews (Case III)			x	Interviews and workshops with industry cluster, which Case III is a part of
43-45	Contextual workshops (Firm representatives, researchers and policymakers)	x	x	x	3 workshops with firms, researchers, and policymakers, discussing barriers and drivers for surplus heat utilization
46	Analysis of written documents	x	x	x	Project reports, deliverables, technical research articles, and media articles describing case studies and center activities
47	Ethnography in center	x	x	x	Participation in the research center over time allowed for informal conversations with industry and research partners, contributing to contextual insights

Acknowledgements

This paper has been funded by HighEFF - Centre for an Energy Efficient and Competitive Industry for the Future, an 8-year Research Centre under the FME-scheme (257632) and the Norwegian University of Science and Technology (NTNU). The authors gratefully acknowledge the financial support from the Research Council of Norway, user partners of HighEFF and NTNU. Also special thanks to Marianne Steinmo, Per Morten Schiefloe and Jens Røyrvik for valuable comments during the development of this paper.

References

Al-Tabbaa, O., Ankrah, S., 2016. Social capital to facilitate 'engineered' university–industry collaboration for technology transfer: A dynamic perspective. Technological Forecasting and Social Change 104, 1–15.

Ankrah, S., Al-Tabbaa, O., 2015. Universities–industry collaboration: A systematic review. Scandinavian Journal of Management. 31, 387–408.

Backman, F., 2018. Local knowledge creation with the use of industrial energy efficiency networks (IEENs): A Swedish case study. Energy Research & Social Science 42, 147–154. https://doi.org/10.1016/j.erss.2018.03.027

Cagno, E., Ramirez-Portilla, A., Trianni, A., 2015. Linking energy efficiency and innovation practices: Empirical evidence from the foundry sector. Energy Policy 83, 240–256.

Cagno, E., Trianni, A., 2013. Exploring drivers for energy efficiency within small- and medium-sized enterprises: First evidences from Italian manufacturing enterprises. Applied Energy 104, 276–285. https://doi.org/10.1016/j.apenergy.2012.10.053

Cagno, E., Worrell, E., Trianni, A., Pugliese, G., 2013. A novel approach for barriers to industrial energy efficiency. Renewable and Sustainable Energy Reviews 19, 290–308.

Chai, K.-H., Baudelaire, C., 2015. Understanding the energy efficiency gap in Singapore: A motivation, opportunity, and ability perspective. Journal of Cleaner Production 100, 224–234. https://doi.org/10.1016/j.jclepro.2015.03.064

Chai, K.-H., Yeo, C., 2012. Overcoming energy efficiency barriers through systems approach—A conceptual framework. Energy Policy 46, 460–472. https://doi.org/10.1016/j.enpol.2012.04.012

Corbin, J.M., Strauss, A., 1990. Grounded theory research: Procedures, canons, and evaluative criteria. Qualitative sociology 13, 3–21.

Cornelis, E., 2019. History and prospect of voluntary agreements on industrial energy efficiency in Europe. Energy Policy 132, 567–582. https://doi.org/10.1016/j.enpol.2019.06.003

Dieperink, C., Brand, I., Vermeulen, W., 2004. Diffusion of energy-saving innovations in industry and the built environment: Dutch studies as inputs for a more integrated analytical framework. Energy Policy 32, 773–784.

Eisenhardt, K.M., 1989. Building theories from case study research. Academy of Management Review 14, 532–550.

Enova, 2009. Potensial for energieffektivisering i norsk landbasert industri. [The potential for utilizing surplus heat in Norwegian industry] Enova Report.

Enova, 2020. Annual Report 2019.

Fleiter, T., Hirzel, S., Worrell, E., 2012. The characteristics of energy-efficiency measures – A neglected dimension. Energy Policy, Renewable Energy in China 51, 502–513. https://doi.org/10.1016/j.enpol.2012.08.054

Gioia, D.A., Corley, K.G., Hamilton, A.L., 2013. Seeking qualitative rigor in inductive research: Notes on the Gioia methodology. Organizational Research Methods 16, 15–31. https://doi.org/10.1177/1094428112452151

Glaser, B.G., Strauss, A.L., 1968. Discovery of grounded theory: Strategies for qualitative research. Weidenfeld and Nicolson.

