sustainability

MDPI

Article

How to Assess Market Readiness for an Innovative Solution: The Case of Heat Recovery Technologies for SMEs

Sune Solberg Hjorth * and Alexander Michael Brem

SDU Innovation and Design Engineering, Mads Clausen Institute, University of Southern Denmark, Sønderborg 6400, Denmark; brem@sdu.dk

* Correspondence: sune.hjorth@myllerup.com; Tel.: +45-6037-9586

Academic Editor: Beatriz Junquera

Received: 1 July 2016; Accepted: 10 October 2016; Published: 9 November 2016

Abstract: The uptake of solutions that increase energy efficiency is significantly lower for small- and medium-sized enterprises (SMEs). This is due to several barriers, among which legislation, motivation, finance and other resources play a large role. In this paper, we describe a framework of market readiness and use it to assess the asymmetry between existing solutions and opportunities in the market. The aim is to identify which steps can be taken in order to introduce more energy optimizations into SMEs, and who should be taking those steps. More specifically, we explore how four Danish SMEs, in different parts of the value chain in the food processing industry, view energy efficiency improvements, focusing on the potential reuse of waste heat, along with what they consider important for taking on such projects. The findings show that while the companies operate very differently, they share common motivations and barriers when it comes to energy efficiency. Based on these findings, this paper argues that the biggest advancements are not to be made within the SMEs, but partly through the legislation that affects the financial benefits of energy improvement solutions, and through the marketing approach that solution suppliers take towards their potential customers when addressing the inherently individual needs of SMEs.

Keywords: readiness level; TRL; SME; energy efficiency; waste heat recovery

---

1. Introduction

European countries are pushing for a green conversion in all energy aspects, yet there is a surprisingly small focus on recycling or recovering the energy we waste. Small- and medium-sized enterprises (SMEs) with high-energy consumptions are especially under pressure, as they have less options to move their operations to lower cost countries or to invest in large-scale energy recovery installations. This is critical because while there are clearly large amounts of energy to be saved for the relatively few large companies, the smaller amounts of energy spread across the much more prolific SMEs add up to a much larger potential. However, SMEs are inherently idiosyncratic and in many ways operate on much more constrained resources than larger companies. This translates into SMEs clearly seeing the potential benefits of lowering energy consumption and their operational costs, but neglect doing it in favor of other, more tangible investments, as will be discussed later in this paper.

SMEs, as defined by the European Commission to have below 50 employees for small and below 250 for medium enterprises with a turnover of less or equal to €10 million or €50 million, respectively [1], make up a very important part of European industry. SMEs constitute a vital 99.8% of the non-financial business economy in the EU and employ 67.1% of the workforce [2]. In a report by the Eurochambers association [3], more than 50% of surveyed SMEs who had implemented energy saving measures had saved over 10%, while another estimate puts the potential at 25% potential energy improvement in the European Union [4]. Clearly there is potential to save large amounts of energy, but these improvements are difficult for governments to focus on due to the highly different needs and operations of SMEs.

Denmark has set an ambitious goal of becoming fossil free by 2050. This creates a big push for the production of clean energy, which is inherently more expensive than fossil-based energies [5]. As a result, energy prices have been climbing steadily and are predicted to keep climbing as fossil fuels are phased out. This puts pressure on Denmark as a whole to increase energy efficiency in order to remain competitive in industries and to allow an affordable conversion to renewable sources.

While energy consumption grows steadily, the Danish government has implemented two major systems in order to stem the growth of energy consumption and, by extension, the amount of clean energy needed to allow the phasing out of fossil fuels. The first system is a regulation, which mandates that all energy suppliers must reduce the amount of energy they supply [6]. At the same time, the government will pay for energy savings that are made in the form of CO_2 quotas. While this scheme is available to any person or business, it is most commonly intermediated by energy suppliers who will help finance energy efficiency improvements in exchange for claiming the savings, which are then "sold" to the state as energy savings [7]. The second system put in place by the government taxes the reuse of energy [8], for example by using waste heat from production to heat offices. While this seems counterintuitive, since reusing the heat lets you save energy on heating the offices separately, it is put in place to force companies to reduce their total energy consumption from the start, rather than finding ways of reusing, or even selling, their waste. Combined, these two systems encourage companies to find ways to improve efficiency by reducing their total consumption and, by extension, their total waste. This is an important distinction between "improving efficiency" and "reusing waste".

Before this background, we describe a framework of market readiness and use it to assess the asymmetry between existing solutions and opportunities in the market with the aim of identifying which steps can be taken in order to introduce more energy optimizations into SMEs and who should be taking those steps. More specifically, we explore how four Danish SMEs, in different parts of the value chain in the food processing industry, view energy efficiency improvements, focusing on the potential reuse of waste heat, along with what they consider important for taking on such projects. The article closes with limitations and further research.

2. Literature

Market readiness is a frequently used term, especially commercially as a consultancy service, but there is no scientific consensus of what such a framework is actually composed. As we will see, however, there are solid suggestions regarding the aspects such a readiness level should consist of and an equally valid reason for why such a framework should exist. The technology readiness level, proposed by Ray Chase and implemented by NASA during the 1980s, was later formally defined and expanded for use in other industries by John Mankins in 1995 [9]. Mankins described and established a framework with the purpose of consistently measuring maturity between different types of technologies. While it is a very useful framework, it is inherently oriented towards technology and innovation push and completely leaves out the notion of innovation or market pull. As such, proponents of other readiness levels suggest complementing this framework with a similar consistent framework of measurement oriented towards innovation, integration or market demand. The complementing framework could be an existing proposed framework, such as innovation readiness [10], system integration readiness [11] or demand readiness [12]. Dent and Pettit note that although technology readiness levels are most commonly in a time-linear fashion, a corresponding market readiness level might not be. They go on to add that:

> "*Both frameworks do however share the important characteristic, in that the extent to which their components are satisfied increases the chances of commercial success for any particular innovation.*" [13] (p. 3)

In order to use market readiness as a framework for assessing the uptake of waste heat recovery solutions, we have to define clearly what we mean by market readiness. Hence, we will go through the previously mentioned readiness levels and how they each complement the technology readiness level.

