Energy efficiency from farm to fork? On the relevance of non-energy benefits and behavioural aspects along the cold supply chain

Lisa Neusel
Fraunhofer Institute for Systems and Innovation Research ISI
Breslauer Strasse 48
76139 Karlsruhe
Germany
lisa.neusel@isi.fraunhofer.de

Simon Hirzel
Fraunhofer Institute for Systems and Innovation Research ISI
Breslauer Strasse 48
76139 Karlsruhe
Germany
simon.hirzel@isi.fraunhofer.de

Simone Zanoni
Università degli Studi di Brescia
Brescia, 25123
Italy
simone.zanoni@unibs.it

Beatrice Marchi
Università degli Studi di Brescia
Brescia, 25123
Italy
beatrice.marchi@unibs.it

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Abstract

Though cooling is an ancient concept to preserve food, only modern artificial cooling and freezing made it possible to offer high quality food worldwide and independently of the season. This makes cooling and freezing important energy end-uses in the food industry: they are responsible for about 30 % of electricity consumption. Energy efficiency could thus be of remarkable importance for companies operating in this field. Energy efficiency measures can entail, additionally to the evident energy savings, non-energy related benefits, e.g. enhanced competitiveness, reduced maintenance requirements or an improved working environment. Such factors have been identified as important for affecting the assessment of energy efficiency measures. When it comes to whole cold supply chains, behavioural and organizational aspects seem to be important for decision making about energy efficiency as well, because factors affecting decisions in individual organizations may also occur as cross-organizational issues. Existing analyses on both non-energy benefits and behavioural aspects related to energy efficiency mainly focus on individual companies and hardly touch whole supply chains, in particular from food industry. To contribute to closing this research gap, this paper investigates both aspects more in-depth along the cold supply chain of the food sector, thereby moving from the single company perspective to a full supply chain assessment. For this purpose, 61 semi-structured interviews with companies active in cold supply chains were carried out across various member states of the European Union. Findings from the interviews suggest that energy efficiency is presently considered more strongly in individual companies than along entire cold supply chains. While non-energy benefits appear to be relevant for both individual companies and the cold supply chain as a whole, awareness along the chain seems to be lower in comparison. Further complexity along the cold supply chain seem added by the prevalence of various behavioural aspects which may impede an easy implementation of energy efficiency measures.

Introduction

The food and beverage sector offers a large variety of products, ranging from hardly processed to sophisticated industrialized convenience products. The sector has a share of about 12.3 % in the value added of manufacturing in the EU and more than 4.7 million employees (FoodDrink Europe 2019). Many intermediary and final food products from food industry need cooling and freezing for preserving them. The International Institute of Refrigeration estimates that about 20 % of perishable foods are lost through a lack of refrigeration (International Institute of Refrigeration 2009). Both cooling and refrigeration techniques are expected to hold a 30 % share in the electricity consumption of food industry. The related technical energy saving potential has been estimated at 30 % with a cost effective potential of 20 to 26 % until 2030 (Monforti-Ferrario et al. 2015). Trade-offs between energy expenditure and preserving food at appropriate temperatures have also been pointed out (Heard and Miller 2016; Ndraha et al. 2018). The share of energy costs per value added (about 10 % in selected European member states in 2012) or turnover (about 2 % in the same

group) is also relatively high (Chan and Kantamaneni 2015). This underlines the relevance of improving energy efficiency in food industry both from an environmental and economic perspective.

On their way from "farm-to-fork", food products pass through many hands under cooling. Depending on the product, they can pass from agricultural production, harvest or slaughter to primary production and or/manufacturing (local, national and/or global processors), they are commissioned and distributed by logistic service providers and they may also pass via wholesalers, retailers and distributors prior to their delivery or serving to final customers. This setup of various independent actors can be termed as "cold supply chain" (CSC) (Figure 1). The entire setup of the CSC is characterized by a considerable complexity, also due to strict hygiene and refrigeration requirements that highly affect the energy consumption and product quality offered to final consumers.

While the relevance of energy demand and energy saving potentials have been pointed out on the level of individual companies, thinking energy efficiency beyond individual company boundaries along entire CSCs could offer additional opportunities to reduce energy demand (Marchi and Zanoni 2017). On the one hand, this could open up the possibility to focus on the most cost-effective energy efficiency measures (EEMs) across all stages of CSCs, e.g. by pooling resources. On the other hand, such cross-company activities could also offer new opportunities for energy savings, e.g. by thinking about joint deliveries or by harmonizing maximum temperature levels along the chain while ensuring a high-quality and safe product.

Though these potentials are appealing, their realization requires a close cooperation of companies along the chain. In literature, it has been pointed out that non-energy benefits (NEBs) may have a substantial impact on the value of EEMs (e.g. Worrell et al. 2003), but non-energy related losses have also been pointed out at (e.g. Cagno et al. 2019). With regard to the adoption of EEMs, literature identifies various economic, but also behavioural and organizational aspects (BOAs) which can act as barriers (e.g. Sorrell et al. 2000; Trianni et al. 2013). Since literature on energy efficiency, NEBs and BOAs mainly focuses on the energy performance of individual firms, this paper aims to make an attempt to close this gap by shifting from a single-company to a CSC perspective for the example of the food sector. In particular, the following research questions are addressed:

- To what degree do companies cooperate along the CSC of the food sector with regard to energy efficiency?
- What is the relevance of NEBs and how are they perceived along the supply chain as compared to the individual company perspective?
- What are particular challenges stemming from BOAs with regard to energy efficiency improvements along the CSCs?

