COMPARATIVE ENVIRONMENTAL LIFE CYCLE ASSESSMENT OF PET/LDPE, MONO PET AND MONO PE FILMS

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22 September 2022

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TNO innovation for life

LCA GOAL & SCOPE

- This comparative LCA is aimed to assess the environmental impact of of existing PET/PE laminates compared to mono PET or mono PE alternative structures in flexible packaging applications, particularly focussing on the global warming potential (GWP) in CO2-eq.
- LCA for a flexible packaging to assess the environmental impact The target application is packaging of **dried food such as muesli.** The function of the polyester film today is to make the package **stiff** enough and allow fast **sealing** cycles in the manufacturing of the pouch due to the high **temperature resistance** of the polyester.

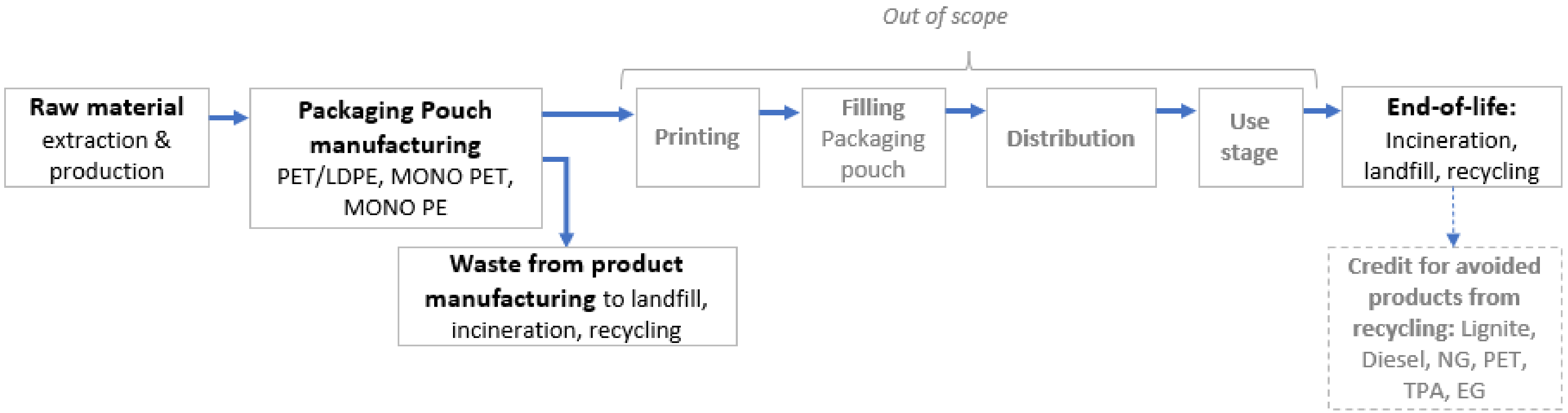
Product system studied:

1. Existing design: PET/LDPE laminate structure PET 12 µm -1.4 g/cm3 - AlOx coated - front printed / 4 µm glue / 60 µm sealable PE.
2. Mono PET solution, BOPET 12 µm -1.4 g/cm3 reverse printed /4 µm glue)/ 30 µm Sealable BOPET film 1.39 g/cm3 AlOx coated on outer side. PET film in 1 contains 50 % mechanically recycled PCR PET
3. Mono LDPE solution, BOPE 25 µm 0.97 g/cm^3 reverse printed /4 µm glue/ 80 µm LDPE 0.94 g/cm^3 (film with 48 µm PE sealing layer/ 4 µm tie layer/4 µm EVOH layer / 4 µm tie layer/20 µm LDPE cover)

Use case	Total	rPET	PET	LLDPE	LDPE	EVOH	Glue (ethylene vinyl acetate)	Tie layer (ethylene vinyl acetate)	AlOx
PET/LDPE	76	6	6	60			2		(20nm)
Mono PET	44	21	21				2		(20nm)
Mono PE	103			25	68	4	2	4	

SYSTEM BOUNDARIES

- The LCA will be a **cradle-to-grave LCA** to consider the full life cycle (extraction to end-of-life).



- Out of scope for this LCA are the printing, filling of the film packaging with dry food (e.g., muesli), the distribution and the use stage of the products.
- The impact of filling of the packaging with products are not the same for all three packing methods, as the packing process will be significantly less efficient due to the need to run at lower sealing temperatures because of the inherent properties of the mono-PE structure. The filling is however not in the scope dure to complexity and lack of data availability.
- The other phases, printing, distribution and use phase also excluded for complexity and lack of data reasons.

