Date	15-02-2022
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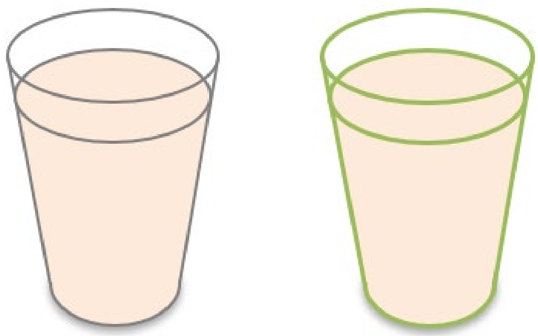
Version	17
Status	Draft

Life Cycle Assessment of PHA biobased festival cup

Part of Interreg North Sea Region Biocas



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Publisher: Hogeschool Van Hall Larenstein

DOI: https://doi.org/10.31715/2022.4

ISBN: 9789083062846

Preface

Worldwide, plastic cups are used for serving drinks. Some typical examples of large-scale consumption are large concerts and festivals. As a part of the BIOCAS project, which focusses on the valorization of biomass through various routes, a PHA biobased festival cup was developed and created to reduce the impact of current fossil plastics. The role of VHL was to assess the environmental impact.

The aim of the report is to inform the BIOCAS-partners about the use of plastic cups, and address the environmental impact in comparison with other types of biobased plastic cups and fossil-based cups.

This report can serve as a basis for making choices within all different types of (plastic/biobased) cups. Besides, it can be used as a public communication tool about the environmental impact of different types of (plastic/biobased) cup applications.

First of all, we would like to express a word of thanks to Pauline Drost, Jan Brouwer, Amarens de Wolff and all the teachers and students for all the effort and enthusiasm they have put into the BIOCAS project. Finally, we would like to thank all project partners for all the educational meetings and their contribution to the BIOCAS project.

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Van Hall Larenstein – Applied Research Centre - Leeuwarden / Velp 2021

Summary

Plastics are used worldwide in many different applications and are almost indispensable in today's society. Public use of plastics is not only easy, the material is also strong, light and versatile. In recent years, however, more and more awareness has grown around the use of plastics and its downsides such as the use of fossil resources and environmental damage.

The European project (Interreg - North Sea Region) BIOCAS (Circular Biomass Cascade to 100%) aims to create new Biocascading Alliances (BCA). One of these alliances is formed by LIMM recycling, NHL University of Applied Sciences, World Perfect, House of Design and VHL University of Applied Sciences. The focus of this alliance was to create a biocup from a biopolastic polyhydroxyalkanoate (PHA). The cup needs to replace conventional fossil-based cups used at music festivals. One of the tasks was to perform an environmental (impact) assessment which was done in this study. The aim of this study was to assess the environmental impact of PHA festival cups, using different biobased resources (corn/maize, cassava, sugar cane, sugar beet and wastewater), and compare them to conventional plastics (PLA, PP, PET, PC and PS) by performing a (consequential) Life Cycle Assessment which aims to show changes in environmental impact throughout the entire product life cycle (production polymer, production cup, use phase, transport/collection and the EOL).

In order to be able to compare the different cups, multiple functional units were used. The first step was to produce polymers out of fossil resources or biomass. The chosen functional unit up to where the polymer leaves the factory is expressed per kg produced polymer. After producing the polymers the next step was to produce cups for use (use phase). After the use phase the cups reach their 'End Of Life' (EOL). When reaching their end of life, it is assumed that the cups will follow one of three conventional end-of-life pathways: recycling, incineration (assuming energy recovery) or landfill. The functional unit was expressed per liter served drink (with and without EOL).

Environmental impact categories considered where climate change, fossil energy use , land use, water use, acidification and fresh water- and marine eutrophication.

The results of the environmental impact ranged from:

- For PHA cups greenhouse gases ranged from 0.09 to 0.15 kg CO_2-eq and for fossil-based cups this was 0.27 to 0.52 kg CO_2-eq. Scores lowest for PHA production from wastewater and corn/maize and highest for production from PP and PC.
- For PHA cups fossil energy consumption ranged from 0.71 to 1.97 MJ and for fossil-based cups this was to 4.74 MJ to 11.5 MJ. Scores lowest for PHA production from sugar beet and wastewater and highest for production from PP and PC.
- For PHA cups land use ranged from -0.04 to 0.13 m^2 and for fossil-based cups this was 0.09 to 0.03 m^2. Scores lowest for PHA production from sugar cane and wastewater and highest for PHA production from corn/maize and PLA production.
- For PHA cups water use ranged from -0.005 to 0.03 m^3 and for fossil-based cups this was 0.001 to 0.003 m^3. Scores lowest for PHA production from sugar beet and wastewater and highest for PHA production from sugar cane and corn/maize.
- For PHA cups acidification ranged from -0,002 to 0.0005 kg SO_2-eq and for fossil-based cups this was 0.001 to 0.002 kg SO_2-eq
- For PHA cups marine eutrophication ranged from -0.0003 to 0.0006 kg N-eq and for fossil based cups this was 0.0002 to 0.0004 kg N-eq. Scores lowest for PHA production from wastewater and sugar beet and highest for PHA production from corn/maize and sugar cane.
- For PHA cups fresh eutrophication ranged from 0.00004 to 0.0001 kg P-eq and for fossil based cups this was 0.0001 to 0.0003 kg P-eq. Scores lowest for PLA production and PHA production from wastewater and highest for production from PP and PHA production from sugar cane.

When production from PHA is compared with production from conventional plastic, it appears that the environmental impact is lower for production from PHA depending on the production route. The average PHA with re-use and with cassava in the average shows that a few of the impact categories (climate change and energy use) score lower than conventional plastic. The average PHA with no re-use and with cassava in the average shows that the average environmental impact is higher than the production of conventional plastic. However, cassava remains biodegradable, while conventional plastic does not.

The largest environmental impact came from production of PP, PC and PHA out of corn/maize. PHA production from wastewater scores best, followed by sugar beet, PLA and sugar cane.

A sensitivity analysis was performed in order to test the final results for changes in fundamental parameters. Sensitivity analysis showed that recycling was critical in reducing environmental impact (up to 75%). When moving to a conversion factor of 2 kg sugar to 1 kg PHA reduce the environmental impact up to 42%. Moving to a situation where the EOL route consists of 100% recycling reduced the overall environmental impact up to 176% mainly being greenhouse gases and fossil energy use.

Results of the sensitivity analysis showed that factors such as conversion factors and re-use are important in determining the end result. Attention is needed for such factors in order further reduce impact of biobased festival cups.

Contents

1. Introduction

Plastics are used worldwide in many different applications and are almost indispensable in today's society. Plastics are the general term of different polymers used for different application such as polyethylene and polypropylene. Public use of plastics is not only easy, the material is also strong, light and versatile (Plastics Europe, 2019). In recent years, however, more and more awareness has grown around the use of plastics and its downsides. Downsides of using plastics include:

- Most plastics are made from (exhaustible) fossil resources.
- Plastics are generally not biodegradable leading to all sorts of problems in the environment including the plastic soup and microplastic concentration in organisms.
- (Derraik, 2002).

Every year around 0.57 million tons of plastics are used in the Netherlands alone (plasticsoupfoundation, 2016). 66% of this plastic is used and incinerated, 34% is recycled and 0% is landfilled (table 2). Traditionally, plastics are polymerized from oil and reworked through either blow molding or injection molding to the final product. Currently, polymers are non-biodegradable and persist in the environment when deposited there. This means that plastics will accumulate in the environment if not treated or recycled. This becomes worse when plastics are degraded to microplastics that become invisible for the eye, but remain in the environment being prone to indigestion by soil life and other animals. Hence, in many ways plastics or residuals of plastics are cycling within the biome and can give side-effects. In this way, biobased polymers that are obtained from 'sustainable' biomass and are generally biodegradable and may form a solution for keeping the benefits of polymers, but at the same time reducing the environmental pressure.

One source of plastic use are music festivals like Parkpop in The Hague in the Netherlands, which is a large three-day festival that attracts around 275.000 visitors each year. During the festival in 2017, 300.000 plastic cups were used for consuming drinks such as beer. This is to indicate how much plastic debris is released from a large festival like Parkpop (Omroep West , 2017). In 2017, the number of festivals in the Netherlands increased to 954 festivals (festivals with more than 3000 visitors). The total number of visitors at these festivals in 2017 was 26.6 million (Dee, Arne VNPF, 2018). With the numbers from the Parkpop festival, it can be estimated that 26.6 million visitors use approximately 29 million plastic cups. Nowadays, during festivals, PET cups are mainly used for serving drinks. On average, a PET cup weighs 23 grams (DI Christian Pladerer & DI Markus Meissner, 2018). Following, yearly around 667 tons of single-use plastic is used at festivals in the Netherlands alone.

Various types of biopolymers exist including polylactic acid (PLA) and polyhydroxyalkanoates (PHA). The biopolymers all have different functions and applications. The most common application of PLA is the packaging of products such as fruit and vegetables (European Bioplastics , 2019) and PHA can be used, for example, in cups and glue. PHA's are a naturally occurring polymer made by bacteria as an energy reserve in their cells. The production of PHA in the cell requires a specific carbon source. The required carbon sources can consist of: oils, sugars (Ingrid Odegard, 2017), volatile fatty acids - which can originate from wastewater sludge- (Visser, et al., 2016), agri-food waste (Kootstra, Elissen, & Huurman, 2017) and much more. Depending on the type of PHA, the extraction process or the composition of combined polymers, PHA can have different properties. In general, some types can be brittle and stiff, such as PHB (Kootstra, Elissen, & Huurman, 2017) but when combined with PHV to PHBV, it can achieve properties almost similar to polypropylene (PP). In addition, it is known that PHA is biodegradable (Gurieff & Lant, 2006). The environmental impact of biopolymers has been determined for e.g. PLA, PHA etc. However, the application into biobased festival cups has not yet been considered in terms of environmental impacts.

The European project (Interreg - North Sea Region) BIOCAS (Circular Biomass Cascade to 100%) aims to create new Biocascading Alliances (BCA). One of these alliances is formed by LIMM recycling, NHL University of Applied Sciences, World Perfect, House of Design and VHL University of Applied Sciences. The focus of this alliance was to create a biocup from biomaterial PHA. The cup needs to replace conventional fossil-based cups used at music festivals. One of the tasks was to perform an environmental assessment which was done in this study.

The aim of this study was to assess the environmental impact of PHA festival cups, using different biobased resources, and compare them to conventional plastics PLA, PP, PET, PC and PS by performing a Life Cycle Assessment at which the environmental impact of the entire product life cycle has been included.

2. Material and methods

2.1. Type of LCA

For this research, a consequential approach to LCA was used to assess the impact of different types of raw materials from which plastic cups are made. Consequential LCA aims to show the changes in environmental impact when moving from fossil-based polymers to biobased polymers. However, where no other data were available, attributional data were used.

2.2. Scope and boundaries

Figure 1 shows the system boundaries used for the LCA. The fossil-based system starts at the top left. First, fossil resources are used to produce polymers, e.g.: Polypropylene (PP), Polyethylene (PE), Polyethylene Terephthalate (PET), Polystyrene (PS) and Polycarbonate (PC). After producing the polymer granulates the next step is to produce the cups via injection molding. After this process, the cups are ready for single use or as a re-useable fossil-based cup. Transport takes place throughout the whole chain, from factories to producers and from producers to users. The entire transport process has been collected and summarized in one chain step (transport and collection). The steps of the fossil-based cups also apply to the biobased cups.

The life cycle of the biobased cups starts in the green block (within the green lines). If biomass is used, it must be produced and processed into biopolymers. Another path is to extract high-value components from wastewater and make biopolymers from them. All other chain steps are similar to those of fossil cups.

After the use phase of the cups, they reach their 'End Of Life' (EOL). This EOL is based on (the three) general routes: 1. recycling, 2. incineration with energy recovery and 3. landfill.

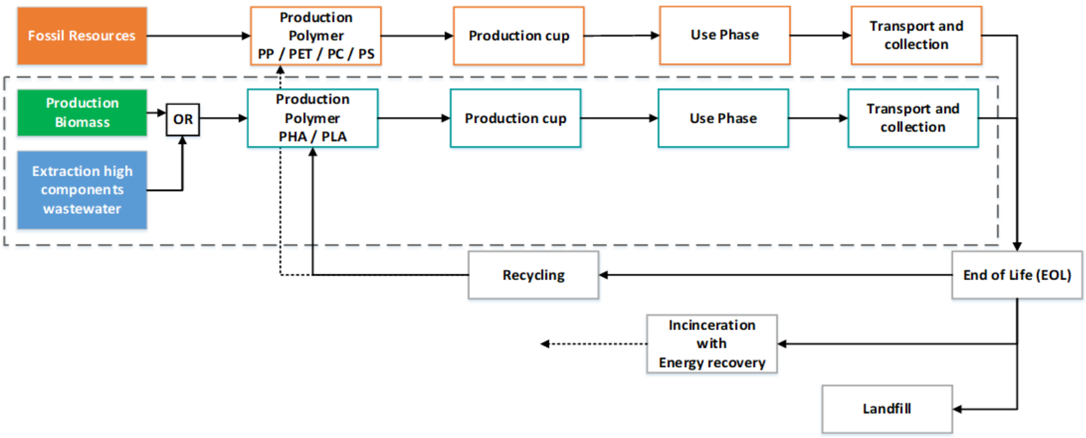

Figure 1, the system boundaries and the assessed process steps for the LCA. Transport and collection is placed at one point in the figure, but includes the transport steps across the entire chain. The orange path shows all the steps for the fossil based polymers and the green path for the biobased polymers. Both paths have the same routes for the End Of Life (EOL).

2.3. Data

Data were collected through literature search (publications and research reports) based on the criteria given in the LCA method. In addition, the Ecoinvent database (version 3.2) was used for most of the background data.

2.4. Functional unit and assumptions

In order to be able to compare the different cups, multiple functional units were used. The first step (Figure 1) is to produce polymers out of fossil resources or biomass. The chosen functional unit up to where it leaves the factory is expressed per kg produced polymer. After producing the polymers the next step is to produce cups for use (use phase). After the use phase the cups reach their 'End Of Life' (EOL). The functional unit is expressed per liter served drink (with and without EOL).

Based on Figure 1, this section discusses the choices and assumptions per process step. The process steps are divided into:

1). Production of the polymer.
2). Production of the cup.
3). Use phase.
4). Transport and collection.
5). End of Life including recycling, incineration and landfilling.

