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9.3 Product carbon footprint in polymer processing – A practical application.

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Abstract

Light weight and synthetic polymer materials form the physical basis of many products across various applications worldwide. Given their reliance on fossil fuel inputs, this increases the importance of environmental assessment in the polymer industry. The energy intensity of plastics manufacturing and processing and the associated high embodied energy of polymer products warrants further investigation. The Carbon Footprint (CFP) methodology enables the estimation of the GHG emissions associated with polymer production. It quantifies the greenhouse gases released from polymer processing. An existing mid-sized polymer processing factory is utilised as a case study in this analysis. In addition, this study provides the data necessary for reviewing energy efficiency measures by estimating their value within CFP analysis. It also identifies the different strengths and weaknesses of the CFP approach. The analysis could then be used in plastics industry 'green' decision making.

Keywords:

Life Cycle Assessment; Energy Efficiency; Plastics Industry; Sustainable Manufacturing

1 INTRODUCTION

Climate change and the increasing production of greenhouse gases (GHG) is an important global issue. According to the IPCC, these emissions are largely caused by anthropogenic activities. The last validation of the goals of Kyoto Protocol highlighted that GHG concentration in the atmosphere is still increasing. [1]

The German Federal Ministry for Environment, Nature Conservation and Nuclear Safety estimated that the energy sector in Germany creates 40 % of the total emissions, followed by the manufacturing industry with 20 %, transport with 17 % and private households with 9 % [2]. As a result, today the major objective of GHG policies has centred on a reduction of emissions through increased energy efficiency. The quantification of industrial production on GHG emissions is important in determining the required environmental strategies.

A number of methods for environmental assessment of production activities exist. Some are focused on a specific industry or a product grouping, whilst others are more generally applied. In Europe the life cycle assessment based on ISO 14040:2006 is currently a very common approach in environmental impact analysis. Most evaluation instruments estimate a large number of assessed indicators. Different indicators and initial conditions make the comparability and the interpretation of the results inherently difficult. This type of data intensive assessment is especially difficult for small and medium-sized businesses and can be time-consuming and expensive.

2 METHODOLOGY

Carbon Footprint (CFP) is a method for the estimation of GHG emissions from both production and service industry activities. A CFP study should quantify the contribution of a product or service to climate change through global warming [3]. The assessment can cover the entire product/service life cycle [3]. The evaluated impact is described by a single indicator the 'CFP'. The CFP is measured through its Global Warming Potential (GWP) and is valued in carbon dioxide equivalent units [3]. The EN ISO 14050:2010 defines GWP as "a characterization factor describing the mass of carbon dioxide that has the same accumulated radiative forcing over a given period of time as one mass unit of a given greenhouse gas" [4]. The main greenhouse gases assessed include:

- Carbon dioxide,
- Methane,
- Sulphur hexafluoride,
- Nitrous oxide,
- Chlorofluorocarbons and
- Per fluorocarbons [5].

The CFP methodology is taken from the life cycle assessment approach [3]. Due to this the inventory and analysis process of the CFP conforms to the LCA principles [6].

3 STUDY DESIGN AND INVENTORY

The purpose of this study is the application of the CFP methodology in assessing polymer production for small and medium polymer processing companies. A medium size

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polymer processing factory was used as a case study for the analysis.

Polymers are highly important manufacturing materials because of their light weight, heat resistance, high performance and extrudability characteristics. A common field for plastics is packaging [7]. In the sample factory different plastic lids are produced via injection moulding (predominantly packaging for food and tobacco products).

Injection moulding is a discontinuous process in the manufacturing of precast elements. The process begins with the heating and melting of polymer granulates. After that, the fluid polymer is injected into the mould´s cavity. Following the cooling down of the moulds they are opened. The lids are then released and packed.

The high variety of lids produced in the sample factory requires the selection of a few representative product types for assessment. Seven different products (lids) were estimated (Table 1). A single lid was defined as the functional unit. These lids have different weights; they are made out of various materials and fabricated on different machines. Additional selection factors were the annual manufacturing volume and the type of handling process.

