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"Gheorghe Asachi" Technical University of Iasi, Romania

GREENHOUSE GAS EMISSION REDUCTION IN FROZEN FOOD PACKAGING

Daina Kliaugaite[1*], Visvaldas Varžinskas[1], Agnė Baikauskienė[1], Valdas Miliūnas[2] Žaneta Stasiškienė[1]

[1]Institute of Environmental Engineering (APINI) Kaunas University of Technology, K. Donelaicio str. 20-308, Kaunas, LT-44239, Lithuania,
[2]Department of Graphic Communications Engineering, Kaunas University of Technology, Studentu str. 56-350, LT-51424, Lithuania

Abstract

This study evaluates the environmental impacts of four types of frozen food packages throughout their lifecycle and suggests strategies for reducing their related environmental impacts. The four most widely used frozen food packaging materials were chosen for this study: (1) pouches composed of low-density polyethylene (LDPE) film; (2) pouches composed of polyethylene terephthalate (PET) and LDPE film laminate; (3) cardboard boxes coated with LDPE; and (4) multipackage composed of cardboard boxes and LDPE film pouches. The packages are processed by a company located in Europe (Lithuania). The assessed environmental impact category was global warming. The global warming potential of packages expressed as greenhouse gas emissions (kg CO_2 eq.) was evaluated using the CCaLC software package based on a life cycle assessment (LCA), which constitutes a quantitative methodology. The mechanical properties of the various types of packaging were examined, and the optimization of plastic film thickness was verified using polymer tension tests. The multipackage consisting of a cardboard box and an LDPE film pouch has the greatest global warming potential (98 kg CO_2 eq./f.u.) followed by packages composed of cardboard and packages composed of laminated film. Production and raw material extraction stages account for most (up to 75%) of the environmental impact. Data from the polymer tension tests indicate that the environmental impact could be reduced by 36% (from 35 to 22 kg CO_2 eq./f. u.) by decreasing the plastic film thickness as well as by reducing the package size by 10%.

Key words: frozen food packaging, global warming, life cycle assessment, tensile pulling force

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1. Introduction

Frozen food is an integral part of everyday life. Frozen pre-cooked foods enable consumers to bypass cooking and instead enjoy fast and easily prepared food (Hui et al., 2004; Ximena et al., 2014). Because frozen food must satisfy high food quality requirements, good packaging plays an important role in protecting food from spoilage, thereby maintaining the quality of the food and increasing its shelf life. The widely used packaging materials are plastics, paper, metal and glass. The most commonly used packaging materials for frozen foods include various polymers (polyethylene, polypropylene, polyamide and others) and paper products (Hui et al., 2004). Metal is used occasionally (for example, aluminum foil may be laminated to plastic films and paper to provide a light and moisture barrier for frozen foods), and glass is seldom used (Hui et al., 2004; Kennedy, 2000). These materials may be used alone or in combination as laminate or multi-material packaging (Verghese and Carre, 2012).

* Author to whom all correspondence should be addressed: e-mail: daina.kliaugaite@ktu.lt, dainiote@gmail.com; Phone:+370-37-300323; Fax.: +370-37-209372.

The main advantages of plastics and paper are flexibility, lightness and good printing properties. Plastic also has many desirable features such as good gas barrier properties, transparency, softness, heat seal ability and a high strength-to-weight ratio (Jedlicka, 2009; Nitaigour et al., 2010; Verghese and Carre, 2012). The use of different packaging materials, i.e., multi-materials, especially plastic and their combinations, is increasing. Global plastic production increased by approximately 8.7% annually from 1950 to 2012 and reached 241 million tons in 2012. In the same year, Europe produced 49.2 million tons of plastic, and the largest portion (approximately 40%) of this was attributed to packaging (Plastic Europe, 2013). The plastics most used in packaging are polypropylene (PP), polyethylene terephthalate (PET), high-density polyethylene (HDPE) and low-density polyethylene (LDPE). They constitute by weight approximately 37.5, 15, 27.5 and 16% of all plastic packaging, respectively (Bio Intelligence Service, 2011). Paper and cardboard materials are also widely used in packaging systems (Iosip et al., 2012; Verghese and Carre, 2012). However, this widespread use of packaging causes adverse environmental effects. Vast amounts of packaging waste end up in landfills, thereby threatening ecosystems and the environment. According to the European Commission, the European Union (EU) annually landfills 5.25 billion Euros worth of recyclable materials such as paper, glass, plastics, aluminum and steel (EC Communication, 2011). The shares of packaging waste by weight generated in Europe are 40% for paper and board, 20% for glass, 19% for plastics, 15% for wood and 6% for metals (Bio Intelligence Service, 2011).

The negative environmental impacts of packaging production, consumption, and disposal include natural resource depletion (for example, over 99% of plastics are of a fossil fuel origin (Nitaigour et al., 2010; Rem et al., 2009); most paper products are made from wood pulp (Jedlicka, 2009)) and increased greenhouse gas (GHG) emissions, thereby accelerating climate change, one of the greatest challenges faced by the modern world (Daneshi et al., 2014; Radu et al., 2013).

GHG are generated at every stage of the packaging life cycle: during material extraction, manufacturing, filling, transport, use and disposal. Most of these emissions, particularly carbon dioxide, are associated with energy consumption. For example, approximately 88 BTUs (British Termal Unit, 1BTU=1055 joules) per gram of raw material are used to produce high-density polyethylene plastic (Billy et al, 2007). In addition, paper and cardboard can produce GHGs when they are buried and subsequently break down in landfills (Verghese and Carre, 2012). According to the European Commission, 80 million tons of carbon dioxide equivalent (or approximately 2 percent of the total GHG emissions of Europe) are emitted annually due to the packaging activities of EU members (EC Report, 2006). WRAP, (2010) has calculated the life cycle GHG emissions of individual packaging materials in the UK. According to the results, 2690 kgCO_2 eq/t was attributed to PP film/bags, 2700 kgCO_2 eq/t to PE film/bags, 3070 kgCO_2 eq/t to average plastics and 1040 kgCO_2 eq/t to paper and cardboard life cycles (Siracusa et al., 2011; WRAP, 2010).

One of the most effective strategies to reducing GHG emissions and increasing resource efficiency is to reduce waste at the source. This can be achieved in a variety of ways, from eliminating excess packaging to developing better designs for the necessary packaging.

The Council Directive 94/62/EC on packaging and packaging waste focuses on the prevention and minimization of waste at the source and specifies that packages must be manufactured with minimum volume and weight while simultaneously ensuring the necessary level of safety, hygiene and consumer acceptance (EC Directive, 1994). The package supplier must ensure that the package system contains minimal packaging material (Varzinskas et. al, 2009). However, the design procedures of such types of packages are not sufficiently developed; thus, companies in most cases refer to their internal standards or to European Standard EN 13428 (EN 13428:2004), which is very vague (Mariesse et al., 2013). Therefore, the manufacturers lack guidelines and methods for packaging optimization, i.e., achieving the minimal packaging weight and/or volume while minimizing the negative environmental impact and ensuring that all safety, hygiene and consumer acceptance requirements are met (Hortal et al., 2009). The life cycle assessment (LCA) methodology is a suitable tool for assessing the environmental impact of packed products or packaging systems in all stages of their life cycles. Most importantly, the systematic life cycle approach shows how each individual improvement contributes to the overall packaging system (Helen et al., 2011; Levi et al., 2011).

