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Juan Daniel Arango Castellanos, Oliver Jelsch,
Michael Freitag

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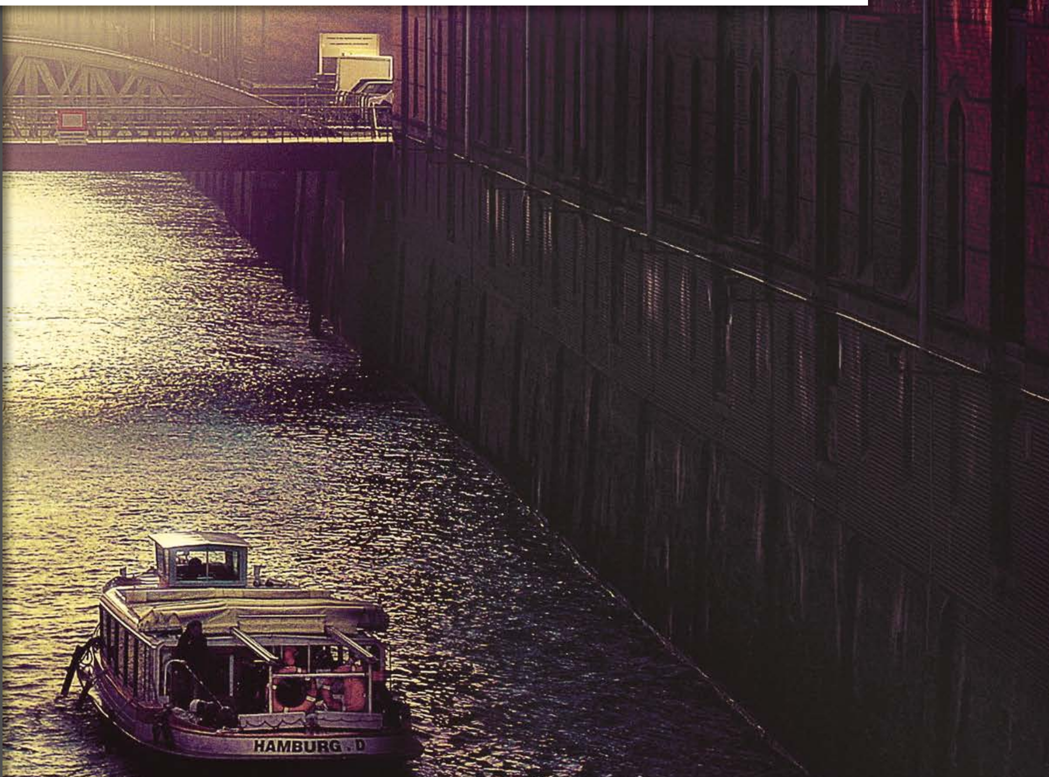

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Life Cycle Assessment for Frozen Food Distribution Schemes

Markus Trapp[1], Michael Lütjen[1], Juan Daniel Arango Castellanos[1], Oliver Jelsch[2], Michael Freitag[1]

1 – BIBA - Bremer Institut für Produktion und Logistik GmbH

2 – K + S Kühl- und Spezialtransporte

The online grocery market is facing big challenges. In addition to products for daily use, it is necessary to deliver fresh, chilled and frozen foods quickly and reliably to the customer. For decades frozen products have been delivered to the customers by using small cooling vans. Since some years, also normal parcel delivery services in combination with insulated shipping containers have been used. This article examines in a comparative analysis the environmental impact based on CO2 emissions of alternative distribution schemes (supermarket, cooling van, parcel delivery) by using a life cycle assessment (LCA) according to DIN EN ISO 14040. Thereby, the parcel delivery of insulated containers made of EPS (Expanded Polystyrene) was studied in detail, including recycling difficulties for the end customer. The LCA study showed that the transport scenario using small cooling vans lead to higher CO2 emissions, whereas the classical transport using high-capacity refrigerator trucks and refrigerated storage houses represented the scenario with less CO2 emissions. Additionally, recycling EPS-packaging in private households showed that reducing its volume is complicated and troublesome. The tests indicated that forces higher than 500 newtons were needed to break certain EPS-packaging.