Table 1: Assessed products (PP: polypropylene, PS: polystyrene, PE: polyethylene)

Lid	Material	Weight [g]
A	PP	5.5
B	PP	5.3
C	PS	16.0
D	PP	5.4
E	PE	9.3
F	PP	15.7
G	PP	15.3

Plastic lids are components of packaging and therefore an upstream product. Consequently the utilization phase and the end-of-life phase contribute significantly to the packaging life cycle. During assessment the system boundaries were restricted to cradle-to-gate in order to avoid the double counting of emissions.

The fabrication of plastic lids requires two separate inputs: the energy and material stream. The energy flows have been limited to electricity, cooling energy, compressed air, heating energy and warm water. The production process includes the different processes requiring chilling machines, compressors, fuel oil boilers, pumps and finished good storage.

In this specific product case study the number of material inputs is limited due to health and safety restrictions given by the food and tobacco industry. Only a few additives are allowed so that the main materials are polyethylene, polypropylene, polyester and dyes. Some of the lids contain paper or alumina gaskets. Apart from the materials involved in production, different packaging like cartons and plastic foil are also utilised.

During injection moulding, only marginal emissions are released to the environment. As a result, the output flows have been limited to scrap components and sprues. Therefore most of the plastic waste produced can be easily recycled. All energy and materials representing less than 5 % of the total flows were not included according to the cut-off boundaries in our assessment [8].

4 IMPACT ASSESSMENT AND ISSUES

Processing materials are usually audited through the internal purchasing systems, and the energy consumption is typically measured via energy meters. The CFP requires the calculation of material and energy flows to a single functional unit. Consequently, representative production lines and services need to be identified, measured and then converted into equivalent load units. Also the timing and duration of the necessary measurements requires planning. It is important to include start-up processes, mould changing time and associated machinery downtime within all processes.

4.1 Allocation of input and output flows

The indicated inputs and outputs are classified as both direct and indirect flows. For example, the energy consumption for the picking up and placing of lids is product-based and would not occur if there is no product to move. In contrast, the power consumption of pumps or general services does not relate directly to the processing system. Therefore, these are measurable only as a total amount. Given assessment norms, the case study applied the economic approach of cost accounting to the assessment of these indirect energy flows [9].

In economics, there are two basic cost-accounting approaches: marginal costing and full cost accounting. The classification of cost types and cost centres is common to both approaches. Full cost accounting is inward-looking. It is characterized by a focus on the product, and how much it costs to make it. Whereas marginal costing looks only at the additional cost of producing one more unit. [10]

Cost accounting differentiates between direct costs and general expenses. Direct costs can be completely attributed to the production of a specific good or service. General expenses are costs like administrative labour, energy, resources, etc. In marginal costing only direct costs are assigned to a product. [10]

Full cost accounting is the attribution of all costs to a production cost unit. The general costs are therefore allocated to a single product through the company-specific distribution criteria. This distribution is similar to the goal of a CFP study with the aim to assign all emission sources to a single product unit.

4.2 Classification of emission sources

The CFP assessment analyses the resultant emissions of a product or service and requires a definition of a functional unit (e.g: a single lid). The differentiation between direct emissions created by energy or by materials consumption is equivalent to the above definition of cost types. The allocation of emissions sources for each life-cycle phase can then be calculated (i.e.: emissions from the supply of goods, polymer production, emissions from the product fabrication processes and emissions in the usage phase, etc.).

Depending on the specific application, energy and material usage can be assigned directly to a specific product unit and was specified in Table 2 for the case study sample.

Whilst it is not always clear, if an energy flow is product-based, the assignment of materials by product category is apparent in most cases. The material compound data include the exact quantities required to produce one lid (the functional unit). All other materials and waste have been considered as indirect flows.

