Selected Aspects of the Environmental Analysis of HDPE Film Using the LCA Method

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Abstract. Environmental pollution and its consequences for our planet have led more and more organisations to pay attention to the environmental impact of their products and services. On the one hand, this is due to the requirements of European Union legislation and, on the other, to consumer demands, which further motivates manufacturers to work towards protecting the planet from the harmful effects of their products.

There are now a number of tools and methods used to assess environmental impact. Among the most popular tools is the LCA – Life Cycle Assessment analysis, which is used to assess the environmental impact of a product/technology/process. As a result of the LCA technique, business managers are able to identify areas that are a source of environmental or human health burdens [3]. The information extracted from the LCA analysis can be used by the company to, among other things, reorganise the manufacturing and distribution process, redesign the product, replace harmful components with cleaner ones and manage the company in an environmentally friendly manner.

This paper performs an LCA analysis for HDPE films, where the main component used for the film production is high-density polyethylene. SimaPro 9.1.1.7 was used for the analysis. The results of the impact of HDEP film technology on the environment were expressed using the ReCiPe Midpoint 2016 eco-indicator.. Based on a life cycle assessment, the environmental effects associated with the HDEP film production technology were estimated, and the impact of the production technology on greenhouse gas emissions was determined.

Keywords: plastics · HDPE foil · LCA method

1 Introduction

In response to climate change and its consequences for the planet, more and more organisations are paying attention to the environmental impact of their products and services. On the one hand, this is driven by European Union legislation (e.g. the CSRD – Corporate Sustainability Reporting Directive), while on the other, manufacturers are aware of the need to take action to protect the environment and want to contribute to improving it. Environmentally friendly measures are also becoming a necessary requirement for consumers, which further mobilises manufacturers to work towards protecting the planet from the harmful effects of their products [1–3].

A. Burduk et al. (Eds.): ISPEM 2023, LNME, pp. 406–414, 2024.
https://doi.org/10.1007/978-3-031-44282-7_32

In 2013, the European Commission published a Communication on creating a single market for green products and a recommendation on the use of common methods for measuring and communicating environmental performance over the life cycle of products and organisations [2, 3]. In the Communication, the Commission proposed two methods for measuring environmental performance [2–4]:

- the Product Environmental Footprint (PEF) method;
- the Organisation Environment Footprint (OEF) method.
- There are now a number of tools and methods used to assess environmental impact. The most popular tools and methods include [4]:
- Environmental Impact Assessment, Ecological Footprint, Environmental Impact Assessment of investments,
- Material Flow Accounting (MFA), Environmental Input-Output Analysis, Energy Footprint Analysis – material requirements, material and energy balance,
- Life Cycle Assessment – the environmental impact of a product/technology/process.

Life cycle assessment (LCA) of a product is a technique that is used to examine the environmental aspects and potential impacts throughout the life cycle of a product from the extraction or creation of raw material from natural resources through production, use and final disposal. As a result of the LCA technique, business managers are able to identify areas that are a source of environmental or human health burdens [4]. The information extracted from the LCA analysis can be used by the company to, among other things, reorganise the manufacturing and distribution process, redesign the product, replace harmful components with cleaner ones and manage the company in an environmentally friendly manner.

One of the most popular materials used in the modern world is plastics. The demand for plastics from Polish processors is increasing year on year and in 2020 was estimated at around 4.1 million Mg, of which around 380,000 Mg will be used for the production of plastics. Mg of postconsumer recyclate (PCR) plastics. Consumption of plastics by individual users and industry – in Poland in 2020 is estimated at 3.4 million Mg [5]. The main areas of plastics use in Poland are shown in Fig. 1.

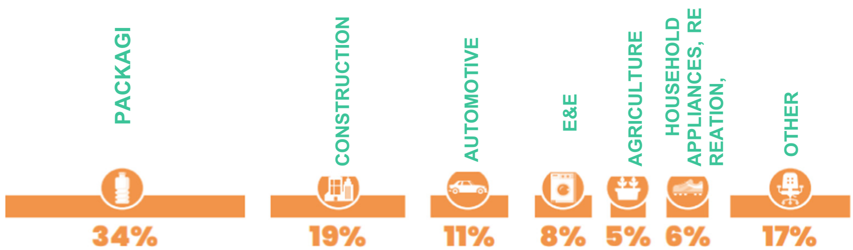

Fig. 1. Main areas of plastics use in Poland in 2020 [5].