Keywords: online grocery; life cycle assessment; city logistics; Expanded Polystyrene-Packaging

1 Introduction

The online food trade is facing great challenges in order to sustain the demanding clientele. In addition to items of daily use, it is also important to bring fresh, chilled or frozen food quickly and safely to the customer. Especially the amount of deep-frozen products has been growing steadily for years. With regard to the shipping business, frozen products are particularly convenient since they can be handled industrially and stored for longer periods than fresh foods. Enhanced manufacturing and freezing processes ensure higher qualities of the products, which now also meet higher requirements. The safe dispatch of deep-frozen foods requires compliance with hygienic standards, in particular, the adherence to the cold chain. In addition to stationary trading, frozen foods are delivered by direct distributors for decades by means of special deep-freeze vehicles. However, for some time now, competitors have been operating the classic online business as a full-range vendor and they are relying on the delivery of frozen products using standard CEP (Courier Express Parcels) service providers. In a comparative analysis, the present paper investigates the environmental sustainability of alternative shipping forms using a life cycle assessment according to DIN EN ISO 14040.

According to a study by the German Frozen Food Institute, more than 3.5 million tons of frozen foods were sold in Germany in 2015, which corresponds to an approximate per capita consumption of more than 43 kilograms and a sale plus of 3.7% compared to the previous year (Deutsches Tiefkühlinsitut e.V., 2015). In addition to ready-made meals such as pizza and buns, there are also vegetables, fish or meat.

Environmental sustainability is an issue in the context of consuming frozen foods since it is an indicator of how products or activities affect protective goods, such as soil, water, air or climate (Die Umweltdatenbank, 2017). The answer to this issue is of crucial importance since more and more people see the environmental sustainability of organic foods as a major factor for purchasing (Bundesvereinigung der Deutschen Ernährungsindustrie, 2013). The ECO-Institute Freiburg provides a comparative analysis of five selected foods and concludes that frozen products are not more climate-damaging than fresh products when all production and distribution stages are taken into account (Öko-Institut e.V., 2015). Industrial processing of fresh products results significantly less climate-costly than processing and storing in them in individual households. Due to the more complex distribution of frozen foods, this consideration is equalized but under certain assumptions it can lead to the statement that frozen products are as harmful to the environment as fresh products. This consideration is based on a customer's purchase in the supermarket. However, it can be observed that the online food trade is gaining in importance in comparison to stationary retail.

In his study for the 'Groceries Forum 2015' in Bremerhaven Professor Seeck mentions essentially three possibilities for logistics networks in e-commerce (Seeck, 2015).There are pure online players with central warehouse delivery, where deliveries are made from agglomeration-related central warehouse locations. To this pure online business also mixed forms from online and stationary trade are conceivable. Thus, the stationary trade can also offer an online sale, in which the customers are supplied from local branches. REWE is one of the German supermarket chains that uses this type of delivery. As alternative online sales and stationary trading may also be consolidated with agglomeration-related "online branches" where the delivery takes place as in stationary trading. In addition, it has to be decided whether the delivery is to take place through an own delivery organization or whether CEP service providers are used. For all considerations, it must be taken into account that the dispatch of foodstuffs and in particular of fresh and frozen foods imposes special requirements on transport. In particular, this concerns compliance with temperature corridors and hygiene regulations.

In addition to fast and safe delivery, ecological aspects are also of great importance to the consumers. Especially for organic food, it should be ensured that the ecological footprint is not impaired by expensive transports, as for example additional transports in low-wage countries for further processing. The distribution of frozen food as a section of the entire supply chain has several potentials for improvement, such as the design of the cold chain infrastructure (Manzini et al., 2013). Particularly the transport costs with heavy-goods-vehicles (HGV) and the accumulating packaging materials have to be analyzed critically, as these two aspects have the greatest impact potential on environmental sustainability (Hoang et al., 2016). One of the most relevant packaging material for frozen food delivery is Expanded Polystyrene (EPS), also known as Styrofoam, which requires thick sections to insulate the products and keep them at the desired temperature for longer periods. However, thicker packaging leads to bulky boxes. In the business-to-business sector, industrial disposal systems are available. For private costumers, storage and disposal from EPS-packaging is cumbersome. According to a study on online food commerce, packaging plays an important role since 36% of the online shoppers would buy groceries regularly online if they are sent using environmentally friendly packaging and generate fewer packaging waste (Fingerhut, 2015). In order to reduce the waste volume of EPS-packaging, it is necessary to break it, which might be a challenging task for some customers.

