Cloud manufacturing system for sheet metal processing

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Green logistics in food distribution - a case study

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Abstract
Environmental impacts, such as GHG emissions, have been introduced to supply chain management as an additional parameter to traditional key performance indicators such as cost, lead-time and on-time delivery. This paper analyses a case example from the food industry on how CO_2 emissions are structured in a value chain. The focus of the analysis covers food factory order-picking operations, transportation, warehousing, and distribution aspects. The paper aims to demonstrate greening and CO_2 saving potential areas of development for thermo-controlled food logistics. The results show the energy saving potential of several supply chain processes giving examples of distribution logistic online-temperature controlling possibilities. Greening decisions in supply chain design in the food industry are considered.

Keywords: supply chain management, green logistics, food industry.

1. INTRODUCTION

The eco-efficiency of logistics refers to analyzing and managing energy-efficiency and emissions such as carbon dioxide (Craig & Eston 2011; Coley, Howard & Winter 2009) in addition to traditional key performance indicators such as logistics costs, delivery time and delivery reliability in supply chains (Christopher 2005). Eco-efficiency can be considered as a decision-making parameter when planning order picking, transportation, deliveries, terminal operations, and the physical, functional and managerial structures of logistics centers. New parameters in investment decisions and the development of operational management add value to traditional industries such as the food industry (Carter & Rogers 2005; Bowersox, Closs, Stank 2000; Cumming 2005).

There have been many recent publications in the field of green logistic (Chunguag et al. 2012; Keeble et al. 2003; Gunasekaran et al. 2015; Fahimnia et al. 2015). Several potential areas of green logistics and supply chain optimization applications have been presented to improve the eco-efficiency of supply chains. The availability of, for example, GHG (Green House Gas) calculation tools and standards has made eco-efficiency analysis more practical. New types of fuels, including CNG (Compressed Natural Gas) and LNG (Liquid Natural Gas) gases are being studied and piloted in long-haul and distribution transportation. New vehicles and distribution structures have been compared at the operative level. Centralized supply chains have been compared with decentralized supply chain structures to evaluate the effects on costs and emissions (Kortelainen & Kuosmanen 2007; Murphy & Poist 2003; Lee 2008; Markley & Davis 2007; Quanriquasi et al. 2007; Rao & Holt 2005). In case of food products, studies have shown several decisions ranging from packaging to distribution and facility location can have an impact of emissions (Ala-Harja & Helo 2014; Ala-Harja & Helo 2016).

In addition to logistics and material handling technology, information technology has opened up the possibilities of real time control. Intelligent telemetric systems make it possible to track vehicles online and make decisions in real-time. Specific truck, container, trailer or pallet information can be tracked through the supply chain. Logistics transaction data such as packing, loading and unloading information may be combined with tracking information. A mash-up of data with weather information and traffic data can be fed into logistics optimization systems. Customer, day, emission and season specific information helps to reduce ton-kilometers (A unit of freight transportation equivalent to a ton of freight moved one kilometer) and fuel consumption. Online optimization creates the potential to adjust settings in a short period of time (Veleva et al. 2003; van der Vorst et al. 2009; Rodrigue et al. 2001).

Despite the emerging possibilities of improving eco-efficiency, few papers have focused on analyzing how GHG emissions are generated in the supply chain and which part of the distribution network has the most lucrative improvement options. This paper presents a case study about the role of logistical functions and operations in food emissions and points out some energy and emission saving potentials in different parts of the supply chain. The data has been collected from

Finnish fresh product chain. More specifically, the paper focuses on analyzing temperature controlled food distribution chains and considers potential improvement areas in the distribution logistics. The main objective is to illustrate typical food distribution characteristics and point out the CO_2 emission sources of the food distribution chain and give ideas on how the CO_2 emissions can be affected. The saving potential of real time temperature controlled cooling is introduced and discussed.

2. GREEN LOGISTICS AND THE SUPPLY CHAIN MANAGEMENT OF FOOD

2.1 Green logistics

The concept of green logistics has attracted wide interest (Fahimnia et al. 2015). Rodrigue, Slack and Claude (2001) define green logistics as the practices and strategies of supply chain management which aim to reduce environmental effects and energy consumption caused by cargo handling, waste handling, packing and transportation. According to Byrne and Deeb (1993), the difference between traditional and green logistics includes reverse logistics and re-use of materials. Van Hoek (1999) suggests green logistics is not enough, and that a supply chain perspective is needed. According to Srivastava (2007), green SCM notices connections and effects between natural resources and supply chain management.

The benefits of green logistics are generally accepted (Meixell & Gargeya 2005). Lower energy consumption and cost savings caused by reduced fuel and resources are typical benefits. Implementation details vary, as do the required investments for changes. There are some empirical studies which connect environmental and supply chain performance. For example, Azevedo, Carvalho and Machado (2011) have presented a case study on the effects of green logistics. According to Srivastava (2007), there is a growing need for supply chain research and practices taking environmental aspects into consideration. McIntyre et al. (1998) and Saadany et al. (2010) state that environmental aspects are typically handled separately from supply chain functions in companies.

2.2 Food supply chains

Food supply chains have not only an essential role in the global economy (Baldwin 2012; Ghosh 2010) but also in global ecology. Food is produced and consumed in every part of the world, and at the same time resources are needed and emissions produced. Food chains are typically quickly delivered and have large production and market volumes. Compared to other supply chains food systems have some special supply chain managerial characteristics (Bourlakis & Weightman 2004). These include short shelf-life time of the products and high demand for traceability and low cost pressure (Opara 2003). According to Cohen and Garret (2010), vulnerability and food safety are global issues. Consumers need information about environmental effects, and sustainable supply chain evaluation is needed (Adams & Larrinaga-Gonzales 2007; Nissinen et al. 2007). These aspects increase interest in and need for green logistics research.

A share of 13.5 % of global emissions is caused by transportation (World Resource Institute, 2011). Vehicle, load capacity, return and distance have environmental effects. The concept of the food mile (Pretty 2005) describes the cumulative distance of parts of the food supply chain. Usually, food miles correlate with environmental effects. The structures of food logistics are more integrated (Gimenez 2006) and hub – distribution center distribution networks are usual.

Based on industrial surveys, logistics costs create 10% to 15% of the price of the food product. This makes food logistics an interesting topic among producers and retailers. Food supply chain sustainability development is also of interest to companies (Hamprecht et al. 2005).

Food production caused 1.2 M CO_2 equivalent tons of emissions at the global level in 2003. About 40 % of Finnish food supply chain CO_2 equivalent emissions, equal to 472 000 tons, was produced in terminals or markets because of the used electric and warming energy. Transportation caused a further 27%, which is equal to 329 000 tons of emissions (Päivittäistavarayhdistys ry, 2004).

