# LIFE CYCLE ASSESSMENT OF SUPERMARKET CARRIER BAGS AND OPPORTUNITY OF BIOPLASTICS

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## ABSTRACT

In this paper a life cycle assessment study of three types of grocery bags is presented. Reference bag is a low density polyethylene (LDPE) bag, while long life polypropylene (PP) and a bag from biodegradable material are compared to the reference bag in terms of environmental impacts and energy consumption. Inventory analysis was conducted in cooperation with bags manufacturers, merchants, waste management companies and policy guidelines and laws. Environmental impacts are presented with environmental indicators by CML 2001 standard. Study covers all life cycle stages with different scenarios in the end life stage and main contributors to environmental burdens were identified through life cycle stages. Since it is shown that end of life stage of carrier bags is very sensitive and depended of customer's behaviour, guidelines for disposal of bags are given in the form of percentage increase/decrease of specific environmental indicator. The studies show that bioplastic bags have some advantages in the production life cycle phase (from cradle to door), but can be questionable in the end of life cycle phase, if not properly disposed and/or composted industrially instead in domestic compost bins. It was shown that long life (PP) carrier bag is by far the best choice if used for five years as proposed by manufacturer.

*Keywords*: Life cycle assessment, Carrier bags, LDPE, Polypropylene, Mater-Bi, Energy consumption

## 1. INTRODUCTION

The use of bio-based plastics in production of carrier bags, packing materials has been increasingly replacing conventional plastics, [6], [8], [14]. Despite being promoted as environmental friendly, bio-based plastics have some advantages but also some drawbacks. To find and emphasize their environmental benefits life cycle of biodegradeble bags need to be studied in detail phase by phase and compared to the conventional fossil fuel based plastic bags, [15].

In this paper three different carrier bags are studied regarding their environmental impacts: reference LDPE bag from low density polyethylene, long life PP bag from polypropylene and bio-based bag from Mater-BI (Table 1). LDPE and Mater-BI bags are produced in Slovenia while PP bag is produced in Vietnam, so transport routes for this type of bags are much longer. Bags are manufacture from granulates produced in Europe (LDPE, Mater-BI) and Middle East (PP).

Mater-Bi® CF05S is a biodegradable thermoplastic material made from corn starch and biodegradable copolyester based on proprietary technology. The copolyester is based on diacids and glycol that are obtained from renewable (from agriculture) and non-renewable resources, [2]. The concept of producing environmentally products is cyclic one, where sunlight, $CO_2$ and other products are absorbed during the growth of feedstock for making bio-plastics, [6]. After the use phase the bio-based plastic can be composted and converted into natural substances via home- or industrial-composting process, [1], [2], [10]. Starch based bio-plastic is suitable replacement for conventional plastic but approx. 30 % more material mass is required for the same strength and endurance, [4]. This article investigates whether bio-based plastic is environmentally sounder in the production phase and what are the main objectives in the usage and disposal phase, where the behaviour of customers comes into consideration.

## 2. LIFE CYCLE ASSESSMENT

Life cycle assessment is a powerful tool to compare environmental impacts of different products. It considers products' resources (ore, water, etc.), energy consumption as well as generation of emissions and wastes in the entire studied life cycle of the product, [21]. In this study a complete LCA from cradle to grave is presented with different scenarios in the end-of-life phase.

## 2.1. LCA goal and functional unit

The goal of LCA study was to compare three types of bag in their entire life cycle (from cradle to grave). The aim was to highlight the contribution of different life cycle stages (production, use, end-of-life) to overall environmental burden and determine if Mater-BI bio-based bag is environmentally sounder compared to conventional LDPE and PP carrier bag.

Functional unit is one standard carrier bag of 16,2 litres and the same carrying capacity in the case of LDPE and Mater-BI bag and 39,6 litre bag in the case of PP bag. Results are afterwards normalized and analysed to obtain proper comparison since in order to ensure relevance and fairness of LCA it is essential that all compared products provide the same function, [19].