In contrast, global plastics production in 2021 reached 390.7 million Mg, of which polyethylene production was over 50 million Mg, indicating that polyethylene is one of the most widely used plastics. in the world [5].

In this paper, an LCA analysis has been carried out for HDPE films. The main component used to manufacture HDPE (High Density Polyethylene) film is high density polyethylene. Amongst other things, this material is used to produce disposable advertising bags, containers for heating oil, or children's toys. HDPE film can also be approved by the PZH (Polish National Institute of Hygiene), which allows it to be used in the food industry for packaging food products. HDEP film owes its widespread use to properties such as a tensile strength of approx. 22 N/mm^2, dimensional stability, good sliding properties, chemical resistance and good insulation against water.

2 Environmental Life Cycle Assessment of Products Technique

Environmental Life Cycle Assessment of Products (LCA) is a technique used to quantify the environmental impact of products/services and is the most effective method used for environmental life cycle assessment of products in terms of flexibility and comprehensive environmental impact assessment [6, 7].

This LCA method is described in detail in the following standards: ISO 14040 [7] and ISO 14044 [6, 7]. It has been defined as a way of quantifying the environmental burden, which is based on an inventory of environmental factors for a product, process, or other activity in the cycle from extraction of raw materials to their final management [6, 7]. This method makes it possible to identify and assess the emission of harmful substances into the environment, as well as material and energy intensity at all stages of a product's existence, from its creation in the production process, through its operation, to its final management/disposal.

The LCA consists of five main stages: definition of the objective, data inventory, impact assessment, interpretation of the results obtained, and suggestions for improvement. The method makes it possible to determine which of the compared products is more harmful to the environment. This method isolates the environmental categories affected by the analysed products throughout their life cycle [9, 10]. The most commonly identified categories include [9, 10]:

- state of ecosystems: – Poisoning of the environment with toxic substances, – Acidification and eutrophication, – Land use and degradation.
- human health: – respiratory diseases, divided into two groups: those caused by organic and inorganic substances, – climate change phenomena, – depletion of the ozone layer, – emissions of carcinogens, – ionising radiation.
- raw material resources: – mineral extraction, – depletion of fossil fuel resources.

We also determine at the outset the extent to which we will study the environmental impact. The scope of the analysis, on the other hand, depends on the stated objective and the available life cycle data. We distinguish between the following scopes of analysis:

- Cradle to Gate – Raw material extraction, transport, and production process
- Gate to Gate
- Cradle to Grave – In addition: product use, transport, and waste disposal.

The results thus obtained are interpreted, taking into account the scope and purpose of the analysis. The final stage of the analysis is the conclusions and the formulation of recommendations, if that was the intention [3, 11].

The primary tasks of LCA are the documentation of the environmental impacts of products during all life stages, the analysis of the probability of related environmental impacts, the continuous improvement of product manufacture and the comparison of different solutions to the same problem or process implementation [11].

LCA methodologies have developed rapidly in recent years, resulting in the development of new calculation techniques and the creation of databases that provide information on the environmental impact of a product over its entire life cycle, which in turn allows reliable comparative analyses to be carried out [3, 11].

3 Description of HDEP Film Production Process Technology

HDEP film is produced by extrusion blow moulding on single or multi-screw extrusion lines. Polyethylene is the basic raw material for film production by extrusion blow moulding. Polyethylene pellets are poured from bags into a container, from where they are drawn by suction nozzles to a dosing unit – a hopper that dispenses appropriate portions of raw material according to the recipe. From the hopper, the raw material is fed into the extruder. The extruder consists of a screw and a sleeve-shaped metal casing, heaters are attached to the casing which heat the polyethylene pellets, the screw spins and pushes the pellets into the head. The raw material then passes into a second zone called the compression zone, where the granules become soft and elastic under the impact of the heat generated by the rotation of the screw. The melted granules are moved to the next zone, where the plastic is homogenised and mixed (homogenisation), which is then forwarded to the filter screens, where any impurities are retained. After passing through the filter screens, the raw material enters the head in liquid form, moves from the bottom to the top and exits under pressure through the slot to the outside. In the next stage, the material is blown out and cooled, resulting in a film-like state from its liquid state, taking the form of a sleeve also referred to as a balloon (see Fig. 2).

