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The importance of including service life in the climate impact comparison of bioplastics and fossil-based plastics

Frida Røyne and Johanna Berlin

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Abstract

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Bioplastics are gaining attention as a means of reducing fossil resource dependence. Most bioplastics differ from fossil-based plastics in molecular structure, and therefore in terms of properties and durability. Still, the life cycle environmental performance of bioplastics has attracted limited attention in research. The purpose of this study is therefore to examine the importance of applying a life cycle perspective and identify key considerations in the environmental evaluation of bioplastics and bioplastic products under development.

The climate impact of the life cycle of an engine component storage box currently made of the fossil-based plastic acrylonitrile butadiene styrene (ABS) is compared to a hypothetical case study, based on laboratory observations, of the same box produced from a blend of polycarbonate and the bioplastic polylactic acid (PC/PLA) and a box made of biopolyamide (PA1010). The comparison is conducted with a cradle-to-grave attributional life cycle assessment. The functional unit of the study is five years of service life, which reflects the required function of the storage box.

Whereas the climate impact of the production of the different plastic materials differ only slightly, the PC/PLA engine component storage box was found to have a significantly higher climate impact that the ABS and PA1010 boxes when the whole life cycle is taken into account. The dominant contributor to climate impact is premature material deterioration due to humidity and heat during service life, which prevents the product from fulfilling the required function. Two other influential aspects are the possibility of material reuse and the share of fossil or biogenic carbon in the product. Production of plastic materials and boxes, and transport distances, are of less importance.

Results demonstrate the high significance of including service life and potential material deterioration when bioplastics and fossil-based plastics are compared. Our findings underline the importance of applying a life cycle perspective and taking into account the intended application and function of bioplastics as part of their development and environmental assessment.

Key words: Life cycle assessment, LCA, Polylactic acid (PLA), Biopolyamide (PA1010), Corn, Castor oil

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Preface

This study was performed as a task in the project “Sustainable recycling of ‘green’ plastics” (RISE 2015), running 2012-2015. The aim of the project was to increase the understanding of recycling of bio-based plastics. Participants in the project were RISE Research Institutes of Sweden, Chalmers University of Technology, University of Borås, and representatives from the plastic industry.

The project was financed by the Swedish Foundation for Strategic Environmental Research (MISTRA) (grant agreement 2011/13 No 15). Bio4Energy, a strategic research environment appointed by the Swedish government, provided additional financial support for this specific study.

The researchers who contributed data and knowledge to this study are gratefully acknowledged, especially Mats Ericson (Lysmask), Jonas Enebro, Ignacy Jakubowicz and Nazdaneh Yarahmadi (RISE), Mats Svensson (KREOL) and Antal Boldizar (Chalmers University of Technology). Thanks are also due to Safeman, Volvo, Logent and Arla Plast for providing life cycle data.

1 Introduction

Plastics are of considerable importance in society due to their reasonably good physical properties, easy processing and low cost. They are widely used and have a variety of applications. In 2016, world plastic production reached 335 million tonnes (PlasticsEurope 2017). As conventional plastics are petroleum-based, the depletion of fossil resources and global warming are growing areas of concern. It is these environmental challenges that inspire the development of alternatives. Several goals have been set to promote bioplastics. One example is the Japanese hair care and cosmetics producer Shiseido, which has set a goal of exchanging 70% of the petroleum-derived polyethylene in the domestic cosmetics business to plant-derived polyethylene by 2020 (Shiseido 2018). A further example is the multinational furniture retailer IKEA, which is aiming for all plastic material used in its home furnishing products to be 100% renewable and/or recycled by August 2020 (IKEA 2014). These are ambitious goals, as bioplastics are used in a limited number of product categories due to the high cost, limited performance or lack of knowledge about commercially available substitutes (Álvarez-Chávez et al. 2012).

The term bioplastic usually refers to a plastic produced from biological sources (Soroudi and Jakubowicz 2013). Bioplastics come in two fundamentally different forms. One is identical to the fossil equivalent, the only difference being that the carbon content is of biogenic and not fossil origin. This plastic has the same function and properties as fossil plastic and it is only the raw material and production process that differ. Since the required constituents do not always exist, and production in some cases is too expensive, only a limited number of conventional plastics have such bioequivalents. The other type of bioplastic does not have the same molecular structure as fossil-based plastic and therefore differs in terms of properties and durability. This study focuses on the latter.