Various studies focusing on the LCA of packages based on comparisons of different types of materials for certain foods and drinks have recently been performed. Xie et al. (2011) compared milk packages made of two packaging types: PA-PE-Al-laminate and plastic polyethylene. Their results demonstrated a preference for the plastic polyethylene instead of the composite packaging because the latter is not easily recycled or reused. Another article compared baby food packaging made of glass and plastic and of different shapes (Humbert et al., 2009). Levi et al. (2011) performed a comparison of different packaging materials for fresh fruits and vegetables. In the studies on milk-based yogurt (González-Garcia et al., 2013) and on carbonated soft drink packaging (Amienyo et al., 2013), both the packaging and the food product were studied. Gonzalez-Garcia et al. (2013) found that yogurt plastic containers are a major contributor to environment degradation compared to other materials such as cardboard boxes and plastic film (Gonzalez et al. 2013). In Amienyo et al. (2012), carbonated soft drinks were found to have lower environmental impacts compared to their packaging. 2 L PET bottles performed the best according to the comparison, 0.33 L aluminum cans finished second, and 0.75 L glass bottles performed the worst. The CCaLC software package was used in this study to compare the life cycle GHG emissions of different packaging (Amienyo et al., 2012). One article concerning frozen product packaging evaluation was found in the literature. Ziegler et al., (2003), performed a life cycle assessment of frozen cod fillets, including fishery-specific environmental impacts.

There is a lack of studies that not only emphasize comparisons but also suggest packaging design solutions that are based on scientific evidence and that make packaging more sustainable. This study investigated potential methods of improving frozen food packaging. The LCA methodology in parallel with polymer film tension tests (for the evaluation of the mechanical properties of a package) can be used to assist companies in their efforts to improve and optimize plastic packaging designs.

This study compared four types of frozen food packaging in an attempt to (1) identify the life cycle stages that contribute the most to GHG emissions as well as to (2) develop potential alternatives for reducing these emissions.

2. Case studies

First, comparative environmental impact analyses of four different frozen food package types as well as the life cycle stages of these packaging types were performed using the CCaLC software package based on a life cycle assessment (LCA) and following the procedures and recommendations of the European standard ISO 14044 (ISO 14044:2006) and PAS 2050 (BSI, 2011).

Second, the mechanical properties of the packaging were assessed in an attempt to create more environmentally friendly packaging. The potential alternative scenarios (optimization of plastic film thickness) were examined and verified using the polymer tension test ISO 527-3 (ISO 527-3:1995).

The environmental impact category was global warming expressed as GHG emissions (kg CO_2 eq.). In accordance with ISO 14044, the life cycle assessment is composed of four phases (ISO 14044:2006): (1) a clearly defined goal and scope definition; (2) an inventory analysis, which involves data collection and the quantification of energy and material inputs and the emissions of a product system; (3) an impact assessment that assigns the inventory data to environmental impact categories; and (4) an interpretation of results in which the findings from the inventory analysis and impact assessment are combined and used to form conclusions and recommendations (Verghese and Carre, 2012; Xie et al., 2011). Further, the separate LCA phases are described in additional detail.

2.1. Goal and scope definition

Frozen food packages were chosen due to the rapid growth currently observed in the frozen food industry. Following a Lithuanian market analysis, the following four most popular frozen food package types were chosen and are listed in Table 1: a pouch composed of LDPE film for dumplings, a pouch composed of plastic film laminate (PET and LDPE films) for shrimp, a cardboard box coated with LDPE (for shrimp) and a multipackage (cardboard box and an inner pouch with an LDPE film) for dumplings.

According to information provided by the companies, all of the analyzed packaging is meant for both types (dumplings and shrimp) of frozen food. In addition, both of the frozen products are friable, have similar packaging processes and can be packed with the same filling equipment. The goal of the LCA study was to compare the environmental impact of four different frozen food packages and identify the packages and the stages in the packaging life cycle that constitute the greatest contribution to this impact.

2.2. Functional unit

A functional unit is used to measure the potential environmental impact of a product system (ISO 14044:2006). The protection and packaging of 1,000 units of frozen food (each unit equal to 500 g of frozen food) were selected as a functional unit in this case. All packages were assumed to have an identical surface area (0.11 m^2) and to contain 500 g of friable frozen product (Table 1).

2.3. Description of the system

The types of packaging assessed in this study were processed by companies located in Lithuania and were composed of plastics and cardboard. Figs. 1(a-d) show the life cycle stages of each analyzed packaging. As shown in Fig. 1(a-d), the three main life cycle stages were considered: production, use and waste disposal. The production stage includes raw material extraction, processing, transportation to the manufacturer and packaging production.

The packaging production processes of the examined packages differ; however, it is possible to distinguish the following general production phases: testing and control, printing on packages, cutting, and forming. The distances for the transport of sub-materials to the manufacturer are defined in flow charts (Figs. 1(a-d)).

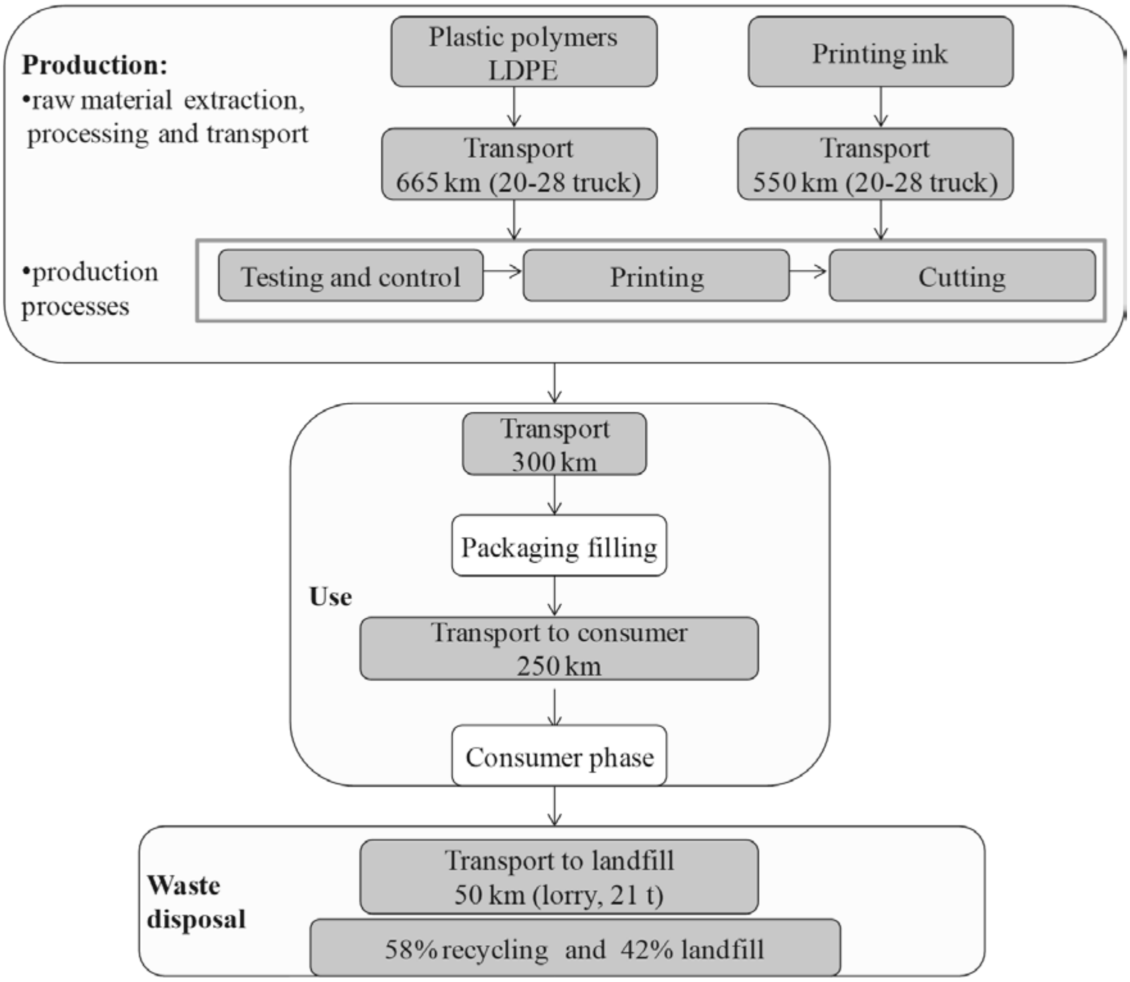
The use stage includes the transportation of packages to filling sites and the distribution of filled packages to stores at an average distance of 300 and 250 kilometers, respectively. The waste disposal stage includes packaging waste transportation to landfill and local waste management scenarios.