2 Methodology

The life cycle assessment technique was used to analyze the environmental impact of the considered transport scenarios for frozen food. Furthermore, since EPS-Packaging plays an important role in distributing frozen food without external cooling, a testbed was built to measure the force required to reduce the dimensions and disposal of such packaging.

2.1 Life cycle assessment of logistics processes

The life cycle assessment methodology is a way of determining the environmental sustainability of products or services. This is a standardized procedure, which is described in DIN EN ISO 14040 (Deutsches Institut für Normung, 2006). The goal is a holistic view of the entire way of life in order to be able to make a quantifiable and comparable statement about the resulting environmental effects. The obtained results are related to the functional unit with the intention of creating a comparability to other LCA results. According to the standard, an LCA is divided into four phases: Goal and Scope Definition, Inventory Analysis, Impact Assessment and Evaluation/Interpretation. The process of accounting is described as an iterative procedure so that not only one-way connections exist between the individual phases. Therefore, it may happen that in a phase new knowledge or questions arise that require a return to the previous phase. This connection of the individual sections is shown, schematically in figure 1.

The first phase of the objective definition and definition of the study framework serves to define all the basic assumptions, describe the product system to be investigated and formulate the question, which is to be answered by the LCA. It is also necessary to determine the functional unit, which is the reference value for all results. In the phase of Inventory Analysis, all required materials and energies are determined and combined with their respective quantity necessary for the production of a product or the provision of the service. For this purpose, a distinction is made between input and output flows that either flow into the product from the environment or vice versa, from the product into the environment. At the end of this phase, an overview of all material and energy flows will be available.

The following step is the Impact Assessment where the previous results are used to calculate the values for different impact categories. This means that all substances or energies from the Inventory Analysis are assigned to the impact categories

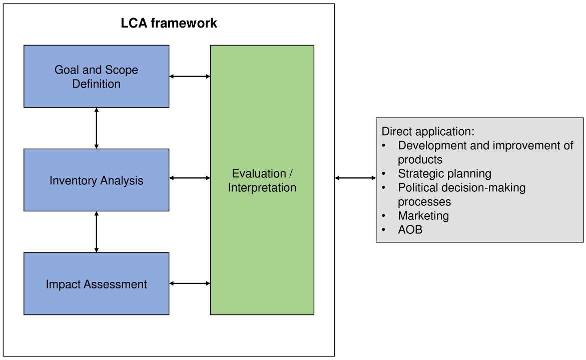

Figure 1: Life cycle assessment according to DIN EN ISO 14040

considered and then indicated by a specific characterization factor as a multiple of the respective basic unit. One of the possible categories is the climate change, characterized by the Global Warming Potential (GWP). For this category carbon dioxide (CO2) is the comparative value to which all results relate and are given in the form of kg CO2 equivalents (CO2e). As one example, methane (CH4) has a value of 23 kg CO2e and therefore the emission of 1 kg methane means 23 times more GWP compared to carbon dioxide.

The accounting is concluded with the Interpretation, where the results from the three previous sections are evaluated critically and conclusions are drawn. Changes in parameters of products or processes can be used to create different scenarios as possible future developments. The special challenges of LCAs occur in the procurement of directional and initial values for special materials or processes (Klöpfer, 2009). There are a number of databases (Ecoinvent, ProBas, ELCD, etc.) that may not contain all the values and in some cases, the present values are unsuitable for the specific application. As a rule, the values for transports are given as a mathematical product of mass and distance covered in the form of ton-kilometers. There are some scientific studies on the distribution of frozen foods that use these values, but therefore they are only partially comparable to other distribution scenarios (FRoSTA, 2009).