The paper first describes the chosen methodology and underlying literature, it then presents and discusses the findings of an interview study and finally, it provides a set of conclusions.

Literature on supply chains and energy efficiency

Various authors have investigated on the cooperation of companies in the field of **sustainable or green supply chain management** in general (Srivastava 2007; Carter and Rogers 2008; Seuring and Müller 2008; Elliott 2013), as well as in the food industry (Murphy and Adair 2013; Li et al. 2014; Govindan 2018). It is generally perceived that green supply chain management promotes efficiency and synergy among business partners and helps to contribute to all three dimensions of sustainable development including economic, environmental and social aspects (triple bottom line approach, see (Elkington 1994). Greening the supply chain to enhance environmental performance, minimize waste and achieve cost savings requires that supply chain partners collaborate upstream towards raw material suppliers as well as downstream in the direction of the final consumer (Li et al. 2014).

While the concept of green supply chains is widespread in current research, little seems known about the particular role and potential of **energy efficiency across several companies of a supply chain** and its integration into supply chain management (Marchi and Zanoni 2017). To the best of our knowledge, only one review has focussed on the topic of energy efficiency in supply chain management with the aim to identify main factors positively or negatively influencing the adoption of energy efficiency initiatives and their impact on supply chain performance (Centobelli et al. 2018). Such initiatives cover the

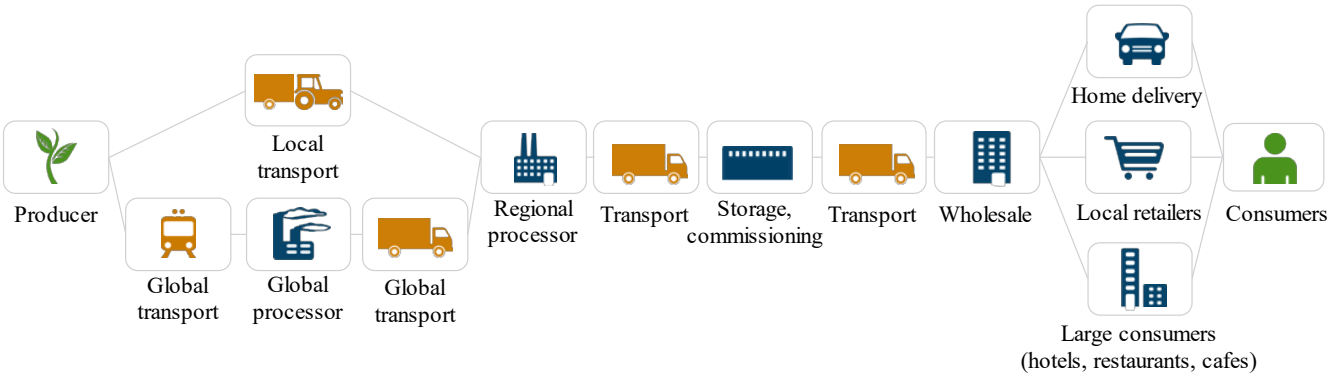

Figure 1. Simplified illustration of a cold supply chain from farm-to-fork (loosely based on Deutsches Tiefkühlinstitut e. V. 2016).

administrative point of view (e. g. corporate policies), the field of transport (e.g. optimized transport management) as well as intra- and inter-organizational aspects (e.g. for process optimization in order to reduce waste or emissions). In addition, the investigation summarizes that the adoption of energy efficiency and environmental sustainability initiatives is mainly driven by relational drivers (e.g. customer expectations) and regulation drivers (e.g. government support) (Centobelli et al. 2018).

When it comes to improvement of **energy efficiency specifically in the cold chain of the food industry**, a classification of different possible stages of the cold chain is available (James and James 2010). Here, EEMs are investigated with a focus on technological issues, while collaboration between the different stages is not considered. Another study proposes an analytical model that jointly looks at economic and energy aspects of the food supply chain (Zanoni and Zavanella 2012). As a key factor of chain optimization it considers specific requirements, in terms of temperature and storage time, to preserve the product quality over time, so as to support decisions makers and improving the sustainability of the supply chain. The missing collaboration among supply chain members is also stressed in the context of decision-making in cold chain logistics (Chaudhuri et al. 2018). Here, the lack of monitoring and control along the cold chain and the missing exchange of temperature data is pointed out. With regard to **coordination schemes in supply chains**, these can either be centralized, i.e. the decision-making process assumes a unique decision-maker managing the whole supply chain, or decentralized, i.e. multiple decision-makers with conflicting objectives are involved which may lead to an inefficient system (Jaber and Goyal 2008). For that reason, supply chain management is pointed out as one of the main opportunities in overcoming existing barriers (Marchi and Zanoni 2017). However, in a case study of three Finnish vegetable supply chains it is observed that economic activities seem to be strengthened by duplex or even multiplex relations, instead of being coordinated by a single coordinative form (Mikkola 2008). In addition one great difficulty within supply chain coordinative relations and structures seems to come from their dynamic, invisible and possibly confidential nature (Mikkola 2008). Given the complexity of CSCs in the food industry, it follows that BOAs are of particular relevance for considering EEMs.