Table 1. Characteristics of four types of packaging for frozen food used in the comparative environmental impact analysis

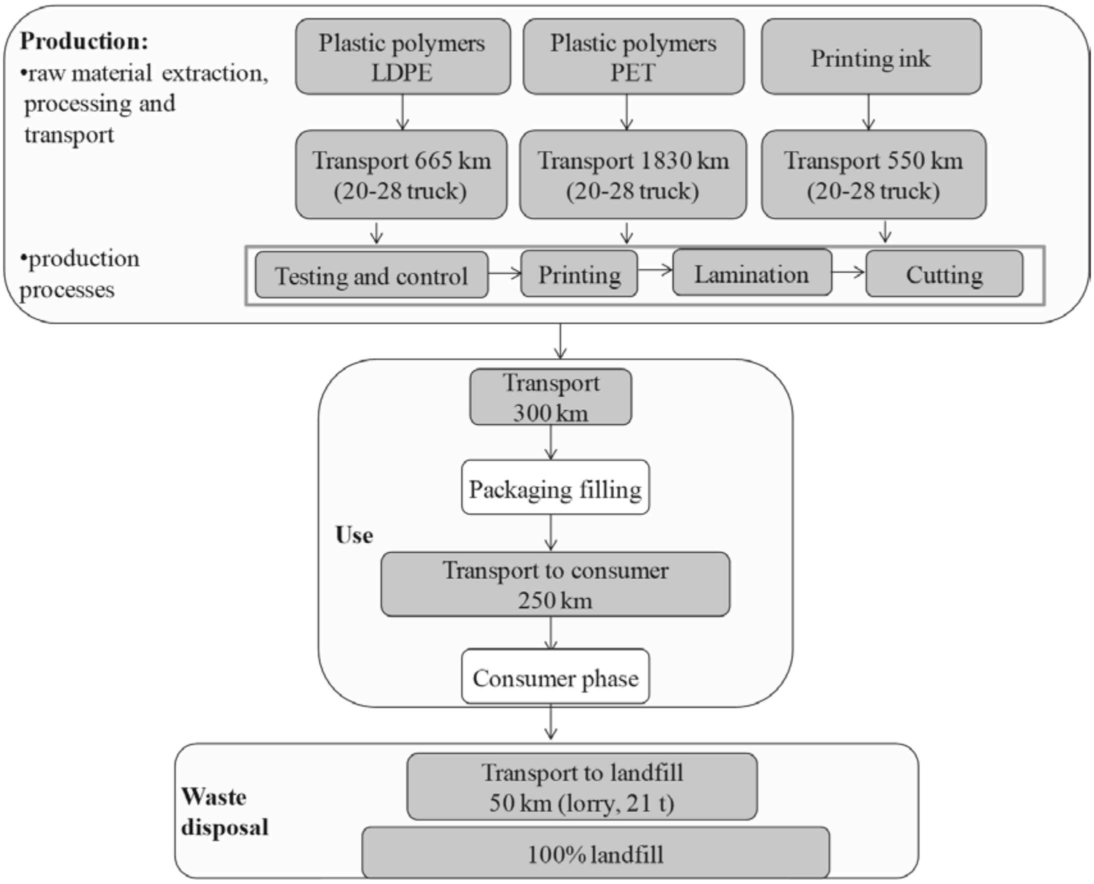
No.	*Material type*	*Frozen product*	*Thickness, microns*	*Surface area, m^2*	*Weight of package, g*	*Amount of frozen product, g*	*Picture of package*
11.	LDPE film pouch **(LDPE film)**	dumplings	40	0.11	4.4	500	
22.	Laminate film composed of LDPE and PET film pouch **(Laminated film)**	shrimp	80 (LDPE) 12 (PET)	0.11	11.2	500	
3.	Cardboard box coated with LDPE **(Cardboard)**	shrimp	300	0.11	28.2	500	
4.	Multipackage (cardboard and LDPE film pouch inside) **(Cardboard and LDPE film)**	dumplings	500 (cardboard) 80 (LDPE)	0.11	51.6	500	

Different scenarios have been considered for the different packaging materials in this study, as shown in Figs. 1(a-d). Packaging waste (after usage) can be recycled or deposited in a landfill.