2.1. Technology Readiness

The technology readiness level (TRL) has seen many different interpretations since it was introduced in the 1980s and expanded in the 1995s to other industries. At its core, TRL is meant to objectively assess the maturity of a technology, starting at fundamental research and ending with a "flight proven" system, or as the European Commission defines it, an "actual system proven in operational environment" [14] (p. 1).

TRL is widely used and widely recognized, but as shall be highlighted in this section, there are many who try to complement its inherent shortcomings when it comes to describing the process in which the technology is developed, how it interacts with other technologies and how such a technology would fare commercially. Table 1 describes the TRL as adapted to European industry through the HORIZON 2020 program.

Table 1. Technology readiness levels described [14] (p. 1).

TRL	Description
1	Basic principles observed
2	Technology concept formulated
3	Experimental proof of concept
4	Technology validated in lab
5	Technology validated in the relevant environment (industrially-relevant environment in the case of key enabling technologies)
6	Technology demonstrated in the relevant environment (industrially-relevant environment in the case of key enabling technologies)
7	System prototype demonstration in operational environment
8	System complete and qualified
9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

This definition is chosen for the purpose of this paper, as it best reflects the implementation of TRL in European Industry.

Companies who work with the reuse of energy at low temperatures already exist for commercial purposes. Solutions in transferring heat using heat pumps or simply heat exchangers are commonly used, but more advanced solutions, such as transferring waste heat into electricity, are also available, though less pervasive. Companies such as Infinity Turbine [15], Enogia [16], Electratherm [17] and Zuccato Energia [18] all produce commercially available solutions that convert waste heat into electricity. As such, we define flexible waste heat recovery solutions in this segment to be at a TRL of 9 already.

2.2. System Integration Readiness

Sauser et al. [19] propose a framework of system readiness (SRL) based on a technology readiness level (TRL) and an integration readiness level (IRL), which is designed to complement the challenge that TRL only speaks about the technology itself, and not how it may technically integrate into a new or existing system. Regardless of a single technology's maturity, it is doomed to fail if it cannot interface with the systems in its environment [20], and as interconnectivity becomes more and more important, this ability to integrate becomes more crucial. Table 2 shows the different levels this measurement comprises.

Table 2. Integration readiness levels and their definitions [19] (p. 6).

IRL	Definition
7	The integration of technologies has been verified and validated with sufficient detail to be actionable.
6	The integrating technologies can accept, translate and structure information for its intended application.
5	There is sufficient control between technologies necessary to establish, manage and terminate the integration.
4	There is sufficient detail in the quality and assurance of the integration between technologies.
3	There is compatibility (i.e., common language) between technologies to orderly and efficiently integrate and interact.
2	There is some level of specificity to characterize the interaction (i.e., ability to influence) between technologies through their interface.
1	An interface (i.e., physical connection) between technologies has been identified with sufficient detail to allow characterization of the relationship.

Common for the IRLs is that they can all be developed through prototyping before a finished product is ready, in contrast to TRL. This means the IRL levels can, and should, be completed before reaching TRL 9 or even 8. Sauser et al. go on to define five system readiness levels (SRL), which are listed below in Table 3.

Table 3. System readiness levels (SRL) and their definitions [19] (p. 7).

SRL	Name	Definition
5	Operations and Support	Execute a support program that meets operational support performance requirements and sustains the system in the most cost-effective manner over its total life cycle.
4	Production and Development	Achieve operational capability that satisfies mission needs.
3	System Development and Demonstration	Develop a system or increment of capability; reduce integration and manufacturing risk; ensure operational supportability; reduce logistics footprint; implement human systems integration; design for producibility; ensure affordability and protection of critical program information; and demonstrate system integration, interoperability, safety and utility.
2	Technology Development	Reduce technology risks and determine an appropriate set of technologies to integrate into a full system.
1	Concept Refinement	Refine the initial concept. Develop system/technology development strategy.

This last framework is developed for the American Department of Defense (DoD), and the authors state that:

> "*We do not promote the DoD phases as the only system phases of development, however, these are consistent with other life cycle models and is used for illustration purposes in the context of this research.*" [19] (p. 7)

The final SRL framework is an aggregate of the individual TRLs and their IRLs in relation to other technologies relevant to their integration in order to rate the interoperability of the entire system [13]. It is also important to note that IRL has since been refined and become the foundation for integration maturity metrics (IMM), which is a much more detailed scoring of IRLs [11], but for the purpose of this paper, the initial definition is considered more than sufficient.

2.3. Demand Readiness

In an analysis of technology transfer practices, Florin Paun has developed a readiness framework based on illustrating the gap, or asymmetry, between technology push, strongly attributed to TRL, and market pull, which he attributes to a demand readiness level (DRL) [12]. The purpose of DRL is to measure the level of market pull corresponding to the level of technology push, and he expresses this by reversing the order in which the levels are related as shown in Table 4:

Table 4. Demand readiness levels (DRL) and descriptions paired with technology readiness levels, adapted from [21] (p. 3).