With regard to the adoption of EEMs, research of BOAs is strongly related to research **about barriers to energy efficiency** (Trianni et al. 2013; DeCanio 1998). Barriers, for instance, have been categorized into economic, organizational and behavioural barriers based on more recent economic theory (Sorrell et al. 2000; Sorrell et al. 2004; Sorrell et al. 2010). In a systematical review about collaboration behavioural factors for sustainable agri-food supply chains, as well as for other types of supply chains to broaden the basis of investigation, ten generic key behavioural factors are identified: joint efforts, sharing activities, collaboration value, adaptation, trust, commitment, power, continuous improvement, coordination and stability (Dania et al. 2018). The author also highlights that the interplay among these factors as well as their impacts for achieving sustainability measures are strongly affected by the characteristics of products, regulations, environmental condition and socio-economic context involved.

Other identified important factors affecting the assessment of EEMs, additionally to the evident energy savings, are **non-energy related effects** such as enhanced competitiveness, reduced maintenance requirements or improved working conditions. These so called non-energy benefits (Mills and Rosenfeld 1996) are investigated in several studies (e.g. International Energy Agency 2014). Earlier works investigate on productivity benefits of industrial EEMs. They identify substantial NEBs categorized in a taxonomy comprising six areas (Worrell et al. 2003). Later works aim at a broader consideration of NEBs by introducing a framework that balances both non-energy benefits and non-energy losses (Cagno et al. 2019). It has also been pointed out that such benefits are more persuasive if they are linked to the values and priorities of decision-makers (Fawcett and Killip 2019). Studies using cost-benefit analysis suggest that the value of these benefits can be higher than direct energy cost savings, with monetised 'non-energy' effects up to several times the magnitude of the energy cost savings. While this might be relevant for an optimization of the supply chain, to the best of our knowledge, existing studies have not investigated detailed on the topic beyond single company level, in particular not for the food industry.

Methodological approach

From the previous outline of literature, it is obvious that the adoption of EEMs is a multi-faceted issue. Drawing on the previously mentioned literature, the framework as shown in Figure 2 has been used for further investigation of CSCs in the food sector. The core aspect of this investigation is the role of energy efficiency (#1) in the CSCs. For the investigation, we assume that the role of energy efficiency is affected by the perception of NEBs (#2), but also by the view on BOAs (#3).

For the investigation, we use semi-structured in-depth stakeholder interviews to gain a first insight into the thinking on energy efficiency of different actors active in the cold chain. The target group are companies from the food industry operating in different stages of the CSC (production and processing, storage and logistics, wholesale and retail). The interviews were conducted with representatives from the organizations with a good knowledge about or responsible for energy and sustainability related topics (e.g. energy managers) and/or who are familiar with the CSC of the food sector.

The interviews had an explorative character combining both open and closed questions. A guideline was used to facilitate and harmonize the interviews. This format was chosen to ensure comparability between the interviews and to allow for exploring relevant new aspects not explicitly foreseen in the guideline which followed the topics covered by the research questions. Regarding NEBs, the interviews sought to both gain insights on the single-company as well as the CSC perspective. BOAs were queried for the CSC only.

While the analysis of closed questions is straight forward, open questions were evaluated by categorizing the answers using a successively enhanced classification scheme. This recursive design allowed for open coding, i.e. for new codes arising from new answers to be added (Saldana 2011). Numerical incidence is used as an indicator of relative salience and hence thematic prominence, helping to synthesise the large number of interviews.

The interviews were conducted via telephone or face-to-face in December 2019 and January 2020 and took between 15 and

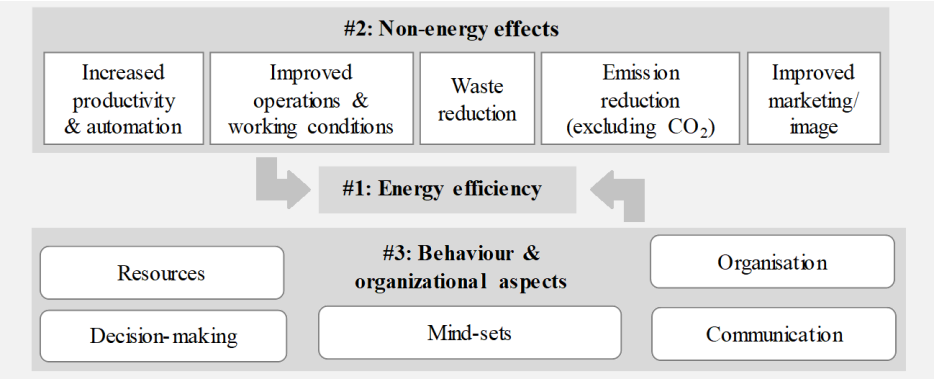

Figure 2. Illustration of the framework of investigation.