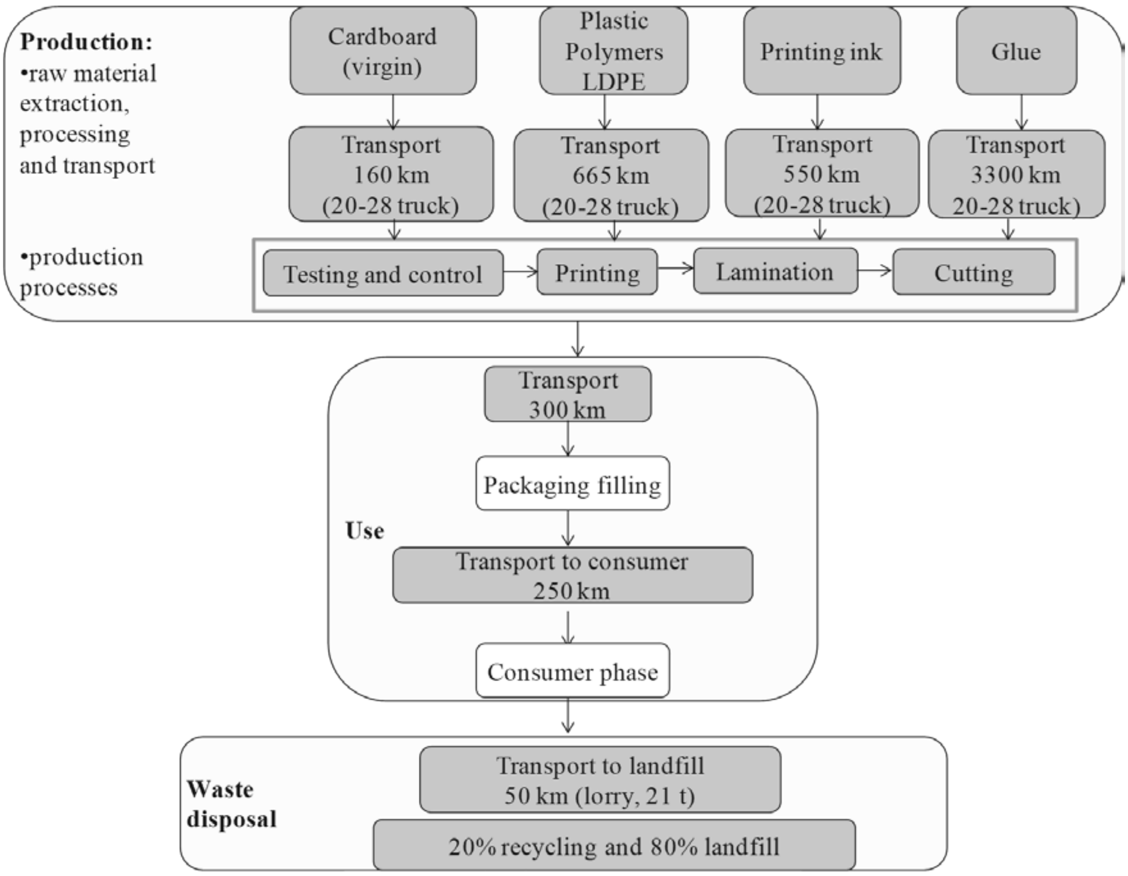
According to The Lithuanian Environmental Protection Agency (Lithuanian EPA, 2013), in 2013, 58% of plastic packages, 74% of paper packages and 20% of combined paper packages were recycled.



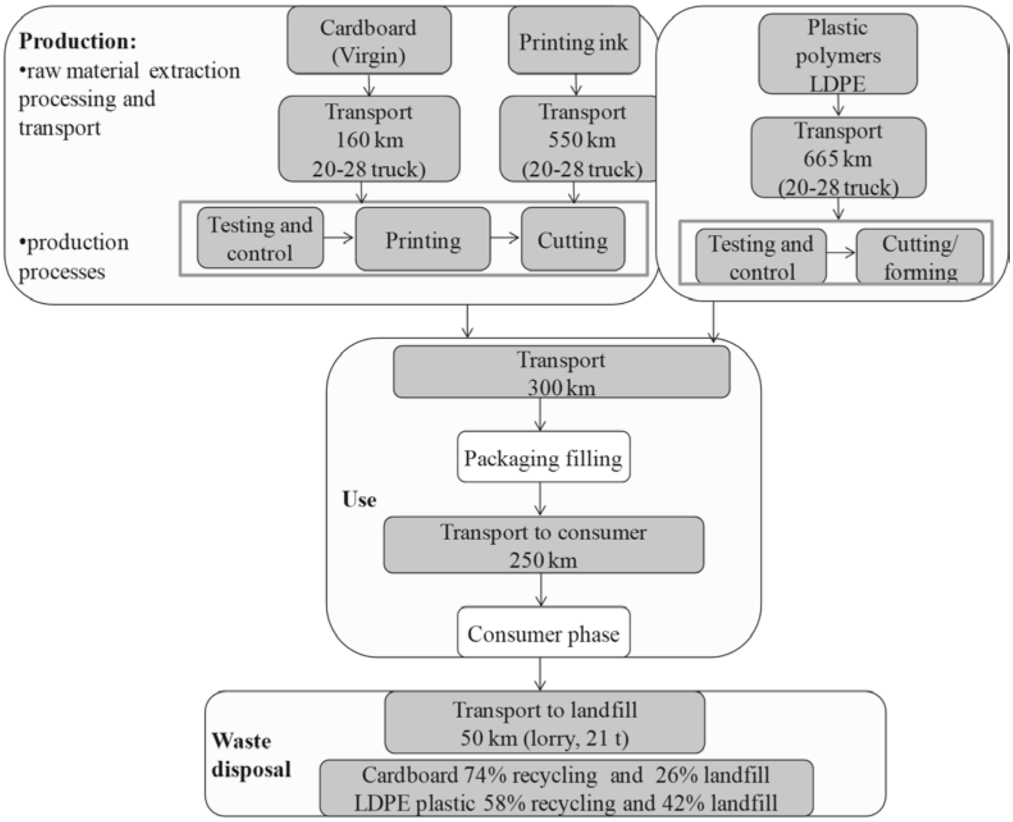
(a)


Production:
•raw material extraction, processing and transport
Plastic polymers LDPE
Plastic polymers PET
Printing ink
Transport 665 km (20-28 truck)
Transport 1830 km (20-28 truck)
Transport 550 km (20-28 truck)
•production processes
Testing and control
Printing
Lamination
Cutting
Transport 300 km
Packaging filling
Use
Transport to consumer 250 km
Consumer phase
Waste disposal
Transport to landfill 50 km (lorry, 21 t)
100% landfill

(b)


Production:
•raw material extraction, processing and transport
Cardboard (virgin)
Plastic Polymers LDPE
Printing ink
Glue
Transport 160 km (20-28 truck)
Transport 665 km (20-28 truck)
Transport 550 km (20-28 truck)
Transport 3300 km 20-28 truck)
•production processes
Testing and control
Printing
Lamination
Cutting
Transport 300 km
Packaging filling
Use
Transport to consumer 250 km
Consumer phase
Waste disposal
Transport to landfill 50 km (lorry, 21 t)
20% recycling and 80% landfill

(c)



(d)

Fig. 1. (a) Life cycle and system boundary for LDPE film packaging (stages in white boxes were excluded); (b) Life cycle and system boundary for Laminated film packaging (stages in white boxes were excluded), (c) Life cycle and system boundary for **Cardboard** packaging (stages in white boxes were excluded); (d) Life cycle and system boundary for multipackage Cardboard and LDPE film packaging (stages in white boxes were excluded)

Laminate plastic packages were dumped at a rate of 100%. Thus, these numbers are included in the packaging waste disposal evaluation.

The packaging filling stage was not considered due to limited data availability and presumably by assuming that this stage was identical for all alternatives. In addition, printing forms used for package printing were excluded from the LCA because they are long term and can be used for printing between 40,000 and 100,000 packages. The total of 1000 items analyzed in this study represents a small quantity compared to the above-mentioned amount.

2.4. Environmental impact assessment of frozen food packaging

The impact category analyzed in this study is a global warming potential that measures the total amount of greenhouse gases emitted during the life cycle of frozen food packages in kilograms of CO_2 per 1,000 units of packaging. In this analysis, LCA was used to quantify the global warming potential of different frozen food packages via the CCaLC v1.1 2010 software tool. The tool was developed by a research group based at the University of Manchester. CCaLC is a simplified carbon footprint tool that enables the easy and quick estimation of the life cycle GHG emissions of products and processes. The methodology used by CCaLC is based on internationally accepted life cycle methodologies such as ISO 14044 and PAS 2050 (CCaLC, 2010). PAS 2050 is a measurement protocol/tool for the assessment of the life cycle GHG emissions of goods and services that is used by companies to demonstrate credible reduction commitments and achievements in terms of life cycle GHG emissions (PPRC, 2009). CCaLC contains three databases: CCaLC, Ecoinvent and User database. Although the Ecoinvent database is comprehensive, only data relating to global warming potential are included in the database (CCaLC, 2010).