This is problematic when goods are transported that have a very low density but a high volume at the same time, such as Styrofoam packages. In order to obtain comparable results, there has to be a combined volume and weight-related determination of the transport costs. However, this requires a deeper consideration of the stowage and an estimation of cargo loading factor sections of the route. The cargo loading factor is an indicator of the utilization of the vehicles, which is calculated as the quotient of used and offered transport capacity (Gabler, 2017). The transport capacity can be either the weight of the maximum payload or the load volume. In the case of the latter, the ratio of volume and weight has to be observed in order not to exceed the permissible total weight. Since in most cases the weight is the limiting factor, in the following, the volume-related cargo-loading factor is used to show which volume reserves are still available.

In particular, in the case of round trips, the specific allocation of emissions is not trivial since the amount of cargo loading decreases dynamically. In the delivery process, the weight to be transported is gradually reduced, which is why theoretically the first delivered product would have to be allocated fewer emissions than the last product. However, since this cannot be resolved properly, an appropriate value for the average utilization or a cargo loading factor has to be found in order to evenly distribute the resulting emissions to all products of a delivery trip.

2.2 Testbed to study and analyze EPS-packaging disposal

With the purpose of measuring how complex it could be to break an EPS-box apart, a simple and logical procedure to break a box without special equipment at home is suggested. First, the box should be empty and without the lid. Then, it should be placed/against a solid wall and stepped on one of its sides with an angle of approximately 45° as shown in figure 2. This procedure should be repeated for each side.

In order to reproduce this scenario a simple testbed to apply discrete force steps was built as shown in figure 2. On top of the testbed, the weight could be gradually incremented, which is transferred to the box through a metal bar and a shoe fixed to it. A linear guide was used to allow the metal bar to displace perpendicular to the ground. The box is placed on an adjustable support, which was set to 45°. The force added to the box was calculated based on the weight of the metal bar plus shoe and the added weight on top. Friction force from the linear guide was neglected.

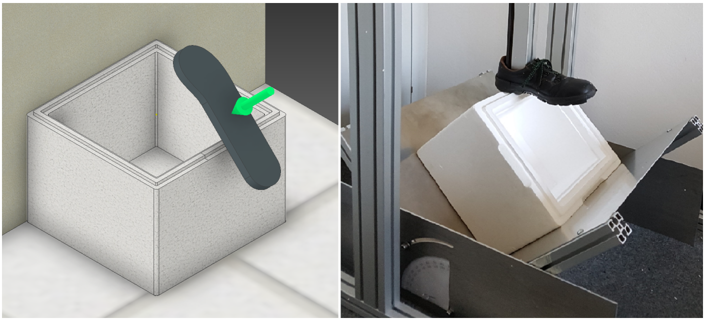

Figure 2: a. Representation of the procedure to break an EPS-Packaging
b. Testbed used to determine the breaking force for EPS-Packaging

3 Scenarios for distribution of frozen foods

The LCA analysis carried out is intended to answer the question of how many kilograms of CO2 equivalent emissions are generated when supplying the consumer with frozen foods. In order to get comparative results, the three most common scenarios are analyzed: delivery to the final consumer with refrigerated vehicles, delivery by CEP service providers with insulating containers as well as the final consumer's purchase journey to the stationary dealer. All calculated results refer to the functional unit transport and storage of "10 liters of frozen food with a total weight of 3.5 kilograms including packaging". This corresponds approximately to the volume/weight ratio of a deep-frozen ready-to-serve meal (e.g. chicken with fried potatoes, 500 grams by FRoSTA).

Within the scope of the following analysis a classical three-stage distribution is chosen with pre-run, main run and post-run (figure 3). Both the transport and the handling are considered. The pre-run describes the transport of frozen foods from the producer to the first transshipping point. The main run represents the section in which the goods are preferably transported by large heavy-goods-vehicles (HGV) over long distances to the second transshipping point. The phase of transport, in which the final consumer is exposed to the goods, is described with the post-run. The three scenarios differ significantly by their distribution network, whose distances chosen for this analysis are shown exemplary in figure 3.