DRL	DRL Description	TRL Description	TRL
1	Occurrence of feeling "something is missing"	Market Certification and Sales Authorization	9
2	Identification of specific need	Product Industrialization	8
3	Identification of the expected functionalities for a new product/service	Industrial Prototype	7
4	Quantification of expected functionalities	Field demonstration of whole system	6
5	Identification of system capabilities	Technology Development	5
6	Translation of the expected functionalities into needed capabilities to build the response	Laboratory Demonstration	4
7	Definition of the necessary and sufficient competencies and resources	Research to prove feasibility	3
8	Identification of the experts possessing the competencies	Applied Research	2
9	Building the adapted answer to the expressed need in the market	Fundamental Research	1

Paun goes on to add that a technology transfer agreement should only exist if the DRL + TRL is 10 or higher. DRL in combination with TRL has been used extensively by ONERA, the French Space Laboratory (Office National d'Etudes et de Recherches Aérospatiales), for the purpose of creating an ecosystem of SMEs around ONERA for commercializing their technologies. The reason given was that SMEs were more in tune with market demands and through the framework of DRL and TRL could mediate the transfer of technology to industry for the purpose of commercialization [12].

2.4. Motivators and Barriers

A quantitative study on the motivators and barriers SMEs face has been conducted in Australia [22], showing that not only do SMEs typically face several barriers, but the barriers they face are also vastly different. It should come as no surprise, considering the diversity of how SMEs operate, that the challenges they face are equally diverse. While not directly applicable in Denmark or even the EU, there are many aspects of this study that are echoed in our SME culture. In summary, the study showed that financial incentives were predominant with 89% of participants rating this as an important motivator for deciding investments in energy efficient solutions.

It is very clear that financial motivation is the most common motivation for SMEs to engage in energy efficiency improvements, but the barriers show a much more diverse picture. Here, the two highest rated priorities are the cost of the project, rated a priority for 33% of participants, and the lack of staff engagement, rated as an equal 33%. General questions about the premises, whether they can modify it or even not, having detailed information, also play a very high role rated at 16% and 14% respectively. Finally, the low morale of business was also a relatively high important issue for 14% of these SMEs. It should be noted that this survey took place during 2009–2011, which was a period heavily affected by the recent financial crisis.

In contrast to the previously discussed readiness ratings, which give us insight into "how" things are, this survey gives us an important insight into "why" things are. Both insights are important in the discussion of what can be done to close the gap between energy efficiency solution providers and SMEs who could benefit from those solutions.

3. Method

To explore the market readiness of waste heat recovery solutions as a means of energy efficiency improvement, four SMEs were interviewed over the course of three months (from March–May 2016) to assess their motivations and barriers and look for evidence of the different market readiness indicators. The objective here is not to methodically assess the market readiness of the solutions they are considering, but to explore their operations and view on energy efficiency improvements. This information will then be compared to the market readiness framework in order to identify where the gap is between technologies and their uptake and what can be done to close it.

The data are collected through semi-structured interviews for the purpose of being able to dig deeper into topics and expose more tacit levels of knowledge in order to better understand how the SMEs view the topics and which challenges they face. One of the pre-sample interviews conducted showed that the representatives of even small companies are very quick to state that the environment is a high priority, possibly from a fear of being viewed negatively. As such, an informal setting and preferably going there and talking to each company face-to-face are highly important for getting a more honest insight into how they prioritize energy efficiency and their environmental impact, aside from what is legally required of them. In order to gain insight into this more tacit level of knowledge, the interviews are structured in an informal way, as described by Kvale [23], to take place as a conversation where the interviewer and interviewee attempt to make sense of the topic together, rather than as a strict data collection. This also means taking an approach of constructionism [24].

The purpose of this study is a qualitative exploration of SMEs' views and conduct in relation to energy efficiency improvements and specifically the reuse of waste heat. The ultimate desire of the interviews is then, as David Silverman would put it, to participate in the debates about how organizations function, to provide new opportunities for people to make their own choices and to offer a potentially new perspective to both practitioners and clients [25].

SMEs are more resource constrained than larger companies [26], which means that the time they have available to spend on topics outside of their core business is significantly smaller. As such, it can prove very difficult to actually get to visit them and talk to them as the typical reply is that they simply do not have anyone available who has time. To overcome this challenge and to complement the highly explorative nature of this study, theoretical sampling was chosen as the method for deciding which SMEs to continuously include [27].

Four companies were chosen at different places in the value chain to help explore whether their distance to the end user and their relative visibility to the general public could have an impact on their decisions about environmental impact. All four companies are limited to the food industry in order to eliminate disparities that could be the results of industry cultures. The companies were not chosen at random, but rather chosen consecutively in order to help explore the topic until no questions within the scope of the study were left unanswered.

4. Findings

The findings of the interviews are summarized here so that similarities and contrasts can be found and the market readiness of their potential energy efficiency improvement can be assessed. This is done through coding the interview transcription to find key evidence that either supports or disputes a certain readiness level or barrier. The interviews are also put into context by summarizing key points that were either very significant for the company or points that were not covered by the interview guide, but that could have a significant importance for the topic of how to bridge the gap between energy-efficient solution suppliers and potential adopters of such solutions.

4.1. LEPO A/S

LEPO A/S is a small Danish company located outside Copenhagen with approximately 35 employees located just outside of Copenhagen. Their main business is the processing and value adding of different meat products, such as cooking, smoking and packaging of different types of meat. They work with small and large Danish companies, such as butchers and ready meal producers, with contracts of varying lengths. LEPO A/S has no products of their own, end users or marketing force; they operate purely as a way for meat processing companies to offload or outsource production of various processes. This company was chosen as a sample because it represents a part of the value chain that is invisible to the general public and as such has no public relations value in adopting energy-efficient solutions, in contrast with other companies in the sample, such as XYZ HOCO Foods (this company from the food industry would like to stay anonymous; hence, we use the term XYZ HOCO Foods to ensure anonymity).

