The Durabilis Award Competition 2020

Life cycle assessment of bio-based synthetic fibers: the case of polyester substitutes

Master Project – Summary of Research

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Textile industry is a resource-intensive sector with a high dependency on fossil resources; which emits excessive amount of greenhouse gases and uses notable amounts of water throughout the supply chain [1]. The main building block of any textile product is a fiber. Half of the present 107-million-ton annual fiber production falls on a specific type of synthetic fiber – the **polyester** [2] and the overall fiber production volumes have been and are predicted to keep on growing rapidly.

Traditionally, polyester is obtained from polyethylene terephthalate polymer (**PET**[1]) by simple melt spinning, i.e. process in which the polymer[2] is melted and drawn out into the fiber. This makes polyester not only a prevalent textile fiber; it means that it is produced from fossil resources through the means of chemical engineering.

It is therefore obvious that business-as-usual practices of the synthetics' production combined with the growth predictions will not be able to break from the fossil-fuels nor mitigate the environmental impacts without some intervention. One proposed solution for decoupling and reducing primarily the climate footprint of the resource-intensive sectors is to "go bio-based", which has also become the priority of the European Union for textiles from 2019 [3]. **"Going bio-based"** means that the fossil-based products (like polyester) are functionally replaced by bio-based alternatives – products where a part or entirety of the product's mass stems from the non-fossil feedstock. At present, the most widely used alternative feedstock are the **agricultural crops**. Bio-based C content of the product is used to express how much of a product has successfully been "bio-sourced". The ultimate idea behind bio-sourcing is to use the non-fossil carbon (C) sources in order to elope additional emissions of carbon dioxide ($C0_2$) and other greenhouse gases, thereby reducing the climate impacts of the product.

At present, **95%** of the polyester put on the market can be substituted by 3 bio-based alternatives [4]:

- bio-based PET fiber (**bio-polyester**) – "drop-in substitution" chemically identical compounds to the fossil-based polyester, but stemming from the bio-feedstock
- polytrimethylene terephthalate (**PTT**) fiber – a bio-based fiber with similar functional properties
- polylactic acid (**PLA**) fiber – "novel" substitute without a fossil counterpart, 100% bio-based

In spite of the existing political will to prioritize bio-based alternatives, the **environmental effects** of the feedstock substitution for polyester fibers are not studies abundantly. Present-day studies related to the performance of the bio-based synthetics focus on a limited number of indicators or are performed for polymers or bottles. No study was performed to corroborate that they are indeed eco-friendlier option. It is in this vacuum of insufficient knowlegde, political prioritization and a need for environmentally-sound products, that this project finds its place.

In the language of engineering and this project, the environmental performance is assessed though the means of a **life cycle assessment (LCA)**. In short, LCA has two steps; it aggregates the overall resource consumption and emissions during the fiber's "life" into an inventory; then, an assessment method evaluates the gravity of these impacts. Among other, it gives the overall score for 1kg of each fiber, whereby different impacts (e.g. water pollution levels, land use and air pollution) are brought together allowing for a comprehensive single-unit comparison. Here, **"fiber's life"** encompasses a cradle-to-gate scope, including the production and transportation of all intermediaries - from sowing and growing crops (cradle), across the polymer all the way to the finished fiber at the factory (gate). State-of-the-art production processes of fossil-, fully and partially bio-based polymers are used, and suitable melt spinning is applied at the end. The **impact assessment** was performed using 2 methods – Swiss Ecological Scarcity and European Environmental Footprint, reflecting the

[1] PET is not specific to the textile industry; it is a well-established, fossil-based polymer used in plastics & packaging sector (e.g. PET water bottles).
[2] Polymer is a chemical compound composed of repeating units called monomers.

priorities of Swiss environmental policy and a scientific classification of environmental and health impacts respectively.

The project found that none of the 3 alternatives performs better than the incumbent on the overall, regardless of the bio-based C content, the crop or the assessment method. Truly limited improvements are obtained only for the environmental and health impacts which carry less weight in the overall score. All 3 alternatives are produced from either **sugarcane or corn grain** and always use a fermentation step to convert the feedstock into an alcohol and then synthetize the bio-monomers out of it. We observed low conversion rates of feedstock into the final products - it takes a staggering 3.5kg of corn to produce 1kg of 100% bio-polyester, pointing to a need for the process improvements.

Additionally, fully bio-based versions of the bio-PET and PTT fibers perform substantially worse that the partially bio-based counterparts. Such a difference is ascribed to the poorer performance of the present-day bio-based PTA relative to the fossil-PTA, a monomer shared between the two polymers. As PTA accounts for 80% and 73% of bio-C content of the two fibers respectively, its amelioration is paramount for the truly sustainable future of these two bio-based products.

So, if the bio-based fibers have a poorer performance than the incumbent, where is the difference coming from? As they all stem from the crops, contribution of **agriculture** to major impacts categories was examined. We find that land use, water resource consumption, pesticide use, acidification (damaging to soil), and eutrophication (provokes algae bloom) all rise with fiber's bio-content. Moreover, around ½ of eutrophication and acidification, the entirety of land and pesticide use and some 2/3 of water consumption are directly tied to the agriculture.

Finally, we refuted that **climate footprint** of the bio-based fibers is better than that of polyester. Indeed, if the climate footprint, for which bio- alternatives are initially prioritized is worse than for the incumbent – the main argument in favor of bio-based alternatives is lost.

In summary, the performance of bio-based alternatives is heavily tied to the agricultural practices. Since their climate footprint is not improved either, it is found bio-based alternatives provoke more environmental damage than they bring in benefits. Sir Winston Churchill once said: “However beautiful the strategy, you should occasionally look at the results”. If bio-sourcing is the strategy, its results for polyester substitution are discouraging at best. As long as the alternatives remain largely agro-based, there can be no word of their “eco-friendlier” performance.

References:

[1] Nathani et al. (2019). Environmental hotspots in the supply chain of Swiss companies, BAFU, 29.04.2019

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[3] European Commission, The European Green New Deal, https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en, last access: April 2020

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