A successful future for bioplastics is dependent on the bioplastics' fulfillment of functions required by society. In the use phase, the material can be exposed to a variety of conditions. Food packaging must withstand cooling and humidity, outdoor furniture must withstand UV light and changes in the weather, and cutlery must withstand frequent washing in a dishwasher. If bioplastics are to compete with petroleum-based plastics on a larger scale, they must endure the same conditions for the same length of time as the fossil plastics they are meant to replace. Another success factor is the possibility of reuse and recycling, as this reduces the demand for virgin resource consumption. Some fossil-based and biobased plastics are biodegradable or compostable, which reduces waste generation. However, once such plastics have degraded they can no longer be reused and maintained, which means that all the energy and material inputs are lost in the soil. For some product segments this can be a suitable solution, but for the majority it is more adjacent to use durable bioplastics that can be recycled and reprocessed.

As not all bioplastics have the same properties and durability as the fossil-based plastics they are meant to replace it is important to apply a life cycle perspective when comparing their environmental performance. Despite this, the life cycle performance of bioplastics has attracted limited attention in the research sector. Hottle et al. (2013) conducted a literature review of published life cycle assessments (LCAs) on bioplastics and bioplastic products and found that less than half of the 21 studies include life cycle phases beyond the production of the product. An explanation for the exclusion of the use phase can be that the majority of the studies concern short-lived products such as plastic bags, containers for food and generic packaging. Only one study evaluates long-lived products (Pietrini and al. 2007). The study includes all life cycle phases, but considers monitor casings and car panels, which are not assumed to experience material deterioration in the use phase. Since the literature review of Hottle et al. (2013), which included studies published until 2010, the focus has mostly remained on bioplastic materials (Hottle et al. 2017; Sun et al. 2015; Tsiropoulos et al. 2015; Boonniteewanich et al. 2014; Hohenschuh et al. 2014; Koller et al. 2013, Wang et al. 2013; Rostkowski et al. 2012; Kendall et al. 2012; Bier et al. 2012a, b) and short-lived products (Horowitz et al. 2018; Lorite et al. 2017; Razza et al. 2015; Papong et al. 2014; van der Harst et al. 2014; Mirabella et al. 2013; Suwanmanee et al. 2013; Piemonte and Gironi 2012; Piemonte 2011; Gironi and Piemonte 2011). The focus could contribute to the impression that challenges related to a transition from fossil-based plastics to bioplastics are limited to resource cultivation and material production. Bioplastics can however be made into a variety of products for a variety of uses. A recent study by Vidal et al. (2018) on the use of bioplastics in long lived aircraft interior panels identifies the use stage as having the greatest impact on overall results.

Due to the limited focus on the total life cycle environmental performance of bioplastics, the purpose of our study is to examine the importance of applying a life cycle perspective and thus identifying what needs to be taken into account in the evaluation of bioplastics and bioplastic products under development. We use a case study of an engine component storage box currently made of the fossil-based plastic acrylonitrile butadiene styrene (ABS), and compare its life cycle climate impact with a hypothetical case of the same box produced using a blend of polycarbonate and the 100% biomass-derived polylactic acid (PC/PLA) or 100% biomass-derived biopolyamide (PA1010). The life cycle assessment includes all life cycle stages, from raw material extraction and agriculture, through to production, use and final disposal. The aim is to examine the product life cycle, not to provide environmental profiles for specific materials and products. The main target group is the plastics industry, as it demonstrates the importance of taking the durability of plastics into account. LCA practitioners are also an important target group, as the study highlights the implications of excluding life cycle phases in LCA.

2 Method

In this section we first introduce the case study. We then explain and give reasons for adopting the assessment approach and present inventory data.

2.1 Case study

Serving as a fossil case is an engine component storage box (Figure 1) made of 100% ABS, of which 90% is recycled ABS.

Figure 1. Plastic storage box for engine components made of acrylonitrile butadiene styrene (ABS).

The life cycle of the storage box is shown in Figure 2. All processes except material production occur in Sweden. The box is produced by the company Safeman, which is based in Olofström. Safeman purchases ABS sheets, mainly from Arla Plast in Borensberg. Arla Plast purchases ABS granulate from different European suppliers. Safeman sells the storage boxes to Volvo in Skövde, which uses them for the in-house storage and transport of engine components.

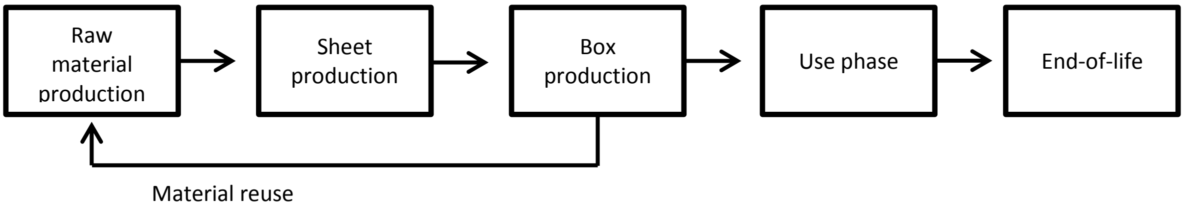

Figure 2. Life cycle of the storage box.