Table 1: Basic data of studied carrier bags

| Bag | Manufacturer | Mass, g | Volume, l |
|---|---|---|---|
| LDPE | Slovenia | 14,8 | 16,2 |
| PP | Vietnam | 127 | 39,6 |
| Mater-BI | Slovenia | 20,21 | 16,2 |

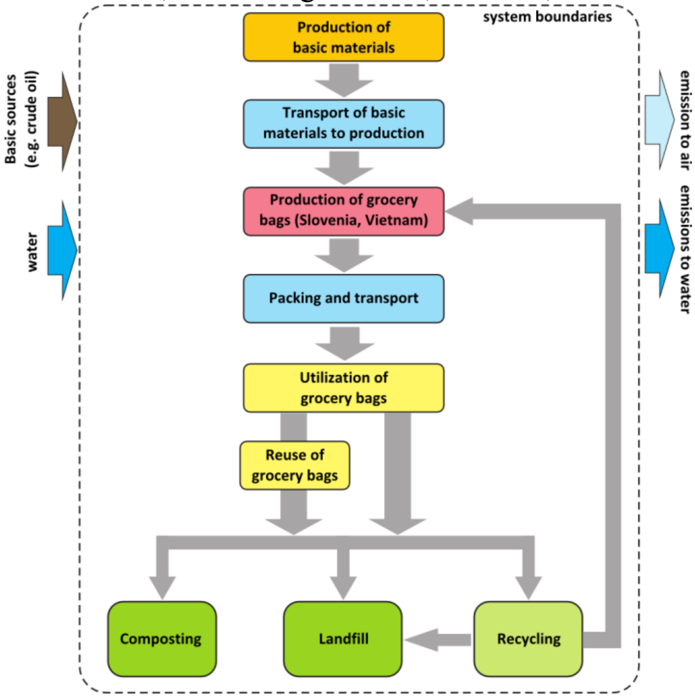


Figure 1: Basic LCA model for carrying bag

## 2.2. LCA Scope and system boundaries

The scope of the study is cradle to grave. All relevant life cycle flows, processes and phases are included in the study: raw material extraction, transport of materials, manufacturing processes of the bags, transportation of the bags to storehouses and markets, recycling in manufacturing chain and in the end-of-life of bags and different end-of-life scenarios (Table 2).

Table 2: End-of-life scenarios of bags

| Bag | Landfill | Incineration | Composting | Recycling |
|---|---|---|---|---|
| LDPE | ☑ | ☑ | | ☑ |
| PP | ☑ | ☑ | | ☑ |
| Mater-BI | ☑ | ☑ | ☑ | |

## 2.3. Raw materials production

Data for raw materials production (granulate) for bag manufacturing for LDPE (low density polyethylene) bag and PP (polypropylene) bag were taken from generic Gabi 5 database from PE International, [3], and for Mater-BI granulate data was acquired from Novamont company, [2]. Because bags are transported packed in cardboard boxes and on EUR-pallets cardboard boxes are also included into the study and pallets add to the transport weight since they are returned back. All relevant data for materials are presented in Table 3.

## 2.4. Manufacturing processes

The blown film extrusion process is used to manufacture carrier bags. The main inputs in the process are granulate and electrical energy that comes from Slovenian energy mix in the case of LDPE and Mater-BI bag and from Vietnam energy mix in the case of PP bag. All data in manufacturing phase are acquired from bag manufacturers in Slovenia and Vietnam and are presented in Table 3 and Table 4. Cut off criteria in manufacturing phase was the mass of titanium oxide that yield less than 5 % in total bag mass, so LCA methodology by ISO standards allows to cut off, [21]. Cut off was also made in the case of industrial systems, human labour and auxiliary materials and processes.