From the supply chain distribution structure point of view, food production occurs in different places compared to food consumption. In order to illustrate this, we can analyse the case of Finland (Figure 1). The region of Seinäjoki in Western Finland produces ca. 19% of food nationally but sales comprise only 8%; the southern part of Finland produces 26% and sales comprise 32%. In addition to this, the role of food logistics is especially important in Finland because most food products produced in Finland are transported to retailers' distribution centers in the Helsinki area for order collection, which means many food products travel long distances before eating or wasting. Most food produced anywhere in Finland is directly transported from factories to retailers' distribution centers. The two main retail chains have together ca. 80% of market share, and their distribution centers are located in the Helsinki area. These retailers have many regional distribution centers (Päivittäistavarayhdistys ry, 2004). After transportation to distribution centers, food products are collected there according to customer orders, and delivered to markets directly or via regional distribution centers. This type of structure is also typical of many other countries.

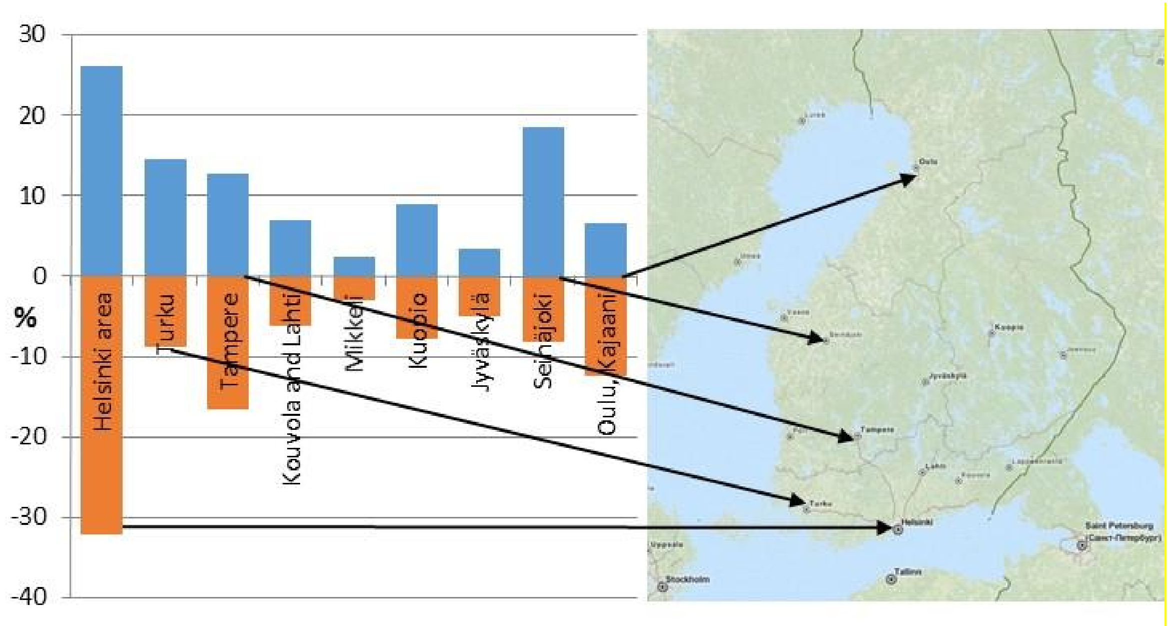


Figure 1. Food production and food consumption occurring in different areas in Finland. (Tilastokeskus, 2004 & Päivittäistavarayhdistys, 2004, OpenStreetMap)

A large proportion of the environmental effects of food is typically caused in the production phase (Nissinen et al. 2007). Emission profiles vary between product categories. For example, Wanhalinna (2010) found that the CO_2 produced by bread production divided into primary production (45%), bakeries (40%) and consumers (13%). Emissions included, for example, fertilizer production, electricity, heating energy, water and waste water and transportation. Total emissions from bread varied from 1.4 to 1.7 CO_2 equivalent kg per 1 kg of bread (Weact, 2014).

2.3. Temperature control in food supply chains

Many food products need temperature control. It can mean that they need cooling or heating energy depending on the ambient temperature. Temperature control is needed in every process, including transportation and warehousing. According to James & James (2010), controlling temperature causes 1% of global CO_2 emissions, and in the UK 11% of total food logistic emissions are caused by 1% of the food consumed. There are 1300 temperature controlled containerships, 80000 railroad cars, 650000 containers and 1.2 million trucks in the world (Heap 2006; James & James 2010).

According to Mc Kinnon and Campbell (1998) and James & James (2010), temperature control uses 40 % of the energy consumption of food deliveries. Frozen products require 1.7 times more energy than those without cooling or freezing. Frozen products also stored in vehicles used 20 % of the cooling energy compared to the markets (Evansin et al. 2007 in James & James, 2010). Cooling needs 68 % of electricity and lighting needs and 23 % respectively.

Insufficient temperature conditions during transportation are usual everywhere even if the right temperature is crucial (James et al. 2008). Insufficiency can be over- or undercooling. The quality of the containers varies and containers are not always very energy efficient. Diesel powered cooling systems use as much as 40 % compared to motor diesel consumption. Many technologies have potential for energy saving during transportation (James et al. 2006; Tassou & Ge 2009). In refrigerated warehouses the most electricity used for refrigeration is 57 % (15,8 kWh / end use ft^2) and interior lighting 12 % (3,23 kWh/ end use ft^2) (Itron, 2008),(see Figure 2).