2.4.1. Production polymers

PHA based polymers

During the literature research, different biomass sources for the production of PHA were found. The production of the biomass occurred in various regions including:

- For Corn/Maize the scope was within the United States of America
- For Cassava the scope was in China or Thailand
- For Sugar cane the scope was North Australia
- For Sugar beet the scope was the United Kingdom
- For the waste stream (wastewater) the scope was the Netherlands

It was difficult to find research papers for cassava, as a result of which not all environmental impact data (land use and eutrophication) were found. It was decided to use the average number of corn/maize, sugar cane and sugar beet. This does not reflect actual numbers.

Products out of sugar cane and corn/maize already have environmental credits (negative emission numbers) because by-products from the process can be used for energy production. This reduces the required amount of the electricity from the mix.

Not all data was expressed per kg PHA. Part of the data was expressed in kg sugar. This is converted into kg PHA using conversion factors. There is no consensus on the conversion factor in the literature. Literature studies show that this factor varies between 1.8 and 5 kg sugar for 1 kg PHA (see Table 1). It was decided to use 3 kg as a factor, and calculate the effects of this factor on the variations using a sensitivity analysis.

Table 1, reported ranges of conversion factors sugar to PHA from literature and the communicated factor from BIOCAS-partner LIMM Recycling

X kg sugar to 1 kg plastic	Type (type of sugar)	Date	Source
3 kg	PHB (Sucrose)	2001	Nonato, Mantel2atto & Rossell (Nonato, Mantelatto, & Rossell, 2001) (3 kg product (PHB) = 3 kg Sucrose)
1.8 kg	PHB (Sucrose)	2007	Harding et. al. 2007 (Harding, Dennis, Von Blottnitz, & Harrison, 2007) (1000 kg PHB = 1810 kg Sucrose needed)
3 kg	PHB (Sucrose)	2010	Koller, Atlic, Dias, Reiterer & Braunegg (Koller, Atlić, Dias, Reiterer, & Braunegg) 1 kg PHB = 3 kg of sucrose (sugar cane)
2.48 kg (3.7 kg corn)	PHA (glucose)	2016	Jiang et al 2016 (Jiang, et al., 2016) 1 kg Corn = 0.67 kg Sucrose = 0.27 kg PHA -> 1 kg PHA = 2.48 kg sugar
5 kg	PHA	2017	ACCRES - WUR (Kootstra, Elissen, & Huurman, 2017) 1 kg product (PHA?) = 5 kg of raw material
3 kg	PHBV (Glucose)	2019	LIMM Recycling pers. communication (2019)

PLA based polymers

For PLA, there were several research papers that used a different biomass source: corn/maize, sugar cane, sugar beet, cassava and more. Most data were available for corn/maize. Therefore it was decided to use these numbers for production. If only one value was found, the number was added to the average and copied to the minimum and maximum values to reduce empty cells and use the impact within the assessment.

Fossil-based polymers

For polymers (PP, PET, PC and PS) the approach was similar except their source is different. Also (as with the other sources) the same approach was used for a single available number (average and also set to minimum and maximum).

2.4.2. Production cups

Once emissions and consumptions of polymer production are known, the next step is to find out what the impact is of converting these polymers into cups. This section describes important steps for collecting data to make calculations. Within this paragraph, a distinction has been made between different types of cups.

PHA and fossil cups

Emissions and consumptions were calculated based on emissions of injection molding from the Ecoinvent database (V.3.2) and emissions related to energy production.

PLA cups

According to (Li Shen, 2012), due to the lower calorific value and properties of PLA the amount of electricity (kWh) needed for the injection molding process was half of the amount needed for PET (2.1 kWh/ kg). This resulted in the use of 1.05 kWh / kg for producing cups from PLA.

2.4.3. Use phase

If the cups were re-used, it was assumed that the cups were washed. Based on the study of (Vercalsteren, Spirinckx, Geerken, & Claeys, 2006) 0.05 liter water was used per cup. The use of water throughout the whole chain furthermore consisted of fractions used for cooling water (cooling pond system and once-through system and recirculating system) and process water (Ecoinvent database V. 3.2).

2.4.4. Transport and collection

For all different polymers, transport during the entire life cycle is summarized in a separate chain step. Transport includes all (transport) means transport to: producers, distributors and events. This transport includes outward and return journeys, as well as waste collection.

Fossil cups

For this analysis, the report of the OVAM stated average distances was used (Vercalsteren, Spirinckx, Geerken, & Claeys, 2006).The data for the collection of waste was found in the Boss paper (A.Boss, 2013) and emission data is from the Ecoinvent database (v 3.2).

PHA and PLA cups

PHA is currently produced at a manufacturer in China (personal communication from LIMM recycling). After production, PHA is transported to Europe where it is sold to various companies. Research by OVAM (Vercalsteren, Spirinckx, Geerken, & Claeys, 2006) shows that PLA is also produced outside Europe. The distances mentioned in this report have also been adjusted for PHA. Waste collection data was found in the Boss paper (A.Boss, 2013) and emissions data came from the Ecoinvent database (v 3.2).

2.4.5. End of Life

When reaching their end of life, it is assumed that the cups will follow one of three conventional end-of-life options: recycling, incineration (assuming energy recovery) or landfill. Plastics Europe (Plastics Europe , 2019) has obtained data on waste distribution from all over Europe. In addition, specifically for the countries participating in the project: Belgium, Denmark, the Netherlands and Germany (see table 2). It was decided to use the percentages from Europe in table 2 as a baseline. Other fractions were tested in a sensitivity analysis.

Table 2, distribution of waste streams on European scale, and per country (Belgium, Denmark, The Netherlands and Germany). The end of life options considered are recycling, incineration with energy recovery and landfill (Plastics Europe, 2019).

Distribution streams EOL – *(data 2018)*	**Europe**	**Belgium**	**Denmark**	**The Netherlands**	**Germany**
Recycling in EU	33%	33%	36%	34%	38%
Incineration in EU with energy recovery	43%	65%	61%	66%	62%
Landfill	25%	2%	3%	0%	1%
Total	100%	100%	100%	100%	100%

Recycling

Research shows that it is not possible to recycle material for the full 100%. This means that material is still lost during the process. The lost material must be replaced with new material to ensure the same quality and production volume of drinking cups. Within the assessment, the emissions/consumption avoided by recycling is used as environmental credit. The emission/consumption fractions produced to replenish the material lost during recycling are added to the credits (resulting in lower credits).

From literature and personal communication (LIMM, 2019), efficiency figures of 90% were mentioned for PET and 79-80% for PS. It has been decided to use 90% as a baseline and test this number in the sensitivity analysis.

Within the assessment it is assumed for PHA that the recycled material does not replace the new PHA, but replaces one of the fossil polymers as this still is the marginal product on the market. Therefore PP is chosen because this material is used the most and the avoided emissions of PP were used in the calculation of PHA.

Incineration

The incineration of plastic is based on an energy and heat recovery system. In addition to emissions from the literature, also emissions based on calorific values of the different polymer types have been used. From this, it is calculated how much energy (heat and electricity) is replaced by this process. It is assumed that the heat and energy replace a regular European energy mix. The electricity data is from the Ecoinvent database (v 3.2).

Landfill

The last end of life option is the waste phase. The Ecoinvent database (Landfill plastic waste mix) was used for emission/consumption calculations. It has been assumed that the plastic hardly degrades over the a time frame of 100 years.

2.5. Environmental impact assessment

Based on the ReCiPe 2016 v1.1 method (Huijbregts, et al., 2016), seven impact categories were used to assess the environmental impact of bringing a new plastic cup to the market. It was decided to use separate environmental indicators (impacts) to express the effects over a period of 100 years (*the hierarchical method*). The chosen environmental indicators were:

1. Climate change *(kg CO_2-eq)*
2. Nonrenewable Energy Use *(MJ)*
3. Land use *(m^2a)*
4. Water use *(m^3)*
5. Terrestrial Acidification *(kg SO_2-eq)*
6. Marine eutrophication (kg N-eq)
7. Fresh eutrophication *(kg P-eq)*

2.6. Indirect land use change (iLUC)

Land used for agricultural purposes involves the change of land covers. This can either be changes from grass to arable farming (direct) or involve the expansion of land area under agriculture into other biomes like forests, called indirect land use change or iLUC. ILUC is important in terms of converting carbon stored in the forest and soil to the atmosphere. This emission in turn contributes to global warming. In case of biobased cup production, land is used for growing raw materials such as corn/maize and sugar beet. In order to take the effects within the LCA, an iLUC factor was used based on (Tonini, Hamelin, & Astrup , 2015). In the paper the authors calculated an overall factor of 4.1 ton CO_2-equivalents/ $ha_{demanded}$ per year, which for this LCA was recalculated to 0.41 kg CO_2-equivalents/ m^2 per year.

2.7. Sensitivity analysis

A sensitivity analysis was performed in order to test the final results for changes in fundamental parameters. The parameters that were tested included: different conversion factors (resp. 2 kg and 5 kg sugar per kg plastic), different EOL rates for Europe (resp. 100% recycling, 100% incineration and 100% landfill), different recycling efficiency's for Europe (resp. 50, 70 and 100% recycling) and different re-use factors (resp. 10x re-use and 20x re-use).

3. Results and analysis

3.1. Total Life Cycle Emissions per kg produced polymer

Table 3 shows the life cycle impact of producing the polymer up to where it leaves the factory. On average, PHA (without cassava) emits less greenhouse gases than fossil polymers (0.7 - 1.3 versus 4.2 kg CO_2-eq), has lower acidification (-0.01 versus 0.03 kg SO_2-eq) and a lower energy use (13.7 versus 86.3 MJ). With cassava in the average, this was 12.5 MJ. On the contrary, production of PHA from crops is related to the use of land and water for growing the crops. Within that bound, corn/maize needs the most land (4.9 m^2) compared to the other subtypes, and sugar cane uses the most water (1.19 m^3). Wastewater scores lowest on almost all impacts categories except for energy use and acidification. For fossil polymers, the highest impact on climate change is mostly related to the production of PC, PET and PS, whereas PP scores lower on climate change, fossil energy use and land use compared to other fossil subtypes.

On average, PLA production scores were lower for climate change and fossil energy compared to fossil types. PLA production does require more land and water than other fossil types.

For both marine and freshwater eutrophication, the averages are approximately equal for PHA and fossil polymers. However, the values for freshwater eutrophication are a little bit higher for fossil types than for PHA. For marine eutrophication it is the opposite.

Table 3, Total Life Cycle Emissions of 1 kg produced polymer

Cradle to Factory gate – *Total Life Cycle Emissions of 1 kg produced polymer – Average numbers (PHA = polyhydroxyalkanoate, PLA = polylactide, PP = polypropylene, PC = polycarbonate, PS = polystyrene, PET = polyethylene) - iLUC = indirect landuse change which is associated with the use of land for agriculture and conversion of land and forest*									
	Subtype	**Climate change**	**Climate change wih iLUC**	**Energy use**	**Land use**	**Water use**	**Acidification**	**Marine eutrophication**	**Fresh eutrophication**
		kg CO2-eq	kg CO2-eq	MJ	m2 a	m3	kg SO2-eq	kg N-eq	kg P-eq
PHA	*Corn/maize*	-0.1	1.9	38.9	4.9	0.65	0.03	0.019	-0.0005
	Cassava	25.6	26.6	7.8	2.5	0.06	0.49	0.010	0.0005
	Sugarcane	1.1	2.1	-9.7	2.6	1.19	-0.06	0.011	0.0016
	Sug. Beet	2.2	2.2	14.2	-0.1	-0.21	0.01	0.001	0.0004
	Wastewater	-0.2	-0.9	11.4	-1.7	-0.10	-0.03	-0.014	-0.0011
Average PHA without cassava		**0.7**	**1.3**	**13.7**	**1.4**	**0.38**	**-0.01**	**0.004**	**0.0001**
Average PHA with cassava		**5.7**	**6.4**	**12.5**	**1.6**	**0.32**	**0.09**	**0.005**	**0.0002**
PLA	*PLA*	1.7	2.4	48.4	1.7	0.21	0.01	0.009	-0.0004
Fossil	*PP*	2.7	*	74.1	0.0	0.02	0.03	0.001	0.0001
	PC	6.4	*	107.1	0.0	0.01	0.04	0.005	0.0002
	PS	3.5	*	84.7	0.0	0.01	0.01	0.002	0.0000
	PET	4.0	*	79.2	0.7	0.04	0.03	0.002	0.0014
Average Fossil		**4.2**	*	**86.3**	**0.2**	**0.02**	**0.03**	**0.003**	**0.0004**

3.2. Total Life Cycle Emissions per liter served drink

Table 4 shows results for the functional unit of serving 1 liter served drink including the end of life and re-use. The effect of re-using the cups is clearly visible. For example the difference in the average numbers for climate change without cassava (0.08 kg CO_2-eq with re-use and 0.39 kg CO_2-eq without re-use). Compared with fossil cups, PHA cups produce less greenhouse gasses (0.08 kg CO_2-eq vs. 0.27 kg CO_2-eq without re-use), have lower acidification (-4.2E-04 kg SO_2-eq vs. 1.1E-03 kg SO_2-eq) and lower fossil energy use (1.32 MJ vs. 5.6 MJ), even when not re-used with cassava left out of the average.

When not re-used and with cassava in the average, the impact is sometimes higher compared to the average fossil no re-use scenario. For instance, when PP is re-used (PP-R 3 times) the average emission of CO_2 (0.17 kg CO_2-eq) is higher than biobased polymers that are re-used (except cassava).

PHA production from crops, however, is associated with higher land- and water use due to the need for land and water for growing crops. Mainly corn/maize has higher land use and associated with iLUC impact compared to other PHA sources. Wastewater reduces this need as there is no additional demand for land and water. This makes PHA from wastewater one of the most sustainable options from environmental point of view. It should be noted that waste water is limited resource as it is only available as a result of societal activity.

Cups made from PLA score lower (0.09 kg CO_2-eq) for climate change and for the use of fossil energy (1.89 MJ) than all other fossil types, even when re-used (PP-R = 0.17 kg CO_2- eq). PHA cups produced from cassava or sugar beet score higher for CO_2 emissions than cups made from PLA while cups made from sugar cane score the same as PLA cups.