Table 3: Energy consumption in manufacturing phase

| Bag type | El. en. consumption / kWh/kg | Tech. waste / % | El. en. consumption for tech. waste / kWh/kg |
|---|---|---|---|
| **LDPE** | 0,608665 | 5 % | 0,3413 (36,6 %) |
| **PP** | 1,5 | n/a | n/a |
| **Mater-BI** | 0,85787 | 10 % | 0,5547 (40,8 %) |

## 2.5. Transport

Transport routes were defined very precisely with materials distributors and bags manufacturers. In the case of Mater-BI bio-based and LDPE bag the transport routes were very similar, while PP bag is produced in Vietnam and therefore the transport is much longer (Table 5).

For LDPE and Mater-BI bags virgin materials are transported from Austria and Italy, bags are then produced in Slovenia and transported within Slovenia with EURO 5 compliant trucks, [1].

Table 4: Raw material consumption and primary packing

| Type | Material-basic | Materials / mass | | Primary packing |
|---|---|---|---|---|
| **LDPE** | Low density polyethylene | LDPE virgin | 14,06 g | cardboard 300 g / 500 bags<br>54 cardboard boxes / 1 EU palete |
| | | titanum oxide | 0,592 g | |
| | | **TOTAL** | **14,8 g** | |
| **PP-Life** | Polypropylene | PP virgin | 127 g | cardboard 752 g / 100 bags |
| | | **TOTAL** | **127 g** | 14 cardboard boxes / 1 palete |
| **Mater-BI** | Mater-BI | Mater-BI | 19,80 g | cardboard 300 g / 500 bags<br>54 cardboard boxes / 1 EU palete |
| | | titanum oxide | 0,40 g | |
| | | **TOTAL** | **20,2 g** | |

Table 5: Transport routes for PP bag

| From | To | Type of transport | Distance |
|---|---|---|---|
| Producers of PP granulate, India, Saudi Arabia, Thailand | Manufacturer of PP long life bags, Ho Chi Minh City | Cargo ship, overseas | 6000 km |
| | | 22 tons, EURO 1 | 50 km |
| Cardboard manufacturer, Vietnam | | 22 tons, EURO 1 | 20 km |
| Manufacture, Ho Chi Minh City, Vietnam | Port Ho Chi Minh City, Vietnam | 22 tons, EURO 1 | 50 km |
| Port Ho Chi Minh City, Vietnam | Port Trst, Italija | Cargo ship, overseas | 12.500 km |
| Port Trst, Italija | Storehouse Mercator d.d., Ljubljana | 15 tons, EURO 3 | 95 km |
| Storehouse Mercator d.d., LJ | Storehouse Mercator d.d., Ptuj | 9,3 tons EURO 3 | 41 km |
| Storehouse Mercator d.d. | Stores / Shops Mercator d.d. | 9,3 tons, EURO 3 | 50 km |

## 2.6. End of life and recycling

As already presented in Table 2 four different processes are included in the end-of-life study that are present in Slovenia: mechanical recycling, landfill, incineration and composting.

For mechanical recycling the mass flow of recyclate input in the manufacturing process is defined by the process demand. In the case of LDPE (Fig.2) and PP (Fig. 3) bag the mass fraction of recyclate is 50 % and other 50 % of mass is virgin LDPE. Energy required for milling process of recyclate in the case of LDPE bag is 0,3413 kWh/kg of electrical energy from Slovenian energy mix. In general the energy requirement for recyclate milling is approx. 0,6 kWh/kg of recyclate, [4], [5], [7]. In the case of Mater-BI bag no mechanical recycling is considered (Fig. 4) and all Mater-BI material is composted.