The storage box is produced using a thermoforming machine, where the ABS sheet is placed over a hole, heated from both sides and then vacuum-shaped. After thermoforming, redundant material is removed from the storage box. Some 25% of the ABS sheets ends up as waste. The waste is shredded and sold directly to ABS granulate producers for material reuse (Siebert 2014). The storage boxes are used for five years at Volvo before they are no longer fit for use. They are washed once every two months for approximately one minute at 70°C and then dried directly for approximately one minute at 90°C. At end-of-life the boxes are incinerated at a waste incineration plant (Axelsson 2015) (waste is an important fuel in the district heating systems in Sweden (Avfall Sverige 2014)). Safeman is not currently considering replacing the material in the storage box. The storage box was chosen for this study purely as a case for exploring the life cycle climate impact of different plastic materials. The choice of materials for the study was the outcome of deliberations by the polymer experts who made up the project group (Professor Jakubowicz' group at SP Technical Research Institute of Sweden, Professor Boldizars group at Chalmers University of Technology, Professor Skrivfars' group at University of Borås, Dr Mats Ericson (Lysmask) and Mats Svensson (KREOL)). They also carried out experiments to assess the service life of the PC/PLA blend and they provided expert estimations of energy requirements for the storage box and sheet production of PC/PLA and PA1010.

PLA is usually produced from lactic acid derived from the fermentation of corn. PA1010 is produced from castor oil. PLA is used as a commodity plastic, as its use is cost-driven. PA1010, on the other hand, is generally regarded as an engineering plastic due to higher performance in terms of its thermal and mechanical properties (Brehmer 2013). A blend of 68% PC and 32% PLA was chosen as one of the materials the ABS was compared with, as it is certain that the PC/PLA blend can withstand the same thermoforming production process as the ABS storage box. Since the durability in the use phase of the material is less certain, as PLA has shown poor heat and humidity durability alone in the past (Soroudi and Jakubowicz 2013), a case involving PA1010 is also included. It is uncertain if PA1010 can be shaped using the same manufacturing technology, but the durability in the use phase is expected to be considerably better (PA1010 is for example currently used in demanding automotive applications). PA1010 can thus be expected to have the same (or even longer) service life as ABS.

2.2 Life cycle assessment

The climate impact comparison is conducted using LCA. LCA is one of the most commonly used tools for environmental assessment of product systems, as it offers the possibility to compile and evaluate the potential environmental impact of a product system throughout its life cycle. In LCA, resource demand, product and process emissions and waste are accounted for and allocated to environmental impact categories (ISO 2006).

LCA comprises goal and scope definition, inventory analysis, impact assessment and interpretation. The issue to be addressed and the research limitations are stated in the goal and scope phase. A functional unit is determined to allow alternative products to be compared on the same basis. The processes of the product system are identified in the inventory analysis. Once the system is established, process-specific or generic data are collected. In the final phase, impact assessment, potential environmental impact contributions associated with the calculated emissions and consumption of resources are determined. This includes choosing relevant impact categories, assigning inventory data to the chosen impact categories, and characterizing the impact level by multiplying the emission inventory by the characterization factors (Baumann and Tillman 2004).

The functional unit of the study is five years of service life, which reflects the required function of the storage box (the ABS box currently has a service life of five years). The assessment is a cradle-to-grave study, covering all life cycle activities associated with the extraction, handling and processing of raw materials and energy input. Also included are the processes required to manufacture the products, the use phase as well as end-of-life and transport. In accordance with the product category rules in the basic module for rubber and plastic products (EPD® 2013), manufacturing of production equipment, buildings, other capital goods and personnel-related environmental impact are omitted from the study.

The impact assessment was limited to one environmental impact category: global warming potential (GWP) (with a timeframe of 100 years). The GWP metric reflects the difference between fossil and biobased products as the CO2 emissions from the incineration of biobased materials are assumed to be climate neutral (based on a carbon neutrality assumption, where the emitted CO2 of biogenic origin is taken up again by regrowing vegetation). The impact assessment was carried out using the CML 2001 method, April 2013 version (Leiden University 2013). As biobased materials require land for cultivation, additional impacts could be relevant to include. One such impact is the potential risk of greenhouse gas emissions from land use changes. In a case study involving a corn-based bioplastic, Piemonte and Gironi (2011) demonstrated that these emissions could be significant and should be included in the greenhouse gas inventory. Such calculations require land use data, which were not available in our PA1010 inventory. It could also be important to include environmental impact categories other than GWP in the assessment of land-intensive products. Loss of biodiversity, soil erosion and deforestation are three such examples (Weiss et al. 2012). The unknown environmental effects of using genetically modified organisms (GMO) have also been discussed with regard to PLA (Álvarez-Chávez et al. 2012). However, as the primary purpose of our study is to demonstrate the relative importance of different life cycle stages, we limited the study to GWP.

