Potential trade-offs between eliminating plastics and mitigating climate change: An LCA perspective on PET bottles in Southwest England

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Abstract

The aim of this study is to investigate the life cycle environmental impacts resulting from the potential substitution of Polyethylene Terephthalate (PET) bottles with glass ones in Cornwall County and examine whether eliminating them under the current practices could have an adverse effect on climate change. Based on data provided by the local authorities and Life Cycle Assessment (LCA) models a tool was created that utilises data for residential waste collection and current management practices. The tool allows the users to define their desirable masses, transport options and handling processes for this waste and provides results for 11 environmental impact categories including the Global Warming Potential (GWP). The results from the application of this tool on the case study of Cornwall County have shown that the substitution of PET bottles with glass ones under the current management practices could lead to significant increases in the GWP and hinder efforts to tackle climate change. Preliminary results from a more comprehensive LCA however, show that when including the production and recycling, and under favourable circumstances a close in the GWP gap should not be excluded. This tool can be expanded further to include more types of plastic waste data from the rest of the administrative divisions of South England and contribute to the design of a new regional paradigm of circular economy with less plastics waste. In order to do that though, it is necessary to identify and address the specific needs of the region and use science-based tools that incorporate life cycle thinking to avoid burden shifting.

Keywords: circular economy, LCA, plastics, waste management, decision support

Introduction/Purpose

Plastic products play a major role in our modern society due to their many useful attributes such as durability, light-weight, flexibility, electrical and thermal insulation, water and air impermeability and low costs. It is projected that following the same use patterns, 12,000Mt of plastic waste will have been discarded in landfills or the natural environment by 2050, which is more than double the estimated 5,800Mt of plastic waste ever generated from primary plastics up to 2015 [1]. Therefore, it is necessary to develop a circular economy approach to plastics that addresses the accumulation, impact and costs in the environment without compromising their use for multiple high value purposes. This work is part of the ExeMPlaR project that contributes to the formation of novel and creative circular economies, using regional demonstrators in the Southwest of England. The aim of this study is to investigate the environmental impacts resulting from the potential substitution of Polyethylene Terephthalate (PET) bottles with glass ones. We focus on PET bottles because they are an easy plastic to eliminate and substitute from other established alternatives such as glass. Despite the good intentions, glass is much heavier than plastic and a higher fuel consumption for their transportation is expected. The nature of such a problem is context specific and should be investigated using data from the local authorities that are responsible for the waste collection and management. In addition, as climate change is a top priority in the environmental agenda of many regions including Cornwall [2], a focus on the Global Warming Potential (GWP) as a consequence of this substitution of PET from glass bottles should be given.

For this reason, we created a tool that utilises local data for residential waste collection and current management practices and combines that with a Life Cycle Assessment (LCA) providing results for 11 environmental impact categories including GWP. This paper continues with the Method section describing how the tool was developed and applied for the specific case study, followed by the Results section which presents the outputs of the tool and closing with the Conclusion section which summarises the potential trade-offs between eliminating plastics and mitigating climate change on Southwest England.

Method

This section describes the case under study, the assumptions and the restrictions, the boundaries, the model developed and the data used. To aid the reader, a map and a flowchart that demonstrate the journey the PET and glass bottles follow and the processes undertaken during the lifecycle under study are provided.

The case study in this preliminary model includes the Cornwall County and it will include other parts of the region at the next stages. Cornwall Council is responsible for the collection of residential waste from the 213 smaller administrative units called civil parishes. The collected residential waste falls into two main categories: the recyclable waste and the residual waste. The recyclable waste are separated by the residents and placed on specific dates set by the council on the kerbside for collection. The Council provides residents in each registered address with special plastic boxes used for putting the recyclable glass as well as hard reusable plastic bags of red, blue and orange colour used for putting the metal, plastics, paper and cardboard. The residual waste is collected on the same day along with the recyclables but they are placed in one-use plastic bags that the residents have to buy. Although these two sets of waste are collected together, they are transferred in different places. The recyclables are transported to two Material Recovery Facilities (MRF) situated in the towns of Bodmin and Pool and the residuals are transported to the Cornwall Energy Recovery Centre (CERC) which started its operational phase in 2017 and has the capacity to recover energy from the processed waste and generate enough electricity to power the equivalent of 21,000 homes [3]. The residents also have the ability to visit the13 Household Waste Recycling Centres (HWRCs) spread in various areas of the county where they can deposit their waste for further processing but that mainly refers to items that cannot be disposed of with the rest of the residential waste (e.g. electrical and electronic devices). As this is a more complex operation, and data recording for the exact type, amount and origin of these waste is not yet available they have been excluded, in this study.