FUNCTIONAL UNIT & IMPACT CATEGORIES

- **The functional unit** for the product under study is: 1 piece of packaging film for food (muesli) packaging application with the surface area of 500 cm2.

- **Environmental impact categories:** the focus is on global warming impact (kg CO_2-eq.) and abiotic fossil fuel and material depletion (ADP-eq.) and if desired water footprint of the cradle-to-grave processes associated with both products. These will be assessed with different LCA methodologies
  - IPCC for Global warming impact, ReCiPe 2016 (see annex 1)/ILCD for water footprint/ material depletion.

- Geographic scope of study is **Europe.**

- **Third party review:** Given the comparative assertions, a third party review was conducted (conform ISO 14044:2006) by Ecochain to decrease the likelihood of misunderstandings or negative effects on external interested parties.

SCENARIOS STUDIED

In order to give an insight into the impact of proposed mono-material films in different periods it is important to include the changes in recycling rate and electricity grid mix in addition to the development in the technologies of recycling.

Two perspectives were analysed:

- **State of the art (SoA):** the avoided energy from incineration with energy recovery is according to the 2021 energy mix in Europe. Sorting and collection of films is done according to state-of-the-art data; collected and sorted with other A4-sized films and sent to incineration. Chemical recycling, as it is still in development, is assumed suboptimal. The recycled content of PET comes from mechanically recycled PET.
- **Future:** the avoided energy from incineration with energy recovery is according to the 2050 energy mix in Europe. Sorting and collecting is assumed optimized to the recycling technology. Chemical recycling, as assumed to be on the market, is more optimized. The recycled content of PET comes from chemical recycling of PET.

Furthermore, sensitivity analysis is carried out to determine the extent of the effect of recycling excluding the disposal of the waste.

Scenario	Scenario definition	Year	Electricity grid mix	Incineration	Landfill	Recycling
1	SoA (energy recovery, landfill)	2021	2021	53%	47%	0
2	Future (energy recovery, landfill)	2050	2050	90%	10%	0
3	Future (energy recovery, landfill, and chemical recycling)	2050	2050	28%	3%	69%
Sensitivity 1	Chemical SoA	2021	2021	0	0	100%
Sensitivity 2	Chemical future	2050	2050	0	0	100%

Film	Chemical recycling
LDPE/PET	Pyrolysis
MONO PET	Glycolysis
MONO PE	Pyrolysis

ASSUMPTIONS ON CHEMICAL RECYCLING

Attention was paid to specifying these assumptions to avoid unrealistic assumptions which can affect the result.

- Currently char fraction of pyrolysis does not have a mature value chain (Russ et al. 2020) and is assumed to change in the future. Thus, in the current (SoA) scenario it is sent to landfill.
- Pyrolysis oil quality is assumed to be only based on lower heating value (LHV) as the product is assumed to be used for combustion.
- The table refers to the yield and carbon efficiency for glycolysis and pyrolysis, respectively. Yield is defined as the ratio (in weight) of PET which is depolymerized through glycolysis and the entire PET which is fed into the process. Therefore, a fraction of the PET is not depolymerized and is send to incineration due to process inefficiency.
- Carbon efficiency is defined as the oil (liquid) fraction of the pyrolysis which is produced as the output.
- For the avoided products of glycolysis for the SoA it is assumed that TPA is avoided. Actually, the product is BHET, however, due to lack of data on BHET, TPA is used as a proxy. For the future scenario, it is assumed that BHET is produced and directly polymerized, yielding EG and PET.