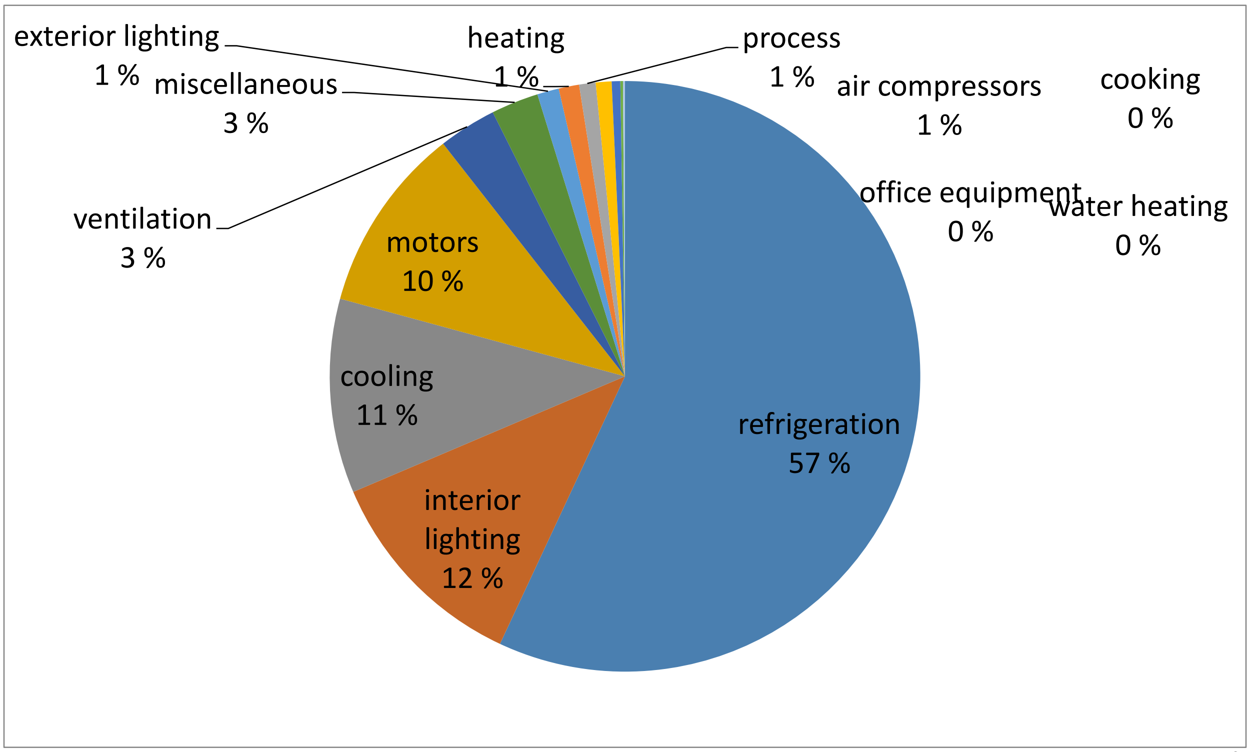


Figure 2. Refrigerated Warehouse Electric Energy Use Intensity (EUIs, kWh/End-Use ft^2) (Itron, 2008)

Singh (2008) found that 22% - 74 % of companies in his study used energy saving technologies in warehouses, such as upgraded insulation, cool roofs, efficient lighting technology and aggressive evaporative condenser and computer control. During transportation it is possible to use, for example, solar panels (Bahaj & James 2002; Tubb 2001; James & James 2010).

Energy consumption in warehouses consists mainly of cooling, melting asphalt yards, warming air conditioning systems, material handling, offices and lighting. According to Duive & Binard (2002) in James & James (2001), warehouse energy consumption depends on building technology, temperatures and lead times.

2.4. Food waste

Gustavsson et al (2011) have defined food loss according to Parfittin et al. (2010), namely that it is created in any part of the chain, while food waste is caused by retailers and consumers at the end of the chain. Food losses can be divided into animal and vegetable waste, for example waste in processing storing and distribution.

Part of the emissions is the food wasted within supply chains. This may represent an important part in certain product categories, such as fish. According to the literature, about one third (1.3 billion kg) of food is wasted (Gustavsson, J., Cederberg, C., Sonesson, U., Van Otterdijk, R., & Meybeck, A. 2011). Waste is typically created in every part of the chain. Food chains cause the use of natural resources and CO_2-emissions.

Food losses are different in different parts of the chain and vary in different products. Food losses are also different in different continents. For example, consumers cause food losses in Europe and North America of from 95 to 115 kg/person/year. Losses of grain products are in the same areas ca. 40 – 50 % (Gustavsson et al. 2011). NRDC (2012) reports that over half of some foods are wasted in North America: for example, vegetables at around 52 %. The reasons for food waste are, for example, bad coordination of the chain, overproduction, quality standards, best before labels, consumers' lack of planning, and consumer behavior (Gustavsson et al. 2011).

2.4 Synthesis

Based on the existing literature we can conclude that green logistics in the context of food supply chains has certain important features. High volumes of demand and cost pressure driven by customers are typical in food markets. Efficient transportation and warehousing operations are important drivers of cost. In addition to physical material handling, temperature control requires energy and causes emissions in all parts of the chain. Products are sensitive and have a short life-cycle. Waste may represent an important share of the total volumes.

3. METHODOLOGY

In order to create a picture of a supply chain CO_2 emissions profile, a case study was conducted in the fresh food supply chain. The case supply chain was analyzed process by process in order to find out how energy consumption and carbon dioxide emissions were divided in the food delivery. The share of temperature control to the outputs was calculated. The case supply chain was analyzed from production plant to market. The products analyzed were consumer packaged meat products packaged in crates and pallets. They need a transportation temperature of between 0 and +4 C°. The case food supply chain consists of the dispatch department at the production plant (P) (excluding production), long haul transportation (L), distribution center (D), and distribution transportation (T) to the market (Figure 3). The data collection covered food manufacturing, transportation companies and a distribution center company. Finally, the results were analysed and then a process analyzing eco-efficiency improvements was conducted.

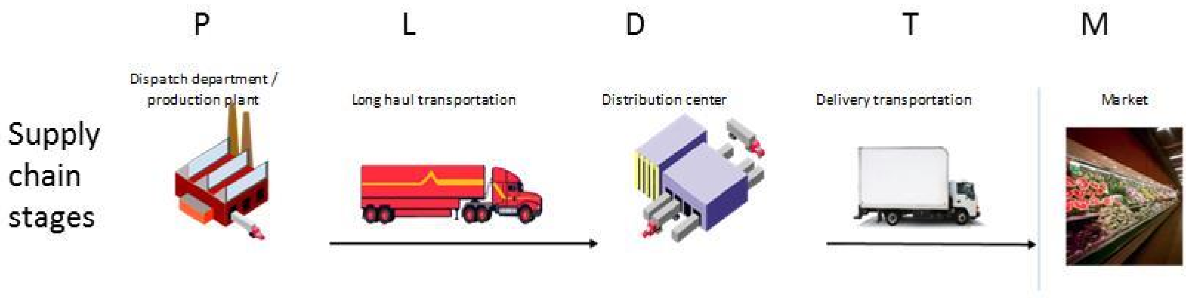


Figure 3. Stages of the case food supply chain.

The information about warehousing and transportation processes was separated into temperature controlling and distribution or sorting or warehousing processes. Information about distances, capacities, lead times, utilization rates, loads and cycle times was collected in every stage of the case supply chain in order to calculate energy consumption and emissions. Emissions and energy consumption were expressed with energy consumption (kWh/1000 kg product) and carbon dioxide equivalent emissions (CO_2 eqv/ 1000 kg product).

Emissions (CO_2 eqv.kg/1000 kg product) were calculated as follows:

(1) $P=P_l+ P_s+ P_k+ Pj$, where

P_l= emissions of the dispatch department (kg CO_2 eqv/1000 kg product), P_s= emissions of long haul transportation (kg CO_2 eqv/1000 kg product), P_k= emissions of the distribution center (kg CO_2 eqv/1000 kg product) and Pj= emissions of delivery transportation (kg CO_2 eqv/1000 kg product).