2.5. Data quality and databases

Inventory data collection is a very important step in LCA studies because high-quality data are essential to a reliable evaluation. The data for this research were collected from a variety of sources. Part of the inventory data was collected from interviews, market research and information obtained from manufacturing companies. Other inventory data for the background system were obtained from databases

(Table 2). Inventory data for the transport and production of printing ink, glue, LDPE and PET film were obtained from the Ecoinvent database. Inventory data for material disposal were obtained from the CCaLC database.

Information on energy and transport was obtained from the ELCD database. Almost all of the parts of the products used to produce frozen food packaging originate from countries located in Europe. Thus, the inventory data are based on European trade. Glue is imported from Switzerland; thus, the emission intensity is based on data from Switzerland (Table 2).

Table 2. Summary of data sources

Energy	***Electricity***	***ELCD database (Lithuania 2002)***
Transport	Truck	ELCD database (Europe 2004)
	Van	ELCD database (Europe 2004)
	Lorry	Ecoinvent database (Switzerland 2010)
Chemicals	Printing ink	Ecoinvent database (Europe 2010)
	Glue	Ecoinvent database (Global 2010)
Structure	LDPE film	Ecoinvent database (Europe 2010)
	PET film	Ecoinvent database (Europe 2010)
	Cardboard	Ecoinvent database (Europe 2010)
Disposal	Paper	CCaLC database (Europe 2010)
	Plastics	CCaLC database (Europe 2010)

The main sub-materials used for packaging production were the following: cardboard (virgin), LDPE and PET films (Table 3). More detailed inventory for the main package materials used was not included because of confidentiality. GHG emission determination for cardboard production includes processes such as wood handling and transport to paper mills, chemical pulping and bleaching, board production and energy use on-site. When considering the extraction of materials, it is important to distinguish biogenic CO_2 in the cardboard life cycle. In our study, biogenic CO_2 over the entire life cycle is considered as neutral and is assumed to be derived from sustainable sources. Other biogenic GHG emissions, such as methane and nitrous oxide, are included in the calculations. The data for PET film GHG emission determination include material and energy input, waste and air emissions from the production of PET from ethylene glycol and purified terephthalic acid, transport and auxiliaries and energy demand for the conversion process (extrusion) of plastics. GHG calculations for LDPE film are based on the ECO-profiles of the European plastics industry (PlasticEurope, 2013). The values reported for recyclable waste, amount of air/N_2/O_2 consumed, unspecified metal emissions to air, mercaptan emissions to air, unspecified CFC/HCFC emissions to air (CCaLC, 2011) were not included.

The other materials and energy inputs used in the packaging production processes, transport details and amounts of packaging waste after usage are presented in the inventory in Table 3**.**

***2**.6. Polymer film tension test*

The tests included the resistance to tension of two laminated polymer films (used for 500-g frozen food packages):

- a plastic laminate consisting of 19-micron-thick PET film and 40-micron-thick LDPE film and
- a plastic laminate consisting of 12-micron-thick PET film and 80-micron-thick LDPE film.

The study was conducted according to the EN ISO 527-3:1995 (ISO 527-3:1995) standard, which determines the test conditions for films and sheets for the determination of tensile properties. Six samples for each test were produced according to the standard sample measurements (Fig. 2).

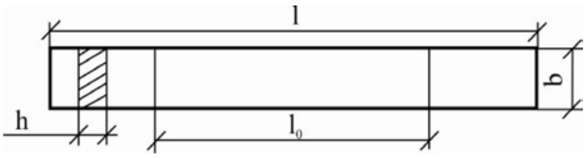


Fig. 2. Sample of polymer film: l, initial length of the sample; l_0, distance between grabs of the stand; h, thickness of the sample; b, width of the sample (Shah, 2002)

Table 3. Inventory for the frozen food packaging

Parameter	***Unit***	***Amount***				***Transport***		
Packaging material type		***LDPE film***	***Laminate film***	***Cardboard***	***Cardboard and LDPE film***			
Printing ink	kg	0.69	0.69	4.08	5.67	20-28 t truck	550	km
PET film	kg	-	1.88			20-28 t truck	1,830	km
LDPE film	kg	4.09	8.76	5.95	19.59	20-28 t truck	665	km
Glue	kg	-	0.28	2.22	1.64	20-28 t truck	3,300	km
Cardboard (virgin)	kg			20.53	33.48	20-28 t truck	160	km
Electricity used by packaging production processes	kWh	2.67	5.47	11.17	12.77	-		
Packaging waste after usage	kg	4.36	11.23	28.16	51.60*	lorry, 21 t	50	km

** 51.60 consist of 43.04 kg cardboard and 8.56 kg LDPE*

The tension machine assesses tensile strength via specimen elongation. The samples are placed on a stand (structure and block diagrams shown in Fig. 3). Deformation data are obtained using the software QmatPro 1.0.20.

3. Results and discussion

3.1. Environmental impact assessment of four types of frozen food packaging

The results of the global warming potential impact category of the analyzed packaging per functional unit are introduced in Fig. 4, which shows

Fig. 4 shows that packages composed of cardboard and LDPE film have the greatest global warming potential followed by packages composed of cardboard and laminated film. Packages composed of LDPE film have 11-fold smaller environmental impact compared to those composed of cardboard and LDPE film. The components of these environmental impact values are shown in Fig. 5, which shows the relative contribution of the life cycle of frozen food packages to the global warming category and considers three process chain stages: production, use and waste disposal. Production is responsible for most of the environmental impact. This is because raw materials (and their transportation) as well as the energy used in production are included in this stage.

The use stage includes the transportation of packages to filling sites, where they are filled with frozen products and transported to stores at an average distance of 300 and 250 kilometers, respectively. The environmental impact of the consumption phase depends on the weight of the products. Packages composed of cardboard and LDPE film have the largest environmental impact because a thousand packages weigh 51.6 kg; they are thus the heaviest of the studied packages. The highest GHG emissions during the disposal phase were found for laminated film packaging, attributing 100% in the land filling scenario. Negative values of other types of packaging in the disposal phase mean that GHG emission reductions were achieved with recycling. The reduction is due to several factors: avoided waste management emissions, reduced process energy emissions and the forest carbon sequestration benefits of recycling paper. Thus, the highest (compared to other packaging) recycling rates (58% of plastic and 74% of paper) of Cardboard and LDPE film packaging are associated with largest GHG emissions savings. Nevertheless, the total life cycle GHG emissions of Cardboard and LDPE film packaging remain the highest (98 CO_2 kg eq./f.u) compared to the other studied packaging types (Fig. 5). Because the greatest environmental impact of all life cycles occurs during the production stage, this stage has been studied in more detail.