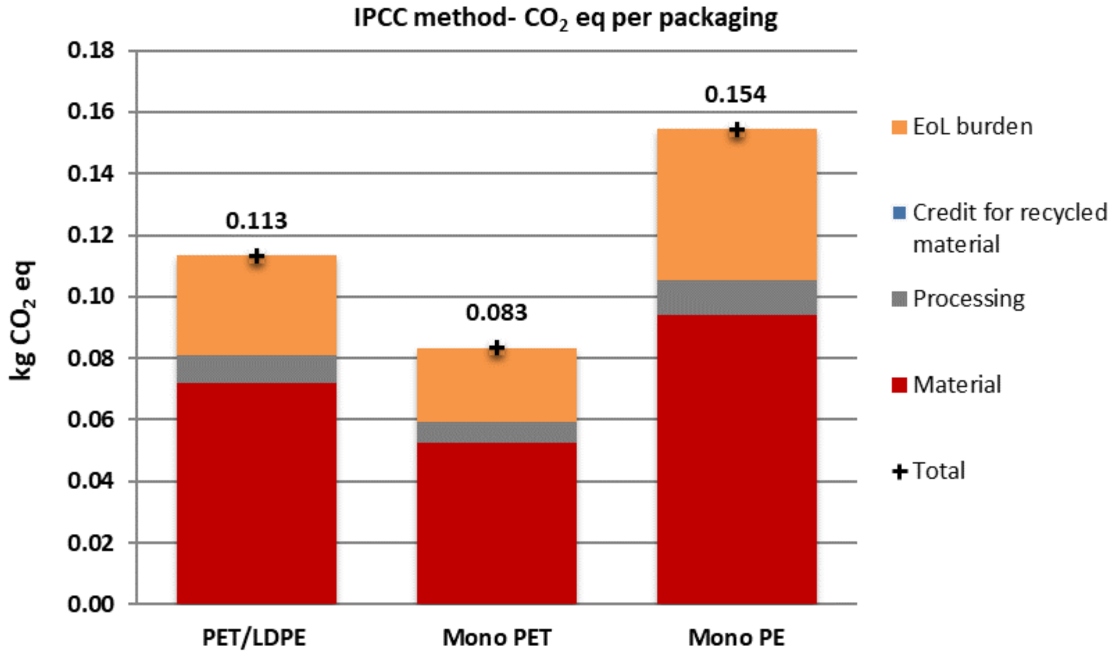
Scenario	Efficiency	Avoided products	Electricity grid mix	Other assumptions
Glycolysis				
SOA	Yield=0.7	Avoids TPA	Electricity and heat current	
Future	Yield=0.9	Avoids PET (in efficient polymerization process of evolved in industry) and EG	Electricity and heat future	The electricity for production is also future grid
Pyrolysis				
SOA	Carbon eff. (%) 30 (PET/LDPE) and 58 (BOPE)	Char landfill	Electricity and heat current	Material efficiency = 90%
Future	Carbon eff. (%) 30 (PET/LDPE) and 58 (BOPE)	Char avoids lignite	Electricity and heat future	Material efficiency = 100%

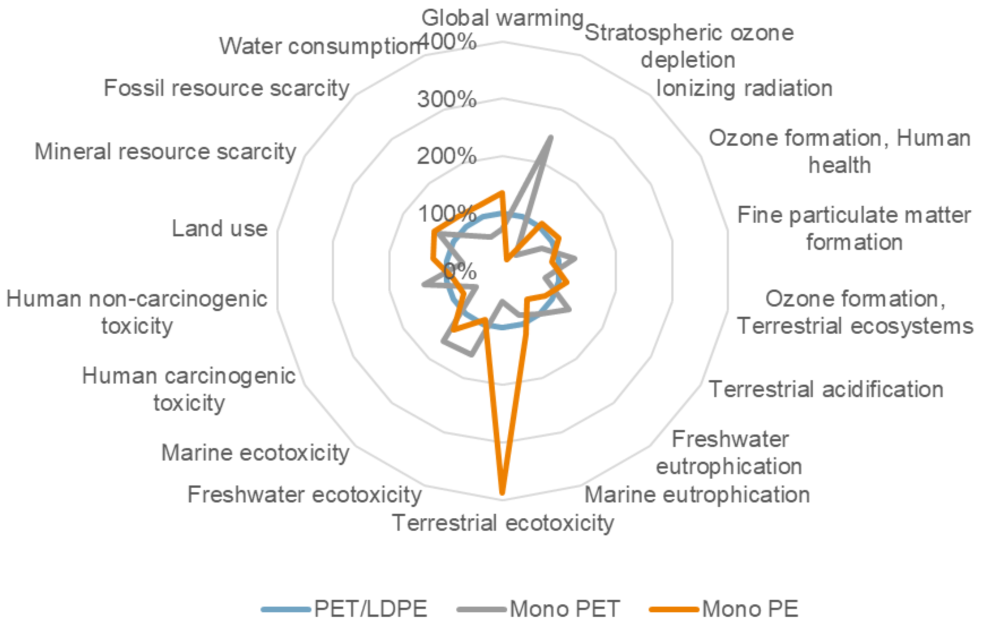
LIMITATIONS OF THE STUDY

- The impact assessment of pyrolysis involves many assumptions.
  - In reality, the results highly depend on the type, scale and pyrolysis condition which leads to different products.
  - The same applies to glycolysis. These technologies have a low technological readiness level (low TRL), requiring further development and therefore, the generated results can only be indicative of the technologies as they are applied in this study. It is recommended to treat the outcome of the study with care.
  - Similarly, the functionality of the films depends on the application of the films and by changing the thickness, where for instance modulus is less relevant, different results may be obtained.