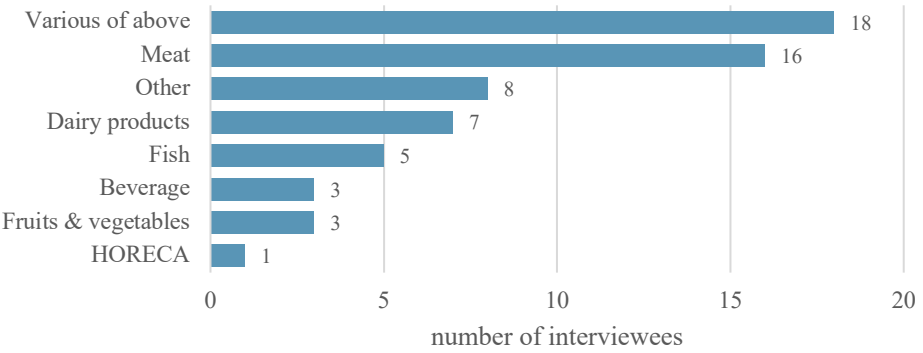

Figure 3. Split of interviewee numbers by sector of origin.

85 minutes with an average of 45 minutes. Within the study a total number of 61 interviews was conducted in 11 different countries (10 of them EU-countries). The majority of interviews was conducted in the three countries Germany (n = 16), Italy (n = 15) and Spain (n = 9). The majority of interviewees work in a private company (n = 59); others are from associations related to the food industry (n = 2). 36 companies are active in production and processing, 11 work in the storage and logistics sector and 10 belong to wholesale and retail (others: n = 4, e.g. refrigeration systems suppliers and associations). A broader range of different sectors was covered (Figure 3). Concerning company size, an almost homogeneous distribution amongst small, medium and large companies is achieved (small and micro: n = 17, medium: n = 21, large: n = 21). About one third of the companies/organizations have a formal energy management system (according to ISO 50001) and about two thirds of the companies are following up on energy-related matters with a formalized energy management system.

Results

THE ROLE OF ENERGY EFFICIENCY IN THE COLD SUPPLY CHAIN

Asking the participants about their perception of currently most relevant topics in the CSC (open question) underlines that product quality assurance including verifiable temperature compliance within cold chain regulations and hygiene and food safety standards is a dominating topic for CSCs. Maintaining controlled cooling conditions from production to delivery is mandatory to assure the quality of the goods. The second most often mentioned topic was attributed to cost reduction. Reduction of energy consumption and hence energy costs is thereby considered as largest lever to deal with increasing energy prices. The majority of the interviewees (53 out of 61) states that energy efficiency is very relevant or relevant in their **individual organization**. Many participants add concrete examples for measures related to refrigeration including efficient materials, equipment and processes. Examples include efficient warehouses and storehouses with up-to-date cooling equipment, improved insulation and cold curtains, excess heat usage, introduction of closed refrigeration units in retail stores and energy saving measures during loading/unloading at loading ramps with modern refrigerated trucks. Energy efficiency is deemed of relevance mainly due the considerable cost saving opportunities which are necessary to ensure competitiveness of their products in the market and to decrease costs of production. This also reflects the relevance of energy efficiency in the organization's decision-making processes (Figure 4). From an individual company's perspective, energy efficiency is claimed as relevant in most or even all decision for nearly 70 % of the organizations while another 25 % consider energy efficiency at least in some decisions.

When asking the same participants to assess the relevance of energy efficiency from the perspective of their whole **cold supply chain** instead of their individual company, the situation seems different: While still nearly 60 % of the interviewees indicate that in the cold chain energy efficiency is considered in most or even all decisions, a larger share (13 %) states that it is

hardly considered it in the chains decision-making processes. There is also a higher number of interviewees not answering the question with regard to the supply chain (23 %). In terms of stumbling blocks for the implementation of energy efficiency along the CSC, answers show that a substantial majority of interviewees see the largest obstacles in economic viability of an EEM and a lack of information and know-how. It is linked to high initial investments and long payback times of EEMs. A lack of knowledge was also underlined. It includes missing competences to optimize especially older refrigeration systems, too little qualified personnel to handle new machines and monitoring systems and a lack of information of the final customer. The problem is compounded by various issues. Among others, sensibility on the topic of energy efficiency is missing for example amongst workers, who cause short-term interruptions of the cold chain by leaving doors of cooling equipment open, due to inefficient stock replenishment with partially filled storages, as well as on a customer-side with little willingness to pay more for the purchased product. Other mentioned obstacles are for example difficulties with the migration from existing to new systems (for instance the conversion to natural refrigerants according to the F-gases regulation or implementation of measures during running operation) and a lack of latest technology and adequate monitoring and maintenance systems. An obstacle particularly addressing the cold chain logistic relations is a lack of communication and coordination of the chain: The different temperature ranges of food producers for their products (f. ex. minced meat at 2 °C, sausage at 7 °C and cheese at 10 °C) lead to the fact that the cold chain is designed for the weakest link, i.e. 2 °C, during transport and if necessary storage. A lack of optimal utilization and organization of the logistic tours which takes all aspects into account is often mentioned.