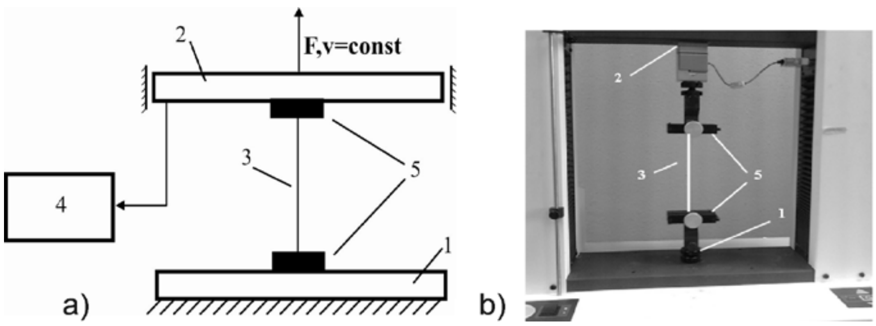


Fig. 3. General overview of the equipment used for the polymer film tension test: a) structural and block diagrams; b) photo of Tinus Olsen H25KT universal test machine (1, stable lower plate; 2, moving upper plate; 3, polymer film; 4, personal computer; 5, grabs)

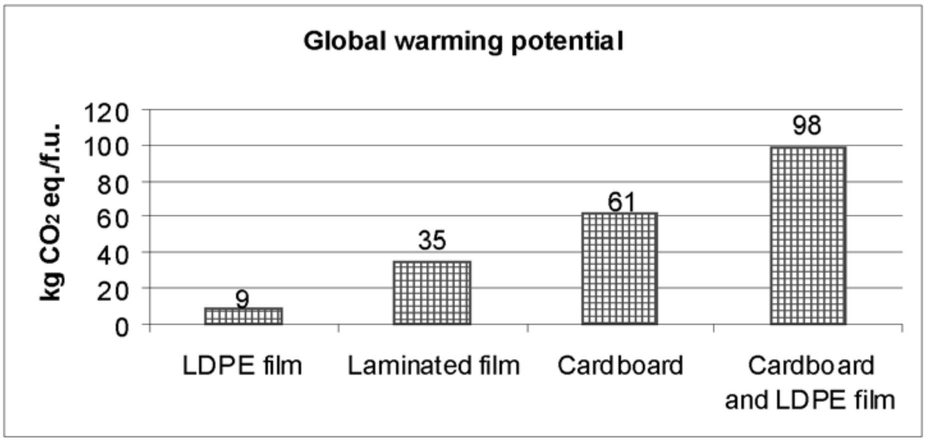


Fig. 4. Characterization phase of global warming impact assessment of frozen food packages

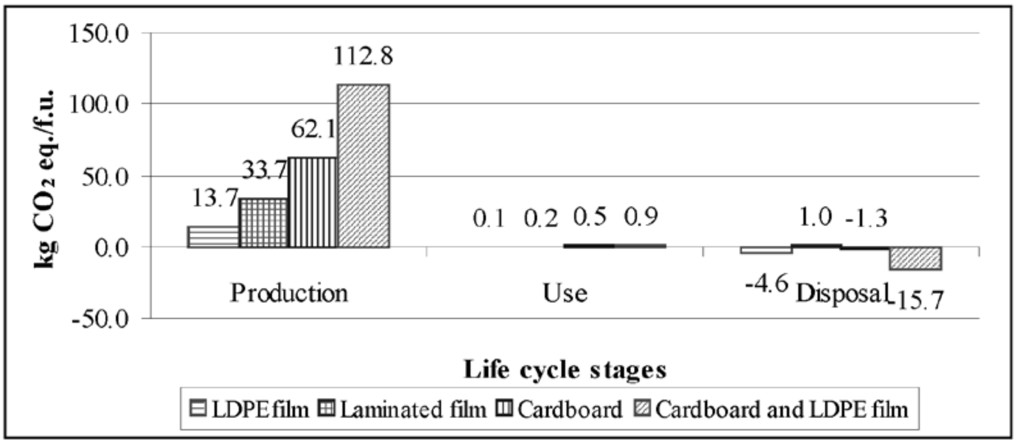


Fig. 5. Impact of packages on the environment during their life cycle stages

Fig. 6 shows the impact of raw materials, transportation and energy used during the production stage. Raw materials have the largest environmental impact (up to 75% of the total impact) followed by their transportation. The impact of energy used in production is insignificant. Despite the identical surface areas of these four packages (0.11 m^2), the amount of materials used and environmental impacts differ.

Fig. 7 indicates that cardboard and LDPE film packages are primarily composed of two materials and are the heaviest of all studied packages; thus, these packages have the greatest environmental impact. The package composed of LDPE film consists of LDPE film and a small amount of printing ink; its impact is the smallest.

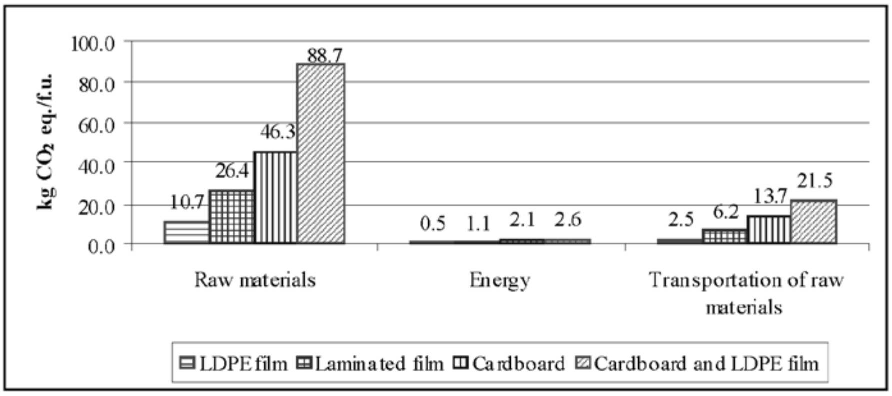
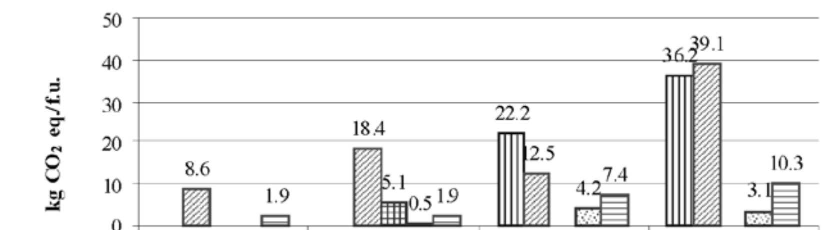


Fig. 6. Detailed environmental impact assessment of frozen food packages in the production stage



	LDPE film	Laminated film	Cardboard	Cardboard and LDPE film
Cardboard			22.2	36.2
LDPE film	8.6	18.4	12.5	39.1
PET film		5.1		
Glue		0.5	4.2	3.1
Printing ink	1.9	1.9	7.4	10.3

Fig. 7. Impact of used raw materials

The quantity of materials needed to produce 1,000 frozen food packages differs according to packaging type. A total of 1,000 pouches made of LDPE weigh 4.4 kg and have a total life cycle CO_2 emission of 9 kg; pouches composed of laminated films weigh 10 kg, with a total CO_2 emission of 35 kg. Cardboard boxes and cardboard boxes with plastic pouches inside are associated with greater CO_2 emissions, increased weight and greater overall impact.