Table 4, Total Life Cycle Emissions per liter served drink

Cradle to Cradle – *Total Life Cycle Emissions of serving 1L beverage – Different size + re-use – Average numbers (PHA - R = polyhydroxyalkanoate re-used, PLA = polylactide, PP (-R) = polypropylene (re-used), PET = polyethylene, PC = polycarbonate, PS = polystyrene) - iLUC = indirect landuse change which is associated with the use of land for agriculture and conversion of land and forest*

	Subtype	Climate change	Climate change wih iLUC	Energy use	Land use	Water use	Acidification	Marine eutrophication	Fresh eutrophication
		kg CO2-eq	kg CO2-eq	MJ	m2 a	m3	kg SO2-eq	kg N-eq	kg P-eq
PHA - R (5 times)	*Corn/maize*	0.06	0.11	1.98	0.1	0.02	0.001	0.001	0.0001
	Cassava	0.72	0.75	1.17	0.1	0.001	0.01	0.0003	0.0001
	Sugarcane	0.09	0.11	0.71	0.1	0.03	-0.002	0.0003	0.0001
	Sug. Beet	0.12	0.12	1.34	0.003	-0.01	0.0002	0.0001	0.0001
	Wastewater	0.05	0.04	1.26	-0.04	-0.003	-0.001	-0.0003	0.00004
Average PHA - R (without cassava)		**0.08**	**0.09**	**1.32**	**0.04**	**0.01**	**-0.0004**	**0.0002**	**0.0001**
Average PHA - R (with cassava)		**0.21**	**0.22**	**1.29**	**0.05**	**0.01**	**0.002**	**0.0002**	**0.0001**
Averagge PHA with no re-use (without cassava)		**0.39**	**0.47**	**6.61**	**0.2**	**0.05**	**-0.002**	**0.001**	**0.0004**
Averagge PHA with no re-use (with cassava)		**1.04**	**1.12**	**6.46**	**0.2**	**0.04**	**0.01**	**0.001**	**0.0004**
PLA		0.09	0.11	1.89	0.03	0.003	0.0002	0.0002	0.00005
Fossil - R	*PP*	0.52	*	11.47	0.02	0.002	0.002	0.0002	0.0003
	PP - R (3 times)	0.17	*	3.82	0.01	0.001	0.001	0.0001	0.0001
	PET	0.14	*	2.60	0.02	0.001	0.001	0.0001	0.0001
	PC	0.27	*	4.75	0.01	0.0003	0.001	0.0003	0.0001
	PS	0.16	*	3.43	0.01	0.0002	0.0003	0.0001	0.0001
Average Fossil no re-use		**0.27**	*	**5.56**	**0.01**	**0.001**	**0.001**	**0.0002**	**0.0001**

3.3. Impact categories

Figure 2 shows the impact categories per liter of served drink divided per type of cup (the numbers and the figures are enlarged in Appendix I). Cassava is not shown in the graphs because most of the average values deviate strongly with other polymers. However, cassava was included in the rest of the analysis. This paragraph describes the share of the four steps in the chain (production raw material, production cup, transport and end of life including recycling) on the seven different impact categories (Climate change, Fossil energy use, Land use, Water use, Acidification, Marine eutrophication and Fresh eutrophication).

Climate change

Climate change ranged from 0.09 to 0.52 kg CO_2-eq per liter of served drink for the different production routes. It is clear to see that the CO_2 emissions per liter served drink are lower for PHA/PLA cups compared to fossil cups. Within PHA, corn/maize and wastewater show the lowest CO_2 emissions. The largest part of the emissions from PHA/PLA cups comes from the production of the cups, which also the case with fossil cups, only the production of the polymer (raw material) itself contributes to a large part of the CO_2 emissions. When looking at the end of life (incl recycling), the figure shows that CO_2 savings are the biggest for fossil cups. However, the total CO_2 emission from fossil cup production is higher than the production of PHA/PLA cups. The influence of transport and collection is minimal compared to other chain steps.

Fossil energy use

Fossil energy use ranged from 0.71 to 11.5 MJ per liter of served drink for the different production routes. Looking at figure 2, it is clear that fossil energy consumption per liter served drink are lower for PHA/PLA cups compared to fossil cups. Most of the fossil energy consumption of PHA/PLA cups arises from the production of the cups. As with climate change, the influence of the production of the polymer (raw material) has a big influence on the fossil energy consumption of fossil cups. When looking at the end of life (including recycling), the figure shows that the fossil energy savings are the biggest for fossil cups. On the other hand, the fossil energy consumption from the production of fossil cups is higher than the production of PHA/PLA cups, so the net fossil energy consumption of fossil cups is bigger than PHA/PLA cups. The influence of transport and collection is minimal compared to other chain steps.

Land use

Land use ranged from -0.04 to 0.13 m^2 per liter of served drink for the different production routes. The use of land per liter served drink is highest for the production of PHA out of corn/maize, relatively low for PC and other products from which PHA is produced (except sugar cane). PHA produced from wastewater even saves land. Without production of PHA from corn/maize and sugar cane, most of the land is used to produce fossil cups made from PP and also for production of PLA. In general, most of the land is lost on producing raw materials, but producing cups also costs land. When looking at the end of life (including recycling) it only seems to have impact on PLA. The influence of transport and collection is minimal compared to other chain steps.

Water use

Water use ranged from -0.005 to 0.03 m^3 per liter of served drink for the different production routes. The use of water per liter served drink is highest for the production of PHA from sugar cane and corn/maize, but relatively low for PLA and fossil components (like PC and PP). PHA produced from sugar beet and wastewater saves water. Without production of PHA from sugar cane and corn/maize, most of the water is used to produce fossil cups made from PP and also for production of PLA. In general, almost all the water is used for the production of raw materials. When looking at the end of life (including recycling) it only seems to have impact on PP and PLA. The influence of transport and collection is minimal compared to other chain steps.

Figure 2, results of the seven different impact categories per liter served drink, divided to the four chain steps: Raw material, Production, Transport and End of Life

Acidification

Acidification ranged from -0.04 to 0.13 kg SO_2-eq per liter of served drink for the different production routes. Looking at the figure of acidification, it is clear that acidification per liter served drink is lower for PHA/PLA cups compared to fossil cups. Within PHA, corn/maize and sugar beet have the highest SO_2 emissions which most is caused by the production of the raw material. The production of PHA out of wastewater and sugar cane saves SO_2 emissions. When looking at fossil cups the emissions of PP and PC are relatively high in comparison with PHA/PLA cups. When looking at the end of life (incl recycling), the figure shows that SO_2 savings are the biggest for fossil cups. On the other hand, the emissions for the production of fossil cups is higher than production of PHA/PLA cups, so the net SO_2 emission of fossil cups is bigger than PHA/PLA cups. The influence of transport and collection is minimal compared to other chain steps.

Marine eutrophication

Marine eutrophication ranged from -0.0003 to 0.0006 kg N-eq per liter of served drink for the different production routes. Looking at the figure of marine eutrophication, there is almost no difference between the eutrophication of PHA and fossil cups. Within PHA, emissions are highest for corn/maize and sugar cane and lowest for sugar beet (except for wastewater). When producing PHA from wastewater, N is saved. Within PHA, most of the eutrophication is due to the production of raw material. A small amount of the emisson is caused by transport and end of life (incl recycling). Within fossil cups, eutrophiation is highest for PC which is comparable with sugar cane. The eutrophication of PP, PC and PLA are almost equal. The only difference is that total eutrophication from PC are higher due to transport.

Freshwater eutrophication

Freshwater eutrophication ranged from 4 x 10^{-4} to 0.0026 kg P-eq per liter of served drink for the different production routes. Looking at the figure of fresh eutrophication, almost all the eutrophication is due to production of the cup itself. There is only little variation within the different PHA/PLA cup(s). Only eutrophicaton of suger cane is slightly higher than other PHA cups. It is noticeable that eutrophication values of PP are high compared to other cups. There is also big difference within the different fossil cups. For example, the eutrophication of PC made cups are much lower, and comparable to most PHA cups. The influence of transport and collection is minimal compared to other chain steps.

3.4. Sensitivity analysis

The merged results of the sensitivity analysis are presented in table 6 (for the numbers see appendix II).

Moving to a situation where PHA cups are re-used 10 to 20 times reduces the environmental impact up to 75% compared to the baseline situation.

When moving to a conversion factor of 2 kg sugar to 1 kg PHA, the environmental impact reduced up to 42%. Greenhouse gases were reduced up to 29%, acidification was reduced up to 42%, land use was reduced up to 32% , fossil energy use reduced up to 9% and water use reduced up to 35%.

When moving to a conversion factor of 5 kg sugar to 1 kg PHA, the environmental impact increased up to 84%. Greenhouse gases increased up to 59%, acidification increased up to 84%, land use increased up to 64%, fossil energy use increased up to 18% and water use increased up to 71%.

Moving to a situation where the EOL route consists of 100% recycling reduced the overall environmental impact up to 176% mainly being greenhouse gases and fossil energy use.

Moving to a situation where the EOL route consists of 100% incineration increased the overall environmental impact up to 82% mainly being greenhouse gases and fossil energy use.

Moving to a situation where the EOL route consists of 100% landfilled increased the overall environmental impact up to 90% mainly being greenhouse gases and fossil energy use.

When recycling efficiency's go up till 100%, the environmental impact reduced up to 10% compared to recycling efficiencies of 50%.

Table 6, Results of the sensitivity analysis testing for different parameters. Changes are represented in fractions compared to the baseline outcomes. Empty cells represent changes less than 0.5%

Production route	Climate change kg CO2-eq	Acidi-fication kg SO2-eq	Land use m^2a	Energy use MJ	Water use m^3	Marine eutroph. kg N-eq	Fresh eutroph. kg P-eq
Re-use 20x							
Corn/maize	-75%	-75%	-75%	-75%	-75%	-75%	-75%
Cassava	-75%	-75%	-75%	-75%	-75%	-75%	-75%
Sugar cane	-75%	-75%	-75%	-75%	-75%	-75%	-75%
Sugar beet	-75%	-75%	-75%	-75%	-75%	-75%	-75%
Wastewater	-75%	-75%	-75%	-75%	-75%	-75%	-75%
Re-use 10x							
Corn/maize	-50%	-50%	-50%	-50%	-50%	-50%	-50%
Cassava	-50%	-50%	-50%	-50%	-50%	-50%	-50%
Sugar cane	-50%	-50%	-50%	-50%	-50%	-50%	-50%
Sugar beet	-50%	-50%	-50%	-50%	-50%	-50%	-50%
Wastewater	-50%	-50%	-50%	-50%	-50%	-50%	-50%
Sugar - PHA 2kg							
Corn/maize		-37%	-32%	0%	-34%	-29%	8%
Cassava	-29%	-34%	-31%	-6%	-35%	-27%	-6%
Sugar cane	-8%	-32%	-31%	12%	-33%	-27%	-13%
Sugar beet	-13%	-42%	25%	-9%	-33%	-8%	-4%
Wastewater							
Sugar - PHA 5kg							
Corn/maize		74%	64%		67%	59%	-15%
Cassava	59%	67%	61%	12%	71%	53%	11%
Sugar cane	16%	64%	61%	-24%	67%	54%	26%
Sugar beet	26%	84%	-50%	18%	66%	15%	9%
Wastewater							
EOL-100% recycling							
Corn/maize		-72%		-56%	-2%	-11%	20%
Cassava		-3%	-1%	-96%	-25%	-18%	14%
Sugar cane		25%		-157%	-1%	-17%	10%
Sugar beet		-176%	-11%	-84%	6%	-70%	14%
Wastewater		54%	1%	-88%	12%	20%	29%
EOL-100% incineration							
Corn/maize		33%		25%	1%	-5%	-29%
Cassava		2%		42%	12%	-9%	-20%
Sugar cane		-11%		68%	1%	-8%	-15%
Sugar beet		82%	1%	36%	-3%	-34%	-20%
Wastewater		-25%		39%	-6%	10%	-42%
EOL-100% landfill							
Corn/maize		37%		32%	1%	23%	23%
Cassava		2%	1%	53%	12%	39%	16%
Sugar cane		-13%	1%	88%	1%	37%	12%
Sugar beet		90%	12%	47%	-3%	149%	16%
Wastewater		-28%	-1%	49%	-6%	-43%	33%

% Recycling eff. 50%						
Corn/maize	16%		13%		1%	
Cassava	1%		21%	5%	1%	
Sugar cane	-5%		35%		1%	
Sugar beet	38%	3%	19%	-1%	5%	
Wastewater	-12%		20%	-3%	-2%	1%
% Recycling eff. 70%						
Corn/maize	8%		6%			
Cassava			11%	3%	1%	
Sugar cane	-3%		18%		1%	
Sugar beet	19%	1%	9%	-1%	3%	
Wastewater	-6%		10%	-1%	-1%	
% Recycling eff. 100%						
Corn/maize	-4%		-3%			
Cassava			-5%	-1%		
Sugar cane	1%		-9%			
Sugar beet	-10%	-1%	-5%		-1%	
Wastewater	3%		-5%	1%		

4. Discussion

Consequential vs attributional LCA

For this research, a consequential approach to LCA was used to assess the impact of different types of raw materials from which plastic cups are made. Consequential LCA aims to show the changes in environmental impact when moving from fossil-based plastics to biobased polymers. During the assessment it was not always possible to use only consequential data. Because most data for PHA (as a biobased polymer) were not available, attributional data were used.

Geographical location

The data used for the LCA varied over different geographical areas and varied per type of polymer and biomass source. In current situation the production of PHBV, and therefore also the biomass sources (corn, cassava and sugar cane) production is taking place in China. For cassava, environmental data from China (Leng, Wang, Zhang, Dai, & Pu, 2008) and Thailand (Papong, et al., 2014) were used. For corn and sugar cane several sources were used, but they were not specific to this region.

Including data from different regions in the assessment can lead to different yields and the use of different fossil fuels and fertilizers. This process can affect the overall impact of the plastic cups. All other production data is assumed to be from Europe. For the EOL it was possible to not only use the average waste distribution of Europe but also per country, making this part applicable for the focus area of the project (for ranges in environmental impact see appendix III).

In the future it would be interesting to consider a new LCA where the whole production would take place in Europe, in specific the North Sea Region, which is the focus area of the BIOCAS project.

Sensitivity analysis

Results of the sensitivity analysis showed that factors such as conversion factors and re-use are important in determining the end result. Attention is needed for such factors in order further reduce impact of biobased festival cups.

Single-use plastic

As mentioned before approximately 667 tons of single-use plastic is used at festivals with more than 3000 visitors in the Netherlands alone. Replacing single-use plastic cups with biobased polymers can save up to 533 tons of single-use plastic at big music festivals in the Netherlands.

Ranges

Average values were used during the analysis. However, maximum and minimum values can be higher/lower than the average values. When climate change of corn/maize is used as an example (page 37) this shows an average value of 0.28 kg CO^2-eq, while the minimum value shows -0.38 kg CO^2-eq and the maximum value shows 0.94 kg CO^2-eq. Calculating with these numbers generates a completely different outcome. To get an idea of this, appendix 3 shows all ranges per environmental impact.

5. Conclusion

The aim of this study was to assess the environmental impact of PHA festival cups and compare them to conventional plastic. PHA can be made from different subtypes. The following subtypes have been included in this analysis: corn/maize, cassava, sugar cane, sugar beet and wastewater. The environmental impact was expressed in emissions/consumption per liter served drink, taking into account different production routes. Environmental impact categories considered where climate change, fossil energy use , land use, water use, acidification and fresh- and marine eutrophication.