When asking which link in the CSC mainly drives or could mainly drive energy-efficiency forward along the chain (multiple answers possible, Figure 5), storage and logistics is on the very top of the list with 38 %, closely followed by the opinion that all different actors are equally relevant.

THE ROLE OF NON-ENERGY BENEFITS

Concerning NEBs, the interview results show that the majority (75 %) of **individual companies** associates positive effects to implemented EEMs besides reducing energy demand and related energy costs and carbon dioxide emissions (Figure 6). NEBs most often mentioned (open question, non-exhaustive list) are increased product quality, increased process reliability and reduced maintenance, improved working conditions and increased automation and productivity. Less frequently mentioned benefits are improved image and stronger community feeling amongst workers as well as waste and emission reductions (excluding CO_2). A substantially smaller number of interviewees (26 %) sees negative effects for their company during or after the implementation of EEMs. These are, for example (open question, non-exhaustive list), the need for additional personnel and financial resources (e. g. for qualified personnel or audits), difficulties with adaptation to new systems which lead to potential frustration for workers or customers and de-

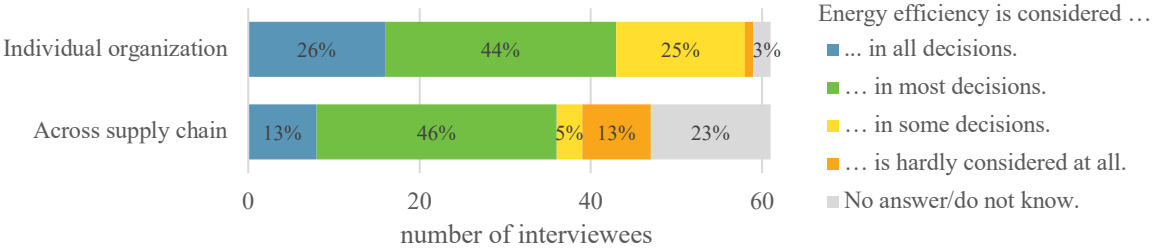

Figure 4. Relevance of energy efficiency in decision-making processes of individual companies vs. the cold supply chain.

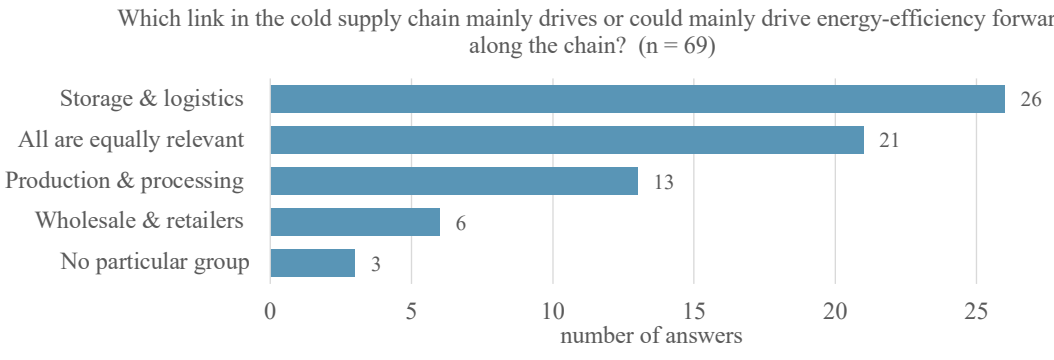

Figure 5. Relevance of different stages of cold supply chain for driving energy efficiency forward along the chain.

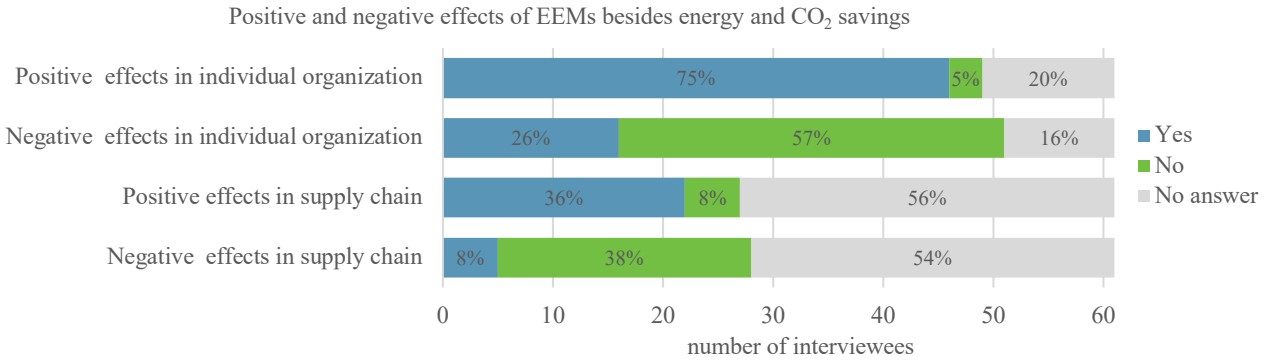

Figure 6. Relevance of positive and negative side effects of energy efficiency measures for individual companies vs. the cold supply chain.