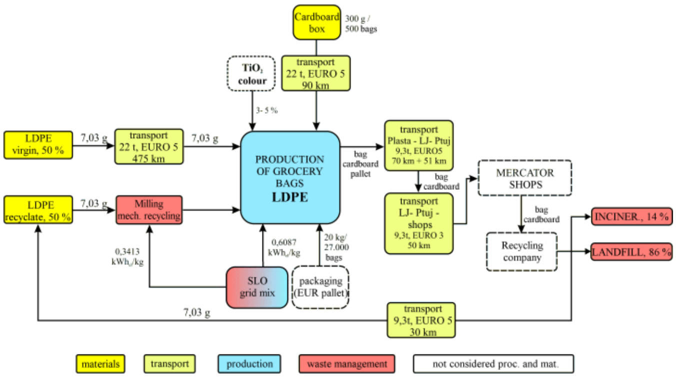


Figure 2. LCA model of LDPE bag

If 50 % of mass is returned as a recyclate back to the manufacturing process, other 50 % of mass flow has to be turned over to other three end-of-life scenarios. Since there is no specific data for Slovenia waste management, data for EU27 average was used, so of all plastic that doesn't end up as recyclate 86 % of mass goes to landfill and 14 % goes to incineration process.

For the landfill process "Landfill of municipal solid waste EU 27" process was used in Gabi 5 database, [3]. In this process landfill gas is utilized to produce useful heat that has positive gains from environmental point of view (environmental credits).

In the case of incineration process the "Waste incineration of municipal waste, EU 27" process was used in Gabi numerical model, where environmental credits are heat and produced electrical energy, [3].

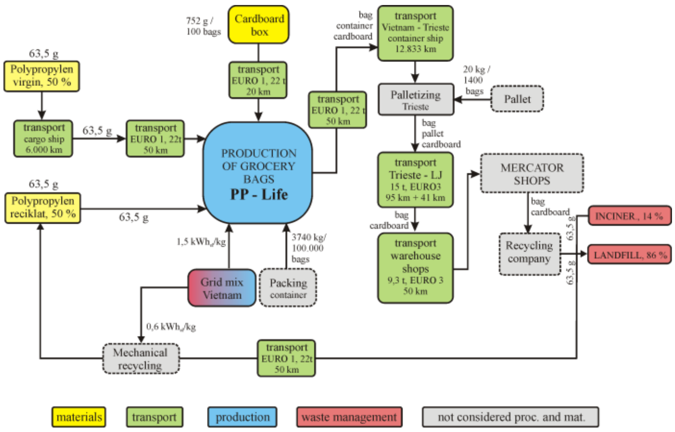


Figure 3. LCA model of PP bag

For composting process industrial composting is applied. The main environmental impact comes from fuel for transport and diesel used in the composting process [10]-[12]. Compost can be used for peat substitute, but in general it was found out that environmental credits from that were insignificant, [20]. According to literature and similar studies the environmental impact from industrial composting process is almost the same as in the case of incineration process, [10]-[12].

## 2.7. Numerical modelling

For numerical modelling Gabi 5 code was used that contains most relevant materials and processes used in numerical models for bags, [3]. Other data that was not in Gabi database was acquired from manufacturers and incorporated into numerical model in analysis. In the case of Mater-BI bag that is presented in the Fig. 4 all material mass flows, energy consumption and environmental impacts in granulate production phase was acquired from material producer Novamont and used in the model, [2]. In the case of low density polyethylene (LDPE) granulate, polypropylene (PP) granulate, electrical energy mixes (Slovenia, Vietnam), transport (cargo trucks, overseas ships, diesel, crude oil), cardboard boxes, end of life processes (incineration, landfill) data was used from generic database from PE International, [3].