Fig.1 PET and glass bottle recycling routes

At the MRFs, the plastic bottles (including the PET bottles) are consolidated and tied with wire in bales and transported by lorry out of the county either in Rochdale, Leicester or Bedford where they are recycled according to the information provided in a document available at the official website of the council [4]. From the same source, we obtained the information that the recyclable glass (which includes bottles) are sent to Portugal for recycling so we assume that they are transported first by lorry from the MRFs to Falmouth Harbour where they are loaded on a ship. Figure 1 shows the journey PET and glass bottles follow before they are processed further (either incinerated or recycled).

The Cornwall Council is aware of the environmental challenges and they try to keep records and share them for research work which could contribute towards a more sustainable world. Therefore, from personal communication we were provided information about the waste management (such as the routes followed) as well as data for the amount of the residential waste collected during an annual period for each one of the more than 200 parishes. In total approximately 160,576 tonnes of residential waste were collected, 128,805 tonnes of which were residual (~80% of total collected) and 31,770 tonnes of which were given for recycling (~20% of total collected). The literature review identified reports [5], [6] from which we obtained the information about the share of plastic bottles in residual waste (1.5%) and that PET may account for 61.5% of the total number of plastic bottles. We also found out that the share of recyclable plastic bottles collected is approximately 2.6%. For the glass, 84% was collected in the black boxes for recyclables and 16% was misplaced in the residual waste. Based on these assumptions, we used the actual masses for the annual collection of the wastes and estimated the amount of PET and glass that is collected to be incinerated as residual waste or recycled for each one of the parishes.

The level of the data granularity for the masses and the ability to calculate the distance of each parish to the incineration (CERC) or recycling destinations (MRFs) allows for the calculation of the transportation requirements for the specific masses and distances. For the distances, we used the closest PET recycling centre (Leicester is 423km and 476km away from Bodmin and Pool MRFs respectively) and the closest Portuguese Harbour (Leixo is 590 nautical miles or 1093km away from Falmouth Harbour) in order to investigate the most favourable transportation scenarios for both PET and glass.

The figure that follows (Fig. 2) shows the life cycle of the PET and glass bottles used in Cornwall. The boundaries of this study (denoted within the rectangular dashed line in the figure) include the handling of the bottles and more specifically their transportation from the kerbside to the CERC and MRFs and finally the recyclers in the UK and Portugal. The production of the bottles, their filling, distribution to the consumers and their use are not included in this study as this a very complicated issue and there are not enough representative data to take into account the production, transportation, potential refrigeration and other processes that are involved. This study also excludes the process of recycling and production of new bottles and the transportation back to the households via the commercial market network. The incineration and energy recovery is also excluded because we could not obtain reliable data for an adequate period. Since our goal is to compare the environmental impacts from the management of the bottle wastes, we have restricted the system boundaries to the collection of the bottles from the residential waste, and their transportation in and out of the county before they reach the incineration or recycling site. We also wanted to focus on the handling of the waste and that is one more reason why we excluded the production and transportation before the use of the bottles and the incineration, energy gain, recycling, material recovery and reforming to new bottles. Therefore, as it currently stands, this is a gate-to-gate LCA and the next steps in our research is to expand the system boundaries to include the other phases when more data are collected.