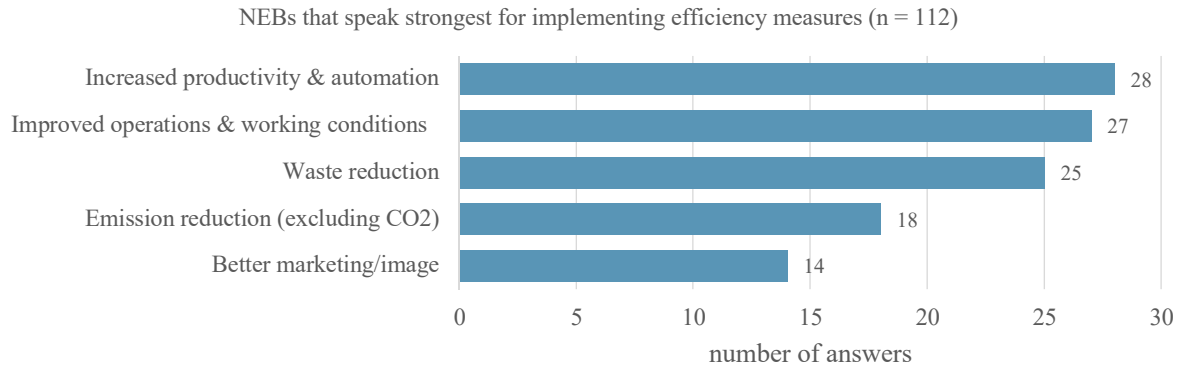

Figure 7. Relevance of non-energy benefits for implementation of energy efficiency measures from a decision-maker perspective.

creases in productivity due to decreased system reliability and higher downtimes. When asking the same questions for the whole **supply chain** again, the number of responses is lower, but the general perception is similar to the situation in individual companies. The majority seems to perceive similar positive effects (36 %), while only a few see negative effects (8 %).

To further understand the relevance of benefits from EEMs, the interviewees are asked to choose from a list of 5 categories of NEBs derived from Worrell et al. 2003. More specifically, they are asked which two of these categories speaks strongest for investing in an EEM from a decision-maker perspective – either for the individual company or from a supply chain view (Figure 7). Increased productivity and automation is considered as most important decision-criterion for the uptake of an EEM, closely followed by improved operations & working conditions and waste reduction.

THE ROLE OF BEHAVIOURAL AND ORGANIZATIONAL ASPECTS ALONG THE COLD SUPPLY CHAIN

With regard to behaviour and organization of the CSC, the majority of the interviewees (72 %) agrees that some energy is wasted due to a lack of CSC coordination (Figure 8, left graph). To further understand the particular behavioural/organizational aspects/challenges with regard to energy efficiency improvements along the CSCs, those are queried on five categories (Figure 9), i.e. concerning communication along the chain, decision-making processes, mind-sets/behaviour of companies, the cold chain's organization and resources.

Regarding exchange or **communication** on energy efficiency along the CSC, 43 % point out that there is no communication or exchange. 38 % of participants are involved in energy-related communication activities and 19 % state that they are not involved (Figure 8, right graph). Slightly more than half of the interviewees who witness such activities name concrete challenges. Challenging for the companies seems that there is often no or no steady communication between the different members of the CSC and that a person in charge for overseeing the whole chain and coordinating the exchange is missing. Communication only takes place within the scope of regulations and contracts in many cases, for example between the quality assurance departments of producers and their logistic partners. If there are common **decision-making processes** related to energy efficiency along the cold chain members, barriers like divergent priorities of the various actors with different (technical) backgrounds, varying regulations on country-level and missing cooperation in terms of common financial means are mentioned. Difficulties in measuring the effectiveness and economic benefits of EEMs due to a lack of common available energy performance indicators are also mentioned. When it comes to **mind-set/behaviour**, the greatest challenge according to the interviewees is the missing feeling of responsibility of the different actors due to a lack of awareness and attention

for energy-related topics ("never change a running system"). Different perceptions of risk as well as different priorities are reinforced by the cultural variety of the international actors. **Organizational** challenges mentioned occur due to a lack of transparency in the CSC causing traceability issues like sub-optimal temperature monitoring or storage planning for example. In addition, many interviewees point to cooperation and coordination issues, especially in the logistic stage. These include excessive cooling of some products, sub-optimal routing and waiting times, partially loaded trucks and non-optimal inventory levels in warehouses. Dense dynamic regulation and administrative burdens are perceived as adding to the problem ("when companies are focusing more on passing the audits than on actually becoming more energy efficient"). **Resources** represent a major challenge in the individual companies as well as for the SC where a sustainable financing solution for the whole network is perceived as missing. Financing EEMs in not always seen as easy due to short payback requirements. Immediate profit often comes first so that decision-makers cannot easily grasp the economic benefits of investing in EEMs in the long run. This comes along with a lack of know-how and missing experts or engineers in the field of refrigeration which requires additional resources for education and trainings. Data availability is also mentioned as a problem by the interview partners.

Discussion

TO WHAT DEGREE DO COMPANIES COOPERATE ALONG THE CSC OF THE FOOD SECTOR WITH REGARD TO ENERGY EFFICIENCY?