As the PC/PLA and PA1010 storage box life cycles do not exist in reality, there are uncertainties associated with how the life cycles might appear. We therefore assessed several scenarios. The PC/PLA material underwent laboratory experiments to test the use phase durability. Two types of test were performed: one to test if the material would be able to withstand the washing cycles, and one to test the durability of the material under the expected service life conditions (23°C and varying humidity) using accelerated aging experiments (50°C, 90% RH). The material withstood the washing cycles as the humidity and high temperature were induced over a short period of time. The accelerated aging tests, however, revealed deteriorating mechanical properties over time in the expected service life conditions. We therefore selected three scenarios for the service life of the PC/PLA storage box: one year, two years and five years. One year and two years were chosen as tests showed that the material would last for approximately that length of time. The five-year scenario was chosen because the material could potentially be strengthened with the aid of additives. Although five years is an optimistic scenario, we wanted to examine how an 'ideal case' would compare to the ABS and PA1010 cases. In the PC/PLA storage box life cycle, no reuse of the material waste is assumed to take place as the material is a blend (there is no market for recycling of blends (Siebert 2014)), and it is therefore assumed that all waste will be incinerated. For the ABS and PA1010 cases, two scenarios were selected. In the first case, 90% of the material comes from recycled material. In the second case, all the material is virgin. The reason for including this second scenario was that it is unlikely, viewed from a global market perspective, that 90% recycled material would be constantly available to meet all product demand, as the plastics cannot be recycled infinitely.

In addition to these 'technical constraint' scenarios we also have two 'location' scenarios relating to electricity mix and end-of-life electricity and heat replacement. In the first scenario we wanted to demonstrate how the results would be affected if the location did not matter, and we therefore used the same electricity mix for all processes. We chose to use European electricity mix, and therefore called the scenario 'European'. The heat replaced in waste incineration is assumed to be produced from natural gas. The second scenario is a 'local' scenario, where the electricity mix is chosen according to the location where production takes place. This means that all plastic material production is supplied with a European electricity mix, except the PLA, which is produced in the US and therefore has a US electricity mix. All other processes take place in Sweden and are therefore supplied with a Swedish electricity mix and replace Swedish electricity in end-of-life incineration. The heat replaced in incineration is assumed to be a Swedish local district heating residual waste mix.

2.3 Inventory data

Inventory data for ABS and PC material production were obtained from PE International (2011, 2007). The production of recycled material requires shredding and transport of shredded material from Safeman back to the European material producer (see Tables 1 and 2). In the case of PLA, inventory data were obtained from Ecoinvent (2007). An inventory for the production of PA1010 is not available in commercial LCI databases, but the company Evonik (one of the four producers in the world (Brehmer 2013)) has published a cradle-to-gate LCA of the plastic (Evonik Industries 2015). Information about if and how Evonik has included biogenic carbon sequestration in the LCA was obtained through e-mail exchange (Brehmer 2014). The LCA practitioners at Evonik assumed that 2.6 kg CO_2 is sequestered by the castor oil plants per kg PA 1010 produced, and that the production of 1 kg PA 1010 therefore results in 4 kg CO_2-eq. To avoid double counting, as we presumed no GWP from emitted biogenic CO_2 at end-of-life incineration, we added the 2.6 kg CO_2 to the PA1010 material production GWP (resulting in 6.6 kg CO_2-eq /kg).

It was assumed that the sheet will have the same thickness for all the materials. The weight of the sheet will thus differ slightly, as the materials have different densities. The density of ABS is 1.06 g/cm3, for PC/PLA it is 1.19 g/cm3 and for PA1010 1.05 g/cm3. This has implications for the weight of the products and waste in the downstream value chain. Since the materials have relatively similar thermal properties (specific heat capacity, thermal conductivity, and density) it was assumed that it is mainly the required temperature increase that influences the required heating energy for processing. The assumed energy demand is shown in Table 1.

Table 1. Energy requirements of processes in the plastic storage box life cycle.