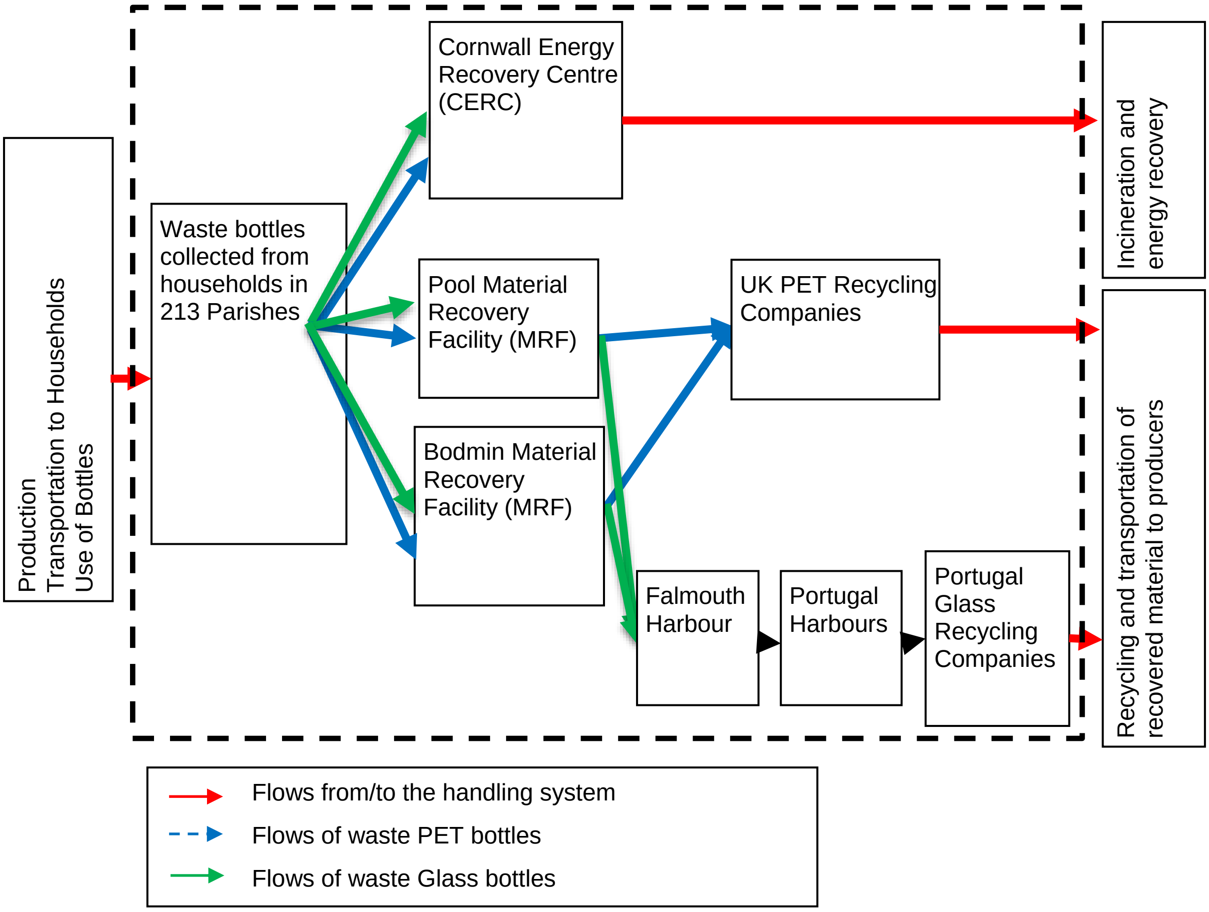

Fig. 2 PET and glass bottle waste management system boundaries in Cornwall

The tool we developed allows the users to define the total mass of residual and recyclable waste collected by the council as well as the shares of the PET and glass bottles in the total. In this way, it is possible to calculate the amounts of PET and glass that go to the incinerator or recycling. The tool entails pre-defined input values but users can also modify the input values if more representative data are available for their cases or if additional scenarios are evaluated (e.g. how much the use of lightweight bottles could help). As far as the transportation distances are concerned, these were calculated in the background and the results of these calculations are provided as predefined values. However, the users have the ability to overwrite these and investigate a combination of scenarios by changing these values and/or by also choosing a different place for PET recycling in England and for glass recycling in Portugal. The life cycle environmental impact results for the transportation of 1 tonne of waste for 1 km by lorry and by ship were calculated and included in the model. Using the GaBi software [7], the ecoinvent database [8] and CML 2001 impact assessment method [9] the tool can calculate the impacts from the preferred waste bottle handing scenario for 11 impact categories. The tool is currently being upgraded so that it incorporates the production and recycling/reforming of the bottles. Nevertheless, these processes are defined by parameters that cannot be controlled by the decision makers at local level, such as the ratio of virgin/recycled PET granules used in the PET bottles or cullet used in the glass bottles and thus they are not presented in the current case study. The next section presents the investigation results.