According to the interview results, companies in the CSC seem to agree that energy efficiency especially in refrigeration is a topic of high relevance due to the related high energy consumption and energy costs. This seems to be both true from the perspective of individual companies as well as entire CSCs. Interviewees claim that companies are regularly considering energy efficiency and that it is a relevant criterion in decision-making. Yet they also underline that economic considerations of food products dominate any exchange between companies and that actual implementation of EEMs also strongly depend on their monetary advantage. Here, high initial investments and long amortization periods are frequently mentioned as impeding the implementation of EEMs. The interviews furthermore suggest that awareness for EEMs is lower along entire SCs than within individual companies. While the interviewees tend to agree that energy efficiency along the chain is important, decision-making routines on it along the entire chain seem far from common practice. This is also suggested by a high number of interviewees unable to describe decision-making processes in the chain; the CSC as a whole is simply not evaluated. In cases where there is dialogue on energy efficiency along the chain,

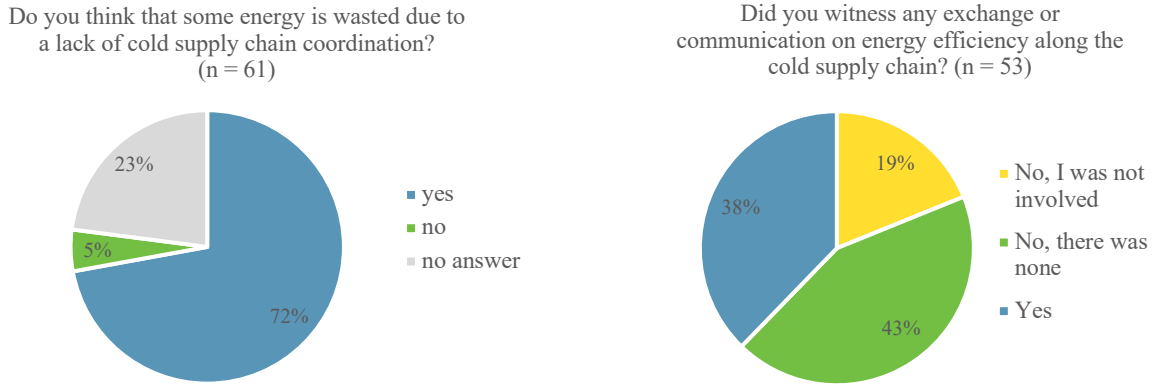

Figure 8. Relevance of communication and coordination related aspects of energy efficiency in the cold supply chain.

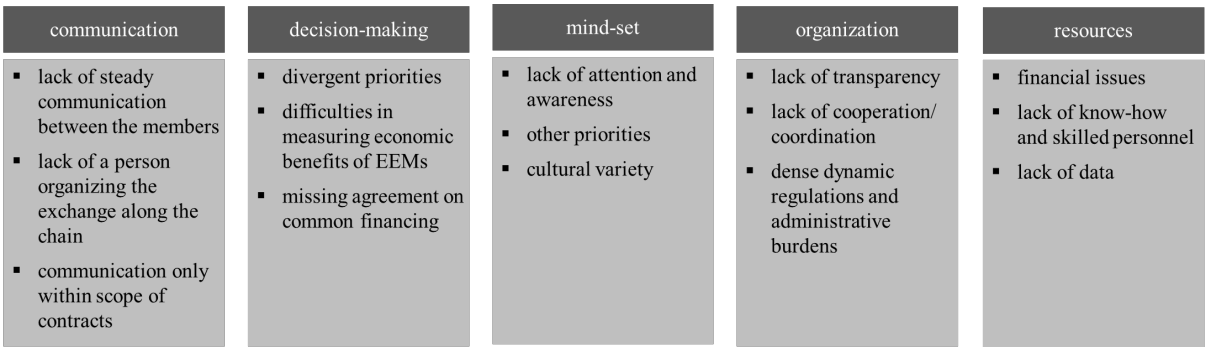

Figure 9. BOAs influencing the implementation of energy efficiency measures along the cold supply chain.

the topic still seems hardly relevant for strategic decisions and is not yet part of everyday decision-making routines along the CSC members . For instance, no interviewee could name concrete EEMs implemented and coordinated together with other members of the CSC. Individual organizations seem to focus on their own situation and interests, independence and flexibility. Yet, especially smaller organizations who are reticent to implement EEMs due to high investments might profit from a cooperation along the chain. In sum, these results suggest that potentials of cross-company activities seem generally agreed upon, yet their realization is far from common practice. To foster such strategic cooperation on energy efficiency amongst supply chain members seems to be an important preparatory step before/while dealing with the relational and regulatory barriers mentioned in the literature (Centobelli et al. 2018).

WHAT IS THE RELEVANCE OF NEBS AND HOW ARE THEY PERCEIVED ALONG THE SUPPLY CHAIN AS COMPARED TO THE INDIVIDUAL COMPANY PERSPECTIVE?

NEBs besides energy and emission savings, as well as non-energy losses, seem to be relevant for both individual companies (see literature section), as well as the CSC as a whole. Based on the results, it can be observed that positive effects seem to outweigh negative associated aspects. Yet economic advantage from the NEBs also seems a dominating aspect here. For example productivity and automation were perceived as important positive side-effects of EEMs. In general, the same NEBs apply to the SC as to individual companies. Moreover, the implementation of EEMs could lead, in addition to reduced costs, to an improvement of the control and monitoring of the chain as a whole. Yet awareness regarding NEBs along the chain seems relatively low and possible impacts difficult to measure for the companies. So, a focus on NEBs can contribute to overcoming the challenge met in CSC energy efficiency improvements, but they seem only one part of the puzzle.