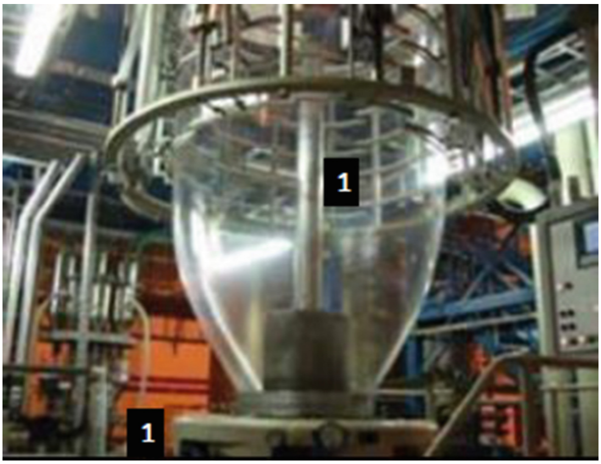

Fig. 2. HDEP film blowout.

There is cooling air outside as well as inside the balloon, which cools the film (reduces the temperature of the polyethylene). The sleeve is pulled upwards at a height of about 1215 m, depending on the extruder, through the top extraction rollers, where it is flattened. The top extraction consists of wooden flattening pallets and a set of rotating rollers. The top extraction rollers pull the film from the bottom at a preset speed, while wooden pallets flatten the cooled sleeve. The sleeve then travels on successive rollers attached to the tower structure, down towards the winders. In front of the winder, the flattened sleeve is slit from the sides into two ribbons of film. Two cardboard sleeves are placed on the winder on both sides, onto which ribbons of film, known as tape, of a specified width and thickness are wound according to the order being carried out.

Once a certain amount of film has been wound onto the rollers, the film is removed from the winder and packaged in a film to protect it from dirt and damage, labels are applied and it is transferred to the finished goods warehouse.

4 Research Methodology

For the environmental assessment using the LCA method, data was collected on the production process of HDPE film by blow out in one Polish production company. The HDPE film analysed had the following dimensions: 710 mm x 0.007 mm. Then, in accordance with EN ISO 14040:2009, the purpose, scope, system boundaries, limitations of the LCA analysis and the Life Cycle Inventory sets of inputs and outputs were determined.

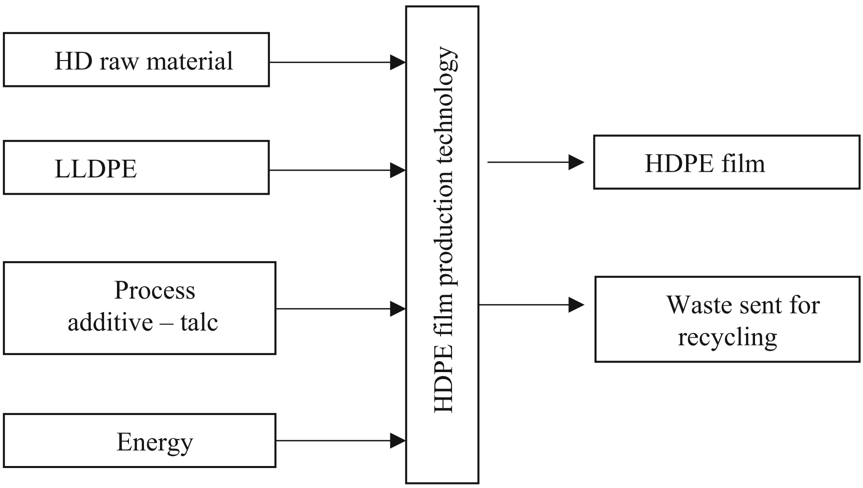

Fig. 3. Input and output data of HDPE film production.

In order to assess the environmental risks caused by the processes in the process line, the input materials for the production process were analysed. It should be noted that the materials taken for analysis come from outside the plant, materials from inside the plant (post-production waste) were not included in the analysis. In order to carry out the LCA analysis in accordance with the standard, the system boundaries were defined (see Fig. 3).

To obtain the data, a spreadsheet was developed to refer to one functional unit, which was 1 Mg of HDPE film.

