

Environmental impacts

The environmental performance of novel bio-based PBS was evaluated through Life Cycle Assessment (LCA). The aim of LCA is to quantify and assess the environmental impacts associated with a product, process or service along their whole life cycle, “from cradle to grave”.

The objective of the screening LCAs carried out in the SUCCIPACK project was to **evaluate the environmental performance of bio-based PBS according to different production scenarios**. Moreover, the studies compared new solutions to establish plastic granulates used for food packaging. The goals of these LCAs were to identify environmental hotspots and to provide ecodesign feedback to the SUCCIPACK consortium. The environmental evaluation was performed with a broad set of environmental indicators, in order to offer an exhaustive analysis.

Several screening LCAs have been conducted on bio-based PBS. Scenario analyses have considered the following aspects:

- Production routes of PBS monomers: use of renewable or fossil-based resources, different production routes for succinic acid (i.e. sodium hydroxide used to neutralise succinic acid, with sodium sulphate as co-product; ammonia used to neutralise succinic acid with ammonium sulphate as co-product both with a higher and a reduced amount of ammonia; direct crystallisation of succinic acid with data from literature).
- Polymerisation process (melt polymerisation of high M PBS; melt polymerisation of low M PBS followed by solid state polymerisation).
- PBS formulations with additives (talc, PLA, PBSA, Joncryl®).
- End of life options (mechanical and enzymatic recycling, landfill, incineration).
- Surface treatment of PBS films (plasma coating).

Results show that the most critical aspect in the life cycle of bio-based PBS is the consumption of energy. In particular, the energy employed for the production of bio-based succinic acid gives the most relevant contribution, since succinic acid is used to produce both BDO and PBS. The reduction of energy consumption, especially for the production of succinic acid, should be considered as a priority in the optimisation of bio-based PBS and its technical feasibility should be evaluated.

The best results concerning synthetic routes for succinic acid production, have been obtained with direct crystallisation modelled with literature data from Cok et al. (2014)¹. The second best production route involves a reduced use of ammonia for neutralisation of fermentation broth, which delivers ammonium sulphate as co-product.

The use of SSP to increase molecular weight of low M PBS could reduce the environmental impact of high M bio-based PBS. This alternative is not currently applied to PBS besides lab scale and therefore the environmental evaluation has been performed with estimated data referring to pilot/industrial scale. For this reason, the potential reduction of environmental impacts due to SSP might not be fully representative for the upscaled system, even though these first results are promising.

¹ Cok B., Tsiropoulos I., Roes A.L., Patel M.K. (2014). Succinic acid production derived from carbohydrates: An energy and greenhouse gas assessment of a platform chemical toward a bio-based economy. *Biofuels, bioproducts & biorefining* 8, 16-29.

Concerning PBS recycling, the environmental impact of recycled materials is lower than the one of virgin bio-based and fossil-based PBS both for enzymatic and mechanical recycling. Enzymatic recycling shows higher environmental impacts than mechanical recycling especially because recycled building blocks need to undergo a new polymerisation process in order to produce bio-based PBS. Nonetheless, enzymatic recycling would be particularly useful in case of PBS compounds and copolymers recycling. A large part of the environmental impacts of recycled PBS is due to the collection and pre-treatment phases. The uncertainty related to these phases is high, due to the use of background data, and recycling techniques are not currently applied to PBS besides lab scale.

Blending of PBS with additives can modify the environmental performance of the material as well. For instance, blending with talc would improve the environmental performance of bio-based PBS, whereas blending with PBSA would increase its environmental impact. The use of PLA as additive would also reduce the environmental impact of the plastic granulate for most impact categories.

Plasma pre-treatment, coating deposition and drying would increase the environmental impact of PBS film, since data on plasma coating and drying mainly refer to pilot scale. The contribution of these processes to the environmental impact of coated PBS film is expected to decrease with upscaling of the technology (industrial scale), even though this reduction cannot be quantified at present.

The environmental performance of bio-based PBS was compared to established plastic granulates (e.g. PET, PA6, PLA) and conventional food packaging materials of interest for the project. Packed food products include fish, vegetarian ready meals, ready-to-eat vegetables, dairy products and raw white meat. The comparison has been conducted from cradle to grave, including end of life of plastic granulates and packaging materials, and food in the case of packed food products. Different plastic materials were compared based on their volume, assuming an equivalent function between packaging items of the same size and thickness. The aim of the comparative analysis was to provide ecodesign feedback to the SUCCIPACK consortium in order **to optimise the production process of the novel material.**

At the current state of development of bio-based PBS production technology, the use of PBS packaging would increase the environmental impacts of the food products under study. The increase of the environmental impact of packaging is more evident in case of vegetable products (vegetable couscous, grilled peppers and marinated tomatoes), whereas for animal-derived products (cheese and ricotta, chicken and fish) it is more limited, both because animal-derived products have higher impacts than vegetarian products, and because for some of these products (e.g. chicken and ricotta) the ratio mass of packaging/mass of food is low.

Currently, the environmental impacts of bio-based PBS are higher than those of some traditional plastic granulates (e.g. PET) and other bio-based plastics (e.g. PLA), whereas PA6 has higher impacts than bio-based PBS for some impact categories. Moreover, a higher amount of bio-based material is needed for the same amount of packed food due to its higher density. The increase of the environmental impact of packaging could be justified if this increase resulted in a lower rate of food waste, reducing the overall environmental impact of the packaged food product.

Whereas traditional plastics are produced through a well-established and mature technology on industrial scale, bio-based PBS is at an early stage of development, and far from full industrial scale. **The main aspect to improve the environmental performance of bio-based PBS is the synthesis of succinic acid; in particular, alternative synthetic routes could be tested.** For instance, according to literature data, succinic acid produced through low pH yeast-based fermentation followed by direct crystallization has lower environmental impacts. In general, **bio-based PBS can be an interesting material for packaging applications but its environmental performance should be further improved.**

The use of LCA in an early stage of development of new processes or products is particularly useful, providing valuable feedback for product improvement. The LCA results obtained in the project derive from screening LCA studies. Screening LCAs enable to make quick comparisons, but use a large amount of background data. The values obtained and the resulting conclusions could change if more precise data were available (e.g. realisation of pilot or industrial plants). **Furthermore, many data used in the evaluation refer to lab or pilot scale; improvement of the environmental performance of the material could be expected if the processes under study were implemented at pilot or industrial scale.**