P_l and P_k were calculated as follows:

(2) P_l or P_k = $(W*t) * k_s * v$, where

W= Power input of the cooling system per area (kWh), t= time of operation hours of the cooling system, operation hours (hours/day), k_s = CO_2-coefficient value of energy (g CO_2 eqv. / kWh) and volume of the department (tons/years).

P_s and P_j were calculated in transportation as follows:

(3) P_s or P_j = $(P_k + P_l,)$, where

P_k = CO_2 emissions of the transportation (kg CO_2 eqv.) and P_c = emissions of cooling during transportation (kg CO_2 eqv.).

P_k was calculated as follows:

$P_k = (s*k)/1000m$, where

s= distance (km), k= emissions g CO_2 eqv / km and m =volume (kg).

$P_c = ktp/v$, where

k= fuel consumption (liters/hour), t= time spent during transportation (hours), p= coefficient value of the fuel (kg CO_2/fuel kg) and volume of the transportation (kg).

The used method can be applied to analyze any temperature-controlled deliveries. The results are sensitive to fuel CO_2 emission value, usage time of the cooling machine, payloads and distances. Depending, for example on the cooling technology and temperature needed, the role of the cooling energy needed may be an essential role of the total CO_2 emissions of the end product.

4. ANALYSIS OF SUPPLY CHAIN

The performance data of vehicles and routes were collected from the expert interviews. Figure 4 summarizes some of the key characteristics of the food chain. The food products of the case supply chain need cooling below +4 C degrees during the entire journey. Long haul transportation (T), 350 km, to the distribution center (D) is performed by EURO5 semi-trailers (max. net weight 25 tons, with 90% payload utilisation) after 24-hour warehousing at the production plant (P). Distribution center (D) products are collected and after 12 hours delivered to market (200 km) with delivery trucks (max. 6-ton net weight, 60 % payload utilisation). Diesel is used for cooling energy during transportation and the warehouses use electricity (Figure 4). This kind of supply chain is typical in Scandinavia with long distances and low-valued short-to-date markets, because production is dispersed and consumption is centralized. Temperatures vary a lot during the seasons.

		Long haul transportation (L)	Delivery transportation (T)
Transportation	Mass of the truck (ton)	40	6
	Full net load (ton)	25	3,5
	Mean usage %	90 %	60 %
	Distance (km)	350	200
	Max.nettonkms	13125	920
	Mean tonkms	7875	420
Cooling	Cooling machine (litres/hour)	3	2,5
	Usage time (hours/route)	1	5
	Fuel usage (litres)	3	12,5
	Fuel CO2-value (kg CO2 eqvs./litre)	2,68	2,68

	Dispatch Department (P)	Distribution center (D)
Power input (kWh/100 m2)	4	4
Usage time (hours/day)	16	16
Electricity usage (kWh/100 m2/day)	64	64
Warehousing time (hours)	24	12
CO2 coefficient value (g CO2 eqv./kWh)	260	260
CO2 emissions (kg CO2 eqv./100m2/day)	17	8
Mass (tons/100 m2 /day)	40	40

Figure 4. Case supply chain input data.

4.1. Energy consumption and emissions in the supply chain

Case data analysis showed that the amount of carbon dioxide equivalent emissions caused by 1000 kg of case supply chain product delivered from the production plant to the market was 66.5 kg (66.5 kg/1000 kg). The greatest emissions (74%) were produced during delivery transportation, of which 33% were caused by cooling. Long haul deliveries produced 24% of emissions, of which 24% were caused by cooling. Cooling caused 27% of all emissions and transportation 73% (Figure 5). Recorded information about food waste during the transportation was not available, but based on interviews, the analysed part of the supply chain had such incidents only a few times per year. Transportation and distribution is very fast and most of the waste is related to best before dates in manufacturing, wholesale or retail parts.

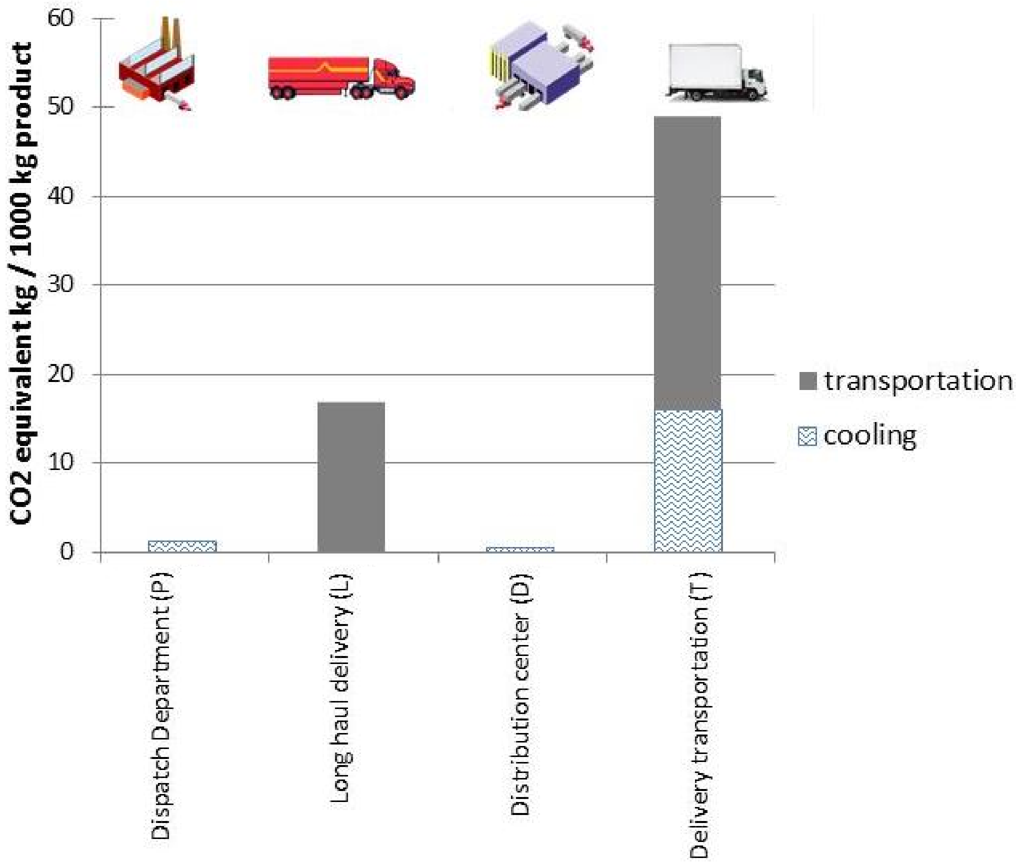


Figure 5. Cooling and transportation emissions in the case food supply chain

Emissions during transportation are greater than in the terminal and warehouse. The vehicle type seems to have an important effect on emissions. In order to consider an alternative scenario, a larger delivery truck could be considered. If delivery was done with larger delivery trucks (mass 15 tons, net mass 9 ton, mean load 60%, then delivery emissions would be 28 kg/1000 kg product and in the whole supply chain 45 kg/1000 kg product (Figure 6).