Results

The tool was used to investigate the life cycle environmental impacts resulting from the potential substitution of Polyethylene Terephthalate (PET) bottles with glass ones in Cornwall County and examine whether eliminating them under the current practices could have an adverse effect on climate change. First a comparison of the PET and Equivalent Glass transport environmental impacts for the 11 impact categories is given and then results for a more detailed comparison that focuses on the GWP are presented accompanied by the results on alternative recycling routes.

As shown in the following figure (Fig. 3), substituting the current PET bottles that are collected in the residential waste with glass ones would lead to an increase at the life cycle environmental impacts for all of the 11 categories: Abiotic Depletion (ADP elements), Abiotic Depletion (ADP fossil), Acidification Potential (AP), Eutrophication Potential (EP), Freshwater Aquatic Ecotoxicity Potential (FAETP inf.). Global Warming Potential (GWP 100 years), Human Toxicity Potential (HTP inf.), Marine Aquatic Ecotoxicity Potential (MAETP inf.), Ozone Layer Depletion Potential (ODP, steady state), Photochemical Ozone Creation Potential (POCP), Terrestrial Ecotoxicity Potential (TETP inf.).

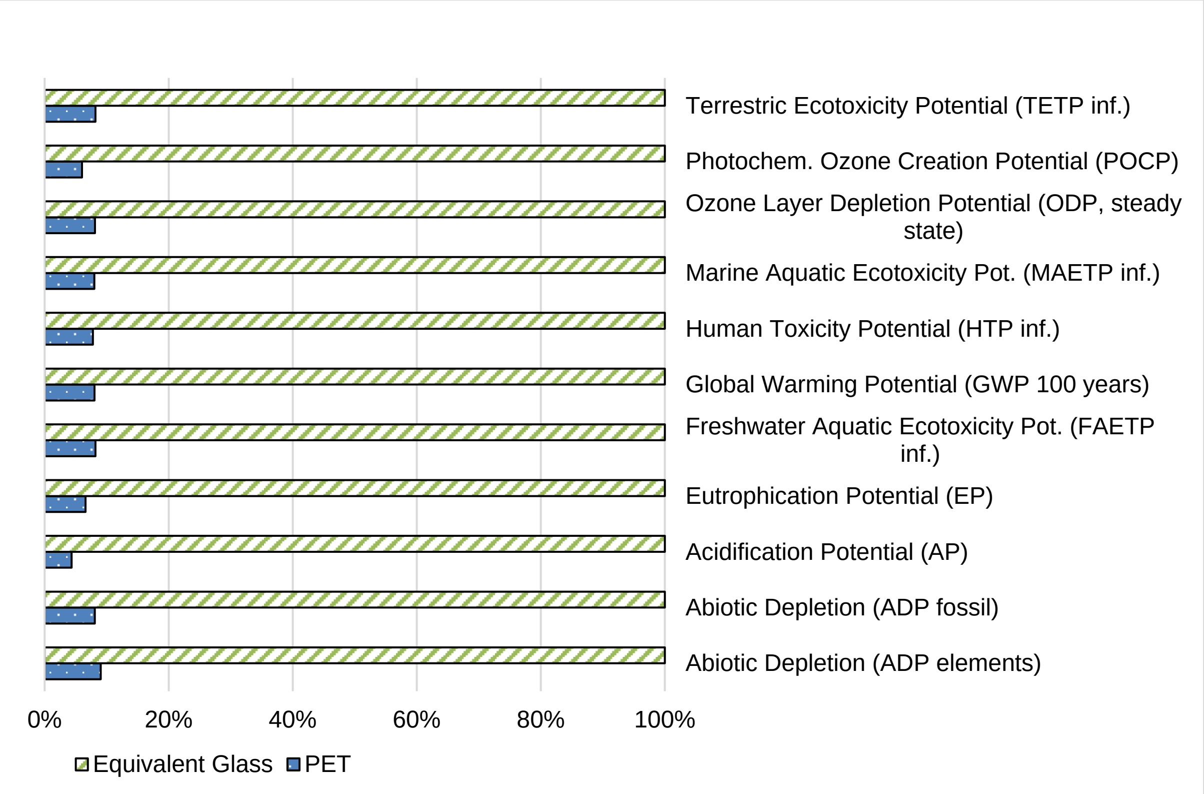

Fig. 3 PET and Equivalent Glass transport environmental impacts