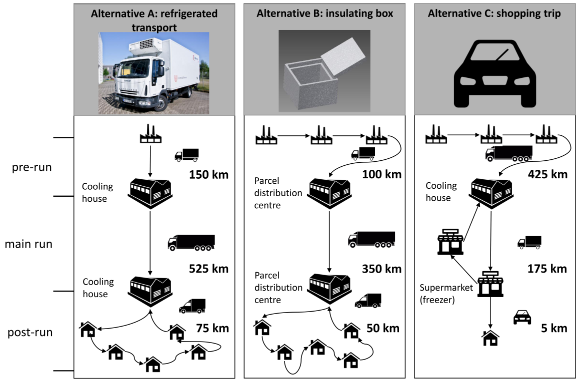

Figure 3: Scenarios for frozen food distribution (pictures: freepik, 2017)

The different distances between the cooling houses or the package distribution centers result from the assumption that there are ten times as many distribution centers for the standard parcel delivery as cooling houses for the handling of temperature-controlled goods. For all vehicle movements, the fuel consumption is an average value, which is calculated from the respective cargo loading factor and a consumption range for empty and full transports. The values are as far as possible based on the relevant literature values (ProBas, 2017).

3.1 Temperature-controlled distribution with refrigerated vehicles to the final consumer

For the pre-run of the temperature-controlled transports, it is assumed that there is a direct load transport between the producer and the cooling house with a 7.5-ton HGV, which has an estimated volume-related cargo-loading factor of 0.38. In this case, the volume-related cargo-loading factor is limited by the weight-related maximum load. There are CO2-equivalent emissions from fuel consumption that are generated by both the actual vehicle movement (18 l/100 km) and the use of the cooling units (3 l/h). In addition, coolant losses in the vehicles and the cooling houses cause emissions, which, however, are not included in the calculation by means of cut-off criteria. In order to be able to keep calculations comprehensively clear with all the complexity of the systems, one agreed on cut-off criteria. These determine the proportion from which an input is no longer relevant for the calculation. As a rule, the limit is 1% of the input of the total system in relation to mass, energy or environmental relevance since it is assumed that minor inputs below this limit have no appreciable influence on the overall result and therefore there is no need of further consideration (Klöpfer, 2009). Although the special vehicle bodies of the refrigerated vehicles and the construction of the cooling houses are made of materials that have high characterization values (e.g. 16.1 kg CO2e per 1 kg aluminum).

However, this may only be attributed to the individual functional unit on a pro rata basis. For a typical depreciation period of 9 years of vehicles with average use, the proportion of the emissions generated for the individual product is so low that this is not taken into account in the calculation. The energy consumption during transshipping is similar. It has to be pointed out, that the use of cooling houses causes emissions, but these also do not flow into the calculation because of the cut-off criteria (Klöpfer, 2009). In the main run, direct transports are carried out between cooling houses with 40-tonnes HGVs with an average volume-related cargo loading factor of 0.63. Here CO2e emissions are generated by fuel consumption for vehicle movement (31 l/100 km) and for the use of cooling units (5 l/h). The critical section of the three delivery phases is the post-run, where the calculations are based on round trips between cooling houses and final consumers. Deliveries are carried out with 3.5-tonnes HGV, which have an average volume-related cargo-loading factor of 0.28. Fuel consumption for the vehicle movement (10 l/100 km) and the use of the cooling units (4 l/h) generate CO2e emissions. The increased fuel consumption of the cooling units with respect to the loading volume is caused by the frequent opening of the cooling cell.