The following bullets summarize the key results of the interview with LEPO A/S:

- LEPO A/S has no internal engineering staff. They hire this competence externally for projects they define themselves.
- They are limited in space, but are able to expand their facilities if needed.
- They are concerned about continuous improvement, but not sure which improvements would be best from an energy efficiency perspective.
- They believe that if there were money to be saved, they would be doing it already.
- In contrast to the above, it is later mentioned that there are potential improvements they are aware of that could be made to their ovens.
- They work with energy efficiency when starting new projects, but do not give a clear answer as to whether they also optimize existing equipment.
- They have not considered leasing a solution, rather than investing in it, but they believe it would be too expensive. If it were not, they would consider it.
- Their latest optimization was done in conjunction with building a new cooling room.
- The latest project took two months to plan and design and two months to build. The expected return of investment was three years, and it cost three million DKK (which was more expensive than anticipated).
- The project was designed and executed by an external engineering company.
- They only use one engineering company to do such projects.
- They do not go into detail with energy legislation; this is left to the engineering company.
- They can finance up to three million themselves for such projects.
- They view their largest barrier to be "lack of time", especially if they have to take machines out of production to do projects.

4.2. XYZ HOCO Foods

XYZ HOCO Foods is a processing plant where milk is treated to extract different compounds, drying them and selling them either internally or externally as additives for milk products or other food-based products. While XYZ HOCO Foods is a large and international corporation based in Denmark and operates in the entire value chain from farmers to milk products on supermarket shelves and even runs their own stores, the XYZ HOCO Foods plant represents an important supplier very early in the value chain where raw materials are broken down for use in different markets. The XYZ HOCO Foods plant also exhibits SME-like behavior, in that it has authority to plan, finance and execute projects, such as product development or energy efficiency improvements, independently from the XYZ Food organization. It has approximately 70 full-time employees and is located in northern Jutland, and while part of XYZ HOCO Foods, it is considered an SME for the purpose of this study because of its autonomy.

The following bullets summarize the key results of the interview:

- XYZ HOCO Foods has internal engineering competencies and plans and designs its own projects.
- If the projects are very large, they will hire in the know-how they are missing.
- They do not do projects specifically about reusing waste heat.
- If there is money available for improvements, they will typically be assigned to new products, rather than energy optimizations.
- They consider human resources a big financial limitation to projects in energy efficiency.
- There are limitations to what they can do with the premises, but they do not consider them barriers.
- They are aware that they have a lot of waste heat, and they believe there are solutions to this. They see the biggest challenge to be raising the temperature to a useable level (for heat treatment in other processes at 80 °C–90 °C)
- They consider it a big challenge to get the needed money assigned for projects in energy efficiency, regardless of how good the business case might be.
- They expect a return of investment between six and 12 months normally.
- They have many ideas of what could be improved, but lack the resources.
- They prefer maintaining equipment themselves, as they consider this to be most cost effective.
- When starting new projects, they look at how they can make the solutions as energy efficient as possible.
- The most recent project they conducted was a change in process for one of their products. This change was driven by their customers, who wanted a lower price. The solution also saved about 50% energy, though that was not the direct focus of the project.
- The recent project has taken about half a year and is expected to take some more years before it is finished.
- They handle energy legislation from their head office.
- Cost and financing is considered the largest barrier to improvements.
- They do not really have a limit to what can be invested, if a project is approved.
- The complexity of a solution is considered crucial to whether or not it is considered.
- They consider themselves to have very high interest, knowledge and motivation for doing improvements.
- They would consider improving capacity rather than reducing energy consumption, even though they acknowledge the value in lowering production costs through lower consumption.
- Stopping production to make improvements is considered a very big financial concern.

4.3. Hiddenfjord

Hiddenfjord, based in Tórshavn on the Faroe Islands, is a small aquaculture company that raises salmon in the Atlantic Ocean for global export. They have a strong focus on their environmental impact and the wellbeing of the ecosystem around their aquacultures, based on the Faroe Islands. Hiddenfjord employs approximately 40 people, and their operation includes raising salmon in the aquaculture and processing the fish on land. Their products are marketed as premium quality and sold through wholesalers around the world with their biggest markets being France, Germany, China and Japan. Hiddenfjord was chosen because they are placed almost at the start of their value chain and because their emphasis on premium quality and environmental responsibility could lead to gaining value from having a “greener” image through renewable energy or the reuse of waste energy.

The following bullets summarize the key results of the interview:

- They do occasional projects focused on energy efficiency, but they will prioritize projects concerned with their products.
- They consider the relative youth of their industry and high pace of innovation to be a barrier for long-term investments in solutions.

- They consider the biggest potential improvement to be in reusing energy when controlling water temperatures.
- In the short term, there is old equipment they would like to replace with newer, more efficient equipment.
- Their most recent improvement was using seawater from their cooling process to heat parts of the building. It had an expected return of investment of 3.5 years and cost around 300,000 DKK.
- In another similar process, they cool seawater in order to cool their products. The waste heat is then used to heat parts of the building. This had an expected return of investment of four years.
- They like to do small continuous improvements to keep the focus on energy efficiency, as well as their products.
- They will typically hire engineering companies with experience in the aquaculture industry to do projects for them.
- Apart from putting up a wind turbine, they are almost free to do what they want with the premises.
- They discuss energy legislation with their energy provider.
- The Faroe Islands expect to be fossil free by 2030, which is another big driver for green energy and energy efficiency.
- They prefer investing rather than leasing solutions, but would consider it if it were financially viable, especially since it would negate the risk of a long-term investment in what they consider to be an industry with a high pace of innovation.