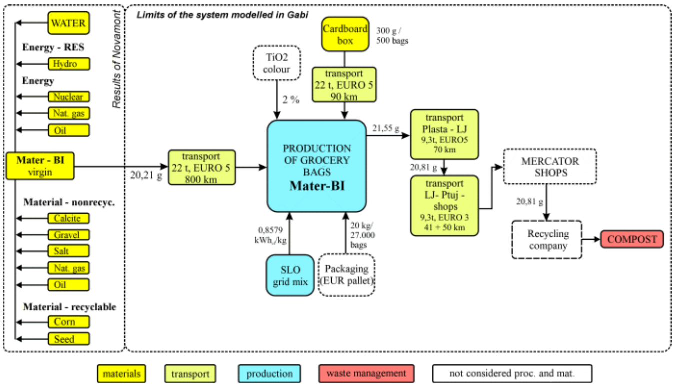


Figure 4. LCA model of Mater-BI bag

## 2.8. Impact assessment

The impact assessment of all inputs and outputs was performed using CML 2001 that is an impact assessment method which restricts quantitative modelling to early stages in the cause-effect chain to limit uncertainties. Results are grouped in midpoint categories according to common mechanisms (e.g. climate change) or commonly accepted groupings (e.g. ecotoxicity), [3], [21]. Environmental impacts of different bags through their life cycle are compared with environmental indicators as global warming potential (GWP), abiotic depletion potential (ADP), acidification potential (AP), eutrophication potential (EP) and ozone layer depletion potential (ODP). In addition to this energy consumption in the terms of primary energy demand from renewable and non-renewable resources was observed.

## 3. RESULTS

Three different plastic materials are used in manufacturing of bags and each has different environmental impact already in the granulate production phase (Table 6). Biodegradable Mater-BI material is very comparable to fossil based granulates. It was found that less primary energy demand is needed for 1 kg of Mater-BI granulate than for same amount of LDPE or PP granulate. On the other hand more water is needed for 1 kg of Mater-BI, abiotic depletion potential (ADP) and eutrophication potential (EP) are higher due to agriculture processes involved in granulate production, [2].

Table 6: Environmental impacts of materials used in the manufacturing of bags, for 1 kg granulate

| | LDPE | PP | Mater-BI |
|---|---|---|---|
| **ADP, kg Sb-Eq.** | $2{,}20 \cdot 10^{-7}$ | $4{,}62 \cdot 10^{-8}$ | $2{,}08 \cdot 10^{-2}$ |
| **AP, kg $SO_2$-Eq.** | 0,00798 | 0,00623 | 0,00919 |
| **EP,kg Phosphate-Eq.** | 0,00050 | 0,00074 | 0,00323 |
| **GWP, kg CO2-Eq.** | 2,13 | 1,99 | 2,0 |
| **ODP, kg R11-Eq.** | 0 | 0 | $3{,}41 \cdot 10^{-7}$ |
| **POCP, kg Eten-Eq.** | 0,00121 | 0,00093 | 0,00219 |
| **Energy, MJ** | 79,27 | 75,12 | 66,0 |
| **Water, kg** | 44,9 | 40,4 | 233 |

### Global warming potential

The comparison on the level of functional unit (1 bag) is in range of expectation since there is a difference in masses of studied bags but nevertheless LDPE and Mater-BI bags are directly comparable and have also the same carrying strength. In all results (impact factors) the share of material production, manufacturing or production of bags, transport phase and end-of-life is visible. With that we can identify the phases in life cycle that contribute the most in overall environmental impact of specific bag.

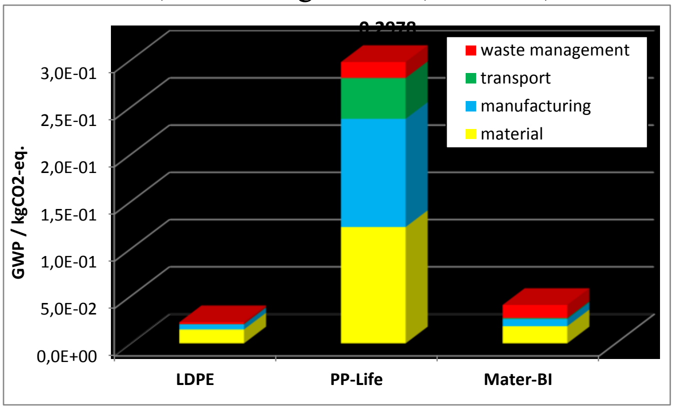


Figure 5. GWP for 1 carrying bag (functional unit)

From Fig. 5 it can be seen that PP life bag has the biggest GWP since the mass is between 6 and 8 times bigger than Mater-Bi and LDPE respectively. But PP bag is used for five years according to manufacturer data while LDPE and Mater-BI bag is most frequently used one single time and afterwards in the best case used again as a litter bag for secondary use. Break even analysis shows us (Fig. 6) that necessary primary reuse of the PP bag is just 14 times to meet the GWP of LDPE bag (reference bag) emissions. Mater-BI bag must also be reused twice to meet GWP from the reference LDPE bag, which is not a promising result for bio based plastic.