3.2 Delivery using EPS-Packaging by means of CEP service providers

In the online frozen food trade, the use of insulating containers made of EPS and dry ice as coolant is increasingly being used due to its good scalability. Such delivery solutions can be operated without external cooling, for example, the "NextGeneration Thermopack" from K+S over a period of 72 hours. Dry ice is solidified carbon dioxide (CO2) that sublimes under normal pressure at a temperature of around – 78.5 °C. Thus, a sufficiently low temperature is provided for the cooling and the solidified gas does not melt but passes directly into the gas phase without residue. The carbon dioxide used for the dry ice can be deposited as a by-product in combustion processes. After a multi-stage purification of the combustion gases, the pure carbon dioxide can be liquefied under pressure and low temperatures. Liquefied CO2 is optimal for transport and storage. Dry ice can be produced in different shapes and sizes. For the use as a coolant in insulated containers, a pellet shape is suitable, since these are easy to produce and to handle. In order to produce the pellets from the liquefied gas, the CO2 is suddenly expanded to normal pressure. The evaporation and adiabatic expansion result in a cooling that is large enough to produce dry ice snow, which can be compacted and pressed into the desired shape.

The subsequent release of the carbon dioxide can be regarded as CO2-neutral since existing combustion gases are used and the deposition only means a delayed release to the environment and no additional load. There are only a few more emissions from the deposition, the liquefaction, the pressing and if necessary the transport of the liquid carbon dioxide or of the dry ice to the place of application. The 10 kg dry ice are calculated with 1.39 kg CO2e and for the EPS-container with a useful load volume of 35.5 liters, there are 1.15 kg CO2e emissions. It can be assumed that there are a 27% material and a 40% thermal utilization of the insulating EPS-packaging.

The use of these EPS-packaging and dry ice allows the delivery by means of conventional CEP service providers, which have a very efficient distribution system. The analysis of this scenario is also based on a three-level distribution. The pre-run is carried out by means of 7.5-tonnes HGVs, which have a cargo loading factor of 0.63 and generate CO2e emissions by fuel consumption (20 l/100 km). In the main run, 40-tonnes HGVs (fuel consumption: 34 l/100 km) are used for the direct transports that have a cargo loading factor of 0.9. The post-run is realized through 3.5-HGVs (fuel consumption: 10 l/100 km) with a cargo-loading factor of 0.4. In order to evaluate EPS-packaging disposal, two standard EPS-Packaging solutions were tested. The packaging's dimensions were 48 cm x 48 cm x 38 cm and 26 cm x 21 cm x 18 cm (LxWxH), with a thick of 4 cm and 3 cm respectively.

3.3 Temperature-controlled distribution and final consumer's shopping trip

This scenario represents the classic distribution to the supermarket and the subsequent shopping trip of the final consumer. In this scenario, deliveries of larger quantities of frozen foods are exported from the producer to the cooling house of supermarket chains. For this purpose, consolidated transports are carried out with 40-tonnes HGV with a cargo-loading factor of 0.8. CO2e emissions are generated by the fuel consumption for vehicle movement (33 l/100 km) and the use of cooling units (5 l/h). The main run is represented by 7.5-tonnes HGV that supply the supermarkets and have a cargo-loading factor of 0.38, producing CO2e emission due to fuel consumption for vehicle movement (18 l/100 km) and use of cooling units (3 l/h). The transshipping and the storage in the supermarket take place in freezer cabinets with a load volume of 770 liters and a power of 300 watts (FRoSTA, 2009). In the post-run, the final consumer drives in its own car (fuel consumption: 8 l/100 km) an average distance of 5 km to the supermarket. Frozen foods take a proportion of 20%. Table 1 shows an overview of all three scenarios and their estimated values.

Table 1: Overview of scenario values

	Refrigerated	Transport	Shopping trip
Pre-run			
Vehicle	7.5-tonnes HGV	7.5-tonnes HGV	40-tonnes HGV
Distance	150 km	100 km	425 km
Fuel consumption for …			
Vehicle movement	18 l/100 km	20 l/100 km	33 l/100 km
Cooling unit	3 l/h	–	5 l/h
Cargo-loading factor	0.38	0.63	0.8
Main run			
Vehicle	40-tonnes HGV	40-tonnes HGV	7.5-tonnes HGV
Distance	525 km	350 km	175 km
Fuel consumption for …			
Vehicle movement	31 l/100 km	34 l/100 km	18 l/100 km
Cooling unit	5 l/h	–	3 l/h
Cargo-loading factor	0.61	0.9	0.38
Post-run			
Vehicle	3.5-tonnes HGV	3.5-tonnes HGV	car
Distance	75 km	50 km	5 km
Fuel consumption for …			
Vehicle movement	10 l/100 km	10 l/100 km	8 l/100 km
Cooling unit	4 l/h	–	–