4.4. Aquapri

Aquapri is a medium-sized company with different locations in Denmark, employing approximately 120 people. They operate aquacultures and fish processing plants at different locations in Denmark. For this sample, we chose the newly-built Vejen aquaculture and processing plant. This plant commenced operations in November 2015 and raises different kinds of fish. In contrast to Hiddenfjord, this plant does not raise the fish from spawning, but only takes care of grown fish until they are fully grown to customer specifications. They also operate on land with indoor aquacultures, as opposed to Hiddenfjord's fish, which swim in the ocean. The Aquapri Vejen plant was chosen as a sample because it was recently completed and was designed with several energy efficiency innovations in place, which have not been previously used in that industry.

The following bullets summarize the key results of the interview:

- The most recent project in energy improvement Aquapri conducted was a special ventilation system, which they designed and built themselves.
- The recent project cost around five million and took about nine months from start to finish, which was longer than they would expect from such a project. The expected return of investment was 2.5 years.
- They consider the limit of the return of investment to be around 7.5 years, due to the expected lifetime of such a solution.
- They strongly prefer to maintain their equipment, since they cannot wait for technicians to arrive, and a stoppage can have serious consequences for the wellbeing of their fish.
- They do not currently lease any equipment, and it would have to be a really good business case to be considered. They would rather invest in equipment.
- They prefer to do the planning and design of improvements themselves.
- They might hire external help to build solutions, but not for the development.
- The highest priority for them when considering projects and improvements is the wellbeing of their fish.
- They keep track of energy legislation themselves and discuss it with their energy supplier, who also helps them with ideas for solutions that could benefit them.

- They had considered putting up windmills, but this was ultimately cancelled due to legislative reasons.
- There are no immediate limitations to what they can do with the premises, unless they negatively impact the environment around them.

It should be noted that outside the transcribed interview, an upcoming project was discussed, where they would be using waste heat from creating ice to heat up the water for the youngest fish. This was estimated to cost around one million DKK with a return of investment of two years and an execution time of three months and was also developed with the help of their energy supplier, who provided calculations and legislative guidance.

5. Discussion

5.1. Market Readiness Level

In order to assess the market readiness level of energy efficiency solutions for reusing waste heat, we use a combined market readiness level as seen below in Table 5. The integration readiness level has fewer levels because it is heavily focused towards the initial design rather than the finalization.

Table 5. Combined market readiness levels.

Level	Demand Readiness	Integration Readiness	Market Readiness
1	Occurrence of feeling "something is missing"	An interface (i.e., physical connection) between technologies has been identified with sufficient detail to allow characterization of the relationship.	An acceptance that viable improvements can be made
2	Identification of specific need	There is some level of specificity to characterize the interaction (i.e., ability to influence) between technologies through their interface.	Ability to highlight where the improvement can be made
3	Identification of the expected functionalities for a new product/service	There is compatibility (i.e., common language) between technologies to orderly and efficiently integrate and interact.	Being able to identify what the system should do
4	Quantification of expected functionalities	There is sufficient detail in the quality and assurance of the integration between technologies.	Putting numbers on what is expected in terms of a solution, financially and technically
5	Identification of system capabilities	There is sufficient control between technologies necessary to establish, manage and terminate the integration.	Ability to define how the system should operate and integrate
6	Translation of the expected functionalities into needed capabilities to build the response	The integrating technologies can accept, translate and structure information for its intended application.	Identify on a component level what the system should be comprised of
7	Definition of the necessary and sufficient competencies and resources	The integration of technologies has been verified and validated with sufficient detail to be actionable.	An understanding of who should be planning, designing and implementing the solution
8	Identification of the experts possessing the competencies		Having contact with the people, internally or externally, who will design and create the solution
9	Building the adapted answer to the expressed need in the market		Solution is being created to solve a defined problem

The focus of the market readiness level is to measure the market pull against the technology push associated with technology readiness levels. As such, it is very strongly based on Florin Paun's demand readiness level [12], but with the crucial consideration that whichever solution is chosen, it has to fit in its designated environment. This is not only true for SMEs, but also big companies, who are also challenged in integrating technology push and market pull in their strategy [28]. The integration readiness level serves as this important link between the technology and environment to ensure that the solution will "fit".

As the integration readiness level [19] is fairly shorter (seven levels) and meant to be completed during the process of going through demand or technology readiness levels, these are condensed and folded into the demand readiness levels at the appropriate points to create the market readiness level framework. After we discuss the main topics affecting the adoption of energy efficiency solutions for SMEs in general, we will apply this framework to see where each company currently finds itself.

5.2. Engineering and Competencies

There is a slight disparity between the interviewed SMEs in whether they hire engineering competencies outside for projects or if they prefer to handle the engineering internally. In the case of XYZ HOCO Foods and Aquapri, they will try to do as much as possible internally, because they see that as most cost effective, while in contrast, LEPO and Hiddenfjord have outsourced this competence to engineering companies who know their respective industry. Regardless of the approach, whether they handle the project internally or externally, all companies struggle to assign this specific resource to projects in energy efficiency improvements. With the exception of Hiddenfjord, all of the companies state that they do not do projects purely on energy efficiency, but are driven by other factors, such as developing new processes in the case of XYZ HOCO Foods, or investing in new equipment, such as LEPO and Aquapri. An explanation for that behavior might be the general lack of resources in SMEs, which is widely acknowledge in the literature [26].

Looking at energy efficiency when creating something new, be it processes or equipment, was a reoccurring theme and seems to hint strongly that retrofitting energy efficiency solutions is much less desirable than waiting until equipment needs replacing and then putting relatively less resources into ensuring that the new equipment is more energy efficient to start with.