The initial LCA study showed that fewer GHG emissions are produced for LDPE film and LDPE/PET laminated film pouches compared to cardboard or multipackage cardboard and LDPE film pouches. Production and raw material extraction represent a “hot spot” stage with the greatest environmental impact. LDPE film pouches had the lowest environmental impact; however, further discussion is needed to draw a final conclusion on the superiority of LDPE vs. LDPE/PET laminated film in reducing the environmental impact of frozen food packaging. It is important to adopt a broad perspective, and packaging functions and packaging-product systems must be analyzed. The primary function of packaging is to protect the product from spoilage, maintain food quality and increase shelf life. According to information provided by the producer, LDPE/PET laminate packaging is preferred by both manufacturers and consumers of frozen food due to its better gas barrier properties and longer shelf life. The shelf life of frozen food packed in an LDPE laminate pouch is twice as long as that packed in simple LDPE film pouches. After evaluating these important criteria and the LCA results, the LDPE laminate film was selected for further analyzes. An analysis of how to reduce the environmental impact of the chosen LDPE laminate film package was performed by assessing various mechanical properties (thickness and strength) as well as size.

3.2 Suggestions for reducing the environmental impact of frozen food packaging

3.2.1 Alternative 1 – reducing environmental impact through the optimization of plastic film thickness and strength

LCA research has revealed that up to 75% of the total environmental impact caused by packaging is determined by the raw materials used. To use fewer raw materials (thereby conserving resources and reducing global warming), it is very important to utilize an optimal amount of packaging material (with minimum weight and volume) while maintaining the same mechanical properties (strength per weight of the product). The thickness of the materials influences the strength of a package. The strength of the materials was thus studied, and the weight of the product to be inserted into a package was calculated using a polymer tension test.

The tension resistance test data of two different laminated polymer films used for 500-g frozen food packages are presented in Table 4 and Fig. 8. The dynamics of the elongation in relation to the tensile strength of both studied laminated films exhibit similar trends (Fig. 8). An increase in polymer deformation could be observed in the initial stage of the experiment.

Table 4. Polymer film pulling force tensile test data

Packaging film type	*Thickness h, mm*	*Width b, mm*	*Cross-sectional area A, mm²*	*Length l_0, mm*	*Elongation Δl_0, mm*	*Breaking force Ff, N*
PET 19 and LDPE 40	0. 09	15	1.35	100	94.2	64. 15
PET 12 and LDPE 80	0. 11	15	1.65	100	72.9	56. 47

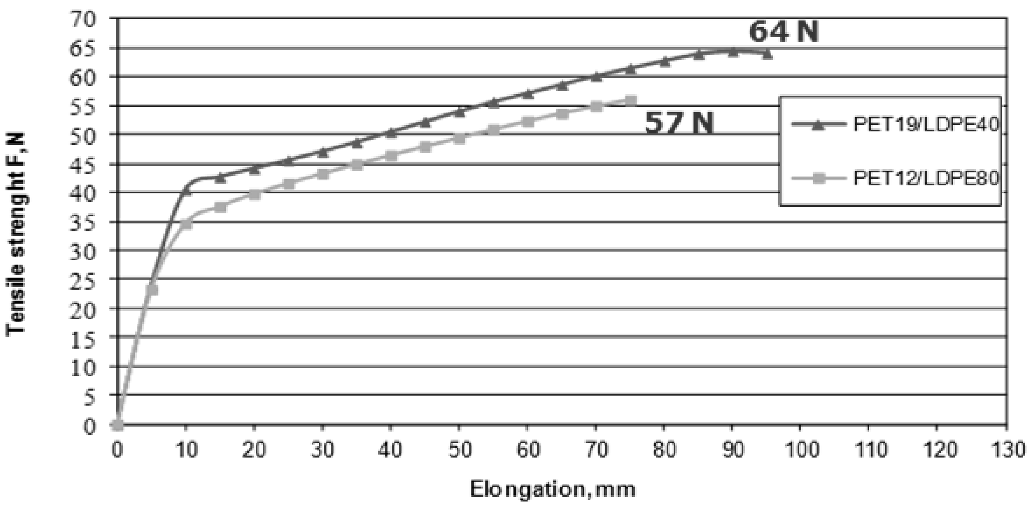


Fig. 8. Polymeric film strength and elongation under tension:
1, PET12/LDPE80 laminated film;2, PET19/LDPE40 laminated film

The tension resistance test data of two different laminated polymer films used for 500 g frozen food packages are presented in Table 4 and Fig. 8. The dynamics of the elongation in relation to the tensile strength of both studied laminated films exhibit similar trends (Fig. 8). An increase in polymer deformation could be observed in the initial stage of the experiment. Deformation exhibited a linear relationship with tensile strength until the fluidity point was reached. Up to this point, plastic deformation is reversible. After the fluidity point, plastic deformation occurs until the tape is broken. According to the results, the breaking force for the PET19/LDPE40 laminated packaging is 56.47 N, and that for the PET19 / LDPE40 is 64.15 N (Fig. 8 and Table 3). This means that the tested films can hold more than 500 g of frozen products. A package composed of PET19/LDPE40 laminated film can hold 6.4 kg; a package composed of PET12/LDPE80 laminated film can hold 5.65 kg.

The experimental data from the tests indicate that all films now used in the production of frozen food packages can be replaced by thinner films to reduce their associated environmental impact.

The tension tests of two different laminated films show that a 7-micron thicker PET film and a 50% thinner LDPE film can withstand up to 12% more force, i.e., the package can hold a 12% heavier product. Thus, a PET12/LDPE80 laminated film package has greater environmental impact and is less mechanically resistant than a PET19/LDPE40 laminated film.

The environmental impact of laminated film plastic packages can be reduced through the use of a 10-micron-thick PET film and 40-micron-thick LFPE film to safely resist a load of the analyzed functional unit (500 g of frozen product).

The environmental impacts of current laminated films (PET12/LDPE80 and PET19/LDPE40) and a suggested laminated film (PET10/LDPE40) have been studied using CCaLC.

Fig. 9 shows the LCA results for the CO_2 emissions during the life cycle of a 12-micron-thick PET film and an 80-micron-thick LDPE film.

They are followed by the CO_2 emissions of a 19-micron-thick PET film and a 40-micron-thick LDPE film and the proposed 10-micron-thick PET film and 40-micron-thick LDPE film. Frozen food packages composed of the last pair of films have the lowest environmental impact and remain capable of holding 500 g of product.

3.2.2 Alternative 2 - package size

The average surface area of a produced frozen LDPE laminate package (PET10/LDPE40) for 500 g of product is 0.11 m^2. This area can be reduced by approximately 10%, considering filling equipment availability. Food producers order packages with a larger surface area than is needed because a larger package is taken by the consumer to indicate a better, larger product. By reducing the package surface area by 10%, a portion of the raw materials and energy used in production can be avoided. Moreover, the product would be lighter, which would reduce transportation costs.

The LCA tests of this alternative solution yield positive results, i.e., the environmental impact could be reduced from 35 to 31 kg CO_2 eq./f. u. This results in a 11,4 % reduction in environmental impact.

3.3 Comparison of current and proposed frozen food packaging designs

The following alternatives were introduced for the proposed packaging design:

- using 10-micron-thick PET film and 40-micron-thick LDPE film as a plastic laminate;
- reducing the package size by 10%.