Process	Materials	MJ	Notes
Sheet production	ABS	166.6/pc	Assumed to be 150% of ABS box production
	PC/PLA	183.3/pc	Assumed to be 110% of ABS sheet production
	PA1010	199.9/pc	Assumed to be 120% of ABS sheet production
Box production	ABS	111.1/pc	Energy consumption of thermoforming machine (Siebert, 2014)

Process	Materials	MJ	Notes
	PC/PLA	122.2/pc	Assumed to be 110% of ABS box production
	PA1010	133.3/pc	Assumed to be 120% of ABS box production
Box cutting	All	1.7/pc	Energy consumption of cutter (Siebert, 2014)
Shredding	ABS and PA1010	0.2/kg	Energy consumption of shredder (Siebert, 2014)
Use phase	All	64.8/5y	Energy consumption of washing and drying (Bergman, 2015)

For the waste and end-of-life incineration, inventory data from PE International (2006) were selected. The GWP from the incineration process was only included for the fossil-based plastics (ABS and PC). The incineration process results in avoidance of the production of electricity (3.62 MJ/kg) and heat (0.90 MJ/kg). Inventory data for process steam from natural gas were obtained from PE International (2009). Inventory data for Swedish district heating from municipal waste were set as the mix in Gothenburg (a city situated close to Skövde) which, including incineration and fuel transport and production, is 87 CO2-eq/kWh (Svensk Fjärrvärme 2013).

Transport modes and distances are shown in Table 2. Inventory data for truck, train and ship were obtained from PE International (2013a, b, c). Environmental impact from transports not occurring in all value chains is included in accompanying life cycle stages in the results presentation: transport of in-house waste to incineration, and transport of in-house waste to recycling.

Table 2. Transport modes and distances in the plastic storage box life cycle.

Goods	From	To	Mode	Distance
ABS, PC and PA1010 granulate	European producers (assumption: Germany)	Arla Plast in Borensberg	Truck	1,300 km
PLA granulate	NatureWorks, Nebraska, USA	Harbor, New York, USA	Train	2,000 km
	Harbor, New York, USA	Harbor, Antwerp, Belgium	Ship	6,000 km
	Harbor, Antwerp, Belgium	Arla Plast in Borensberg	Truck	1,300 km
Plastic sheet	Arla Plast in Borensberg	Safeman in Olofström	Truck	300 km
In-house waste to recycling	Safeman in Olofström	European producers (assumption: Germany)	Truck	1,000 km
In-house waste to incineration	Safeman in Olofström	Waste incineration plant	Truck	150 km
Plastic storage box	Safeman in Olofström	Volvo in Skövde	Truck	300 km
End-of-life plastic storage box	Volvo in Skövde	Waste incineration plant	Truck	150 km

The electricity mix represents the different technologies supplying a country or region with electricity. European (131 g CO2-eq/MJ), US (178 g CO2-eq/MJ) and Swedish (18 g CO2-eq/MJ) electricity mixes were obtained from PE International (2013d, e, f). The low GWP of the Swedish electricity mix is due to that the majority of electricity production in Sweden relies on hydro and nuclear power.

3 Results and discussion

The results of the LCA of the different storage boxes and technical scenarios with a European electricity mix for all processes are shown in Figure 3. In the ABS case, two scenarios are shown: the current case where 10% is virgin material and the remainder is produced from recycled material, and a case where 100% of the material is virgin. The three PC/PLA scenarios reflect the uncertainty of the durability of the material in the use phase and thus the service life. The two PA1010 scenarios are the same as for ABS.