5.3. Priorities

SMEs are very good at what they are doing. This is also pointed out by Florin Paun [21] in his case about technology transfer in the French aerospace industry. One of the reasons SMEs are good at what they are doing is that their focus is on their core product. Everyone employed is directly related to the product in some way, and as Hiddenfjord put it "We are producing fish, not energy" (roughly translated from the interview). While this can seem obvious at first glance, it actually goes a very long way in telling why SMEs are slow to adopt energy-saving solutions, especially if they are emerging; the focus of their business is on the product and not on everything around it. With that said, they all acknowledge that saving energy is important, partly for the sake of the environment, but also in order to reduce production costs, but given a lump of money, they will rather invest it in increasing sales and capacity, because such is the nature of their business.

5.4. Financial Expectations

The financial expectations of the SMEs ranged widely in what they would expect to pay, how long it would typically take to execute a project and how long the return of investment should be. XYZ HOCO Foods had no real limit to what could be invested, which is expected when the money comes from a head office, but at the same time, they had the shortest expected return of investment with 6–12 months, explaining that this would be the kind of return they would expect if they invested in new products or capacity improvements. Hiddenfjord was the strongest contrast in investment, as they preferred to do smaller projects continuously, and Aquapri would accept the longest return of investment at 7.5 years. The result derived from this is that financial expectations are very individual to SMEs, and no two are really alike. However, common for each of them is that they rate improvements in energy efficiency to compete in a budget against other improvements closer to their core business. The discrepancy between expectations can then most likely be assigned to the distinct nature of each SME's segment in the market.

In regards to barriers to the uptake of energy efficiency improvements, it should also be pointed out that none of the participants recognized "low morale of business" as a cause for not investing, neither within themselves nor among their partners. This could either be because that part of the survey on motivators and barriers does not fit to Danish SMEs or because the limited sample size by chance did not include such an SME. Most likely though, this can be explained by the survey taking place during 2009–2011, in which many SMEs were strongly affected by the recent financial crisis and, as such, had a lower morale of business.

5.5. Legislation

Only one out of the four SMEs, Aquapri, felt that they had the competencies in-house to deal with legislation concerning energy use and reuse. In the case of Aquapri, they did work together with their energy supplier in order to develop solutions around this legislation. This is an indication that there is no widespread understanding within the company of what can and cannot be done with the energy they consume. Once again we see a focus on priorities where their core business takes center stage and where the awareness of legislation regarding the use and reuse of energy is not within the scope of their core business and is therefore prioritized lower or outsourced; either to their energy suppliers or to other consultants.

5.6. Aggregate Market Readiness Level

In order to identify the gap between what is on offer and what is being adopted in terms of energy efficiency solutions, we try to assess the market readiness score level by level, using the definition from before.

(1) An acceptance that financially viable improvements can be made.

All of the SMEs have ideas about what can be improved in their surroundings, which means they can all pass this level of the rating.

(2) Ability to highlight where the improvement can be made and where critical interfaces exist.

Again, each SME had a clear idea of where the improvement could be made in terms of which process or equipment could be improved.

(3) Being able to identify what the system should do and what it should interact with.

Here, we start to see a slight separation in how well-defined the solutions are for the SMEs. In the case of XYZ HOCO Foods, they knew they wanted to do something with heat pumps, but they were not entirely sure where or how. LEPO knew they could save money by improving the ovens, which is enough to pass this point. Hiddenfjord also knows that a potential solution would be reusing energy when controlling temperatures, and Aquapri has planned a project to reuse waste heat from creating ice and using it for heating.

(4) Putting numbers on what is expected in terms of a solution, financially and technically.

XYZ HOCO Foods has the quantification that any reuse of waste heat should be around 80 °C–90 °C, but had no quantification of the amounts of energy that would be needed. Only Aquapri had calculations at hand, which they had developed in cooperation with their energy supplier, Trefor. This seems to be a result of quantification taking relatively significant engineering resources, which none of the participating SMEs had readily available.

(5) Ability to define how the system should interoperate and communicate.

Aquapri was the only company to have considered how its solution should interoperate and communicate. This was largely due to their technical insight, internally, and legislative guidance externally from Trefor.

(6) Identify on a component level what the system is made of and how it is controlled.

Aquapri is the only company to pass this, as their current solution has been made and is waiting for the environment, in which it will be installed, to be finalized.

(7) An understanding of who should be planning, designing and implementing the solution.

All companies have a very good understanding of who should be responsible for which part of a project.

(8) Having contact with the people, internally or externally, who will design and create the solution.

In the case of LEPO, they strongly preferred to use the same company for all of their projects. XYZ HOCO Foods and Aquapri preferred to do everything in-house, and Hiddenfjord would seek various solution providers within their industry.

(9) Solution is being created to solve a defined problem in its designated environment.

Only Aquapri comes close to this point, as their next solution exists, but is awaiting its designated environment to be completed before it can be connected.

Below, Table 6 shows the different companies and their individual values at each level of the market readiness framework:

Table 6. Market readiness levels (MRL) of samples.

MRL	LEPO A/S	XYZ HOCO Foods	Hiddenfjord	Aquapri
1	Yes	Yes	Yes	Yes
2	Yes	Yes	Yes	Yes
3	Yes	No	Yes	Yes
4	No	Partially	No	Yes
5	No	No	No	Yes
6	No	No	No	Yes
7	Yes	Yes	Yes	Yes
8	Yes	Yes	Partially	Yes
9	No	No	No	Partially

"Yes" means that there is evidence that this part is already covered; "No" means that they have not yet discussed how to approach this topic; and "Partially" indicates that some efforts have been made on this topic, but insufficiently to consider it complete.

It is clear to see that the most common deficit is around calculating numbers for a specific solution and describing how it should interoperate with other systems, as well as how to control it on a component level. These are also the most technically demanding areas of the scale and therefore also the most resource intensive in terms of assigning manpower to work on them. Aquapri managed to get past these largely with the help of their energy supplier, who helped pinpoint the potential improvement and calculated the savings it could achieve.