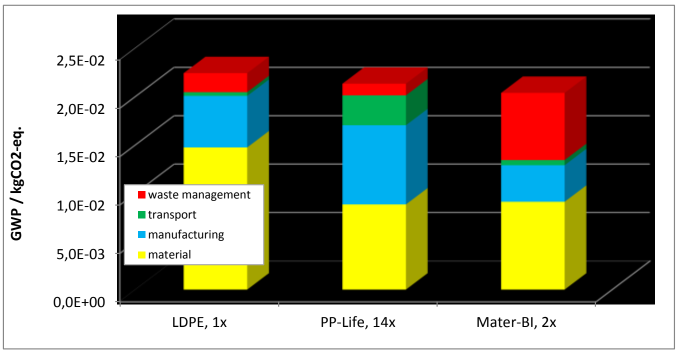


Figure 6: Break even analysis (LDPE as reference)

Deeper analysis of the results show that considerable environmental impact of Mater-BI bag comes from waste management phase (Fig. 7) since industrial composting has relatively small, if not negligible, environmental credits (avoids peat production), but in the terms of environmental impacts is on the same level as incineration, [20]. Incineration on the other hand has environmental credits with heat and electricity production which makes it more favourable over industrial composting.

From Fig. 5 to Fig. 7 it is also found out that the biggest part of total environmental impact is due to granulate production process (from 40 up to 70 % of total GWP). Transport is almost negligible in the case of LDPE and Mater-BI bag but come to 15 % of total GWP in the case of PP bag produced in Vietnam.

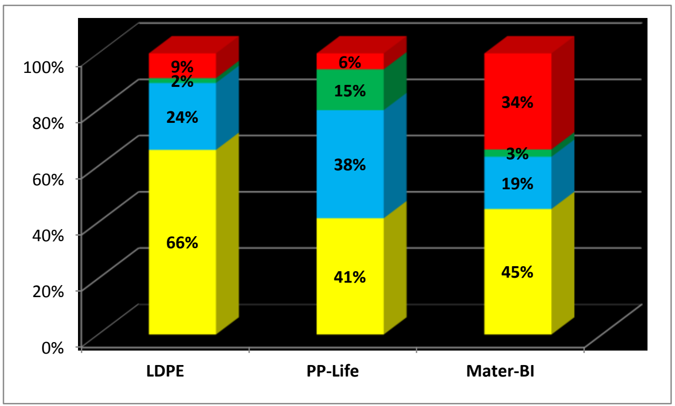


Figure 7. Relative contribution to overall environmental impact

## Other environmental indicators

In Fig. 8 environmental impacts in all CML 2001 studied categories are presented for Mater-BI bag expressed in share of life cycle phases. The biggest impact comes from granulate production (80 % in average), the share of composting process (end-of-life) is very influential only in the case of GWP, transport has very small impact and manufacturing process has some influence because of electrical energy mix consumption.