The environmental impacts of the current and improved packaging were evaluated using CCaLC. Fig. 10 shows that the environmental impact of the production, usage and recycling stages would be reduced after the introduction of the suggested alternatives. The reduced plastic film thickness and package size would also reduce the environmental impact by 36% (from 35 to 22 kg CO_2 eq./f. u.). The CO_2 emission differences for the life cycle stages are shown in Fig. 10.

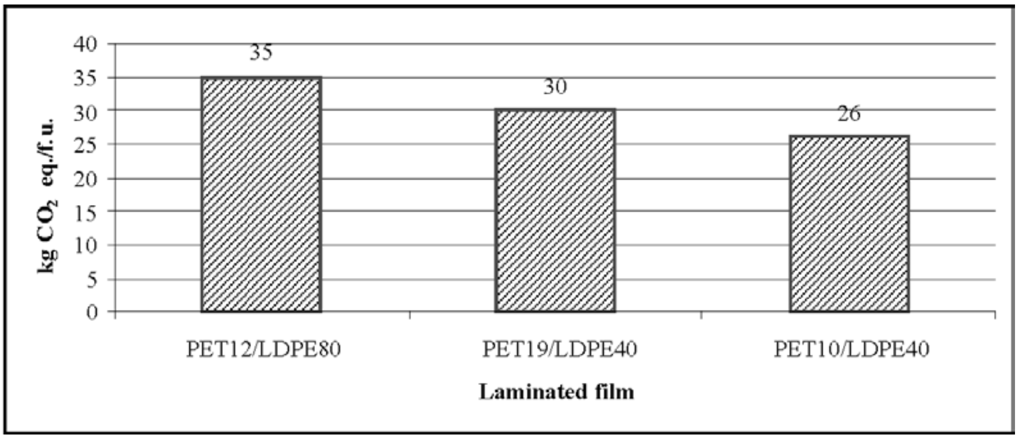


Fig. 9. Environmental impact of alternative materials

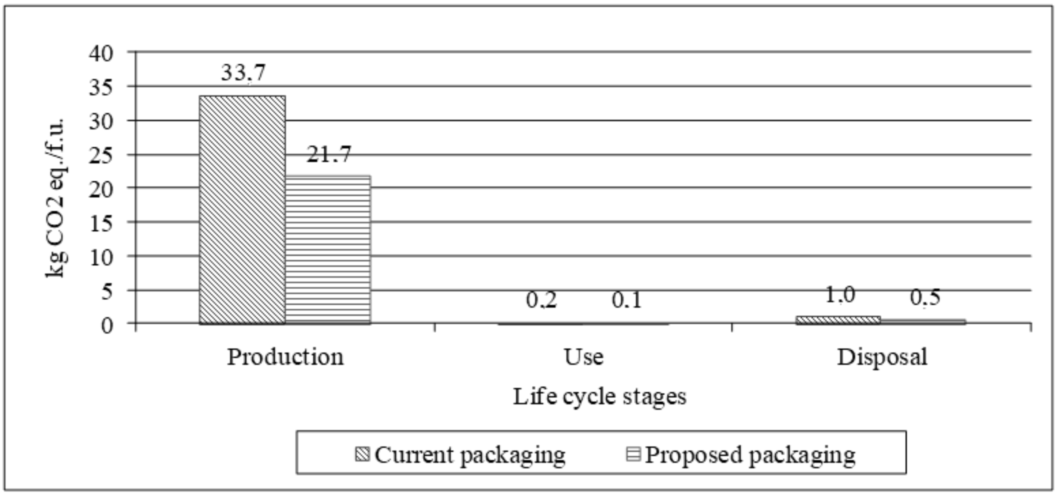


Fig. 10. Environmental impacts of current and proposed LDPE l aminate film packaging in life cycle stages

In the usage stage, the environmental impact is reduced by 47%. This reduction occurs because the weight of a functional unit is reduced from 11 to 6 kg. The weight is very important in the transportation stage because transportation costs decline when goods are lighter and smaller. In the waste disposal stage, the environmental impact is reduced by 50% due to reduced raw material usage.

In the production stage, the environmental impact is reduced by 36%. This impact is shown in detail in Fig. 11. The diagram shows that the introduction of the suggested alternatives to the production stage also reduces the environmental impact of the transportation stage. The electricity used in the production stage decreases from 5.5 to 3.4 kWh for 1,000 packages, thereby reducing the environmental impact by 37%. A smaller quantity of used raw materials also decreases CO_2 emissions by 46%. A further study showed that after the introduction of the suggested alternatives, the amount of LDPE film was decreased by 45%, PET film by 7%, and glue by 20%.

In summary, the LCA methodology in conjunction with the polymer film tension test can be used to assist companies in performing packaging optimization and compliance with packaging requirements to reduce packaging waste.

4. Conclusions

LCA analyses showed that the life cycle of multipackage consisting of a cardboard box and an LDPE film pouch has the highest GHG emissions (98 kg CO_2 eq./f.u.) followed by packages composed of a coated cardboard box (61 kg CO_2 eq./f.u.) and packages composed of laminated film (35 CO_2 eq./f.u.), whereas the LDPE film produced the lowest emissions (9 kg CO_2 eq./f.u.).

The data from the polymer tension tests indicated that the films currently used in the production of frozen food packages can be replaced by 45% thinner and 10% smaller versions of packages, thereby reducing the environmental impact by up to 36%.

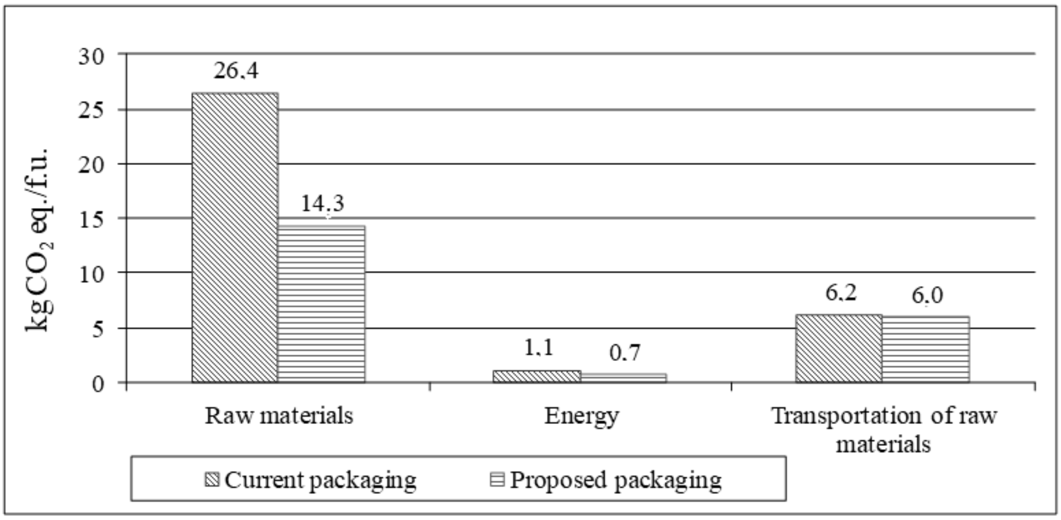


Fig. 11. Environmental impact of different alternative materials in production stage

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