Hirst, E., Brown, M., 1990. Closing the efficiency gap: Barriers to the efficient use of energy. Resources, Conservation and Recycling 3, 267–281.
Huang, F., Zheng, J., Baleynaud, J.M., Lu, J., 2017. Heat recovery potentials and technologies in industrial zones. Journal of the Energy Institute 90, 951–961. https://doi.org/10.1016/j.joei.2016.07.012
IEA, 2014. Capturing the multiple benefits of energy efficiency. International Energy Agency, Paris.
Johansson, M.T., Thollander, P., 2018. A review of barriers to and driving forces for improved energy efficiency in Swedish industry–Recommendations for successful in-house energy management. Renewable and Sustainable Energy Reviews 82, 618–628.
Kemp, R., Volpi, M., 2008. The diffusion of clean technologies: A review with suggestions for future diffusion analysis. Journal of Cleaner Production 16, S14–S21.
Kosmadakis, G., 2019. Estimating the potential of industrial (high-temperature) heat pumps for exploiting waste heat in EU industries. Applied Thermal Engineering 156, 287–298. https://doi.org/10.1016/j.applthermaleng.2019.04.082
Miah, J.H., Griffiths, A., McNeill, R., Poonaji, I., Martin, R., Morse, S., Yang, A., Sadhukhan, J., 2015. A small-scale transdisciplinary process to maximising the energy efficiency of food factories: Insights and recommendations from the development of a novel heat integration framework. Sustainability Science 10, 621–637.
Nehler, T., Rasmussen, J., 2016. How do firms consider non-energy benefits? Empirical findings on energy-efficiency investments in Swedish industry. Journal of Cleaner Production 113, 472–482.
Papapetrou, M., Kosmadakis, G., Cipollina, A., La Commare, U., Micale, G., 2018. Industrial waste heat: Estimation of the technically available resource in the EU per industrial sector, temperature level and country. Applied Thermal Engineering 138, 207–216. https://doi.org/10.1016/j.applthermaleng.2018.04.043
Rasmussen, J., 2017. The additional benefits of energy efficiency investments—A systematic literature review and a framework for categorisation. Energy Efficiency 10, 1401–1418. https://doi.org/10.1007/s12053-017-9528-1
Rennings, K., Markewitz, P., Vögele, S., 2013. How clean is clean? Incremental versus radical technological change in coal-fired power plants. Journal of Evolutionary Economics 23, 331–355. https://doi.org/10.1007/s00191-010-0198-9
Solnørdal, M.T., Foss, L., 2018. Closing the energy efficiency gap—A systematic review of empirical articles on drivers to energy efficiency in manufacturing firms. Energies 11, 518.
Solnørdal, M.T., Thyholdt, S.B., 2019. Absorptive capacity and energy efficiency in manufacturing firms – An empirical analysis in Norway. Energy Policy 132, 978–990. https://doi.org/10.1016/j.enpol.2019.06.069
Sorrell, S., Mallett, A., Nye, S., 2011. Barriers to industrial energy efficiency: A literature review. United Natation Industrial Development Organization
Sorrell, S., O'Malley, E., Scott, S., Schleich, J., 2004. The economics of energy efficiency: Barriers to cost-effective investment. Edward Elgar.
Steinmo, M., Rasmussen, E., 2018. The interplay of cognitive and relational social capital dimensions in university-industry collaboration: Overcoming the experience barrier. Research Policy 47, 1964–1974.
Svensson, A., Paramonova, S., 2017. An analytical model for identifying and addressing energy efficiency improvement opportunities in industrial production systems–Model development and testing experiences from Sweden. Journal of Cleaner Production 142, 2407–2422.
Thollander, P., Danestig, M., Rohdin, P., 2007. Energy policies for increased industrial energy efficiency: Evaluation of a local energy programme for manufacturing SMEs. Energy Policy 35, 5774–5783. https://doi.org/10.1016/j.enpol.2007.06.013
Thollander, P., Ottosson, M., 2008. An energy efficient Swedish pulp and paper industry–Exploring barriers to and driving forces for cost-effective energy efficiency investments. Energy Efficiency 1, 21–34.

Thollander, P., Palm, J., 2012. Improving energy efficiency in industrial energy systems: An interdisciplinary perspective on barriers, energy audits, energy management, policies, and programs. Springer Science & Business Media.

Trianni, A., Cagno, E., De Donatis, A., 2014. A framework to characterize energy efficiency measures. Applied Energy 118, 207–220. https://doi.org/10.1016/j.apenergy.2013.12.042

Trianni, A., Cagno, E., Marchesani, F., Spallina, G., 2017. Classification of drivers for industrial energy efficiency and their effect on the barriers affecting the investment decision-making process. Energy Efficiency 10, 199–215.

Trianni, A., Cagno, E., Thollander, P., Backlund, S., 2013. Barriers to industrial energy efficiency in foundries: A European comparison. Journal of Cleaner Production, Special Volume: Sustainable consumption and production for Asia: Sustainability through green design and practice 40, 161–176. https://doi.org/10.1016/j.jclepro.2012.08.040

Walton, S., Zhang, A., O'Kane, C., 2020. Energy eco-innovations for sustainable development: Exploring organizational strategic capabilities through an energy cultures framework. Business Strategy and the Environment 29, 812–826. https://doi.org/10.1002/bse.2399

Weber, L., 1997. Some reflections on barriers to the efficient use of energy. Energy Policy 25, 833–835.

Worrell, E., Biermans, G., 2005. Move over! Stock turnover, retrofit and industrial energy efficiency. Energy Policy 33, 949–962. https://doi.org/10.1016/j.enpol.2003.10.017

Yin, R.K., 2009. Case study research: Design and methods. SAGE.