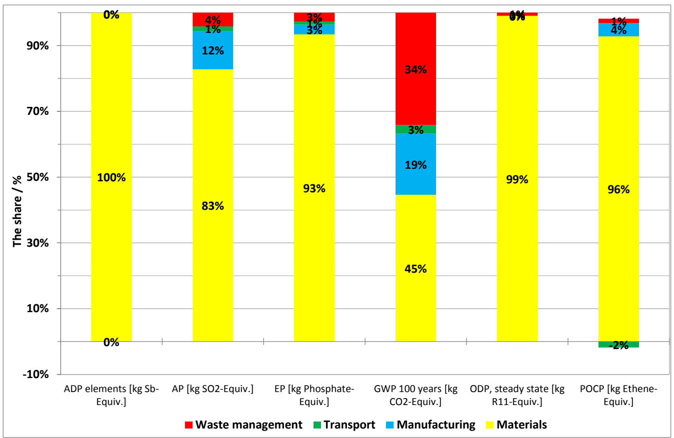


Figure 8. Relative contribution of life cycle phases for Mater-BI bag

For PP bag the share of transport is bigger (Fig. 9) up to 60 % in AP indicator. Negative values in ADP, AP and POCP indicators represent environmental credits from heat and electricity production in the case of landfill and incineration process in the end-of-life.

In the case of LDPE bag (Fig. 10) the biggest share in all indicators represents granulate production (57 – 81 %). The next most influential life cycle phase is manufacturing of the bag, up to 30 %.

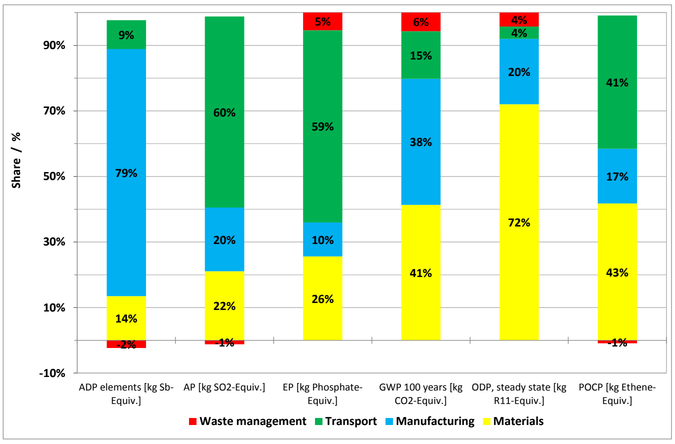


Figure 9. Relative contribution of life cycle phases for PP bag

Transport has a minor share in overall environmental impacts and end-of-life processes (incineration, landfill) represent the share from 10 % to 20 % in EP, GWP and ODP. Some environmental credits come from incineration and landfill processes.

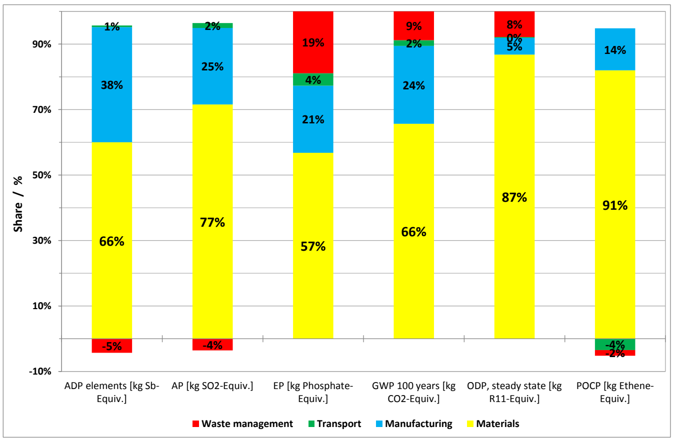


Figure 10. Relative contribution of life cycle phases for LDPE bag

## Normalized results - equality of bag masses

If we normalize results with respect to bag mass and calculate all impact categories for 20 grams bags the results look promising for biodegradable Mater-BI bag. If the usage of $CO_2$ in the Mater-BI granulate production phase, which is 1,07 kg of $CO_2$ per 1 kg of produced granulate, is considerred results of GWP show the superiority of Mater-BI bag (Table 6).

In all other impact categories Mater-BI bag is in average still below both LDPE and PP but the impact are of the same magnitude. If industrial composting was changed to agricultural composting in end-of-life which is also technically possible in the case of Mater-BI (starch based granulate) the credits due to avoided fertiliser production would put the Mater-BI bag in much better position. Nevertheless energy consumption in the case of mass equality is the smallest in Mater-BI life cycle.