4 Findings

4.1 Life cycle assessment

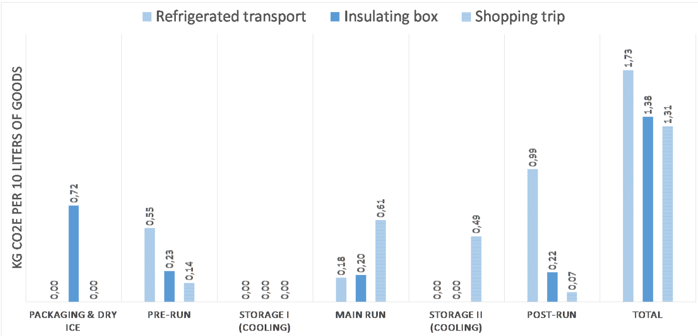

Figure 4: LCA results as kilograms of CO2e per 10 Liters of goods

The LCA is carried out using the above-mentioned parameters as well as the characteristic values known from the literature for the conversion of all emissions into carbon dioxide equivalent ones (ProBas, 2017). As described above, the emissions for dry ice are calculated based on the entire production chain, including transports from the source of the CO2 to the dry ice production. Figure 4 shows an overview of the results of the individual scenarios divided by phases. Therefore, the LCA shows a uniform picture. Having 1.31 kg CO2e, the "shopping trip" scenario is about 5 percent ahead of the scenario "insulating containers" with 1.38 kg CO2e. Only the scenario "temperature-controlled distribution" with 1.73 kg CO2e deviates by 32 percent from the "shopping trip" scenario. In the overview, it can be seen that the scenario "temperature-controlled distribution" has weaknesses in the post-run, whereas in the scenario "insulating container" the necessary packaging including dry ice leads to emissions independent of the actual distribution. The introduction of a deposit system, through which the insulating containers could be used several times, offers no ecological advantage in the case of the packaging considered here. In the case of a ten-time use of the insulating container, approximate 1.55 kg CO2e per 10-liter goods would be incurred per circulation. In order to improve this value, for example, foldable insulating containers would have to be used to save volume and thus to achieve a higher weight-related cargo loading factor.

The scenario “shopping trip” shows weaknesses both in the main run and in the necessary temporary storage in the supermarket. Here, the other two scenarios have corresponding advantages in the direct delivery to the final consumer, but these are fully equalized in the transport in particular in the “temperature-controlled distribution” scenario. In order to verify the calculation, reference should be made to ’Deutsche Post DHL’s’ experience values, which indicate less than 500 grams of CO2e for shipping an average package via its delivery system (Deutsche Post, 2011). In this calculation, 650 grams are omitted, which is probably due to the fact that there is a more efficient distribution in metropolitan areas that could not be taken into account and on the other hand, the fact that neither volume nor weight of an average package was specified by DHL. From the ecological point, this also shows that the online food trade with delivery via CEP service provider is also a clear alternative to traditional shopping trips. Even with a total range of 5 kilometers with a modern medium-sized class car, there are more CO2e emissions than for a parcel shipping (Deutsche Post, 2011). In this LCA, frozen foods only have a proportion of 20% of the total consumption, since no average values could be found in the literature.

4.2 EPS-packaging disposal tests

Due to the complications related with EPS-Packaging recycling for private users, two different packages sizes were destroyed systematically. The first side of the bigger box (48cmx48cmx38cm) required 514.5 newtons and broke irregularly as shown in figure5a. The opposite side required almost 10 newtons more to break. After the four sides broke, the edges of the box were almost intact as seen in figure 5b. For that reason, the testbed was also used to break the borders of the box as shown in figure 5. Since the shape of the rupture is uneven, the force required to break the edges varies from 328.3 newtons to up to 588 newtons. Finally, the remaining pieces longer than 30 cm were also crushed.