Environmental impact ranged from:

- 0.09 to 0.52 kg CO_2-eq per liter of served drink. Scores lowest for PHA production from wastewater and corn/maize and highest for production from PP and PC.
- 0.71 to 11.5 MJ per liter of served drink. Scores lowest for PHA production from sugar cane and wastewater and highest for production from PP and PC.
- -0.04 to 0.13 m^2 per liter of served drink. Scores lowest for PHA production from sugar cane and wastewater and highest for PHA production from corn/maize and PLA production.
- -0.005 to 0.03 m^3 per liter of served drink. Scores lowest for PHA production from sugar beet and wastewater and highest for PHA production from sugar cane and corn/maize.
- -0.04 to 0.13 kg SO_2-eq per liter of served drink. Scores lowest for PHA production from sugar cane and wastewater and highest for production from PP and PC.
- -0.0003 to 0.0006 kg N-eq per liter of served drink. Scores lowest for PHA production from wastewater and sugar beet and highest for PHA production from corn/maize and sugar cane.
- 0.0004 to 0.0026 kg N-eq per liter of served drink. Scores lowest for PLA production and PHA production from wastewater and highest for production from PP and PHA production from sugar cane.

When production from PHA is compared with production from conventional plastic, it appears that the environmental impact is lower for production from PHA, depending on the production route. Even with cassava (re-used) in the average, it appears that a few of the impact categories (climate change and energy use) score lower than conventional plastic. When cassava is not re-used, the average environmental impact is higher than the production of conventional plastic. However, cassava remains biodegradable, while conventional plastic does not.

The largest environmental impact came from production of PP, PC and PHA out of corn/maize. PHA production from wastewater scores best, followed by sugar beet, PLA and sugar cane.

Sensitivity analysis showed that re-use was critical in reducing environmental impact (up to 75%). When moving to a conversion factor of 2 kg sugar to 1 kg PHA reduce the environmental impact up to 42%. Moving to a situation where the EOL route consists of 100% recycling reduced the overall environmental impact up to 176% mainly being greenhouse gases and fossil energy use.

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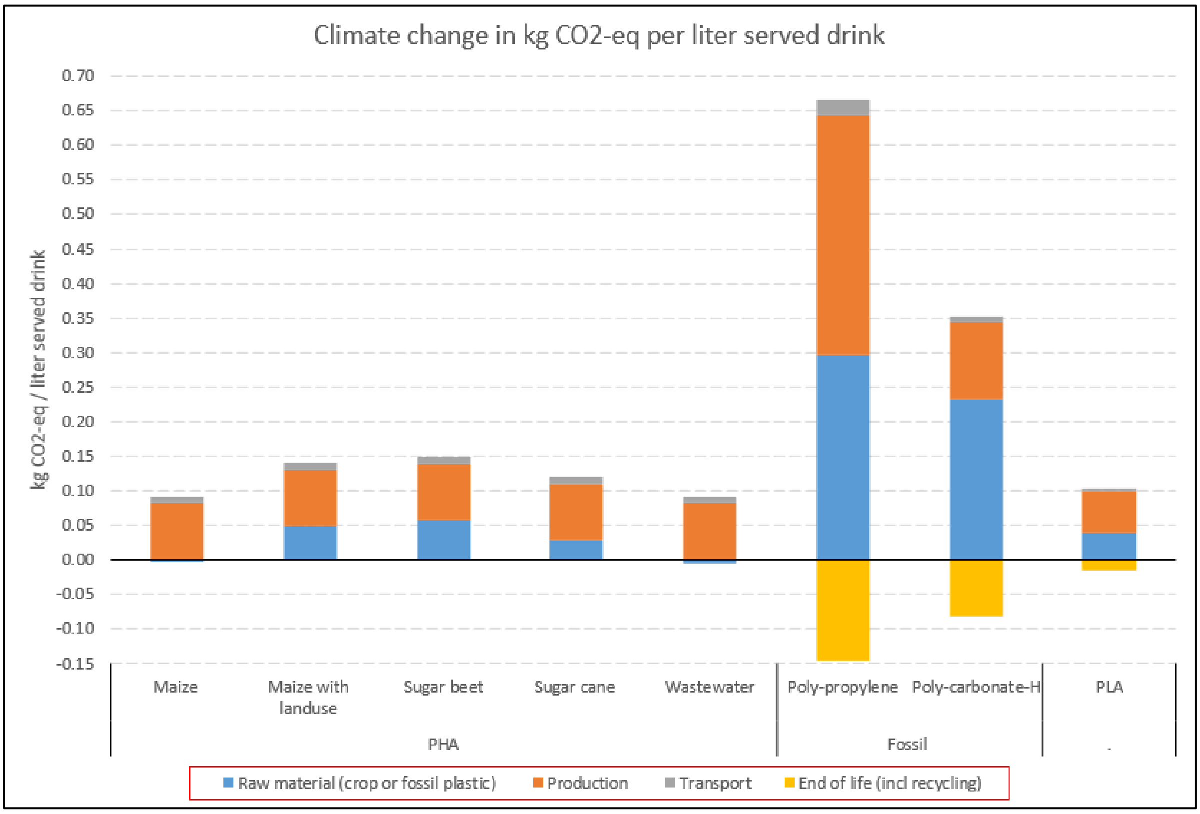
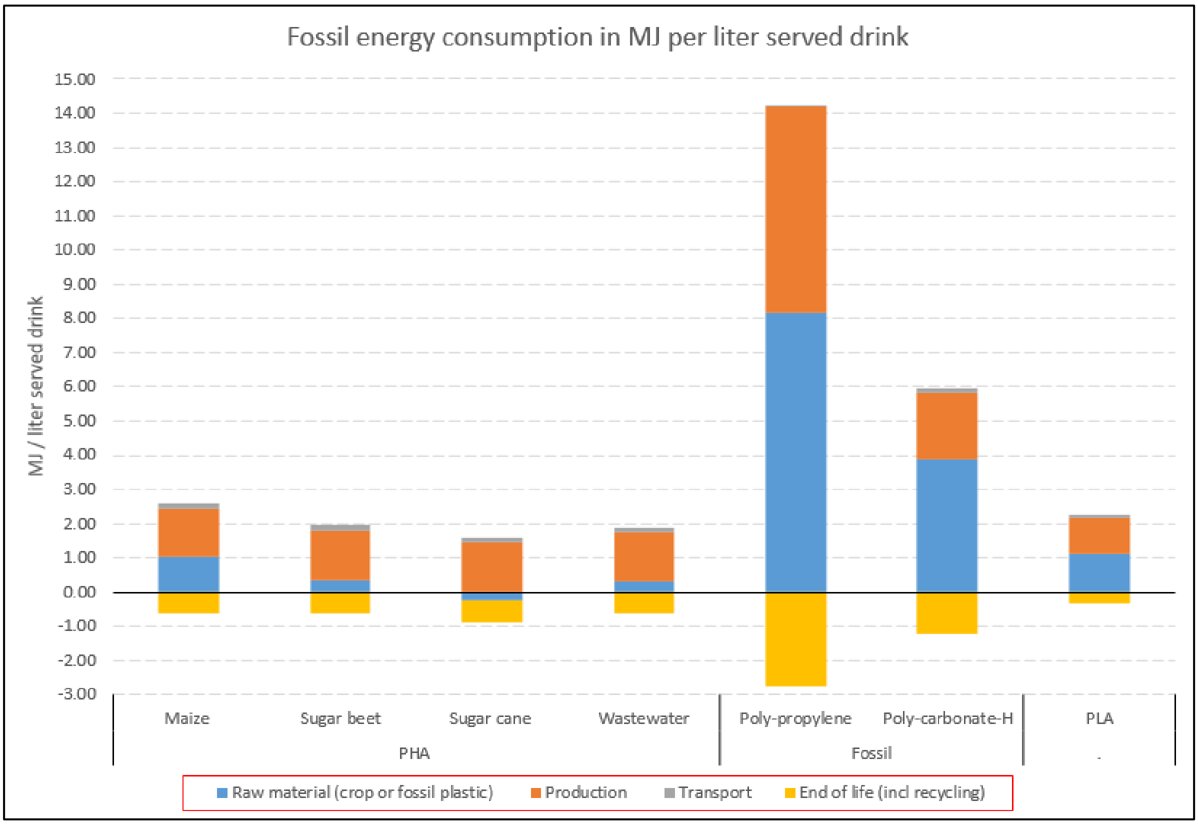
Appendix I

Climate change kg CO_2-eq/ kg polymer		PHA					Fossil		PLA
		Maize	Maize with landuse	Sugar beet	Sugar cane	Wastewater	Poly-propylene	Poly-carbonate-H	PLA
Raw material	Crop cultivaltion/ raw material	-0.10	1.91	2.20	1.07	-0.19	2.70	6.43	1.68
	Production	3.15	3.15	3.15	3.15	3.15	3.15	3.15	2.69
	Use								
	Transport	0.38	0.38	0.38	0.38	0.38	0.21	0.21	0.21
	End of life	0.00	0.00	0.00	0.00	0.00	-1.33	-2.24	-0.69
	Total	3.43	5.44	5.73	4.60	3.34	4.73	7.54	3.88
Raw material with R	Raw material (crop or fossil plastic)	0.00	0.05	0.06	0.03	0.00	0.30	0.23	0.04
	Production	0.08	0.08	0.08	0.08	0.08	0.35	0.11	0.06
	Transport	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.00
	End of life (incl recycling)	0.00	0.00	0.00	0.00	0.00	-0.15	-0.08	-0.02
	Total	0.09	0.14	0.15	0.12	0.09	0.52	0.27	0.09
Raw material %	Crop cultivaltion/ raw material	-2.9%	35.1%	38.4%		-5.8%	57.1%	85.2%	43.2%
	Production	91.8%	57.9%	55.0%		94.3%	66.5%	41.7%	69.3%
	Transport	11.1%	7.0%	6.7%		11.4%	4.4%	2.8%	5.4%
	End of life	0.0%	0.0%	0.0%		0.0%	-28.1%	-29.7%	-17.9%

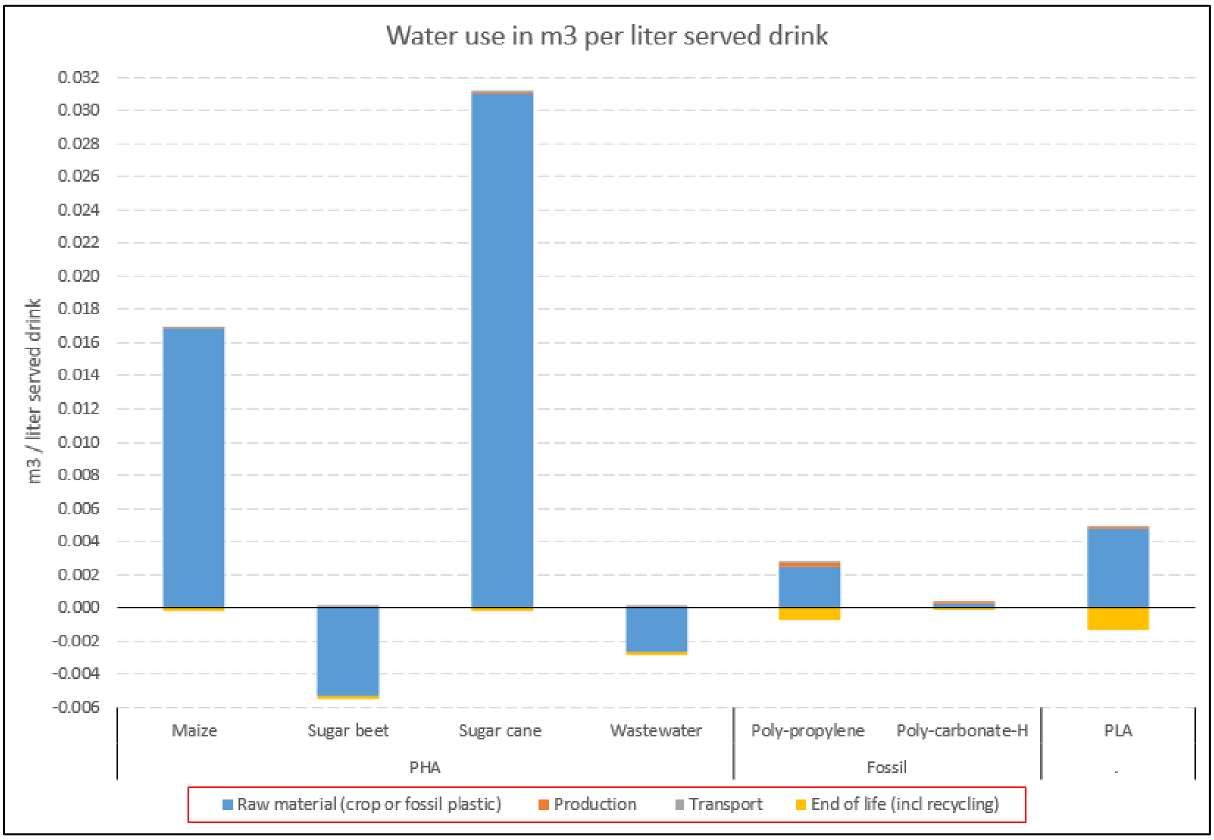


Energy use MJ/ kg polymer		PHA				Fossil		PLA
		Maize	Sugar beet	Sugar cane	Wastewater	Poly-propylene	Poly-carbonate-H	PLA
Raw material	Crop cultivaltion/ raw material	38.92	14.20	-9.75	11.44	74.12	107.06	48.37
	Production	55.07	55.07	55.07	55.07	55.07	55.07	46.99
	Use							
	Transport	5.85	5.85	5.85	5.85	0.04	3.43	3.43
	End of life	-23.75	-23.75	-23.75	-23.75	-24.94	-33.52	-15.42
	Total	76.09	51.37	27.42	48.61	104.30	132.04	83.37
Raw material with R	Raw material (crop or fossil plastic)	1.01	0.37	-0.25	0.30	8.15	3.85	1.10
	Production	1.43	1.43	1.43	1.43	6.06	1.98	1.07
	Transport	0.15	0.15	0.15	0.15	0.00	0.12	0.08
	End of life (incl recycling)	-0.62	-0.62	-0.62	-0.62	-2.74	-1.21	-0.35
	Total	1.98	1.34	0.71	1.26	11.47	4.75	1.89
Raw material %	Crop cultivaltion/ raw material	51.2%	27.6%		23.5%	71.1%	81.1%	58.0%
	Production	72.4%	107.2%		113.3%	52.8%	41.7%	56.4%
	Transport	7.7%	11.4%		12.0%	0.0%	2.6%	4.1%
	End of life	-31.2%	-46.2%		-48.9%	-23.9%	-25.4%	-18.5%