The main reason is that the means of land transportation are the same for both types of bottles and but each PET bottle can weight less than 10% of the equivalent glass one. The additional sea transportation required for the glass to reach the recycler in Portugal is also a reason, but the impacts per tonne-km transported is between 20 to approximately 1000 times less than that of land transportation with the GWP one having 3% of the impact that land transport has.

The results for the GWP are presented in Figure 4 and are more analytical than the previous ones as they also show the contribution of each activity to the total impact. As shown, the highest GWP score is attributed to the transport from the Portugese Harbour to the glass recycler (1,001,891 ts CO2-eq) followed by the transport from the MRF to the Falmouth Harbour (331,441 ts CO2-eq). As also shown in the previous graph, the impacts on climate change for the handling of the PET bottles scores a GWP of 143,493 ts CO2-eq which is less than ten times that of the impact the substitution with equivalent amount of glass would have (1,784,894 ts CO2-eq). Just the transportation of the equivalent glass from the MRF to the Falmouth Harbour within Cornwall or the transportation of the equivalent glass from the Kerbside to the MRFs which scores 181,119 ts CO2-eq renders them both higher than the total GWP that all the waste PET bottle activities have. That means that even if the equivalent glass bottles did not have to travel to Portugal to get recycled, the impact to climate change would still be the same.