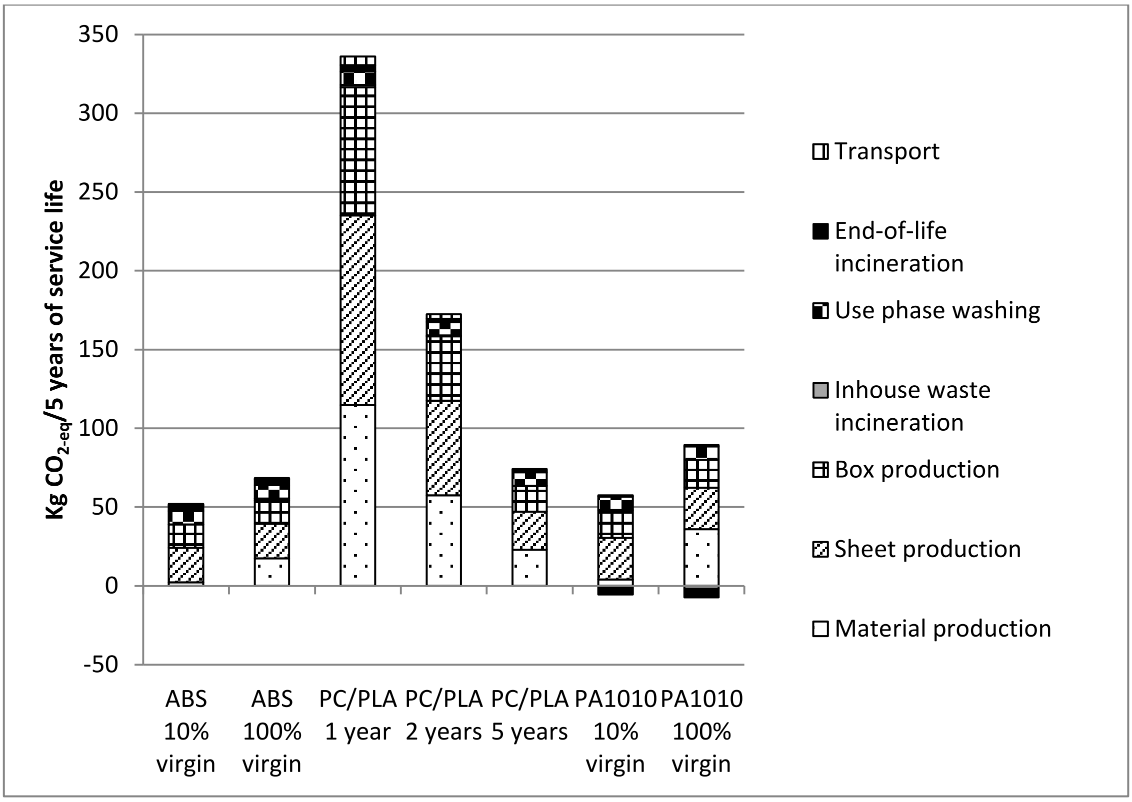

Figure 3. Global warming potential of five years of plastic storage box service life.
The electricity mix is European.

The GWP of the PC/PLA scenarios where service life is only one year and two years exceeds the others substantially. The GWP of the PC/PLA box with a service life of one year is more than six times that of the ABS storage box made of 90% recycled ABS. The reason for the high GWP is that when the storage box only lasts one year, five boxes need to be produced (with subsequent augmented GWP from production, transport and end-of-life incineration) to provide the function required (five years of service life). We can thus see that whether a material sustains the expected length of service life or deteriorates prematurely plays a crucial role for the life cycle climate impact of the intended function. It is therefore important to include service life in order to determine whether a certain material is suitable for a specific application. The importance of including service life when assessing the environmental impact of novel materials has also been emphasized by Miller et al. (2015), who included material deterioration in an

LCA of natural fiber-reinforced composite materials. They found that differing moisture and temperature conditions resulted in increased demand of material volumes to serve the function required.

Another influential aspect for the life cycle climate impact of this case study is the possibility of material reuse. In the life cycle of the storage box with 90% recycled ABS, material production accounts for just 4% of the total GWP, as opposed to 26% in the scenario where 100% is virgin ABS. The PA1010 storage box life cycle shows a similar tendency. As there is currently no market for the recycling of blends, material waste from the PC/PLA storage box production does not have a recycling option, resulting in the material production phase accounting for 31% and upwards.

A third aspect that exerts an influence is the share of fossil or biogenic carbon in the product. As we assume that CO_2 emissions with a biogenic origin do not have a climate impact, waste and end-of-life incineration GWP from PLA and PA1010 is zero. While the impact is 7% and 8% of the total life cycle GWP for the ABS cases, it is -9% and -11 % for the PA1010 cases. The negative figures are due to the avoidance of electricity and heat production. Although virgin material, sheet and box production has a higher GWP in the PA1010 case, the fact that the material is bioderived means that the 90% recycled PA1010 scenario performs as well as the 90% recycled ABS scenario.

The aspects that have less influence on the results are the differences in virgin material, sheet and box production and transport distances. This can be seen in the ABS and PA1010 cases and the PC/PLA with five years of service life. The major impact of material, sheet and box production on the PC/PLA scenarios with limited service life is due to the fact that two and a half and five boxes respectively are required.

The results for the scenarios with a local electricity mix are shown in Figure 4. We can see that the total GWP for the different cases is lower than in Figure 3. We can also see that the difference between the cases is larger than when a European electricity mix is applied to all processes. PC/PLA with a service life of one year now has a GWP that is 11 times higher compared with the scenario where 90% of the ABS derives from recycled material. The largest contributor to the PC/PLA case is material production, accounting for 62% of the total life cycle GWP. The reason is that it is the only process that takes place outside Sweden and the European electricity mix has a GWP per kWh that is more than seven times higher. Applying a local electricity mix also decreases the GWP of recycled material as the shredding takes place in Sweden. As all the other processes apart from material production decrease in importance, GWP from end-of-life incineration increases in importance. For the ABS case where 90% of the material is from recycled ABS, as much as 47% of the total life cycle GWP derives from this life cycle phase. This means that PA1010 with 90% recycled PA1010 material performs ~40% better. Adding a locality scenario thus makes durability in the use phase, the ability to source recycled material for production and the share of biogenic carbon in the product even more influential to total life cycle climate impact.