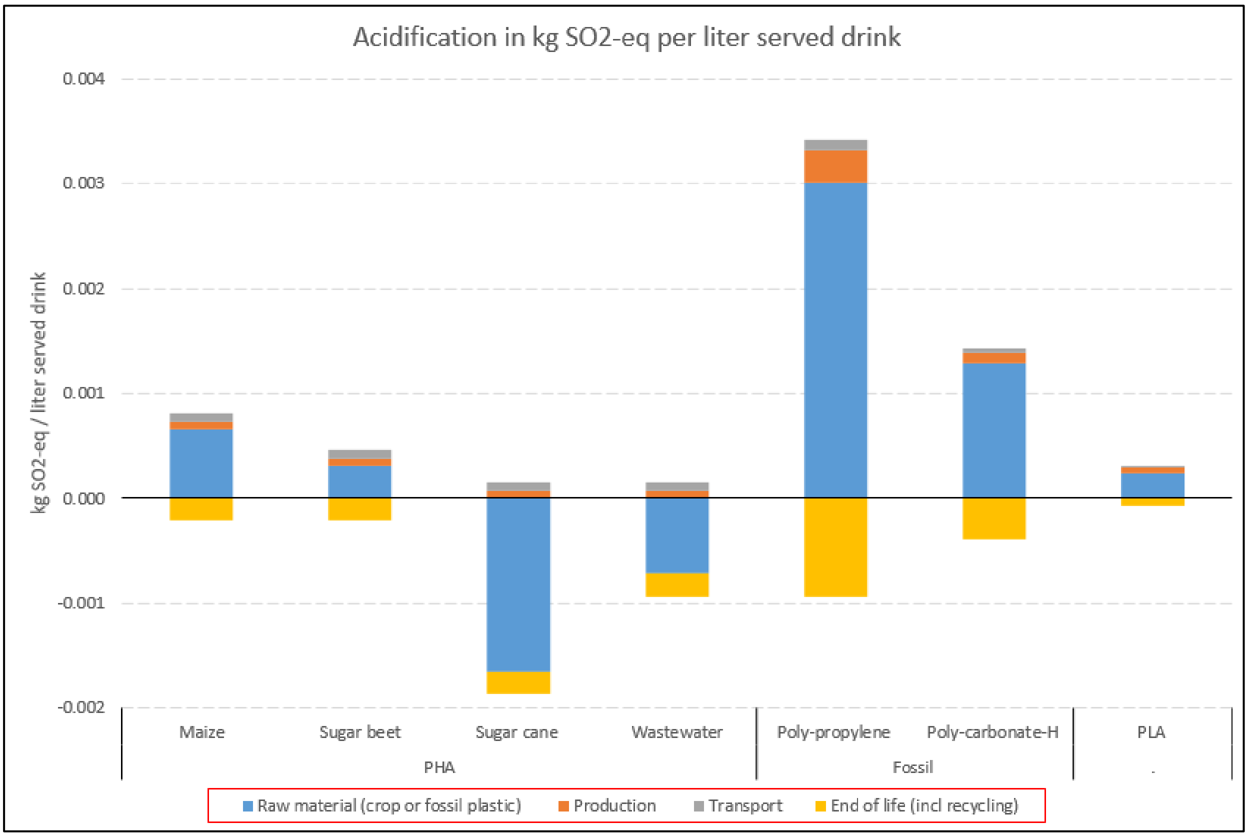


Land use m2/ kg polymer		PHA	PHA			Fossil		PLA
		Maize	Sugar beet	Sugar cane	Wastewater	Poly-propylene	Poly-carbonate-H	PLA
Raw material	Crop cultivaltion/ raw material	4.90	-0.09	2.59	-1.67	0.00	0.01	1.66
	Production	0.16	0.16	0.16	0.23	0.18	0.18	0.16
	Use							
	Transport	0.07	0.07	0.07	0.07	0.04	0.04	0.04
	End of life	-0.01	-0.01	-0.01	-0.01	-0.01	0.00	-0.48
	Total	5.12	0.13	2.81	-1.38	0.22	0.23	1.37
Raw material with R	Raw material (crop or fossil plastic)	0.13	0.00	0.07	-0.04	0.00	0.00	0.04
	Production	0.00	0.00	0.00	0.01	0.02	0.01	0.00
	Transport	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	End of life (incl recycling)	0.00	0.00	0.00	0.00	0.00	0.00	-0.01
	Total	0.13	0.003	0.073	-0.036	0.024	0.008	0.031
Raw material %	Crop cultivaltion/ raw material	95.7%	-74.5%		121.1%	1.2%	4.3%	120.6%
	Production	3.1%	126.4%		-16.7%	83.3%	78.5%	11.4%
	Transport	1.4%	55.8%		-5.1%	20.1%	19.0%	3.2%
	End of life	-0.2%	-7.7%		0.7%	-4.6%	-1.8%	-35.3%

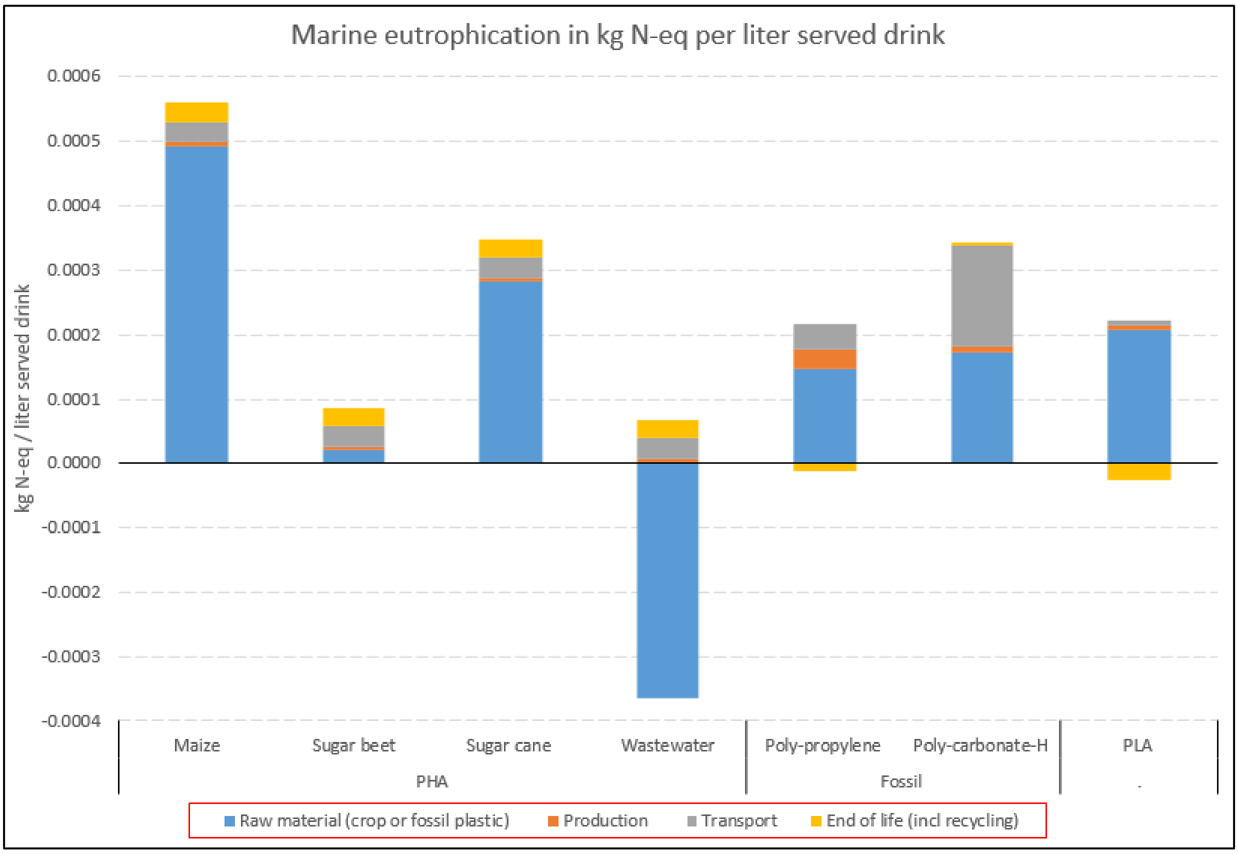
Water use m3/ kg polymer		PHA				Fossil		PLA
		Maize	Sugar beet	Sugar cane	Wastewater	Poly-propylene	Poly-carbonate-H	PLA
Raw material	Crop cultivaltion/ raw material	0.6461	-0.2053	1.1941	-0.1047	0.0221	0.0061	0.2115
	Production	0.0026	0.0026	0.0026	0.0026	0.0030	0.0030	0.0026
	Use							
	Transport	0.0005	0.0005	0.0005	0.0005	0.0002	0.0002	0.0002
	End of life	-0.0065	-0.0065	-0.0065	-0.0065	-0.0065	-0.0018	-0.0619
	Total	0.6427	-0.2088	1.1907	-0.1081	0.0189	0.0076	0.1525
Raw material with R	Raw material (crop or fossil plastic)	0.0168	-0.0053	0.0310	-0.0027	0.0024	0.0002	0.0048
	Production	0.0001	0.0001	0.0001	0.0001	0.0003	0.0001	0.0001
	Transport	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	End of life (incl recycling)	-0.0002	-0.0002	-0.0002	-0.0002	-0.0007	-0.0001	-0.0014
	Total	0.0167	-0.0054	0.0310	-0.0028	0.0021	0.0003	0.0035
Raw material %	Crop cultivaltion/ raw material	100.5%	98.4%	100.3%	96.9%	116.9%	80.2%	138.7%
	Production	0.4%	-1.2%	0.2%	-2.4%	16.0%	40.1%	1.7%
	Transport	0.1%	-0.2%	0.0%	-0.4%	1.2%	3.1%	0.2%
	End of life	-1.0%	3.1%	-0.5%	6.0%	-34.2%	-23.3%	-40.6%



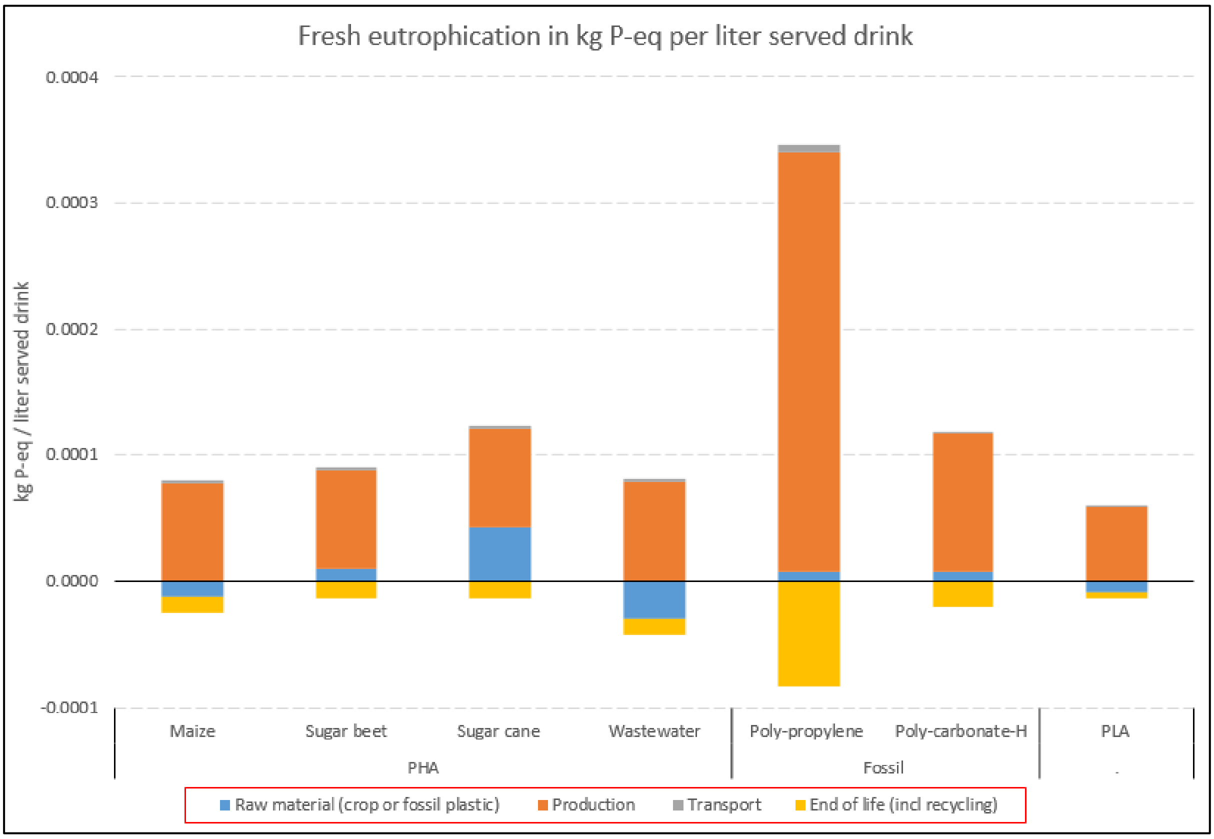
Acidification kg SO_2-eq / kg polymer		PHA				Fossil		PLA
		Maize	Sugar beet	Sugar cane	Wastewater	Poly-propylene	Poly-carbonate-H	PLA
Raw material	Crop cultivaltion/ raw material	0.0253	0.0118	-0.0635	-0.0276	0.0274	0.0359	0.0105
	Production	0.0027	0.0027	0.0027	0.0027	0.0028	0.0028	0.0024
	Use							
	Transport	0.0031	0.0031	0.0031	0.0031	0.0009	0.0009	0.0009
	End of life	-0.0083	-0.0083	-0.0083	-0.0083	-0.0085	-0.0108	-0.0032
	Total	0.0228	0.0093	-0.0660	-0.0301	0.0226	0.0288	0.0105
Raw material with R	Raw material (crop or fossil plastic)	0.0007	0.0003	-0.0017	-0.0007	0.0030	0.0013	0.0002
	Production	0.0001	0.0001	0.0001	0.0001	0.0003	0.0001	0.0001
	Transport	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0000
	End of life (incl recycling)	-0.0002	-0.0002	-0.0002	-0.0002	-0.0009	-0.0004	-0.0001
	Total	0.0006	0.0002	-0.0017	-0.0008	0.0025	0.0010	0.0002
Raw material %	Crop cultivaltion/ raw material	110.8%	126.5%	96.3%	91.8%	121.1%	124.7%	99.5%
	Production	11.8%	28.8%	-4.1%	-8.9%	12.5%	9.8%	22.9%
	Transport	13.8%	33.8%	-4.8%	-10.5%	3.9%	3.1%	8.5%
	End of life	-36.4%	-89.2%	12.6%	27.6%	-37.6%	-37.6%	-30.8%