RESULTS

SCENARIO 1: SOA (ENERGY RECOVERY, LANDFILL)

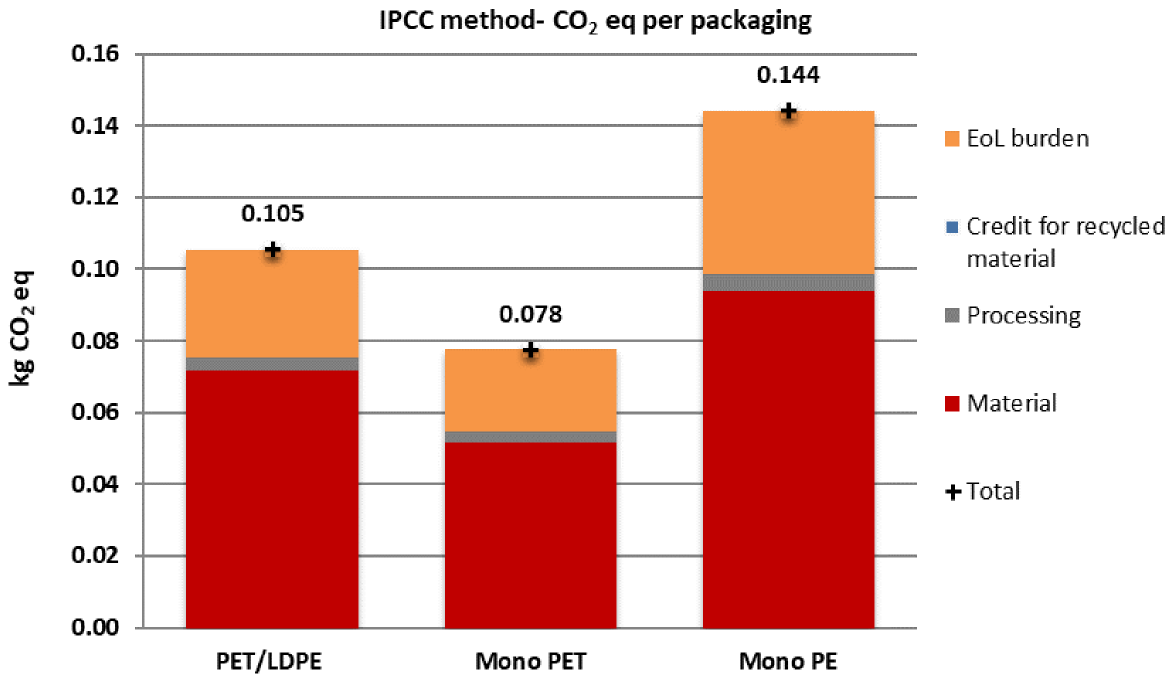


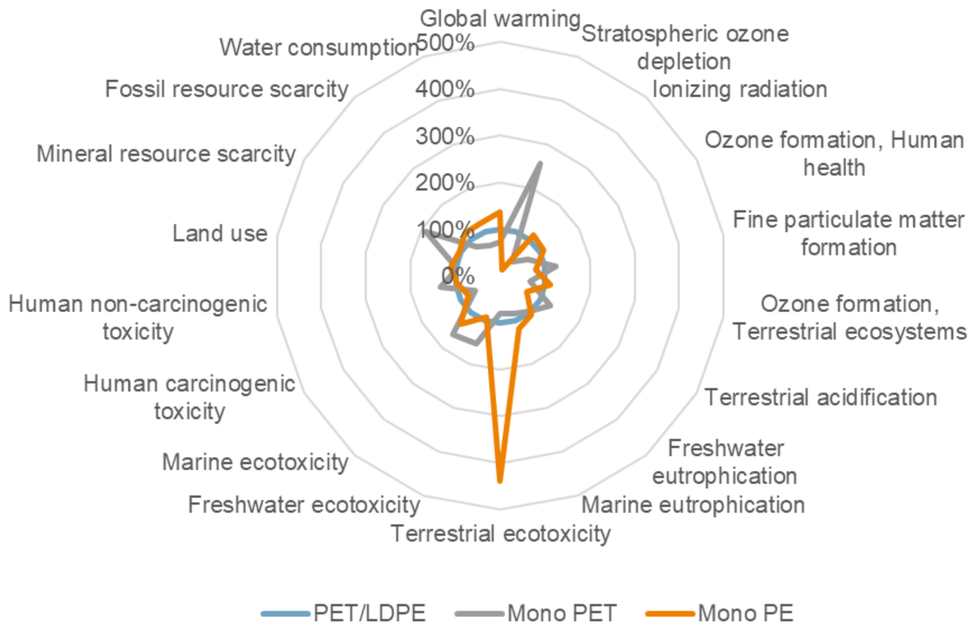


- Mono PET has 27% lower GWP compared to PET/LDPE as a result of thinner film and 50% recycled content.
- The mono PE alternative has a 36% higher GWP compared to PET/LDPE.
- Production of virgin (Mono)PET has a 150% higher potential stratospheric ozone depletion impact than the PET/LDPE due to the emission of Methane, bromo-, Halon 1001. Bromomethane is an unwanted side product of the xylene oxidation reaction which is used to produce TPA
- Mono PE has a 250% higher terrestrial ecotoxicity impact than PET/LDPE due to incineration at EoL whereby a significant amount of vanadium is emitted. Terrestrial acidification and particulate matter formation are also higher due to the emissions of ammonia during ethylene production.

RESULTS

SCENARIO 2: FUTURE (ENERGY RECOVERY, LANDFILL)