An important aspect to recall is that unlike the technology readiness level, the market readiness level is not a linear path. This is evident in the results where companies have a very good idea about who should make the solution and what competencies are needed even before they have any details about what the solution should do. As Dent and Pettit note, it is about how many components that are satisfied and not necessarily the sequence in which they are satisfied, which increases the chances of commercial success [13].

6. Conclusions

This study was based on two methods: assessing the market readiness of solutions considered by four SMEs in Denmark and to identify the motivations and barriers behind such projects. These two methods were important to both understand "what" was going on and "why", neither of which would give an accurate or useful picture on its own. Based on the existing literature about the motivations and barriers for the adoption of energy efficiency solutions for SMEs, it was suggested that the major constraints to adopting new solutions would be the investment required for such an adoption. While we found this to be mostly true, we also found that the financial barrier is not so much the investment itself as the human resources needed to plan and execute such a project. The companies we interviewed were typically able to finance between three and five million DKK towards projects that had a return of investment between one and 3.5 years. However, for SMEs to hire an engineer to work with a project in energy efficiency improvement is unfeasible because an increase in staff is generally more of an impact the smaller the company is, and there might not be sufficient engineering work to merit the extra employee once such a project was concluded. The alternative is hiring the competence externally as engineering consultants, like LEPO A/S preferred in this case, but this creates the problem that there must be a significant known improvement in the potential project, as it suddenly costs money just to "think" about energy efficiency improvements through calculations and estimations when you do not have the competence in-house.

The conclusion to draw from this is that SMEs need engineering and technical help from outside, which has a different business model than being payed up front to help find the solution for the SME. This can be in the form of government subsidized help, such as Aquapri did with their energy supplier, Trefor. It can also be in the form of the solution supplier offering to evaluate the savings potential for the company, and while that would require a larger workforce of engineers on the supplier side, this study suggests that it would also translate into more sales, as more companies would be willing and have the financial means to adopt their solutions. This is supported by the market readiness framework, which suggests that the most immediate barriers to progress are "Putting numbers on what is expected in terms of a solution, financially and technically" and the "Ability to define how the system should operate and integrate", both of which will typically require engineering competences.

Another valuable finding was that regardless of whether or not there is a positive or attractive return of investment in an energy efficiency improvement, that solution has to compete in a budget for other improvements, which might have a more desirable return of investment. This was further enforced as companies would unanimously state that while energy consumption was important, they were in the business of food production and not energy consumption. As a result, they would by default prefer to invest in new products or in production improvements relating to quality or capacity, in order to increase revenue, rather than investing in energy efficiency to reduce cost. This is a very understandable approach, as focus on the core business is essential for SMEs. Knowing that energy efficiency improvements for SMEs are important to lowering the consumption by industry, we again argue that the solution should come externally from the company through government-subsidized incentives, which not only encourage the adoption of energy efficiency solutions, but also help mediate which solutions can be implemented and what their benefits will be in order to unload this burden from the SMEs. As to addressing the technical challenges, it was clear that companies were well aware of which types of solutions would be beneficial for their particular production and even who would likely create the solution for them. The technical limitations are therefore not considered as big a challenge as the previously discussed legislative and competency-based challenges.

7. Future Research and Limitations

There are very clear limitations for this study, most of which are defined by its scope. The sample companies were limited to the food industry in order to reduce variables that might be inherent to different industries, such as access to financing and channels of information about technical production solutions. The food industry is also a prevalent industry, which operates similarly worldwide, increasing the likelihood that this study will also be applicable in other countries. It should however still be noted that any similar studies should take into account to what extent this will limit the results of this study when applied in other countries and industries.

Regarding readiness levels, there is evidence that more and more competing frameworks of measurement are invented and developed. While this positively highlights the different perspectives and complexities that each framework focuses on, there is a strong need for a unified framework to compliment the dominant and widely accepted, and understood, technology readiness level. This paper has attempted to unify such a framework, but there is clearly much more work to be done in this field to increase the effectiveness of such a framework while keeping it practical. A general categorization of readiness levels is difficult at the SME level, as SMEs tend to make an individual scale of customer readiness than an overall market readiness. Further research should take this differentiation into consideration. For instance, an individual and idiosyncratic scale could be developed for different industries.

Denmark has very specific regulations in regard to the reuse of energy and tariffs that apply to such reuse. These regulations will be different in other countries, even within the EU, and the tariffs, where applicable, are also different, which can skew the financial viability of a particular solution. While it is unlikely that the regulations will change drastically in Denmark, it is still expected that the regulations, at least within the EU, will become more streamlined and homogenous. As such, it will be important to follow up on the regulation changes as they evolve in the future in order to continuously evaluate the effect on the uptake of energy efficiency solutions.

In the future, we are likely to see improvements in heat pumps and a more pervasive district heating network, which could allow companies a much better way to make use of waste heat. However, the legislation on the reuse of energy makes it very unfavorable to use it for district heating, as the company producing the heat will be taxed, whereas if they let it escape into the air, they will not be taxed. While the legislation is put in place to try and reduce the overall energy consumption by not allowing companies to keep producing waste and reusing it, more research is needed to highlight the implications of this decision in both its positive and negative effects.

Finally, there is room to broaden the scope of this exploratory study to other industries and to improve upon the qualitative basis that it is built, with a quantitative study for statistical evidence of the trends in the uptake of energy efficiency solutions, which could then be validly extrapolated for better legislative decision-making.

Author Contributions: All authors have read and approved the final version of the paper.