The environmental impact score of the production technology was expressed using the ReCiPe Midpoint 2016 eco-indicator. This method allows the environmental impact of a process to be presented in 18 impact categories (min. radiation, climate change) and three harm categories (human health, ecosystem diversity and resource availability).

5 Test Results and Discussion

The LCA analysis of the HDPE film was performed using Simapro 9.1.1.7 together with the databases included in the programme.

The impacts of the technologies with respect to the 11 impact categories are shown in Table 1.

Table 1. Categories of environmental impact of HDEP films

Impact category	Unit	Total
Global warming	kg CO2 eq	2,399.31
Stratospheric ozone depletion	kg CFC11 eq	0.0005
Ionizing radiation	kBq Co-60 eq	8.17
Ozone formation, Human health	kg NOx eq	5.11
Fine particulate matter formation	kg PM2.5 eq	2.59
Ozone formation, Terrestrial ecosystems	kg NOx eq	5.47
Terrestrial acidification	kg SO2 eq	6.59
Freshwater eutrophication	kg P eq	0.061
Marine eutrophication	kg N eq	0.009
Terrestrial ecotoxicity	kg 1,4-DCB	4,439.114
Freshwater ecotoxicity	kg 1,4-DCB	1.503
Marine ecotoxicity	kg 1,4-DCB	4.446
Human carcinogenic toxicity	kg 1,4-DCB	16.890
Human non-carcinogenic toxicity	kg 1,4-DCB	336.392
Land use	m2a crop eq	21.676
Mineral resource scarcity	kg Cu eq	4.963
Fossil resource scarcity	kg oil eq	1,678.123
Water consumption	m3	28.867

As illustrated by the data in Table 1, HDPE film production has the greatest impact on three categories, i.e. global warming terrestrial ecosystems and scarcity of natural resources.

The next stage of the analysis was to determine the impact of raw materials on greenhouse gas emissions, as shown in Fig. 3. High-density polyethylene was found to have the greatest impact on greenhouse gas emissions among the raw materials used (Fig. 4).

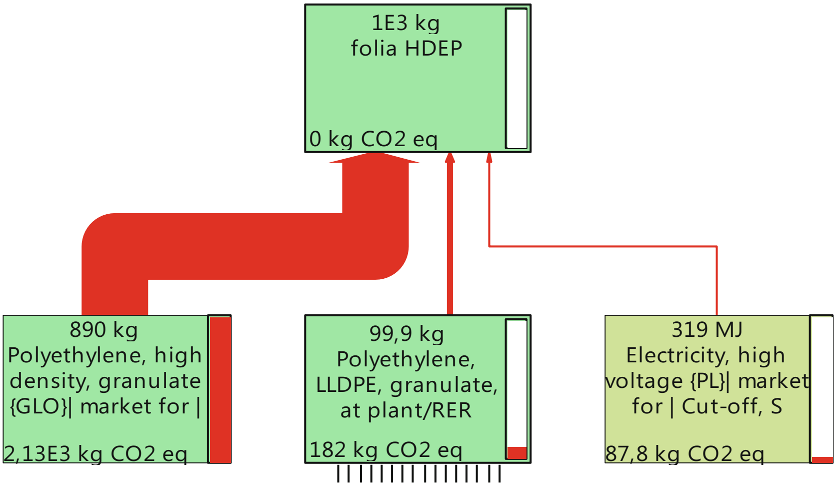

Fig. 4. Impact of primary input materials on greenhouse gas emissions.

The manufacture of HDPE films involves the use of mineral-based raw materials, i.e. primarily ethylene – a major component of natural gas. Therefore, the impact of HDEP film production on the environmental indicator of resource scarcity was determined (see Fig. 5).

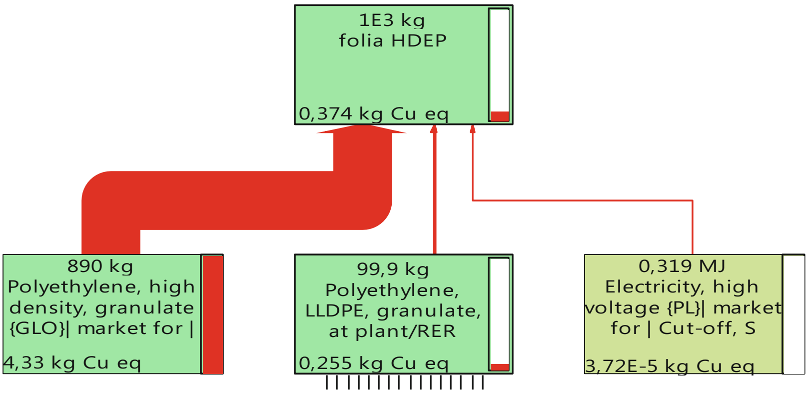

Fig. 5. Impact of basic raw materials on the scarcity of mineral resources.