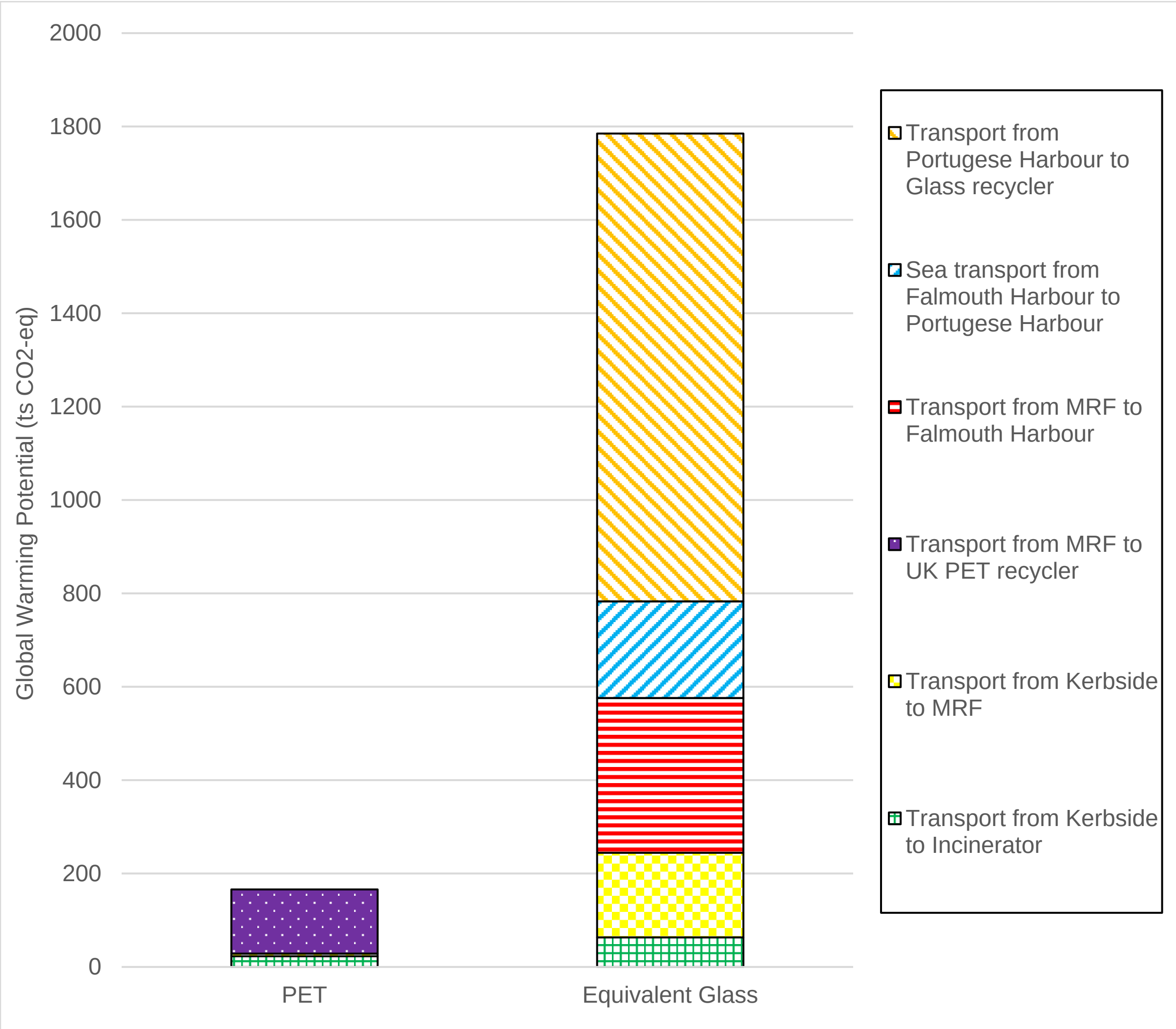

Fig. 4 Global Warming Potential for PET and Equivalent glass for every handling process activity

On that point, it would be worth presenting Figure 5, which illustrates the preliminary results from the incorporation of the production and recycling processes so that a full LCA is taken into account. These results are only for one case which is based on the assumption that the glass that substitutes the PET bottles is of white colour and contains 62.5% cullet from the recycling process. For the PET bottles, the recycled content is assumed to be 35% [10] and the additional production processes of injection moulding and stretch blow moulding had to be taken into account increasing the impacts of PET bottle production at a level similar to that of glass bottles. On that point, it is worth noting that according to some sources [11] glass is an infinitely recyclable material as opposed to PET, and other plastics, that can be recycled only for a restricted number of times, due to the breakdown of the polymer chain and the deterioration of their quality. The results presented here refer to one round of recycling only and it is expected that for a proper life cycle assessment comparison more elaborate scenarios have to be developed to take into account more rounds. Therefore, it is apparent that for the inclusion of the production and recycling processes more information is required about the type of plastics and glass bottles, the recycling ratio, the energy recovered during the incineration process, and how many times they can be recycled and at present, that level of detail is not available. Assumptions can be made but because of the number of the parameters, the combinations require the investigation of a large number of scenarios and sub-scenarios. For this reason, it is advised to use the following figure and the results shown as indicative only and acknowledge the need for more work on the subject.