WHAT ARE PARTICULAR CHALLENGES STEMMING FROM BOAS WITH REGARD TO ENERGY EFFICIENCY IMPROVEMENTS ALONG THE CSCS?

At the organizational and behavioural level of the CSC, it is evident that some energy is wasted due to a lack of coordination and communication along the chain – especially in the transport and logistics sector. This further includes the lack of know-how and skilled personnel or the lack of attention for energy-related topics – all barriers which relate to individual companies, as well, but might be more pronounced when looking at the entire CSC. It reveals that cooperation of food companies in the field of sustainable or green supply chain management (Murphy and Adair 2013) can be expanded even further. Due to the complex structure of the different actors in CSCs, additional challenges arise like different priorities and cultural variety as well as missing common regulations or common financial means. Given the complexity of CSC's multiplex relations in the food industry (Mikkola 2008), it follows that behavioural and organizational aspects in their interaction are of particular relevance for the uptake of energy-efficiency measures and matter even more than for individual companies.

With regard to the interpretation of the findings, typical **limitations** of interview approaches apply (Yin 2009). First, they include a potential bias in the selection of interviewees since only those interested in the topic tend to take part. Second, the quality of interviews could vary due to different interviewers and translations. Emphasis has been given to ensure a common understanding of questions by the guideline with formalized questions to interviewees and additional separate instructions and examples for the interviewers. Third, interviewees could feel the need to provide socially desirable answers in an interview situation. To minimize this, the focus is set to factual information on existing processes rather than desirable situations. Fourth, the interview design, e.g. the order of questions, might affect responses. Finally, the interviewees work in different areas of the CSCs, they have different cultural and technological backgrounds and they operate under sometimes varying conditions, e.g. with regard to climate, energy prices and/or national policy measures. Yet, with reoccurring trends across interviews carried out in different contexts and institutions, the authors assume that the results tend to have some degree of robustness. This is reflected in the broad range of companies and actors across all stages of the food industry cold supply chains covered within the study.

Conclusions

The aim of this paper was to complement literature on energy efficiency along the CSC in the food industry. For this purpose, an investigation was carried out which details on the role of energy efficiency, the relevance of NEBs and the influence of BOAs with regard to energy efficiency along the chain. For this purpose, 61 interviews with stakeholders from the cold chain of the food sector were conducted.

The results from the investigation suggest that energy efficiency is presently considered more strongly in individual companies than along entire CSCs. Though there seems to be a common understanding that energy efficiency must be tackled along the chain, the complexity of CSC operations turns out to be a challenge for implementation. There are various behavioural and organizational challenges related to the organization of the CSC which seem to impede the implementation of EEMs along the chain. The narrative of the interviews suggests that the focus on individual company goals and on regulatory and price matters dominates the exchange in the CSC. Opportunities for a focused exchange on energy efficiency thus seem to be missing, knowledge and know-how on energy-efficient techniques and operational behavior could be improved and common resources for cross-company activities enhanced. Yet there remains a need for further investigations on this topic beyond the conducted interview study to enhance the empirical basis. With regard to the role of non-energy effects, EEMs are attributed both positive as well as negative effects with the positive effects seem to outweigh the negative ones. Increased productivity in particular seems to play an important role for driving energy efficiency decisions due to its direct economic relevance.

In term of policy conclusion, one way to enhance the awareness of cross-organizational opportunities could be to encourage them to systematically reflect upon potential opportunities, e.g. with support of dedicated standards. Thus, corporate policies and qualitative measuring instruments to verify the levels of achievement of objectives in this area could be beneficial (Centobelli et al. 2018). Another way to tackle the issue

of exchange and communication along the cold chain could also rely on putting information exchange on energy-related matters on a more regular basis, e.g. by adapting the concept of energy-efficiency networks (Dütschke et al. 2018) to CSCs. Such an exchange could also help to positively influence the attitude towards new efficient technologies and information campaigns could help to raise awareness on energy issues, also amongst workers. National and cross-national organizations dealing with cold processing, storage and logistics could also offer a forum to convene and exchange on new technologies in the market. Spreading technical solutions for adjusting temperature levels and to follow-up and optimize transportation of products along the CSC could also reveal possible energy-saving potentials along the chain. This includes creating a common understanding in terms of optimized production, distribution, logistics and storage planning (e.g. via joint deliveries, coordinated storage of inventory, predictive maintenance or smart temperature monitoring systems). To meet the specific requirements of the cold chain and enable evaluation from a more holistic perspective an analysis of technical, information technology and regulatory building blocks beyond standard business processes is required as proposed in (Bremer 2018). Moreover, the prevalence of SMEs in the food sector could benefit from tailored funding schemes for cross-company measures. Lastly, the introduction of decision support models conveying the additional financial and other benefits of EEMs and bringing quantification of NEBs to the fore could also be helpful.

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