As illustrated by the data in Fig. 5, high-density polyethylene has the greatest impact of the raw materials used on the mineral shortage indicator, at 4.33 kg Cueq. HDPE film, on the other hand, has an indicator of 0.374 kg Cueq.

A significant environmental impact is the formation of particulate matter, the estimated values for the individual product components are shown in Fig. 6.

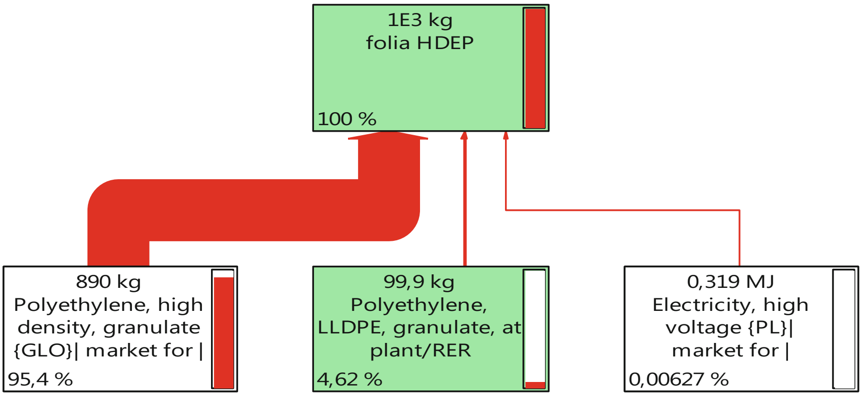

Fig. 6. Influence of basic raw materials on particulate matter formation.

As illustrated by Fig. 5, high-density polyethylene also accounts for the largest share of the dust generated during the HDPE film formation process.

6 Summary

The LCA analysis is one of the most advanced and effective techniques for assessing potential environmental risks and is recommended by the European Commission. The essence of this method is to focus not only on evaluating the end result of a given technological process, but also to assess and evaluate the environmental consequences of the whole process. The implementation of the LCA technique in an organisation can bring many benefits in the environmental assessment of the organisation, including its individual components, and offers even more opportunities to reduce life-cycle environmental impacts, e.g. through rational materials and energy management. The data collection and calculation procedures carried out as part of the life cycle harvesting analysis create a register of material and energy streams and assign them (according to a specific model) a numerical environmental impact. Owing to the LCA analysis, it is possible to assess the environmental effect of the changes planned at the organisation's site in various areas of its operations (technological, administrative, infrastructure-related). The results of research using LCA can form the basis for a new environmental management strategy for an organisation [2]. An additional advantage of using LCA analysis can be to improve its image, which is extremely important especially for companies operating on the international market.

The plastics industry in Poland is an important component of the Polish economy, ranking third in terms of gross value added generated among industrial processing sectors, just after food and metal production. One of the most commonly used plastics in the world is polyethylene. It is from polyethylene that HDPE film is made, which, due to its resistance to acids, alcohols, petrol and certain cleaning agents, is used in the manufacture of fuel oil containers, petrol storage canisters and waste sacks, as well as for the storage of detergents and cleaning products. HDPE film can also be used to produce disposable advertising bags.

The paper discusses the environmental impact of HDPE film production technology. The analyses and calculations were carried out in SimaPro 9.1.1.7 using the ReCiPe Midpoint 2016 eco-indicator method.

Based on a life cycle assessment, the environmental effects associated with the analysed HDEP film production technology were estimated, and the impact of the technology on greenhouse gas emissions was determined. HDPE film was found to cause the greatest impact on three categories, i.e. global warming terrestrial ecosystems and scarcity of natural resources. High-density polyethylene was found to have the greatest impact among the raw materials used on greenhouse gas and particulate matter emissions.

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