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

References

1. European Commission. *EU Recommendation 2003/361/EC*; European Commission: Brussels, Belgium, 2003; p. 4.
2. Business Economy—Size Class Analysis. Retrieved from Eurostat. Available online: http://ec.europa.eu/eurostat/statistics-explained/index.php/Business_economy_-_size_class_analysis (accessed on 12 Octorber 2016).
3. EUROCHAMBERS–CHANGE: The European Association of Chambers of Commerce and Industry: Energy Efficiency in SMEs: Success Factors and Obstacles. Available online: http://www.eurochambres.eu/Content/Default.asp?PageID=1&DocID=2852 (accessed on 12 Octorber 2016).
4. Thollander, P.; Palm, J. *Improving Energy Efficiency in Industrial Energy Systems*; Springer: London, UK, 2013.
5. Energy Strategy 2050—From Coal, Oil and Gas to Green Energy. Available online: http://www.ens.dk/en/info/publications/energy-strategy-2050-coal-oil-gas-green-energy (accessed on 12 October 2016).
6. Energiselskabernes Spareindsats. Retrieved from Energistyrelsen. Available online: http://www.ens.dk/forbrug-besparelser/energiselskabernes-spareindsats/information-net-distributionsselskaber (accessed on 12 October 2016).

7. Lov om Ændring af lov om Fremme af Besparelser i Energiforbruget, lov om Statstilskud til Produktrettede Energibesparelser og lov om Afgift af Elektricitet og om Ophævelse af lov om Elsparefonden. Available online: https://www.retsinformation.dk/Forms/R0710.aspx?id=129379 (accessed on 19 June 2016). (In Danish)
8. Bekendtgørelse af Lov om Afgift af Elektricitet. Skatteministeriet. LBK NR 310, 01.04.2011. Available online: https://www.retsinformation.dk/Forms/R0710.aspx?id=173417 (accessed on 15 April 2015).
9. Mankins, J.C. *Technology Readiness Levels*; White Paper; Advanced Concepts Office, Office of Space Access and Technology, NASA (The National Aeronautics and Space Administration): Washington, DC, USA, 1995.
10. Tao, L.; Probert, D.; Phaal, R. Towards an integrated framework for managing the process of innovation. *R&D Manag.* **2010**, *40*, 19–30.
11. Sauser, B.; Grove, R.; Forbes, E.; Ramirez-Marquez, J. Integration maturity metrics: Development of an integration readiness level. *Inf. Knowl. Syst. Manag.* **2010**, *9*, 17–46.
12. Paun, F. The Demand Readiness Level Scale as New Proposed Tool to Hybridise Market Pull with Technology Push Approaches in Technology Transfer Practices. In *Technology Transfer in a Global Economy*; Audretsch, D.B., Lehmann, E.E., Link, A.N., Starnecker, A., Eds.; Springer: New York, NY, USA, 2012; Volume 28, pp. 353–366.
13. Dent, D.; Pettit, B. *Technology and Market Readiness Levels*; Dent Associates White Paper 11-01; Dent Associates Ltd.: Winchester, UK, 2011; p. 3.
14. European Commission. Technology Readiness Levels (TRL). In *HORIZON 2020—Work Programme 2014–2015. Commission Decision C (2014)4995*; General Annexes; European Commission: Brussels, Belgium, 2014; p. 1.
15. Infinity Turbine. Available online: http://www.infinityturbine.com/ (accessed on 12 Octorber 2016).
16. Enorgia. Available online: http://www.enogia.com/index.html (accessed on 12 Octorber 2016).
17. Electratherm. Available online: https://electratherm.com/ (accessed on 12 Octorber 2016).
18. Zuccatoenergia. Available online: http://www.zuccatoenergia.it/index.php/en/ (accessed on 12 Octorber 2016).
19. Sauser, B.; Verma, D.; Ramirez-Maquez, J.; Grove, R. From TRL to SRL: The concept of systems readiness levels. In Proceedings of the Conference on Systems Engineering Research, Los Angeles, CA, USA, 7 April 2006; pp. 6–7.
20. Baines, T. An integrated process of forming manufacturing technology decisions. *Int. J. Oper. Prod. Manag.* **2004**, *24*, 447–467. [CrossRef]
21. Paun, F. *"Demand Readiness Level" (DRL) a New Tool to Hybridize Market Pull and Technology Push Approaches: Evolution of Practices and Actors of Eco-Innovation*; ANR-ERANET Workshop: Paris, France, 2011; p. 3.
22. Meath, C.; Linnenluecke, M.; Griffiths, A. Barriers and motivators to the adoption of energy savings measures for small- and medium-size enterprises (SMEs): The case of the ClimateSmart Buisiness Cluster program. *J. Clean. Prod.* **2016**, *112*, 3597–3604. [CrossRef]
23. Kvale, S. *Interviews: An Introduction to Qualitative Research Interviewing*; SAGE Publications: London, UK, 1996.
24. Gubrium, J.F.; Holstein, J.A. *The Active Interview*; SAGE Publications: London, UK, 1995.
25. Silverman, D. *Interpreting Qualitative Data*; SAGE Publications: London, UK, 1993.
26. Brem, A.; Kreusel, N.; Neusser, C. Performance measurement in SMEs: Literature review and results from a German case study. *Int. J. Glob. Small Bus.* **2008**, *2*, 411–427. [CrossRef]
27. Charmaz, K. Grounded Theory: Objectivist and Constructivist Methods. In *Handbook of Qualitative Research*; Denzin, N., Lincoln, Y., Eds.; SAGE Publications: Thousand Oaks, CA, USA, 2000.
28. Brem, A.; Voigt, K.I. Integration of market pull and technology push in the corporate front end and innovation management—Insights from the German software industry. *Technovation* **2009**, *29*, 351–367. [CrossRef]