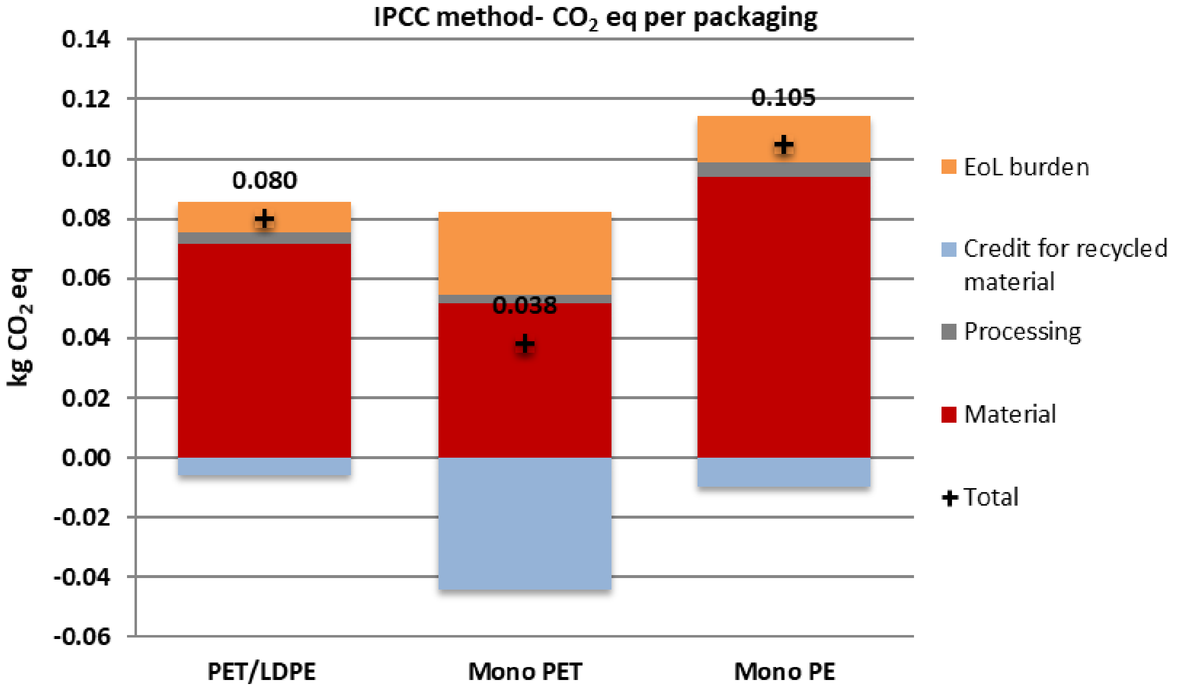


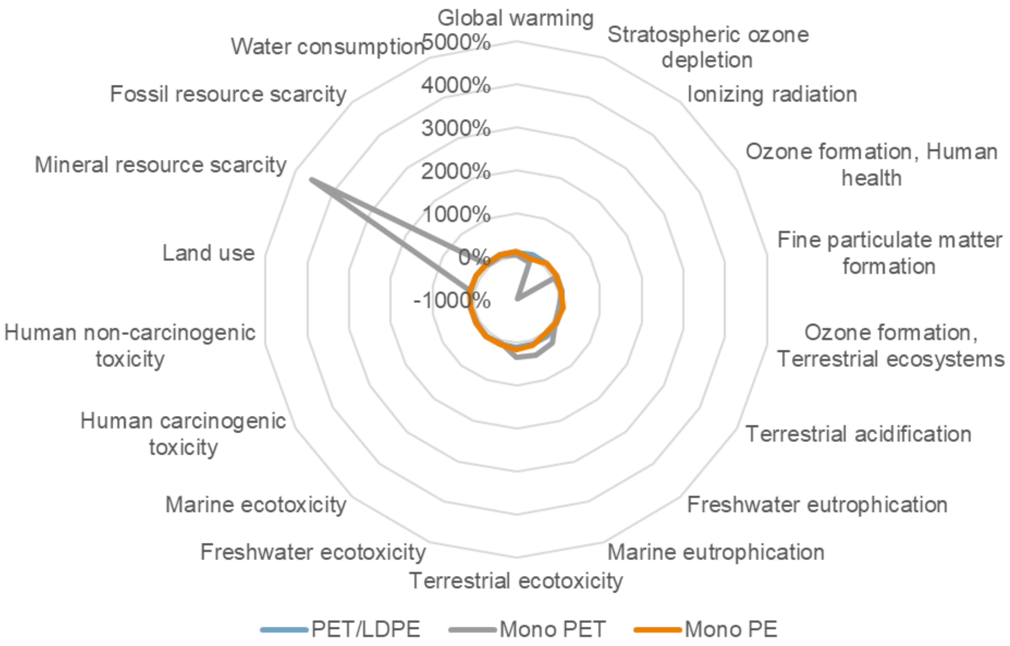


- The future electricity grid mix is used (with a larger renewable energy part). This results in a smaller GWP burden for the processing of all three films. For PET/LDPE this reduction is 7%, for mono PET 6% and for mono PE films 7%.