Table 6: Environmental impacts of in the case of normalized results, all bags have mass of 20 grams

| | LDPE | PP | MaterBI |
|---|---|---|---|
| **ADP, kg Sb-Eq.** | $4{,}40\cdot10^{-9}$ | $9{,}23\cdot10^{-10}$ | $4{,}16\cdot10^{-4}$ |
| **AP, kg $SO_2$-Eq.** | $1{,}60\cdot10^{-4}$ | $1{,}25\cdot10^{-4}$ | $1{,}84\cdot10^{-4}$ |
| **EP, kg Phosphate-Eq.** | $1{,}01\cdot10^{-5}$ | $1{,}49\cdot10^{-5}$ | $6{,}46\cdot10^{-5}$ |
| **GWP, kg $CO_2$-Eq.** | $4{,}25\cdot10^{-2}$ | $3{,}98\cdot10^{-2}$ | $1{,}86\cdot10^{-2}$ |
| **ODP, kg R11-Eq.** | 0,00 | 0,00 | $6{,}82\cdot10^{-9}$ |
| **POCP, kg Eten-Eq.** | $2{,}42\cdot10^{-5}$ | $1{,}86\cdot10^{-5}$ | $4{,}38\cdot10^{-5}$ |
| **Energy, MJ** | 1,59 | 1,50 | 1,32 |
| **Water, kg** | 0,90 | 0,81 | 4,66 |

If industrial composting excluded and the credits from agricultural composting are not considered the GWP of Mater-BI bag is almost the same as LDPE bag (Fig. 11).

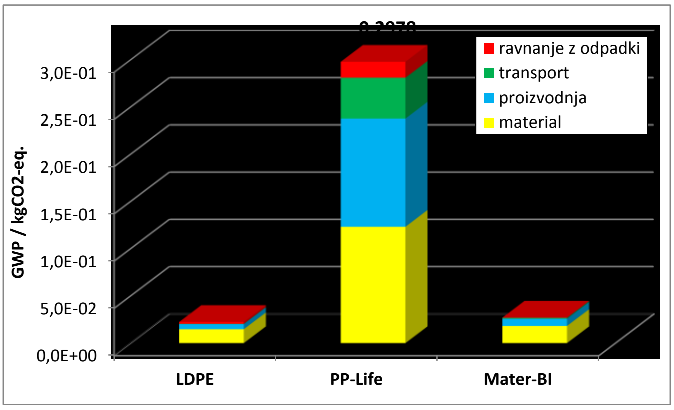


Figure 11. GWP for 1 carrying bag in the case of no impacts from industrial composting (agricultural composting)

## 4. CONCLUSIONS

In the paper the life cycle assessment study of three types of grocery bags is presented: low density polyethylene (LDPE) bag; long life polypropylene (PP) and biodegradable bag from Mater-BI. Gabi 5 software was used for numerical modelling of the life cycle phase. Functional unit was 1 bag and the scope of the study was from cradle to grave. It was found out that:

- When comparing results of functional unit (1 bag) PP bag is the worst case, on the other hand PP bag is used for five years. In that time approx. 550 pieces of LDPE or Mater-BI bags are used in one household in Slovenia. That puts PP bag in GWP results 75 times better in the case of Mater-BI and 41 times in the case of LDPE bag.
- The biggest impact in all environmental indexes comes from granulate production process.
- Biodegradable granulate Mater-BI seems competitive in material production phase, requires less energy consumption but more water.
- Electrical energy consumption in the bag manufacturing phase represents an essential share in overall environmental impact.
- End-of-life scenario has a considerable impact for Mater-BI bag because in the case of industrial composting impacts are the same as in incineration process, but there are no environmental credits.

Biodegradable plastics has opportunity to break through as technology, but it has to be carefully introduced and all pros and cons have to be considered during all life cycle phases. In this study surprisingly the biggest reserve lies in composting process since industrial composting should be omitted as it has a relatively big environmental impact and agricultural composting should be introduced instead.

## ACKNOWLEDGEMENTS

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