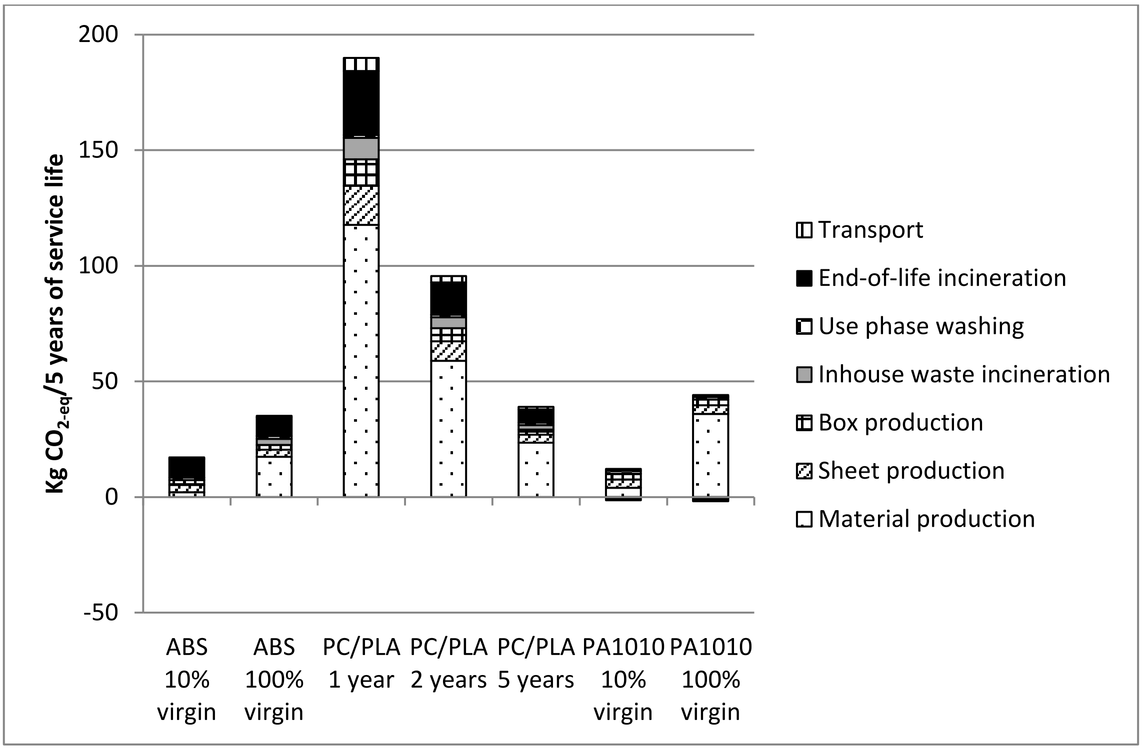

Figure 4. Global warming potential of five years of plastic storage box service life. The electricity mix is local.

Figure 5 shows how the result of the LCA would appear if the scope was limited to material production. We see that the GWP of the plastic materials ABS, PC/PLA and PA1010 only differs slightly. Including the whole life cycle and assuming a service life of five years for all boxes does not change the result considerably (see the bars for ABS 100 % virgin, PC/PLA 5 years and PA1010 100% virgin in Figure 3 and 4). However, when material deterioration is taken into account (see the bars for PC/PLA 1 and 2 years in Figure 3 and 4) the life cycle climate impact differs substantially. This underpins the situation that performing a cradle-to-gate LCA of bioplastics without discussing possible effects on the results if the total life cycle of potential products were to be taken into account could make the audience of the study believe that the challenges with bioplastics are limited to the resource cultivation and material production. It also stresses that if by only publishing LCAs of short-lived products, where the use phase is excluded, the research field might lose focus on key aspects related to the environmental performance of bioplastics.