Marine eutrophication kg N-eq / kg polymer		PHA				Fossil		PLA
		Maize	Sugar beet	Sugar cane	Wastewater	Poly-propylene	Poly-carbonate-H	PLA
Raw material	Crop cultivaltion/ raw material	0.01898	0.00076	0.01082	-0.01405	0.00133	0.00478	0.00920
	Production	0.00024	0.00024	0.00024	0.00029	0.00028	0.00028	0.00024
	Use							
	Transport	0.00119	0.00119	0.00119	0.00119	0.00036	0.00433	0.00036
	End of life	0.00112	0.00112	0.00112	0.00112	-0.00011	0.00011	-0.00118
	Total	0.02153	0.00332	0.01338	-0.01145	0.00186	0.00950	0.00862
Raw material with R	Raw material (crop or fossil plastic)	0.00049	0.00002	0.00028	-0.00037	0.00015	0.00017	0.00021
	Production	0.00001	0.00001	0.00001	0.00001	0.00003	0.00001	0.00001
	Transport	0.00003	0.00003	0.00003	0.00003	0.00004	0.00016	0.00001
	End of life (incl recycling)	0.00003	0.00003	0.00003	0.00003	-0.00001	0.00000	-0.00003
	Total	0.00056	0.00009	0.00035	-0.00030	0.00020	0.00034	0.00020
Raw material %	Crop cultivaltion/ raw material	88.1%	23.0%	80.9%	122.7%	71.6%	50.3%	106.8%
	Production	1.1%	7.3%	1.8%	-2.5%	15.2%	3.0%	2.8%
	Transport	5.5%	35.9%	8.9%	-10.4%	19.2%	45.5%	4.1%
	End of life	5.2%	33.8%	8.4%	-9.8%	-6.0%	1.2%	-13.7%



Fresh eutrophication kg P-eq / kg polymer		PHA				Fossil		PLA
		Maize	Sugar beet	Sugar cane	Wastewater	Poly-propylene	Poly-carbonate-H	PLA
Raw material	Crop cultivaltion/ raw material	-0.00049	0.00041	0.00165	-0.00115	0.00007	0.00022	-0.00040
	Production	0.00299	0.00299	0.00299	0.00304	0.00303	0.00303	0.00259
	Use							
	Transport	0.00010	0.00010	0.00010	0.00010	0.00005	0.00005	0.00005
	End of life	-0.00049	-0.00049	-0.00049	-0.00049	-0.00076	-0.00057	-0.00018
	Total	0.00211	0.00300	0.00424	0.00150	0.00239	0.00273	0.00205
Raw material with R	Raw material (crop or fossil plastic)	-0.00001	0.00001	0.00004	-0.00003	0.00001	0.00001	-0.00001
	Production	0.00008	0.00008	0.00008	0.00008	0.00033	0.00011	0.00006
	Transport	0.00000	0.00000	0.00000	0.00000	0.00001	0.00000	0.00000
	End of life (incl recycling)	-0.00001	-0.00001	-0.00001	-0.00001	-0.00008	-0.00002	0.00000
	Total	0.00005	0.00008	0.00011	0.00004	0.00026	0.00010	0.00005
Raw material %	Crop cultivaltion/ raw material	-23.1%	13.5%	38.8%	-76.8%	2.8%	8.0%	-19.6%
	Production	141.7%	99.5%	70.4%	203.1%	127.1%	111.2%	126.1%
	Transport	4.8%	3.4%	2.4%	6.8%	1.9%	1.7%	2.3%
	End of life	-23.4%	-16.5%	-11.6%	-33.0%	-31.8%	-20.9%	-8.8%



Appendix II

Reuse time - 20 x

Type	Split in Material	CC kg CO2-ec average	Acidificat kg SO2-ec average	Land occu m2a average	Energy us MJ average	Water us m3 average	Eutrophic kg N-eq average	Eutrophication kg P-eq average							
Serving FU [dif. Spec.]															
Cup 7	PHA														
	corn/maize	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							
	Cassava	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							
	sugarcane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							
	Sug. Beet	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							
	Wastewater	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							
Cup 7	R-PHA														
	corn/maize	0.02	0.00	0.03	0.49	0.00	0.00	0.00	-75.00%	-75.00%	-75.00%	-75.00%	-75.00%	-75.00%	-75.00%
	Cassava	0.19	0.00	0.02	0.29	0.00	0.00	0.00	-75.00%	-75.00%	-75.00%	-75.00%	-75.00%	-75.00%	-75.00%
	sugarcane	0.03	0.00	0.02	0.18	0.01	0.00	0.00	-75.00%	-75.00%	-75.00%	-75.00%	-75.00%	-75.00%	-75.00%
	Sug. Beet	0.04	0.00	0.00	0.33	0.00	0.00	0.00	-75.00%	-75.00%	-75.00%	-75.00%	-75.00%	-75.00%	-75.00%
	Wastewater	0.02	0.00	-0.01	0.32	0.00	0.00	0.00	-75.00%	-75.00%	-75.00%	-75.00%	-75.00%	-75.00%	-75.00%
Cup 8	PLA														
		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							
Cup 1	PP														
	fossil	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							
Cup 1	R-PP														
	fossil	1.1732	0.7278	1.6187	0.0058	0.0016	0.0635	0.0564							
Cup 2	PET														
	Fossil	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							
Cup 5	PC														
	Fossil	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							
Cup 7	PS														
	Fossil	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							

Reuse time - 10 x

Type	Split in Material	CC kg CO2-ec average	Acidificat kg SO2-ec average	Land occu m2a average	Energy us MJ average	Water us m3 average	Eutrophic kg N-eq average	Eutrophication kg P-eq average							
Serving FU [dif. Spec.]															
Cup 7	PHA														
	corn/maize	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							
	Cassava	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							
	sugarcane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							
	Sug. Beet	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							
	Wastewater	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							
Cup 7	R-PHA														
	corn/maize	0.04	0.00	0.07	0.99	0.01	0.00	0.00	-50.00%	-50.00%	-50.00%	-50.00%	-50.00%	-50.00%	-50.00%
	Cassava	0.38	0.01	0.03	0.58	0.00	0.00	0.00	-50.00%	-50.00%	-50.00%	-50.00%	-50.00%	-50.00%	-50.00%
	sugarcane	0.06	0.00	0.04	0.36	0.02	0.00	0.00	-50.00%	-50.00%	-50.00%	-50.00%	-50.00%	-50.00%	-50.00%
	Sug. Beet	0.07	0.00	0.00	0.67	0.00	0.00	0.00	-50.00%	-50.00%	-50.00%	-50.00%	-50.00%	-50.00%	-50.00%
	Wastewater	0.04	0.00	-0.02	0.63	0.00	0.00	0.00	-50.00%	-50.00%	-50.00%	-50.00%	-50.00%	-50.00%	-50.00%
Cup 8	PLA														
		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							
Cup 1	PP														
	fossil	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							
Cup 1	R-PP														
	fossil	1.1732	0.7278	1.6187	0.0058	0.0016	0.0635	0.0564							
Cup 2	PET														
	Fossil	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							
Cup 5	PC														
	Fossil	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							
Cup 7	PS														
	Fossil	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							

SUGAR - PHA 2 kg

Type	Split in Material	CC kg CO2-eq average	Acidification kg SO2-eq average	Land occupation m2a average	Energy use MJ average	Water use m3 average	Eutrophication kg N-eq average	Eutrophication kg P-eq average							
Serving FU [dif. Spec.]															
Cup 7	PHA														
	corn/maize	1.67	1.67	1.67	0.02	0.02	0.02	4.08							
	Cassava	22.13	22.13	22.13	0.41	0.41	0.41	2.05							
	sugarcane	1.78	0.76	2.80	-0.05	-0.12	0.01	2.16							
	Sug. Beet	1.82	0.36	3.27	0.01	0.01	0.01	-0.08							
	Wastewater	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
Cup 7	R-PHA														
	corn/maize	0.09	0.00	0.09	1.98	0.01	0.00	0.00	0%	-37%	-32%	0%	-34%	-29%	8%
	Cassava	0.53	0.01	0.05	1.10	0.00	0.00	0.00	-29%	-34%	-31%	-6%	-35%	-27%	-6%
	sugarcane	0.11	0.00	0.05	0.80	0.02	0.00	0.00	-8%	-32%	-31%	12%	-33%	-27%	-13%
	Sug. Beet	0.13	0.00	0.00	1.21	0.00	0.00	0.00	-13%	-42%	25%	-9%	-33%	-8%	-4%
	Wastewater	0.09	0.00	-0.04	1.26	0.00	0.00	0.00	0%	0%	0%	0%	0%	0%	0%
Cup 8	PLA														
		0.00	0.00	0.00	0.00	0.00	0.00	0.00							
Cup 1	PP														
	fossil	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
Cup 1	R-PP														
	fossil	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
Cup 2	PET														
	Fossil	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
Cup 5	PC														
	Fossil	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
Cup 7	PS														
	Fossil	0.00	0.00	0.00	0.00	0.00	0.00	0.00							

Sugar - PHA 5 kg

Type	Split in Material	CC kg CO2-eq average	Acidification kg SO2-eq average	Land occupation m2a average	Energy use MJ average	Water use m3 average	Eutrophication kg N-eq average	Eutrophication kg P-eq average							
Serving FU [dif. Spec.]															
Cup 7	PHA														
	corn/maize	-3.35	-3.35	-3.35	-0.04	-0.04	-0.04	-8.16							
	Cassava	-44.27	-44.27	-44.27	-0.82	-0.82	-0.82	-4.11							
	sugarcane	-3.56	-1.52	-5.59	0.11	0.24	-0.02	-4.32							
	Sug. Beet	-3.63	-0.72	-6.55	-0.02	-0.01	-0.02	0.16							
	Wastewater	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
Cup 7	R-PHA														
	corn/maize	0.09	0.00	0.22	1.98	0.03	0.00	0.00	0%	74%	64%	0%	67%	59%	-15%
	Cassava	1.20	0.02	0.11	1.30	0.00	0.00	0.00	59%	67%	61%	12%	71%	53%	11%
	sugarcane	0.14	0.00	0.12	0.54	0.05	0.00	0.00	16%	64%	61%	-24%	67%	54%	26%
	Sug. Beet	0.19	0.00	0.00	1.58	-0.01	0.00	0.00	26%	84%	-50%	18%	66%	15%	9%
	Wastewater	0.09	0.00	-0.04	1.26	0.00	0.00	0.00	0%	0%	0%	0%	0%	0%	0%
Cup 8	PLA														
		0.00	0.00	0.00	0.00	0.00	0.00	0.00							
Cup 1	PP														
	fossil	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
Cup 1	R-PP														
	fossil	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
Cup 2	PET														
	Fossil	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
Cup 5	PC														
	Fossil	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
Cup 7	PS														
	Fossil	0.00	0.00	0.00	0.00	0.00	0.00	0.00							

EOL - 100% Recycling

Type	Split in Material	CC kg CO2-eq average	Acidification kg SO2-eq average	Land occupation m2a average	Energy use MJ average	Water use m3 average	Eutrophication kg N-eq average	Eutrophication kg P-eq average							
Serving FU [dif. Spec.]															
Cup 7	PHA														
	corn/maize	4.3354	4.4613	4.2094	0.0409	0.0079	0.0739	0.0337							
	Cassava	4.3354	4.4613	4.2094	0.0409	0.0079	0.0739	0.0337							
	sugarcane	4.3354	4.4613	4.2094	0.0409	0.0079	0.0739	0.0337							
	Sug. Beet	4.3354	4.4613	4.2094	0.0409	0.0079	0.0739	0.0337							
	Wastewater	4.3354	4.4613	4.2094	0.0409	0.0079	0.0739	0.0337							
Cup 7	R-PHA														
	corn/maize	0.09	0.00	0.13	0.86	0.02	0.00	0.00	0%	-72%	0%	-56%	-2%	-11%	20%
	Cassava	0.76	0.01	0.07	0.05	0.00	0.00	0.00	0%	-3%	-1%	-96%	-25%	-18%	14%
	sugarcane	0.12	0.00	0.07	-0.40	0.03	0.00	0.00	0%	25%	0%	-157%	-1%	-17%	10%
	Sug. Beet	0.15	0.00	0.00	0.22	-0.01	0.00	0.00	0%	-176%	-11%	-84%	6%	-70%	14%
	Wastewater	0.09	0.00	-0.04	0.15	0.00	0.00	0.00	0%	54%	1%	-88%	12%	20%	29%
Cup 8	PLA														
		0.1702	0.1049	0.2354	0.0014	0.0015	0.0013	0.2278							
Cup 1	PP														
	fossil	1.0385	0.6376	1.4394	0.0176	0.0033	0.0319	0.0136							
Cup 1	R-PP														
	fossil	0.3462	0.2125	0.4798	0.0059	0.0011	0.0106	0.0045							
Cup 2	PET														
	Fossil	0.4759	0.3350	0.6168	0.0041	0.0013	0.0068	0.0962							
Cup 5	PC														
	Fossil	6.1799	4.5635	7.7962	0.0384	0.0237	0.0531	0.0076							
Cup 7	PS														
	Fossil	0.4479	0.4267	0.4691	0.0017	0.0016	0.0018	-0.0022							

EOL - 100% Incineration

		CC	Acidificat	Land occu	Energy us	Water us	Eutrophic	Eutrophication							
		kg CO2-eq	kg SO2-ec	m2a	MJ	m3	kg N-eq	kg P-eq							
Type	Split in Material	average	average	average	average	average	average	average							
Serving FU [dif. Spec.]															
Cup 7	PHA														
	corn/maize	-2.1596	-3.2746	-1.0445	-0.0190	-0.0031	-0.0348	-0.0028							
	Cassava	-2.1596	-3.2746	-1.0445	-0.0190	-0.0031	-0.0348	-0.0028							
	sugarcane	-2.1596	-3.2746	-1.0445	-0.0190	-0.0031	-0.0348	-0.0028							
	Sug. Beet	-2.1596	-3.2746	-1.0445	-0.0190	-0.0031	-0.0348	-0.0028							
	Wastewater	-2.1596	-3.2746	-1.0445	-0.0190	-0.0031	-0.0348	-0.0028							
Cup 7	R-PHA														
	corn/maize	0.09	0.00	0.13	2.47	0.02	0.00	0.00	0%	33%	0%	25%	1%	-5%	-29%
	Cassava	0.76	0.01	0.07	1.66	0.00	0.00	0.00	0%	2%	0%	42%	12%	-9%	-20%
	sugarcane	0.12	0.00	0.07	1.20	0.03	0.00	0.00	0%	-11%	0%	68%	1%	-8%	-15%
	Sug. Beet	0.15	0.00	0.00	1.82	-0.01	0.00	0.00	0%	82%	1%	36%	-3%	-34%	-20%
	Wastewater	0.09	0.00	-0.04	1.75	0.00	0.00	0.00	0%	-25%	0%	39%	-6%	10%	-42%
Cup 8	PLA														
		-0.0177	0.0191	-0.0545	-0.0006	-0.0007	-0.0006	-0.1088							
Cup 1	PP														
	fossil	0.2253	0.3495	0.1011	-0.0078	-0.0011	-0.0145	0.0005							
Cup 1	R-PP														
	fossil	0.0751	0.1165	0.0337	-0.0026	-0.0004	-0.0048	0.0002							
Cup 2	PET														
	Fossil	-0.1489	-0.0737	-0.2241	-0.0019	-0.0005	-0.0032	-0.0453							
Cup 5	PC														
	Fossil	-2.1484	-1.2931	-3.0037	-0.0177	-0.0104	-0.0250	0.0055							
Cup 7	PS														
	Fossil	-0.0394	-0.0126	-0.0662	-0.0007	-0.0006	-0.0007	0.0028							