Table 2: Classification of measured flows

	Product-based	Indirect
	Energy	
Production	Power supply of machines Power supply of hot runners Compressed air demand of the mould Power and compressed air demand of handling systems	Power required for cooling energy generation Power for pumps, illumination, others
General services	None	Illumination Power demand of heating system pumps Other power
	Materials	
Production	Polymers Colour	Fuel Packaging Waste
General services	None	Fuel Waste

5 CFP RESULTS AND ANALYSIS

CFP calculation

The product-based flows were calculated from a production planning data base or were measured directly. Indirect energy and materials usage was calculated from the difference between bottom-up calculated annual product-based amounts and the total quantities consumed. For the assignment of these to a production unit two allocation possibilities exist: firstly the total number of units produced annually and the annual volume of polymers processed.

The allocation with the differentiation ratio “the total number of units produced” estimates an equal off-set of emissions to each lid (Equation 1). Whereas the second calculation approach “the annual volume of polymers processed” assigns the indirect emissions to 1 g of polymer. In the next step, these are multiplied with the lids weight (Equation 2).

Once the flow amounts are assessed the calculation of emissions produced is simple and requires the specific GWP values. The estimated amounts of the input and output flows are then multiplied by the GWP.

$$CFP = \sum_{i=1}^{n} CFP_i = \frac{1}{k_1} \cdot (m_1 \cdot GWP_1 + m_2 \cdot GWP_2 + \dots + m_n \cdot GWP_n) \quad (1)$$

with:

i: number of the emission source 1 to n

m: total amount of an indirect flow

k_1: allocation factor – total number of units produced

$$CFP = \sum_{i=1}^{n} CFP_i = \frac{a}{k_2} \cdot (m_1 \cdot GWP_1 + m_2 \cdot GWP_2 + \dots + m_n \cdot GWP_n) \quad (2)$$

with*:*

i: number of the emission sources 1 to n

m: total amount from an indirect flow

a: weight of a product unit

k_2: allocation factor – annual volume of polymers processed

The result of the calculation with the first differentiation ratio is 2.0 g CO_2e. The second approach considers the individual lid weight. Consequently, the indirect emission amount on the total CFP varies between 1.2 and 1.7 g CO_2e.

$$CFP = CFP_{direct} + CFP_{indirect} \quad (3)$$

The CFP is the sum of all direct and indirect emissions in the defined system boundaries under consideration of the chosen cut-off rules (Equation 3). The values estimated for the chosen lids are summarized in Figure 1. According to the given differentiation ratios, there are two scenarios for total CFP:

Scenario I: allocation of indirect emissions via the total number of units produced,

Scenario II: allocation of indirect emissions via the annual volume of total polymers processed.

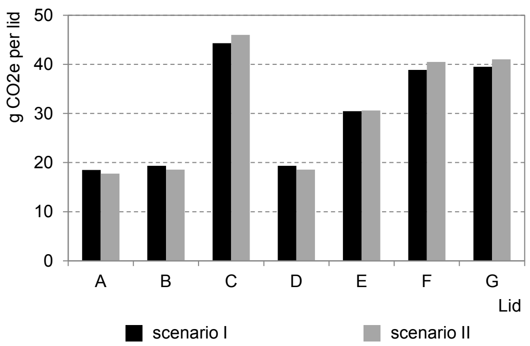

Figure 1: CFP of polymer lid (functional unit)

The estimated CFP values are between 18 and 44 g per unit. The total CFP of a lid varies between both scenarios by an average of 3.5 %. This gap depends on the indirect flow allocation coefficient utilised.