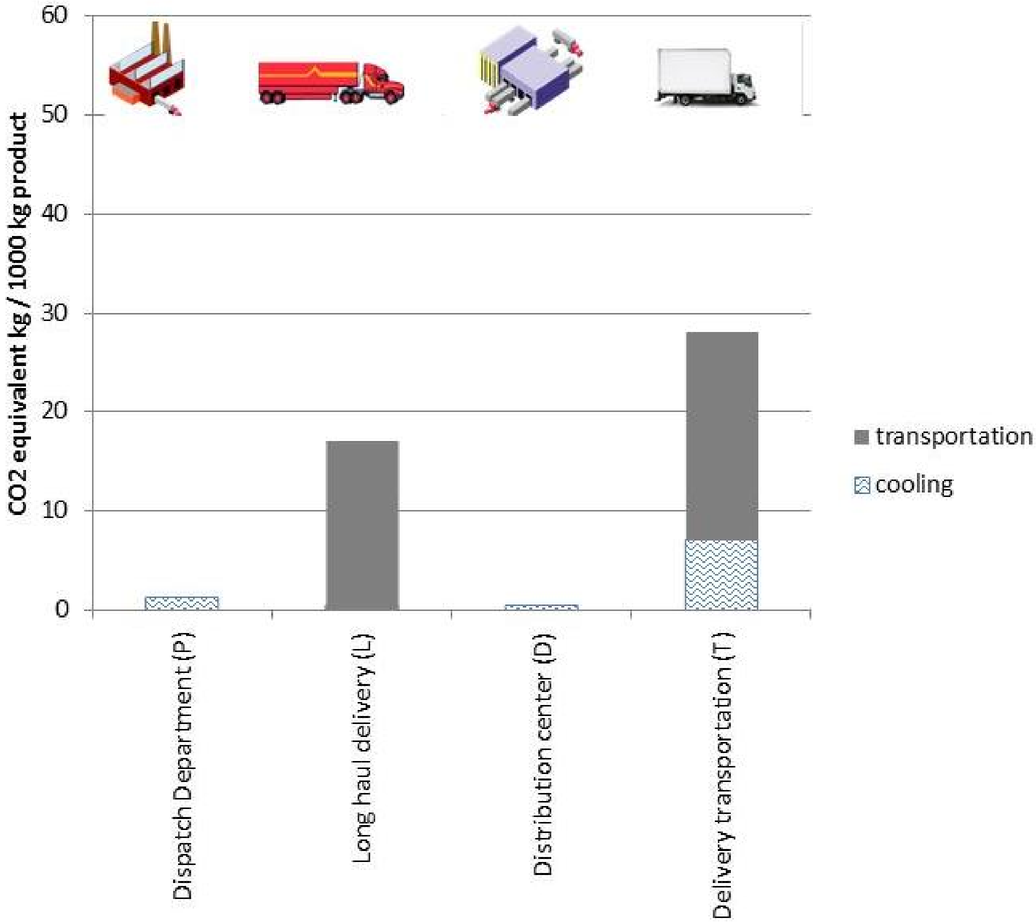


Figure 6. Emissions in the case food supply chain with larger delivery truck (15 tons).

The overall CO_2 emissions profile is summarized in Figure 7. Transportation causes most (70%) CO_2 emissions of the total supply chain emissions and cooling 30%. Most of the cooling energy is used during delivery transportation.

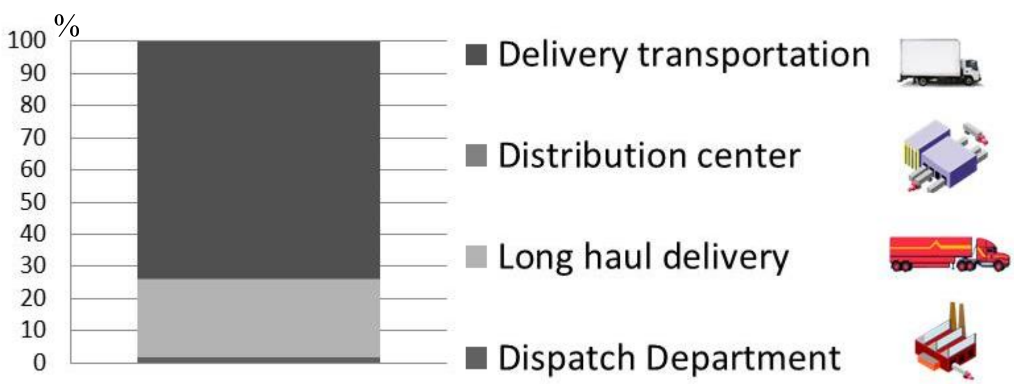


Figure 7. Cooling emissions in the case food supply chain

4.2 Distance and payload-utilization

Payload utilization and transportation distances are important parameters. Emissions are smallest when the share of long haul delivery of the total distance is the biggest. Sensitivity analysis shows that every 24 kilometers of delivery transportation distance (large 15 ton delivery truck) has the same effect on the total emissions as 100 kilometers of long haul delivery. The bigger the mean load, the smaller the emissions are. A 10 % unit increase of the delivery transportation load improves from 60% to 70% CO_2 equivalent emissions 4 kg/1000 product kg. This is equivalent to a 9 % improvement when long haul deliveries have a 90 % mean load. (Figure 8)