- Even in the future scenario 2 mono PE does not perform better in terms of environmental impact than PET/LDPE. Mono PET keeps a lower impact compared to PET/LDPE.

RESULTS

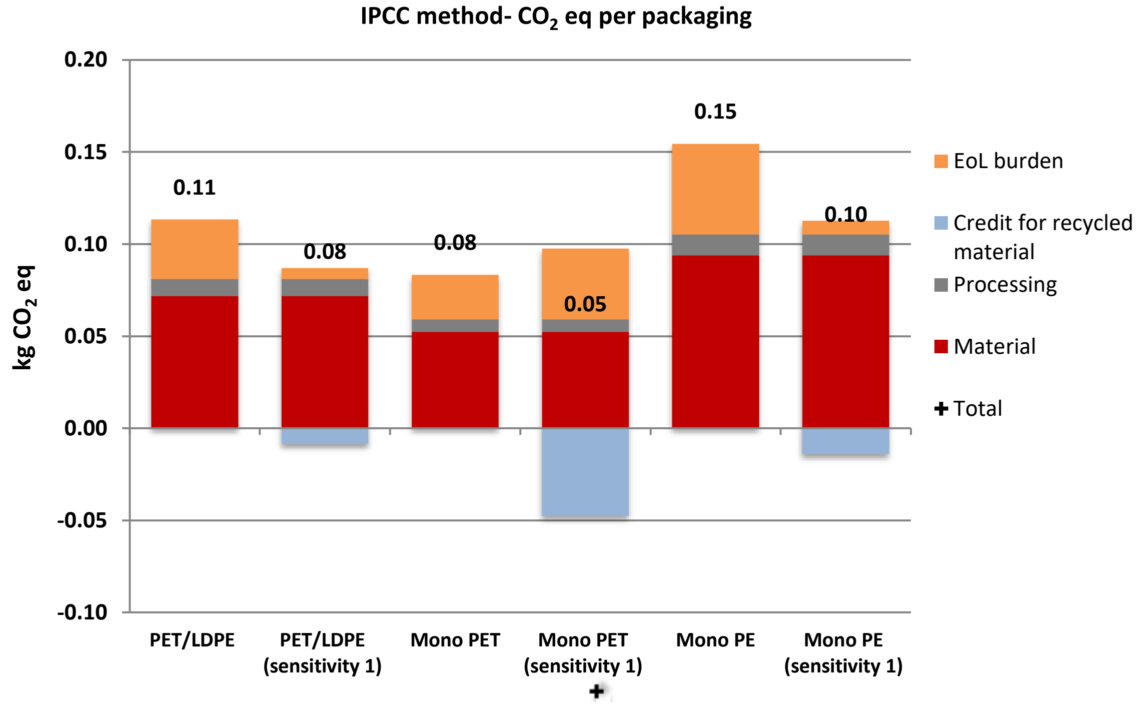
SCEN.3:FUTURE(ENERGY RECOVERY,LANDFILL,CHEMICAL RECYCLING)