Analysis of the results

GHG emission reduction is a key factor in the context of both continuous improvement and efficiency management in polymer industries and within the broader corporate sustainability agenda. This analysis of the estimated CFP associated with the production of a polymer lid was aimed at the identification of potential measures to decrease the environmental impacts associated with various production inputs in polymer processing. As a result, the total CFP values were split into four categories:

- emissions created from product-based energy flows during production,

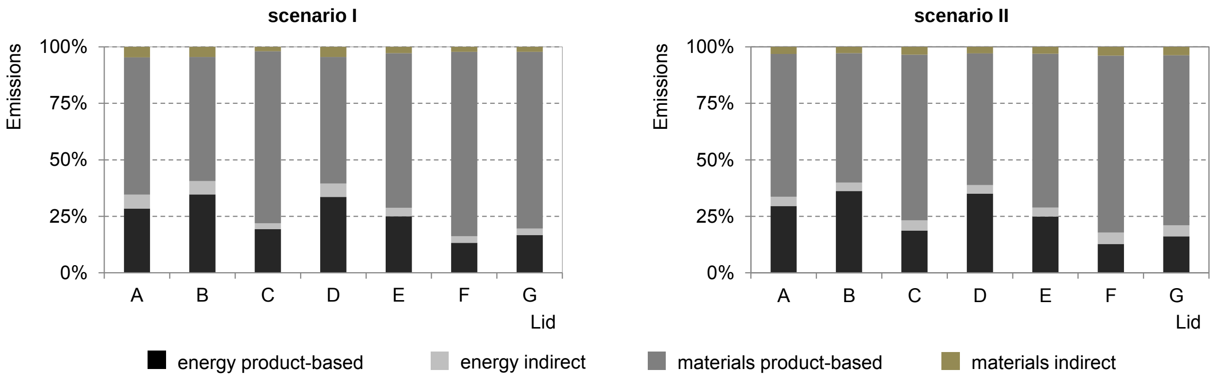

Figure 2: Emissions according to the flow type

- emissions created by indirect energy flows associated with production,
- emissions created from product-based material flows and
- emissions caused by indirect material flows.

The total emission amounts per production flow are shown in Figure 2. On average the indirect emissions were between 5 and 11 % of total emissions produced. Due to different general services the indirect emissions of energy are higher than those of the material inputs. The product-based emissions are up to 95 % of the total CFP and largely determine the total quantity of emissions. Overall more than 50 % of total CFP is attributed to materials. The GHG emissions of the materials are mainly released during the production and transportation stages. Consequently, the CFP is significantly determined by the emissions of the supply chain both prior to and after the processing stage.

Biopolymers are an alternative to conventional polymer plastics. Renewable materials are utilised in the production process and some are considered bio-degradable in the end-of-life waste stage. These new materials are currently commercially available but there are still a few challenges in their wider application. However, the physical properties of a biopolymer alternative do not always meet the high requirements of the packaging industry, particularly in the food industry. In addition, biopolymers are not always as suitable in many conventional plastics processing applications. The high costs of biopolymers are also a major limiting factor in current polymer processing technologies. [11]

A detailed examination of the emissions created during polymer processing is necessary in the identification of environmental improvement strategies for the polymer processing industry. As noted above, in this case study the emissions are largely created from the energy consumption associated with polymer production.

The comparison between total CFP and the lid's physical weight has indicated a positive correlation. This aspect was eliminated by normalizing the determined CFPs via the lid weight. In the Figure 3 the energy flows associated with lid production were further classified by the emissions associated with the moulding machines, hot runners and packaging (robot) systems.

Moulding machines in polymer processing consume the largest proportion of energy (including their control system, temperature aggregates, extruders and moulds) and are the main cause of CO_2e emissions in polymer processing. The physical ejection required from some moulds needs additional energy consumption in the form of compressed air. The company analysed in this research works with hydraulic machines and has also invested in the new hybrid machines. These include the advantages associated with hydraulic and electric drives which result in higher productivity and energy efficiency. The machines F and G are hybrid and the mentioned advantages were also confirmed by measurement. In the case of the purchasing of new assets an investment in hybrid moulding machines could also be recommended.