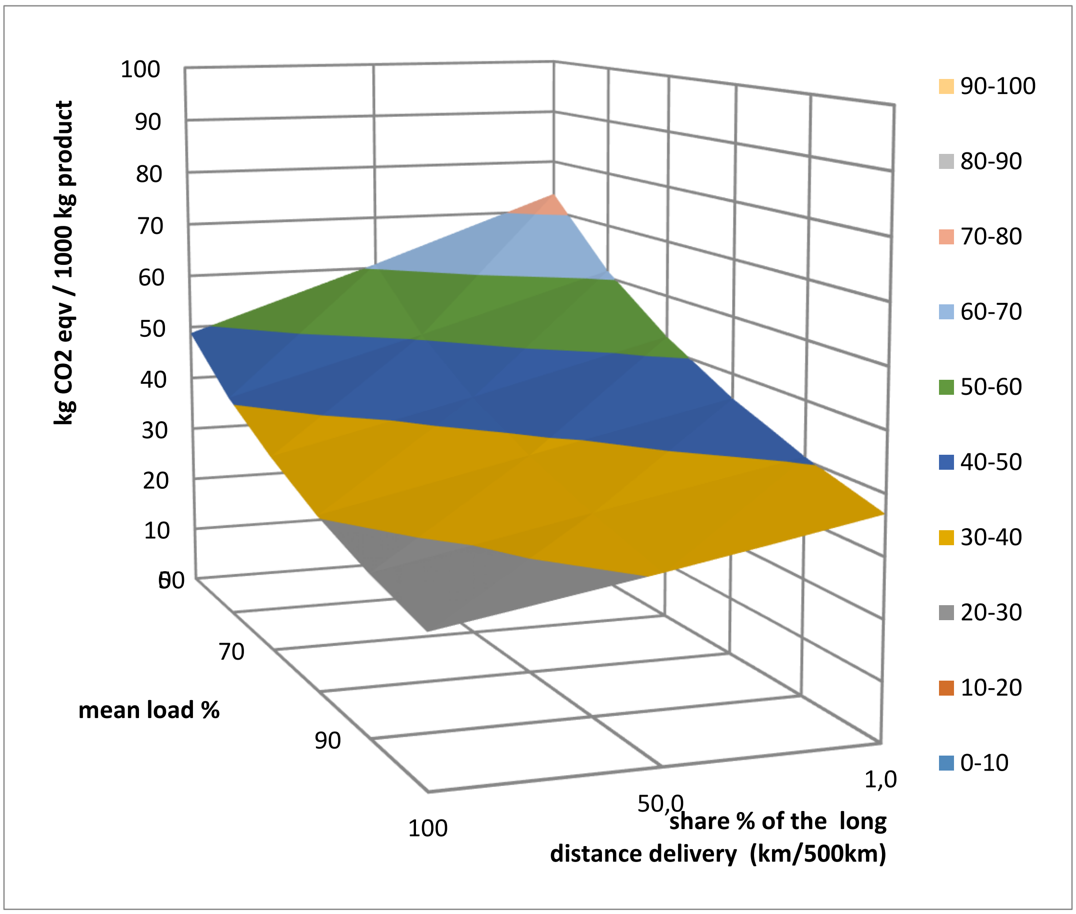
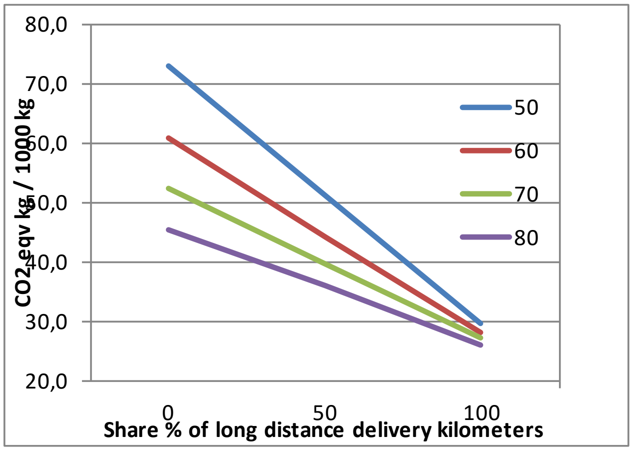


Figure 8. Emissions when mean load (%) and share of long distance (%) varies.

Delivery transportation mean load (%) and share of long haul transportation have a great effect on total emissions. When the long haul delivery mean load is 95% and share of long distance deliveries of total distance (500 km) varies from 0 - 100 % the emissions varies. The emissions are larger when the share of long haul deliveries and the share of the delivery's mean load are smaller (Figure 9).



Share of long haul delivery %	Delivery mean load % 50	60	70	80
100	29,5	28,1	27,2	26,1
80	37,7	34,3	31,3	30
70	42,1	37,6	34,4	32
50	51	44,3	39,5	35,9
30	59,8	51	44,6	39,9
20	64,2	54,3	47,2	41,9
1	73	60,9	52,3	45,5

Figure 9. Emissions with different delivery mean loads (%) when delivery transportation mean load is 95%.

4.2. Analysis of the potential of delivery cooling energy savings

The potential of cooling energy saving during deliveries was identified in the supply chain analysis. Measurements of the transportation conditions were performed on November 13th 2014 at 9 p.m. and on 14th November 2014 at 1 p.m. The temperature and other conditions of the trailer were measured with the system presented in Figure 10. The measurement device system consisted of wireless sensor nodes, GPS-locator on the roof and a satellite radio unit and data logging server. The system labeled data with time and coordinates and sent data on the GSM network.