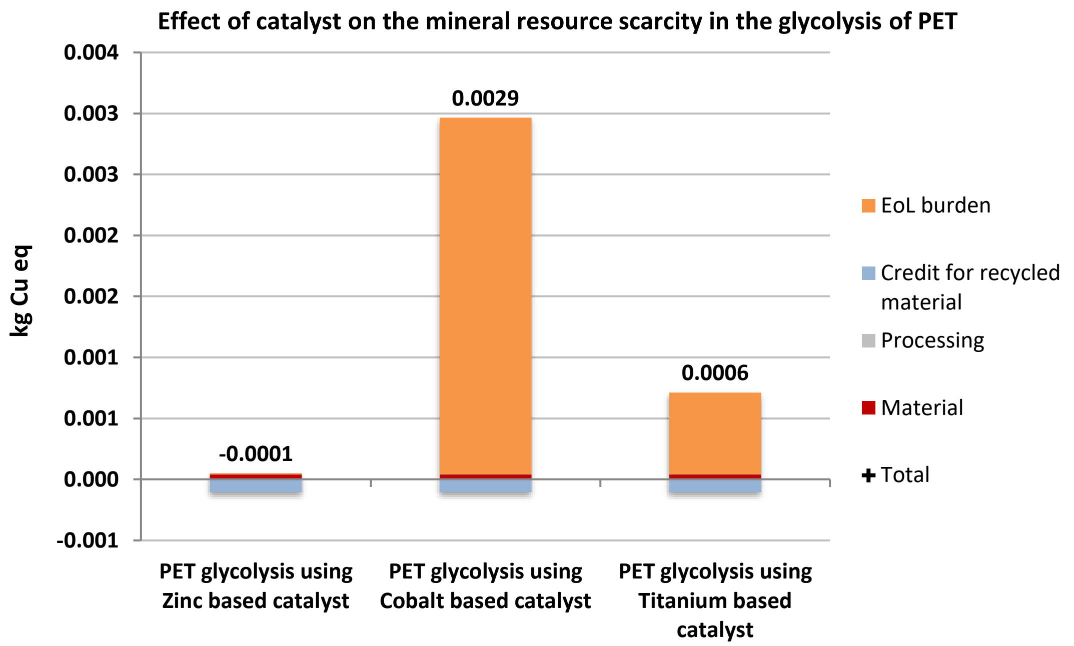




- The chemical recycling of films has reduced the GWP impacts by 24% for PET/LDPE films, 51% for mono PET films, and 27% for mono PE compared to scenario 2. For mono PET the chemical recycling is glycolysis and it is pyrolysis for the other two packaging alternatives.
- The avoided CO2-eq. impact for the PET/LDPE film is 48% lower than mono PE film, mainly due to higher weight of the mono PE film.
- The fact that 26.8g PET/LDPE is pyrolyzed (entire film is pyrolyzed) in comparison to 34.64g for mono PE, per packaging, explains the higher burden and avoided product (natural gas and diesel) for the mono PE use case.