The same procedure was applied to the smaller box (26cmx21cmx18cm), which required an average force of 280 newtons to break its sides. For the smaller box, it was not necessary to continue breaking the remaining part of the box, since the edges were mostly damaged as seen in figure 6, proving to be easier to dispose

Table 2: Required force to reduce the volume and dimensions of two EPS-Packages.

	Force (Newton) for the …	
	Big box	Small Box
Side 1	514,5	291,06
Side 2	524,3	305,76
Side 3	504,7	276,36
Side 4	475,3	246,96
Edge 1	328,3	–
Edge 2	588	–
Edge 3	475,3	–
Edge 4	328,3	–
Piece 1	142,1	–
Piece 2	75,95	–
Piece 3	220,5	–
Piece 4	308,7	–

than the big box. A summary of the force required to break each EPS-Packaging solution using the before explained methodology is presented in table 2.

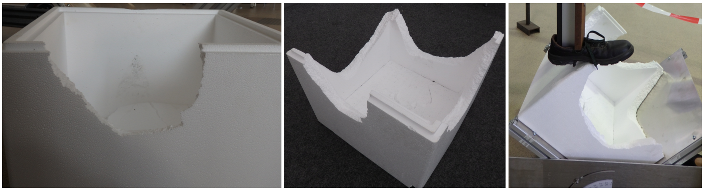

Figure 5: a. Rupture shape from the first side of the bigger box.
b. Remaining of the box, once all the sides are broken. c. Procedure to break the remain-ing edges of the box.

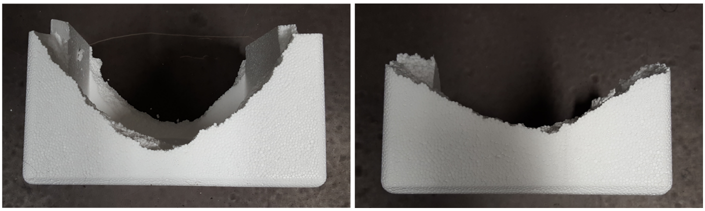

Figure 6: a. Rupture shape of the first and second side of the smaller box.
b. Remaining of the smaller box after breaking its sides.

5 Discussion and Conclusion

Distribution of frozen goods to the final consumer presents a special challenge for the online food trade in Germany. In addition to meeting hygienic standards, the safe dispatch of frozen foods requires compliance with the cold chain. Besides, these requirements, the final consumer is increasingly focusing on the environmental sustainability of the food, which also includes distribution.

In the present paper, three alternative scenarios of the distribution of frozen foods were examined from the ecological point of view: the classic shopping trip to the supermarket, the shipment by means of special refrigeration vehicles as well as the delivery CEP service providers with corresponding packaging solutions for deep frozen products. The LCA according to DIN EN ISO 14040 shows that none of the scenarios has clear advantages in ecological terms. The classical cooling transports are the worst performers, while the classic shopping trip causes the least greenhouse gas emissions. The shipping solution, which is preferred by many online grocers, by means of EPS-box and dry ice is scarcely inferior and benefits from the efficient distribution network of the CEP service providers. Additionally, it can be evidenced that breaking an EPS-Packaging requires a great effort from the private customers; especially for bigger EPS-Packaging. Considering that the average weight of an adult is 62 kg (Walpole et al., 2012), the required breaking force might be difficult to achieve without using fast and strong movements or impulse before stepping on the side of the box. This could even lead to dangerous situations or accidents. The big Package had to be hit 12 times to achieve a reasonable shape for disposal, which makes the process time consuming, where the time needed to clean the small pieces that are present after the process should also be considered.

In conclusion, although insulated containers' ecological impact is comparable to the impact of a classic shopping trip to the supermarket, disposing of EPS-packaging is a complicated, time consuming and possibly an unsafe process for private households.

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