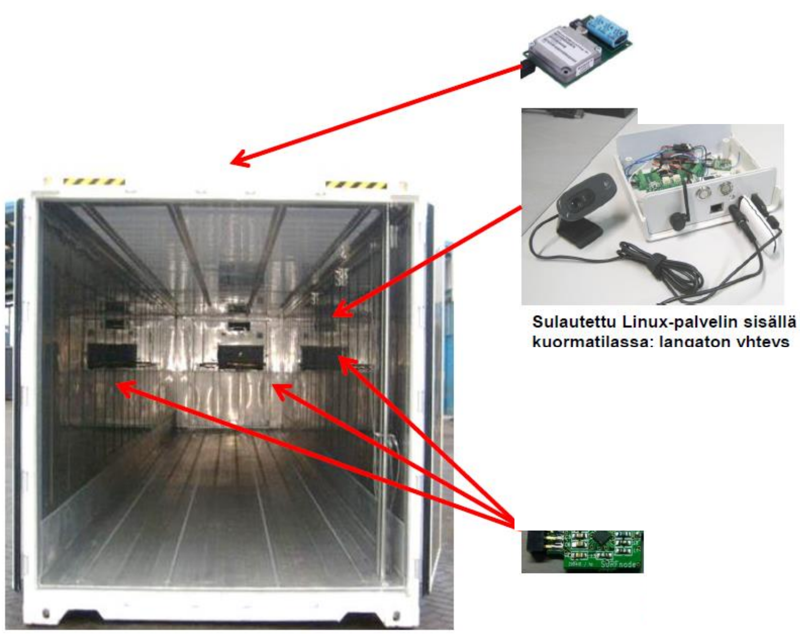
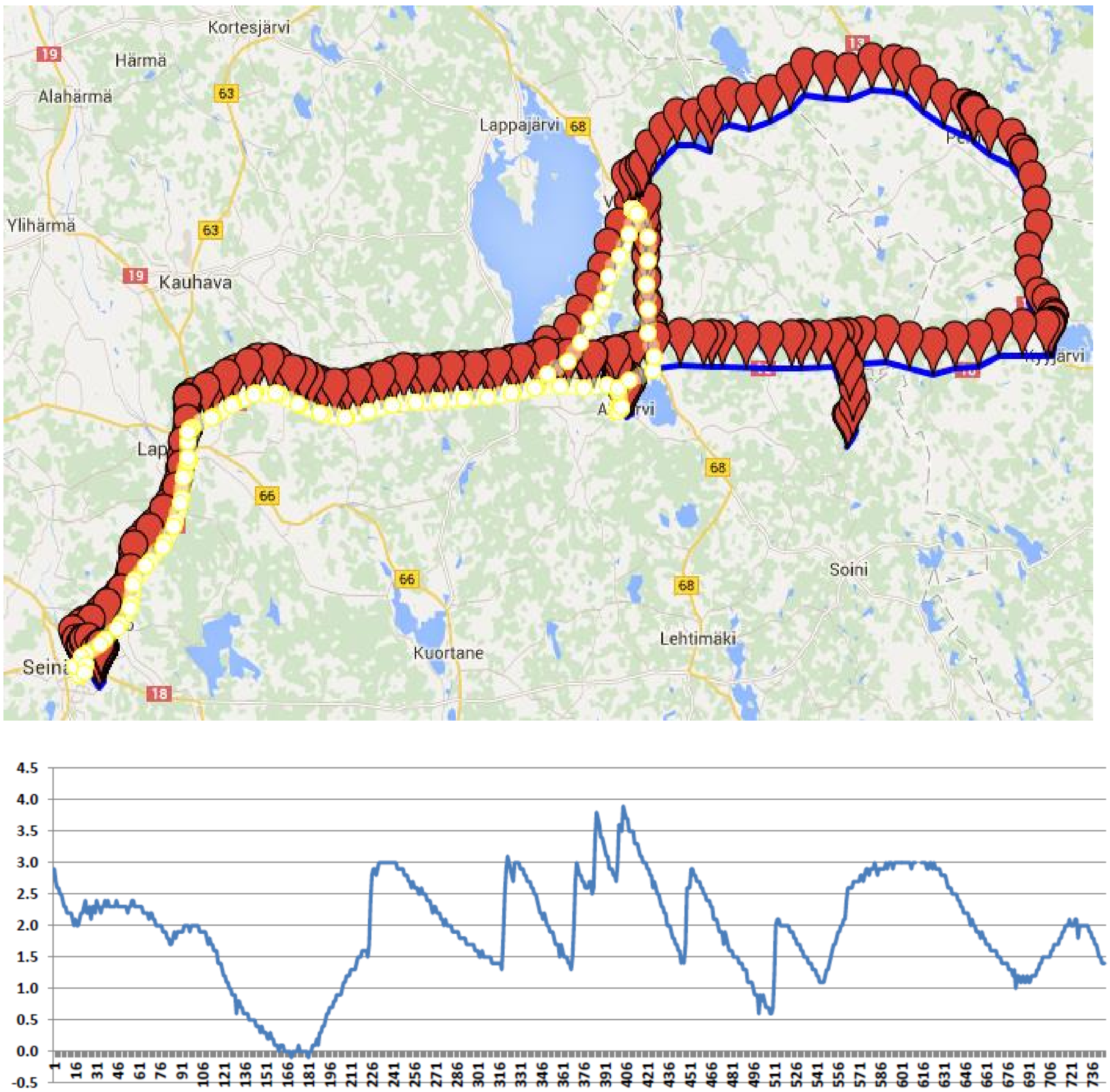


Figure 10. Temperature measuring system for temperature controlled distribution truck.

The measurement data was collected within one day. During the measurement period, the transportation truck completed two distribution tasks. The truck was loaded twice at the local distribution center. The daily distribution route lengths were 164 km and 285 km respectively. Figure 11 illustrates the route on map and temperature profile. According to the measured data the temperature varied during the route from -0.05 to +3.90 C. There is potential to decrease the amount of delivery cooling energy.



Y-axis = Temperature (C°), X-axis = Distance (km)

Figure 11. Transportation route, Nov. 2014.

The energy saving potential of temperature optimization would create energy savings of 50 % during the case route (Figure 13). It would mean a decrease of total logistic emissions from 45 kg

CO_2 eqv/ton of product to 42 kg CO_2 equivalent/ton of product in the case of a larger truck. Even in this situation delivery cooling represents a share of 63 % of all emissions from dispatch department to market.

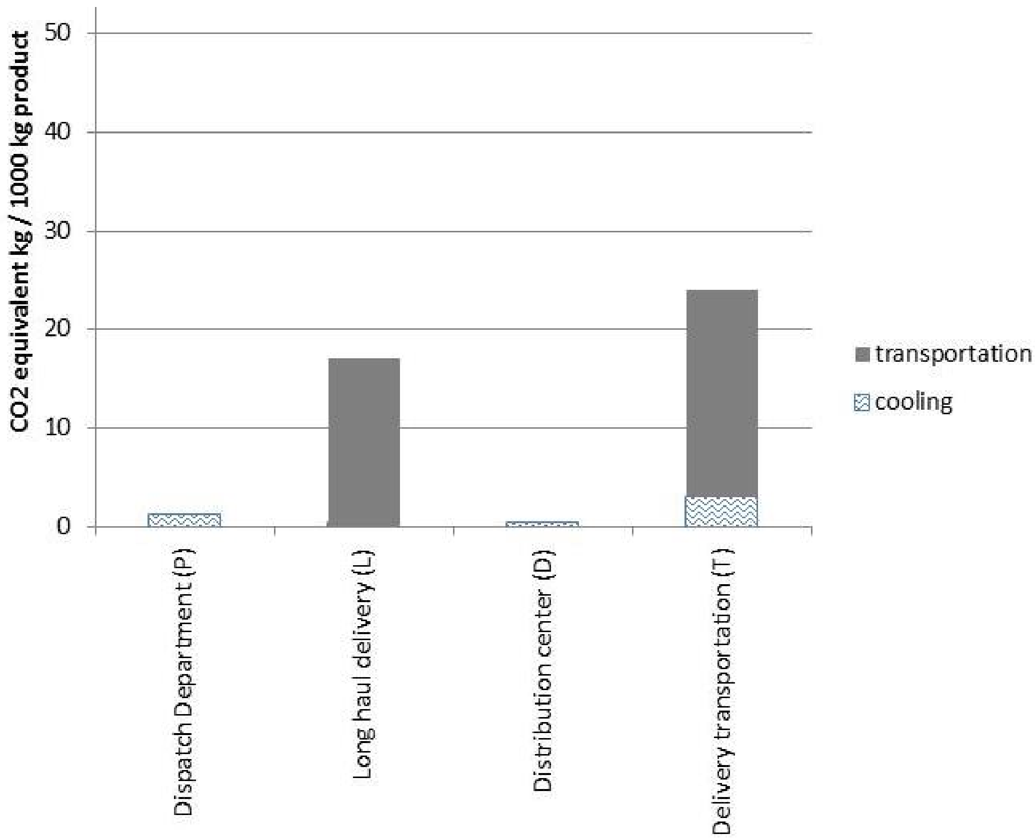


Figure 12. Emissions of the case food chain when delivery cooling energy consumption is reduced by 50%.