RESULTS
SENSITIVITY 1: CHEMICAL SOA

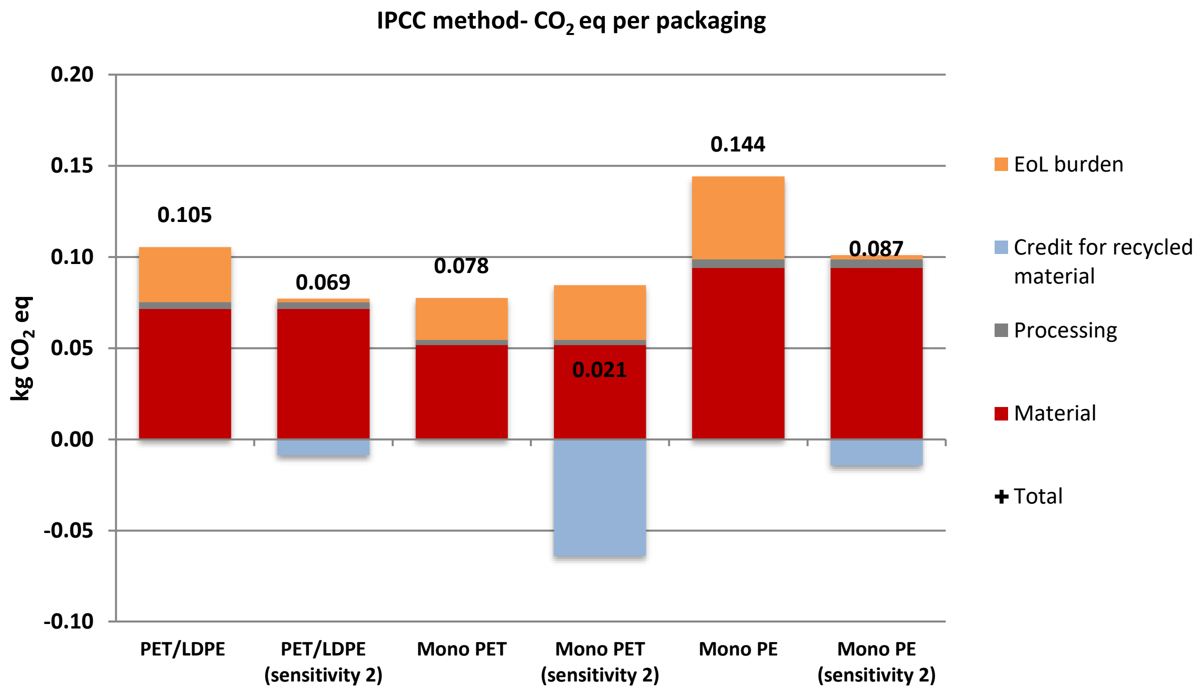




- For fully recyclable films (100% recycling rate), mono PET performs 37% better than PET/LDPE. Mono PE however, even with the 100% recycling rate does not show a lower environmental impact than PET/LDPE.
- While using CoO2 has a large impact on the mineral resource scarcity the use of ZnO2 can decrease the impact of catalyst significantly. Additionally, the use of Cobalt as a catalyst for food contact material is no longer used as a catalyst in Europe and is going to be further phased out globally in the near future. Thus, the effect of Cobalt can be neglected for the production and recycling of the films.

RESULTS

SENSITIVITY 2: CHEMICAL FUTURE



- This reduction is even higher for the future scenario (sensitivity 2) where renewable electricity is used for the recycling: 41% for mono PE, 75% for mono PET and 36% for PET/LDPE films, respectively.
- Again here, mono PE does not show a lower environmental impact than PET/LDPE.

CONCLUSIONS AND RECOMMENDATIONS

- From this comparative cradle-to-grave LCA study it is clear that the mono-material design for packaging films made from Mono PET, has a lower overall global warming potential (GWP in CO_2-eq.). This is the case in all three scenarios (1: state-of-the art, 2: future without recycling, 3: future with 69% recycling) and is due to the lower overall weight of the film (30.74g for mono PET, 38.84g for PET/LDPE, and 50.21g for mono PE), and due to it being better recyclable.
- This benefit can be increased if the collection and sorting infrastructure is improved.
  - When reaching a hypothetical 100% recycling rate for packaging films, 36%, 40% and 30% reduction in global warming potential (GWP in CO_2-eq.) is observed for mono PE, mono PET and PET/LDPE, respectively.
  - This reduction is even higher for the future scenario where renewable electricity is used for the recycling (mechanical, pyrolysis and glycolysis); 41% for mono PE, 75% for mono PET and 36% for PET/LDPE films, respectively.
- Currently packaging films smaller than A4, although collected, are often not sorted to a DKR-fraction (quality specification) for recycling in Europe. This leads to limitations for the recyclability of the newly designed films.
- For the specific application of dry food (muesli) packaging the mono PE films do not show an environmental impact improvement compared to PET/LDPE films due to the importance of stiffness of the pouch and thus a higher required thickness. The thickness of the films and their functionality has a critical role in the environmental performance. The use of thin film in addition to recycled fraction (50%) for PET can improve the results significantly.

ANNEX 1 - RECIPE 2016 IMPACT METHOD
17 INDICATORS FOR IMPACT

The LCA method used is ReCiPe 2016. This methodology includes 17 indicators.

The figure shows an overview of the impact categories in the ReCiPe 2016 methodology and their relation to the areas of protection, human health, ecosystems and resource availability.

All impact categories are reviewed and results are shared in this ppt. The Global warming potential (GWP) category, expressed in CO2eq., is specifically zoomed in on and results are also shared separate from the other impact categories in this ppt.

Since all categories are expressed in different units they can not be compared one-on-one.

Source: Huijbregts, Mark AJ, et al. "ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level." The International Journal of Life Cycle Assessment 22.2 (2017): 138-147.