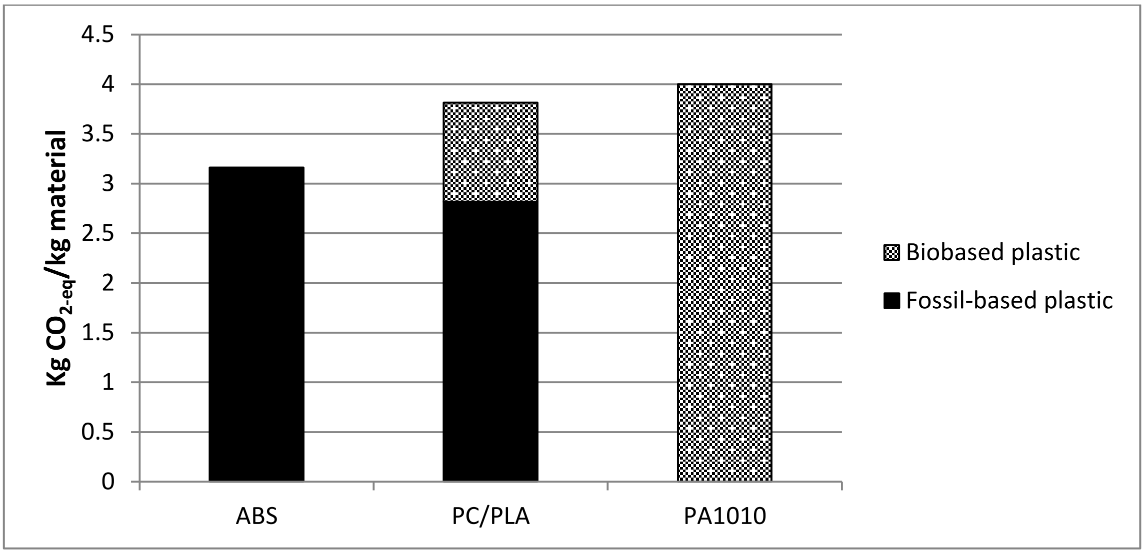

Figure 5. Cradle-to-gate global warming potential of the production of 1 kg plastic material. Carbon sequestration is included. The electricity mix is local.

In this study, we examined specific techniques, conditions and materials. Different contexts and scenarios could yield different results. The case study considers a product which must have a certain level of resistance to high temperature and humidity. Several types of long-lived products, such as car panels, computer cases and plastic shelving are not exposed to conditions caused by additional maintenance that would contribute to additional life cycle impacts. The case study is thus not representative for all long-lived products. It does, however, demonstrate the importance of integrating potential material degradation in LCA. In addition, maintenance is not the only potential source of material degradation. Proximity to overheated mechanical and electrical components, as experienced by car panels and computer cases, could also inflict deterioration (Pietrini et al. 2007).

The major drawback with the study is the use of hypothetical cases. To our knowledge, no engine component storage boxes are currently being produced using PC/PLA or PA1010. Better-suited bioplastics or bioplastic blends for this type of product could be developed in the future, but currently there are no perfectly suited bioplastics on the market. The material selection was, however, not a random choice but the result of expert discussions.

As our analysis includes a bioplastic blend, this study contributes with a demonstration of the advantages and disadvantages of material constellations of that nature. PLA on its own has poor heat and humidity durability in the use phase of the product investigated in this study, but blending it with another material excluded the possibility of recycling. This is something that must be taken into account in the development and use of blends and composites. As our analysis includes a high-performance bioplastic, PA1010, it is also demonstrated that bioplastics with the right functions, and thereby a low life cycle GWP, might be available on the market but at a price that makes them unattainable for certain product segments.

The case study focused on a single environmental impact category: GWP. As explained in the methods section, limited transparency in the PA1010 inventory excluded the possibility to include land use (change) derived environmental impacts. If such impacts would have been included in the study, accounting for possible material degradation in the use phase would influence the result as the impacts would increase with an increased material demand. Models available for assessing land use (change) induced environmental impacts are however still under development (De Baan et al. 2015; Piemonte and Gironi 2011), so the levels of such impacts are uncertain. Water use also appears as a relevant indicator to include in the comparison of the different storage boxes, as the cleaning process in the use phase consumes water. However, as the functional unit was chosen to be five years of service life, water use would not have an influence on the product comparison.

Although our study focuses on the challenges related to the use of bioplastics, our message is not to avoid a transition from fossil-based to biobased materials. Plastics have acquired major importance in society and a reduction in the use of plastic cannot be the only strategy for reducing the use of fossil resources. It is therefore important that the introduction of novel materials, products and solutions is supported by holistic evaluations in which the intended product function is central.

4 Conclusion

In this study we examined the importance of applying a life cycle perspective to identify what needs to be taken into account in the evaluation of bioplastics and bioplastic products under development. We compared the life cycle climate impact of an engine component storage box currently made of fossil-based plastic with a hypothetical case of the same box produced using a fossil-bio blend or 100% bioplastic.

Our study demonstrated the importance of including potential material deterioration when bioplastics and fossil-based plastics are compared. A shorter service life than the required customer function results in an increase in climate impact from the rest of the life cycle, as more products need to be produced for the function to be fulfilled. LCAs of long-lived bioplastic products should therefore apply cradle-to-grave system boundaries, and include the use phase. In all LCAs of bioplastics and bioplastic products, the implications of excluding certain life cycle phases should be taken into account in the discussion section.

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Box 24036, SE-400 22 GÖTEBORG, Sweden
Telephone: +46 10 516 50 00
E-mail: info@ri.se, Internet: www.ri.se

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