5. CONCLUSIONS

The data collected from the case of a temperature controlled food distribution system shows that a major share of CO_2 emissions takes place in the actual transportation task due to fuel consumption. Control of temperature represents an important source of fuel consumption, especially in the distribution route, less on long haul transfer.

On the whole, logistic emissions compared to total food emissions are minor, supporting also the findings of Päivittäistavarayhdistys ry (2004), Nissinen, et al. (2007), and Wanhalinna (2010), but there is still potential to decrease emissions. Depending on the type of end product, logistic emissions are from 0.4% - 5% (Figure 14). The share of logistic emissions is smaller in meat products and larger in vegetables, because the total emissions of meat products are larger than those of vegetables. Also, the share of food waste is larger with fresh products.

Analysing the CO_2 emissions during distribution helps to understand the impact of different activities and see the barriers to environmental improvements. Efficient logistics can help to reduce food waste, because the reasons for food waste, according to Gustavsson et al. (2011), are bad coordination of the chain and best before labels. The share of the CO_2 emissions of e.g. production, cooling energy, transportation and warehousing from the supply chain viewpoint varies, depending on, for example, distances, warehousing time and cooling technologies. There is variation in the energy needed during transportation, but this and previous studies such as Evansin et al. (2007), McKinnon and Campbell (1998) and James & James (2010), point out that there is great potential. Real time online optimization makes it possible to adjust to optimal conditions and save energy.

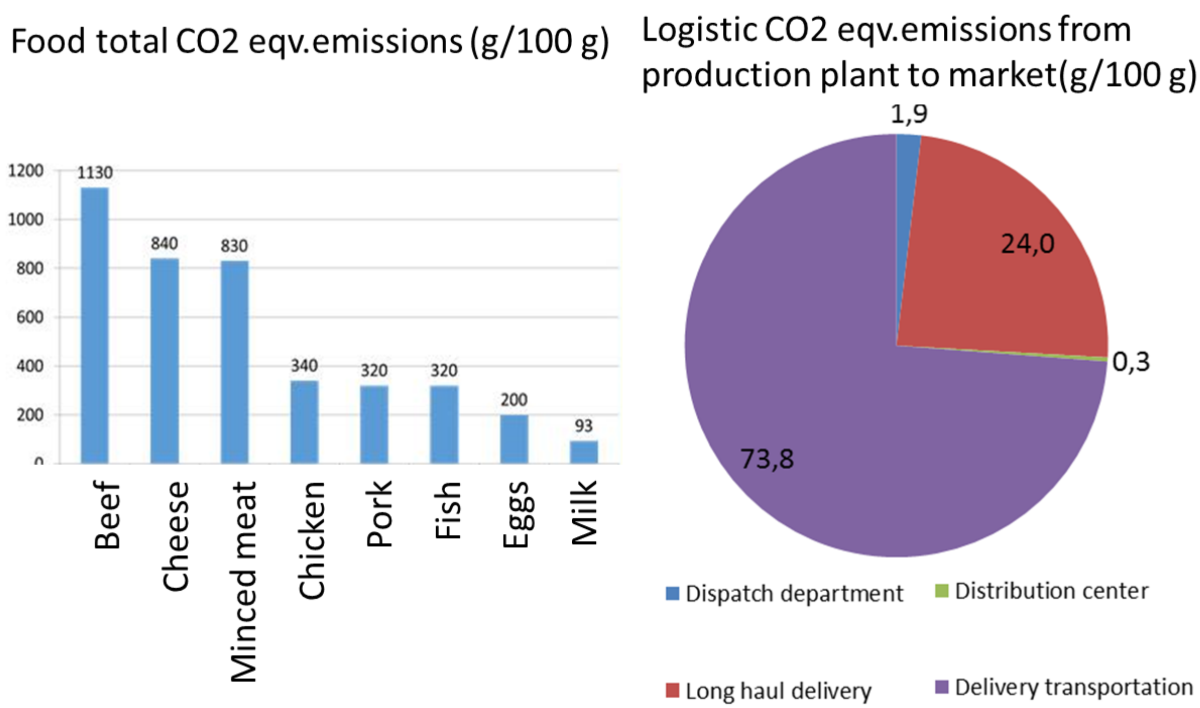


Figure 14. Logistic emissions compared across different food products.

The payload utilization of the transportation trucks is an important driver of emissions reduction. Typically, the average utilization of delivery transportation is usually much lower than in long haul deliveries. Short haul delivery transportation usually involves delivery to many retailers and additional freight may be difficult to organize. This means that delivery transportation is partially loaded and the biggest deliveries are delivered as soon as possible. Hub distribution center networks can create benefits, which supports the findings of Gimenez (2006). Emissions are smallest when the share of long haul delivery of the total distance is biggest. Trucks meant for long haul deliveries are not meant for local delivery transportation and are not as efficient in that kind of driving.

Cooling needs energy and the role of cooling is significant, which also supports James and James' (2010) findings. Especially much cooling energy is needed in deliveries from distribution centers to markets. Large-sized and more energy efficient trucks with good utilization rates improve energy efficiency. Logistic structure improvements may improve distances and mean loads, which also improves energy efficiency.

The results of this study show that there is potential in online optimization to optimize the temperature of the cooling energy needed during transportation. Further studies are needed to estimate temperature optimization possibilities throughout all the delivery tasks. The results are sensitive to CO_2 value of the fuel used for cooling and transportation processes. For example, the usage of the LNG or CNG would affect the results. The right conditions during food transportation are crucial but also offer saving potential. Cooling during transportation needs more energy than in terminals. Overcooling in conditions which are not so energy efficient means wasting energy. Different weather conditions like temperature and humidity, for example summer and winter, daytime and nighttime, set the needs for temperature control and energy consumption optimization. These conditions also set limitations to the results and saving potential. The closer the outside conditions are from the transportation conditions needed, the more minor the saving potential is. The results will vary also if the route structure and number of stoppages and driving and unloading vary. As long as driving and unloading are not automated, human errors and operation variation create limitations.

The results from this case study show that there is a saving potential and possibility to improve eco-efficiency by concentrating on distribution side operations and thermo-control generally. Generalization of the results is challenging. Very likely the results would be comparable in other cases when products are short-dated but quite low-value and requiring temperature control. However, different volumes or distribution distances could affect the performance of a supply chain.

More actual supply chain data driven analysis is needed in building understanding about the potential environmental developments in food supply chains. Each product or national level supply chain structure may have own characteristics which need to be taken into account.

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