By implementing the above measures, plastics processing factories could decrease their total energy demand and reduce their GHG emissions. An additional solution is the substitution of the electric heating of the barrels with alternative energy sources. Although this process needs external thermal energy, the usage of electric energy is the standard practice. In most countries the primary energy factor

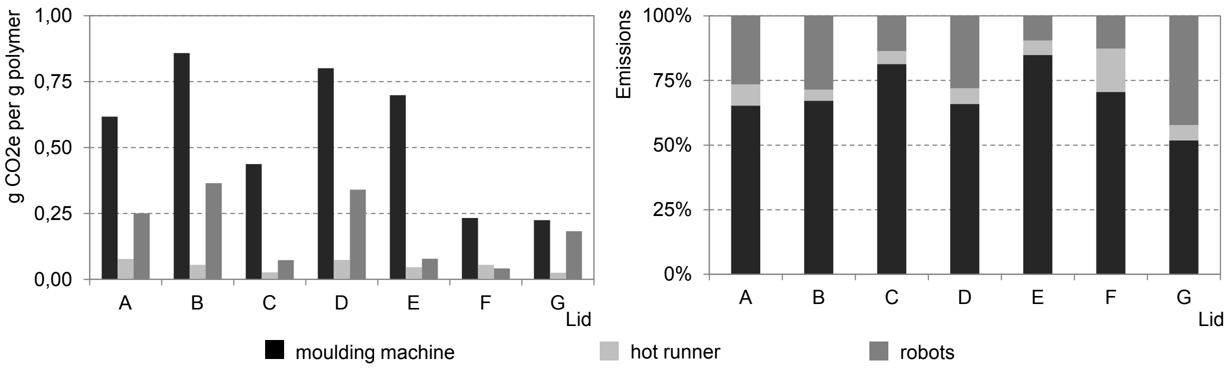

Figure 3: Normalised CFP

of electric power is very high. In Germany it is around 2.8 [12] due to the transmission and distribution losses (TND) in the transfer energy from electric power stations and the energy lost in conversion from heat (steam) to electric energy.

Decentralised energy generation can be one possibility for higher energy efficiency in various regions of the world (except for regions with high availability of wind or other renewable energy) [13]. The heat generated in combined heat and power plants (CHP) can also be used to supply the heating of the machines barrels. The linking with absorption chillers and other heating purposes enables the use of the rest of the available heat energy. The result is a higher utilisation factor. Additionally, emissions of the whole CHP system could be decreased through renewable fuels, like biogas or bio-methane.

The emissions associated with robotic packaging systems are largely created from electric power production and the generation of compressed air with its very high energy intensity factor (about 10 % of the compressor´s electric demand) [14]. According to own measurements, the substitution with electric alternatives could enable a saving of up to 70 %.

The above energy efficiency and co-generation options could certainly assist with the development of more eco-friendly plastics production.

6 CONCLUSION

This study has investigated the application of CFP in assessing the environmental footprint of polymer processing and production. Alternative cost management approaches were utilised in the analysis to provide a more objective assessment of the functional unit chosen. The various cost accounting methodologies available are assessed and compared to polymer production. This cost accounting assessment helps to clarify some of the difficulties that may be faced in estimating of CFP.

Reducing environmental impact assessment into one parameter/indicator is a challenge for any methodology. Other issues especially in comparison between different products are analogous to the challenges faced in life cycle assessment with different system boundary assumptions and different input and output data bases.

However, the CFP analysis provides an opportunity to develop an essential performance metric that can be used to improve sustainability management particularly in energy intensive industries. CFP can examine the value and importance of energy efficiency achieved in the product life cycle as well as in the important transition to renewable energy sources and materials/processes to reduce the overall carbon footprint.

In addition, packaging industries, whilst crucial in the transportation and storage of many products, often suffer from being over-engineered, with unnecessarily high material and energy intensity. CFP helps to highlight those areas of production that could benefit from further optimisation, in particular the potential reuse of the packaging to further enhance polymer industry sustainability.

Calculating and reducing the GHG emissions from polymer processing can also provide a significant competitive advantage for plastics companies for both economic growth and sustainable development.

Polymer processing relies on fossil fuel oil resources and high energy use in production both suggesting an inherent value from CFP analysis. The results in this research indicate that the key challenge for the plastics industry is in its ability to increase its level of energy efficiency whilst seeking alternative energy options.

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