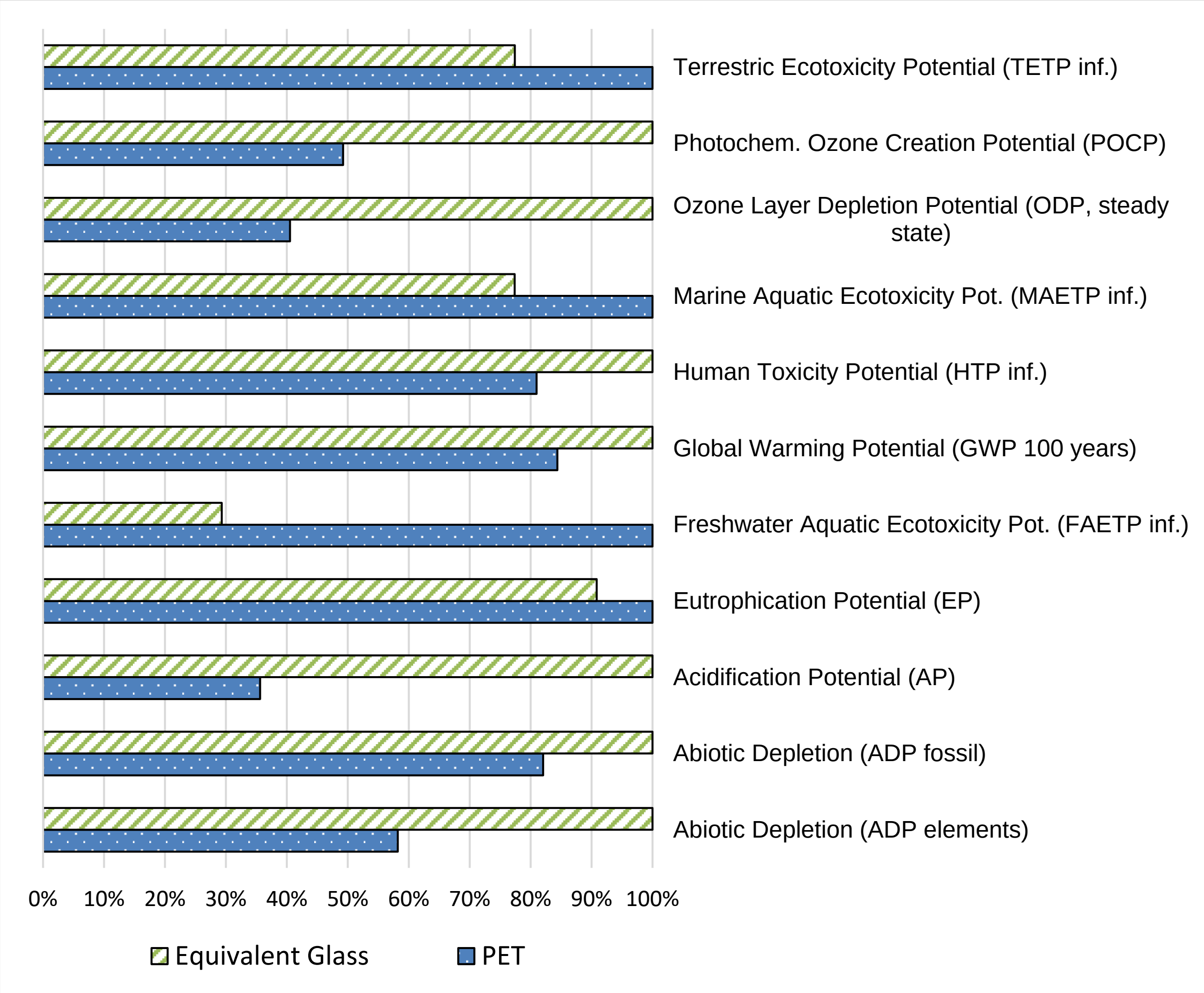

Fig. 5 Indicative preliminary results for full LCA of PET and equivalent glass

As shown in Fig.5 comparing the impacts from the PET bottles with the equivalent glass bottle ones the PET bottle scores do not fall below 30%. In addition, this time the PET bottles score higher than the equivalent glass ones in all three ecotoxicity potential impact categories (Terrestrial, Marine and Freshwater aquatic) as well as in the eutrophication potential. For the other categories, the equivalent glass bottle impacts still score higher than these for the PET bottles. Especially, for the GWP, the difference between the two bottling material alternatives is less than 20%. That potential reduction in the difference could be expected when bold interventions take place such as the development of a glass recycling plant in the county and the introduction of lightweight glass bottles. That might render the glass bottles equally or even lower carbon alternative than the PET bottles. Of course, this depends on a wide range of parameters and caution should be exercised when such scenarios are investigated and policies are designed. With the objective to acquire more reliable results, more robust data should be gathered and a wider range of parameters should be investigated and this is why these results are marked as preliminary.

Conclusion

The research so far shows that the substitution of PET bottles with glass ones under the current management practices could lead to significant increases in the GWP and hinder efforts to tackle climate change. Potential improvements might be achieved by keeping the recycling activities within the county geographic boundaries and by making glass bottles lighter. When taking into account the preliminary results from a more complete LCA, it seems that the PET bottles thanks to their light weight are contributing positively in keeping the GWP at low levels, but the development of more favourable conditions for the glass bottles does not exclude the overturn of this finding. In an effort to design a new circular economy with less plastic, it is necessary to identify and address the specific needs of the region and use science-based tools that incorporate life cycle thinking in order to avoid burden shifting like the one presented in this paper.

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