EOL - 100% Landfill

		CC	Acidificat	Land occu	Energy us	Water us	Eutrophic	Eutrophication							
		kg CO2-eq	kg SO2-ec	m2a	MJ	m3	kg N-eq	kg P-eq							
Type	Split in Material	average	average	average	average	average	average	average							
Serving FU [dif. Spec.]															
Cup 7	PHA														
	corn/maize	-1.9639	-0.2205	-3.7073	-0.0209	-0.0051	-0.0368	-0.0392							
	Cassava	-1.9639	-0.2205	-3.7073	-0.0209	-0.0051	-0.0368	-0.0392							
	sugarcane	-1.9639	-0.2205	-3.7073	-0.0209	-0.0051	-0.0368	-0.0392							
	Sug. Beet	-1.9639	-0.2205	-3.7073	-0.0209	-0.0051	-0.0368	-0.0392							
	Wastewater	-1.9639	-0.2205	-3.7073	-0.0209	-0.0051	-0.0368	-0.0392							
Cup 7	R-PHA														
	corn/maize	0.09	0.00	0.13	2.60	0.02	0.00	0.00	0%	37%	0%	32%	1%	23%	23%
	Cassava	0.76	0.01	0.07	1.79	0.00	0.00	0.00	0%	2%	1%	53%	12%	39%	16%
	sugarcane	0.12	0.00	0.07	1.34	0.03	0.00	0.00	0%	-13%	1%	88%	1%	37%	12%
	Sug. Beet	0.15	0.00	0.00	1.96	-0.01	0.00	0.00	0%	90%	12%	47%	-3%	149%	16%
	Wastewater	0.09	0.00	-0.04	1.89	0.00	0.00	0.00	0%	-28%	-1%	49%	-6%	-43%	33%
Cup 8	PLA														
		-0.1918	-0.1696	-0.2139	-0.0008	-0.0009	-0.0007	-0.1112							
Cup 1	PP														
	fossil	-1.7410	-1.4302	-2.0518	-0.0096	-0.0024	-0.0168	-0.0186							
Cup 1	R-PP														
	fossil	-0.5803	-0.4767	-0.6839	-0.0032	-0.0008	-0.0056	-0.0062							
Cup 2	PET														
	Fossil	-0.3664	-0.3111	-0.4217	-0.0021	-0.0008	-0.0034	-0.0480							
Cup 5	PC														
	Fossil	-4.3905	-3.7441	-5.0370	-0.0198	-0.0131	-0.0265	-0.0192							
Cup 7	PS														
	Fossil	-0.5172	-0.5355	-0.4990	-0.0011	-0.0012	-0.0010	-0.0020							

% Recycling efficiency 50%

Type	Split in Material	CC	Acidificat	Land occu	Energy us	Water us	Eutrophic	Eutrophication							
		kg CO2-ed	kg SO2-ec	m2a	MJ	m3	kg N-eq	kg P-eq							
		average	average	average	average	average	average	average							
Serving FU [dif. Spec.]															
Cup 7	PHA														
	corn/maize	-0.8780	-0.6444	-1.1116	-0.0089	-0.0018	-0.0160	-0.0084							
	Cassava	-0.8780	-0.6444	-1.1116	-0.0089	-0.0018	-0.0160	-0.0084							
	sugarcane	-0.8780	-0.6444	-1.1116	-0.0089	-0.0018	-0.0160	-0.0084							
	Sug. Beet	-0.8780	-0.6444	-1.1116	-0.0089	-0.0018	-0.0160	-0.0084							
	Wastewater	-0.8780	-0.6444	-1.1116	-0.0089	-0.0018	-0.0160	-0.0084							
Cup 7	R-PHA														
	corn/maize	0.09	0.00	0.13	2.23	0.02	0.00	0.00	0%	16%	0%	13%	0%	1%	0%
	Cassava	0.76	0.01	0.07	1.42	0.00	0.00	0.00	0%	1%	0%	21%	5%	1%	0%
	sugarcane	0.12	0.00	0.07	0.96	0.03	0.00	0.00	0%	-5%	0%	35%	0%	1%	0%
	Sug. Beet	0.15	0.00	0.00	1.59	-0.01	0.00	0.00	0%	38%	3%	19%	-1%	5%	0%
	Wastewater	0.09	0.00	-0.04	1.51	0.00	0.00	0.00	0%	-12%	0%	20%	-3%	-2%	1%
Cup 8	PLA														
		-0.0494	-0.0368	-0.0620	-0.0003	-0.0003	-0.0003	-0.0488							
Cup 1	PP														
	fossil	-0.3863	-0.2835	-0.4891	-0.0039	-0.0008	-0.0070	-0.0037							
Cup 1	R-PP														
	fossil	-0.1288	-0.0945	-0.1630	-0.0013	-0.0003	-0.0023	-0.0012							
Cup 2	PET														
	Fossil	-0.1191	-0.0907	-0.1474	-0.0009	-0.0003	-0.0015	-0.0206							
Cup 5	PC														
	Fossil	-1.5039	-1.1770	-1.8307	-0.0084	-0.0053	-0.0115	-0.0023							
Cup 7	PS														
	Fossil	-0.1356	-0.1352	-0.1360	-0.0004	-0.0004	-0.0004	0.0003							

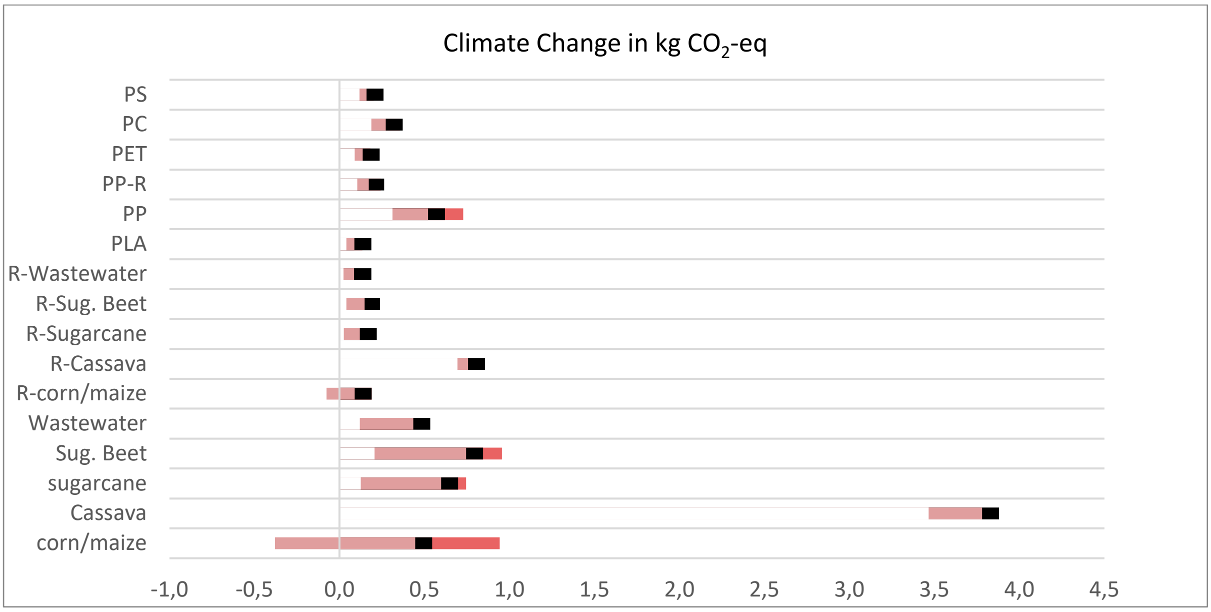
% Recycling efficiency 70%

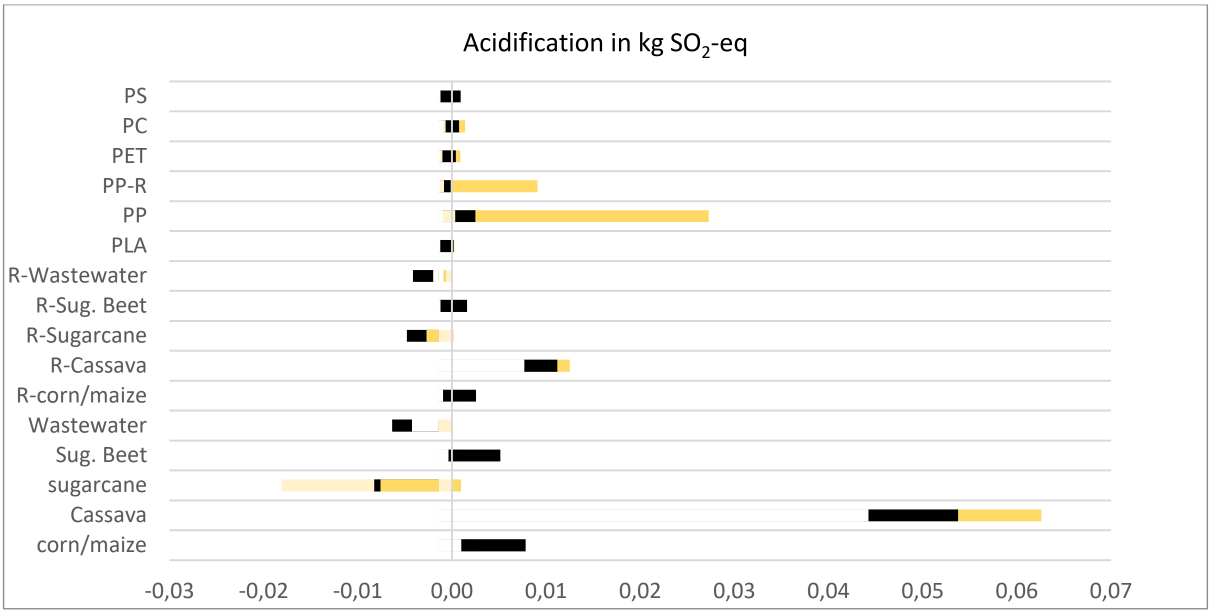
Type	Split in Material	CC	Acidificat	Land occu	Energy us	Water us	Eutrophic	Eutrophication							
		kg CO2-ed	kg SO2-ec	m2a	MJ	m3	kg N-eq	kg P-eq							
		average	average	average	average	average	average	average							
Serving FU [dif. Spec.]															
Cup 7	PHA														
	corn/maize	-0.4390	-0.3222	-0.5558	-0.0045	-0.0009	-0.0080	-0.0042							
	Cassava	-0.4390	-0.3222	-0.5558	-0.0045	-0.0009	-0.0080	-0.0042							
	sugarcane	-0.4390	-0.3222	-0.5558	-0.0045	-0.0009	-0.0080	-0.0042							
	Sug. Beet	-0.4390	-0.3222	-0.5558	-0.0045	-0.0009	-0.0080	-0.0042							
	Wastewater	-0.4390	-0.3222	-0.5558	-0.0045	-0.0009	-0.0080	-0.0042							
Cup 7	R-PHA														
	corn/maize	0.09	0.00	0.13	2.10	0.02	0.00	0.00	0%	8%	0%	6%	0%	0%	0%
	Cassava	0.76	0.01	0.07	1.29	0.00	0.00	0.00	0%	0%	0%	11%	3%	1%	0%
	sugarcane	0.12	0.00	0.07	0.84	0.03	0.00	0.00	0%	-3%	0%	18%	0%	1%	0%
	Sug. Beet	0.15	0.00	0.00	1.46	-0.01	0.00	0.00	0%	19%	1%	9%	-1%	3%	0%
	Wastewater	0.09	0.00	-0.04	1.39	0.00	0.00	0.00	0%	-6%	0%	10%	-1%	-1%	0%
Cup 8	PLA														
		-0.0247	-0.0184	-0.0310	-0.0002	-0.0002	-0.0001	-0.0244							
Cup 1	PP														
	fossil	-0.1932	-0.1418	-0.2446	-0.0020	-0.0004	-0.0035	-0.0019							
Cup 1	R-PP														
	fossil	-0.0644	-0.0473	-0.0815	-0.0007	-0.0001	-0.0012	-0.0006							
Cup 2	PET														
	Fossil	-0.0595	-0.0454	-0.0737	-0.0004	-0.0002	-0.0007	-0.0103							
Cup 5	PC														
	Fossil	-0.7519	-0.5885	-0.9154	-0.0042	-0.0026	-0.0057	-0.0012							
Cup 7	PS														
	Fossil	-0.0678	-0.0676	-0.0680	-0.0002	-0.0002	-0.0002	0.0001							

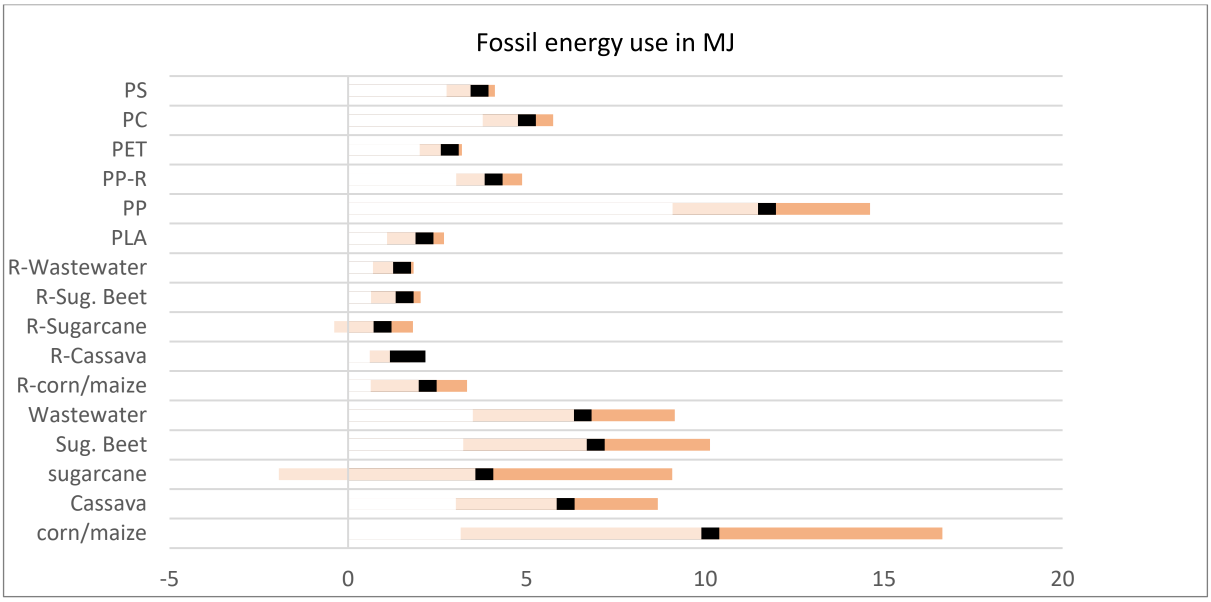
% Recycling efficiency 100%

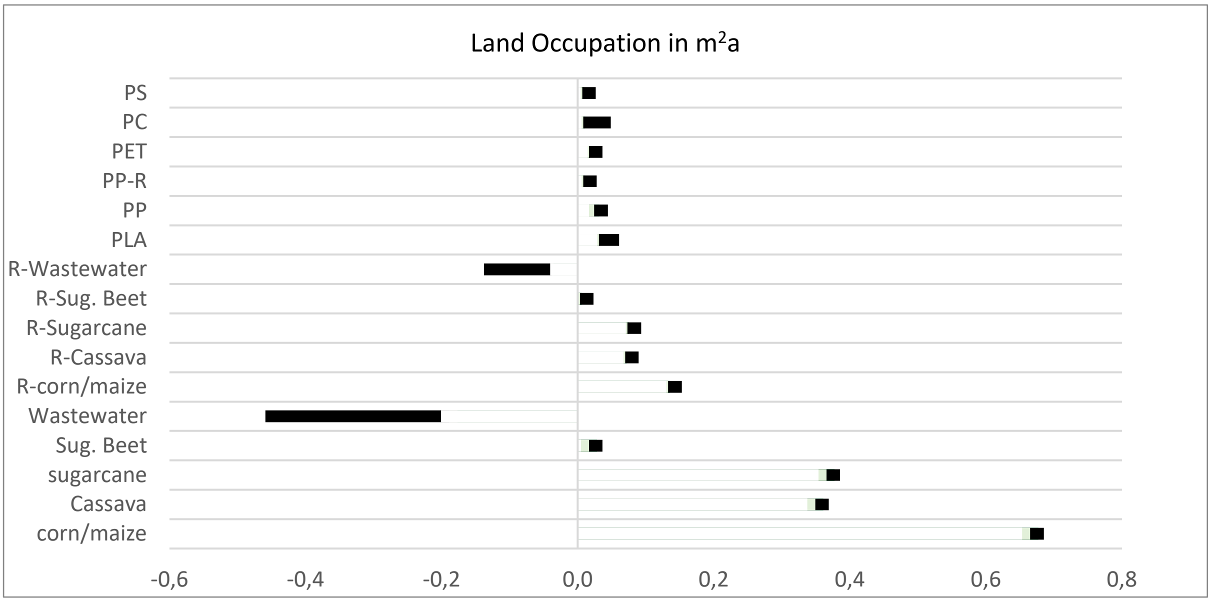
Type	Split in Material	CC kg CO2-eq average	Acidification kg SO2-eq average	Land occupation m2a average	Energy use MJ average	Water use m3 average	Eutrophication kg N-eq average	Eutrophication kg P-eq average							
Serving FU [dif. Spec.]															
Cup 7	**PHA**														
	corn/maize	0.2195	0.1611	0.2779	0.0022	0.0005	0.0040	0.0021							
	Cassava	0.2195	0.1611	0.2779	0.0022	0.0005	0.0040	0.0021							
	sugarcane	0.2195	0.1611	0.2779	0.0022	0.0005	0.0040	0.0021							
	Sug. Beet	0.2195	0.1611	0.2779	0.0022	0.0005	0.0040	0.0021							
	Wastewater	0.2195	0.1611	0.2779	0.0022	0.0005	0.0040	0.0021							
Cup 7	**R-PHA**														
	corn/maize	0.09	0.00	0.13	1.92	0.02	0.00	0.00	0%	-4%	0%	-3%	0%	0%	0%
	Cassava	0.76	0.01	0.07	1.11	0.00	0.00	0.00	0%	0%	0%	-5%	-1%	0%	0%
	sugarcane	0.12	0.00	0.07	0.65	0.03	0.00	0.00	0%	1%	0%	-9%	0%	0%	0%
	Sug. Beet	0.15	0.00	0.00	1.27	-0.01	0.00	0.00	0%	-10%	-1%	-5%	0%	-1%	0%
	Wastewater	0.09	0.00	-0.04	1.20	0.00	0.00	0.00	0%	3%	0%	-5%	1%	0%	0%
Cup 8	PLA														
		0.0123	0.0092	0.0155	0.0001	0.0001	0.0001	0.0122							
Cup 1	PP														
	fossil	0.0966	0.0709	0.1223	0.0010	0.0002	0.0018	0.0009							
Cup 1	**R-PP**														
	fossil	0.0322	0.0236	0.0408	0.0003	0.0001	0.0006	0.0003							
Cup 2	PET														
	Fossil	0.0298	0.0227	0.0368	0.0002	0.0001	0.0004	0.0052							
Cup 5	PC														
	Fossil	0.3760	0.2943	0.4577	0.0021	0.0013	0.0029	0.0006							
Cup 7	PS														
	Fossil	0.0339	0.0338	0.0340	0.0001	0.0001	0.0001	-0.0001							

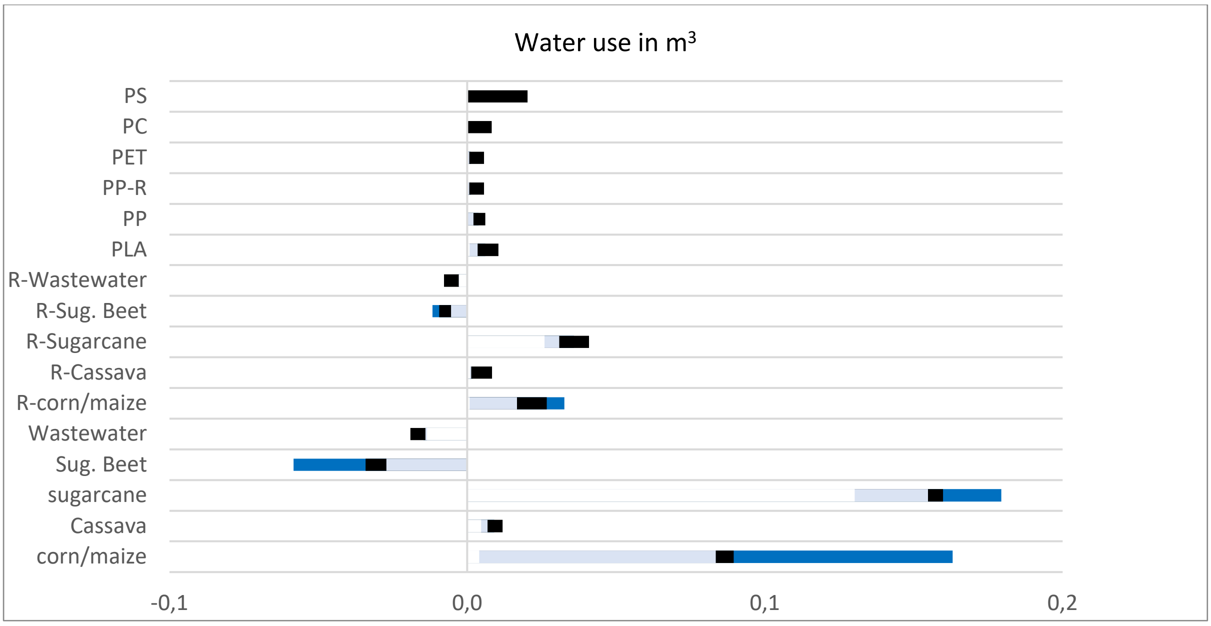
Appendix III

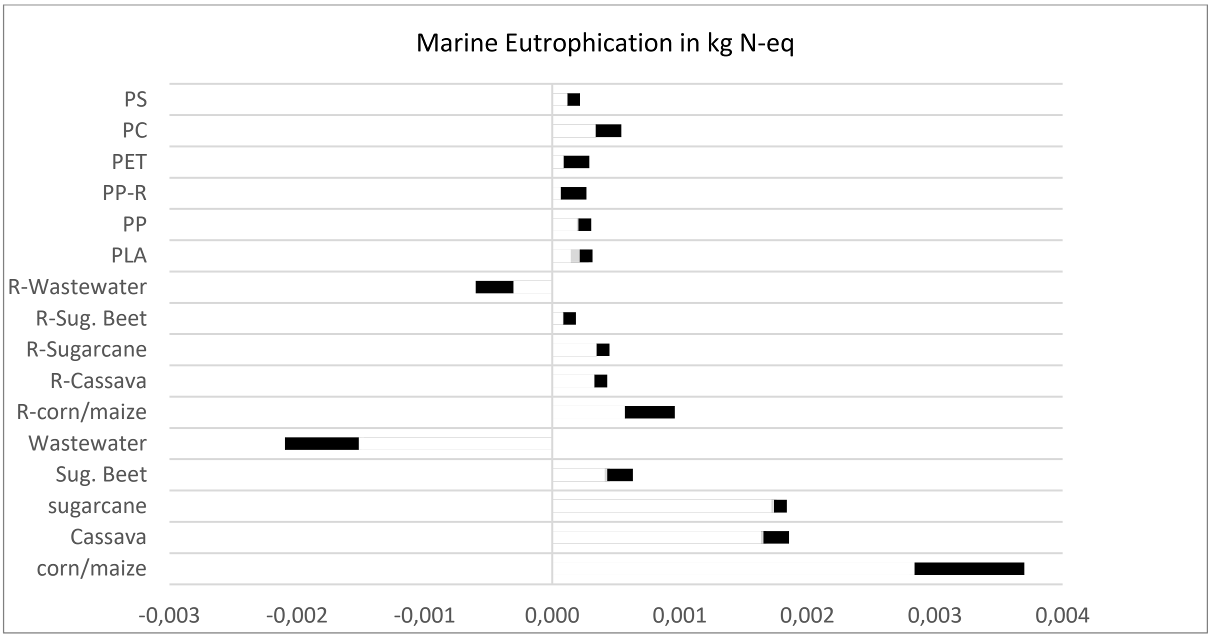


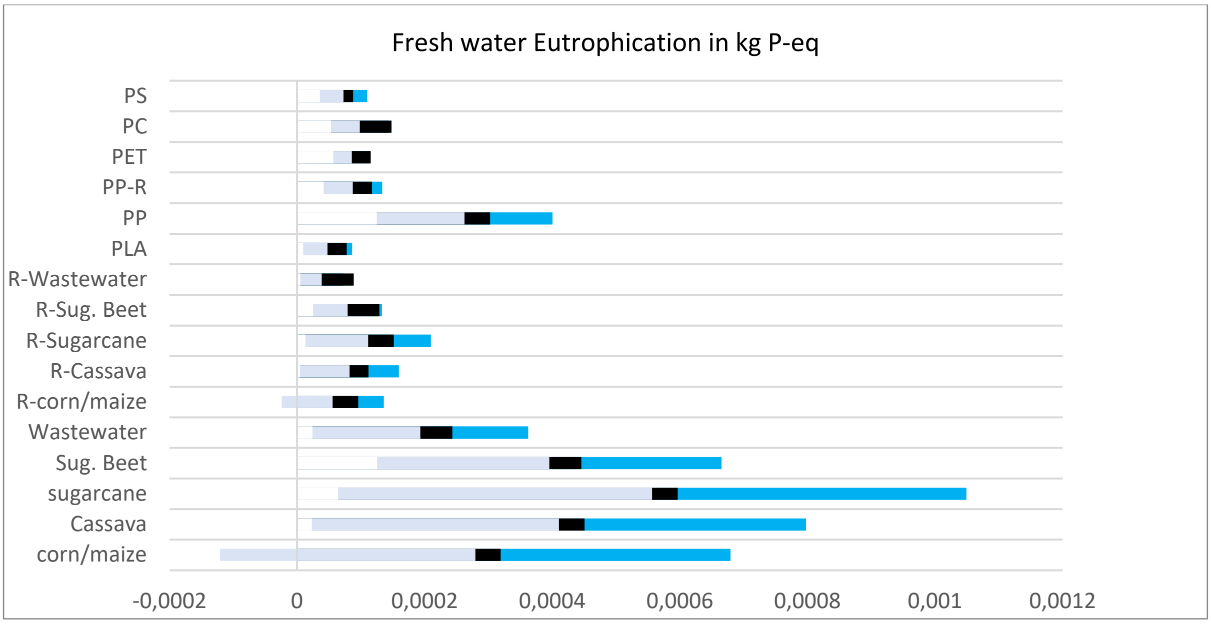



Fossil energy use in MJ
PS
PC
PET
PP-R
PP
PLA
R-Wastewater
R-Sug. Beet
R-Sugarcane
R-Cassava
R-corn/maize
Wastewater
Sug. Beet
sugarcane
Cassava
corn/maize
-5
0
5
10
15
20


Land Occupation in m²a
PS
PC
PET
PP-R
PP
PLA
R-Wastewater
R-Sug. Beet
R-Sugarcane
R-Cassava
R-corn/maize
Wastewater
Sug. Beet
sugarcane
Cassava
corn/maize
-0,6
-0,4
-0,2
0,0
0,2
0,4
0,6
0,8


Water use in m³
PS
PC
PET
PP-R
PP
PLA
R-Wastewater
R-Sug. Beet
R-Sugarcane
R-Cassava
R-corn/maize
Wastewater
Sug. Beet
sugarcane
Cassava
corn/maize
-0,1
0,0
0,1
0,2


Marine Eutrophication in kg N-eq
PS
PC
PET
PP-R
PP
PLA
R-Wastewater
R-Sug. Beet
R-Sugarcane
R-Cassava
R-corn/maize
Wastewater
Sug. Beet
sugarcane
Cassava
corn/maize
-0,003
-0,002
-0,001
0,000
0,001
0,002
0,003
0,004


Fresh water Eutrophication in kg P-eq
PS
PC
PET
PP-R
PP
PLA
R-Wastewater
R-Sug. Beet
R-Sugarcane
R-Cassava
R-corn/maize
Wastewater
Sug. Beet
sugarcane
Cassava
corn/maize
-0,0002
0
0,0002
0,0004
0,0006
0,0008
0,001
0,0012