Supplementary Material

Lab-on-a-chip – fostering a sustainable future

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# Supplementary Data

The identification of a product’s environmental load is usually performed through a life cycle assessment (LCA), which quantifies potential impacts on the natural environment, human health and resources during each step of the life cycle of a product or service. A LCA, as defined in the International Organization for Standardization (ISO) 14040 and 14044 documents, includes four different steps, which are (1) goal and scope definition; (2) inventory analysis; (3) impact assessment; and (4) interpretation of the results (Guinée, 2002). The goal and scope define the system boundaries and the functional unit, which determine the emissions and extractions to be included in the model. The inventory analysis quantifies the environmental emissions and the raw material extraction for the functional unit. The impact assessment evaluates the environmental impacts of the emissions quantified in the inventory analysis. The interpretation phase identifies the key parameters of the model and performs sensitivity studies on them. Therefore, the environmental impacts of different materials depend on a large number of factors, such as the functional unit, the country of production, the type of use and disposal, and the methodology and assumptions made to conduct the study. The heterogeneity of scenarios makes general comparisons of environmental impacts among different materials difficult unless proper and in-depth analyses are carried out. To illustrate this complexity, we present some examples of studies that compare different materials under different aspects, focusing on the global warming potential (GWP) impact category in kg CO2-equivalents (CO2-eq). This is one of the most used impact categories for assessing the environmental performance of materials. However, we also emphasize the need for specific LCA studies for lab-on-chip applications, as they may have different environmental implications. In addition, it would be of paramount importance to define key common parameters and assumptions among different scenarios to enhance the utility of LCA studies and reduce their variability.

Cherrett *et al.* (Cherrett, 2005) show how cultivation and production of cotton in the USA has ca. 62% lower CO2 emissions compared to polyester fibers, and that the cultivation of organic cotton could further lower CO2 emissions (Table 1). However, the study does not consider the use phase of the different fibers, the socio-economic impacts associated with agrochemicals used in crops and the potential air and water pollution. It however highlights how significantly emissions can vary when an environmental impact study is carried out in different countries, as the fossil fuels and energy systems differ. As a further illustration in a different application, Schmutz *et al.* (Schmutz et al., 2021) performed LCA to inform about 4 environmental impacts of a globally produced t-shirt (Table 2).

Supplementary Table . Carbon footprint analysis for different textile materials, adapted from (Cherrett, 2005). Functional unit: tons of spun fibers.

|  |  |
| --- | --- |
|  | Carbon footprintKg CO2-eq/ton of spun fiber |
| Material | Crop cultivation | Fiber production | Total emissions |
| Organic cotton, USA | 0.9 | 1.45 | 2.35 |
| Organic cotton, Punjab, India | 2 | 1.8 | 3.8 |
| Conventional cotton, USA | 4.2 | 1.7 | 5.9 |
| Polyester, USA | 0 | 9.52 | 9.52 |

Supplementary Table . Global warming potential of textile fiber production involved in the production of a t-shirt on a global scale, adapted from (Schmutz et al., 2021). Functional unit: t-shirt of 154 g.

|  |  |  |
| --- | --- | --- |
| Material | Carbon footprintKg CO2-eq/264 g of fiber | Water consumptionm3 water-eq |
| Silk | 36.0 | 360.2 |
| Wool | 9.7 | 2.5 |
| Nylon | 2.7 | < 1 |
| Cotton | 1.2 | 50.0 |
| Polyester | 1.1 | < 1 |

From an analysis of the global warming impact of different types of fuel-based plastics compared to biobased plastics, PMMA appears to be the polymer with the highest greenhouse gas emissions (Table 3), in contrast with the production of the bio-based poly L-lactic acid (PLLA) (Groot and Borén, 2010). Posen *et al.* (Posen et al., 2017) highlight how switching to renewable energy to produce regular plastics can reduce industry-wide emissions by 50%–75%, with less cost than switching to corn-based biopolymers, such as PLA, that would reduce emissions by 25% (Table 4). In the long term, both advanced feedstocks, e.g., switchgrass, and renewable energy can make bio-based plastics almost carbon-neutral. Nevertheless, bio-based products also negatively impact ozone depletion, acidification, eutrophication, water use, and food security, due to their reliance on agriculture (Posen et al., 2017; Rosenboom et al., 2022; Walker and Rothman, 2020).

Supplementary Table . CO2 emissions analysis of the production and incineration phase of polymers, adapted from (Groot and Borén, 2010). Functional unit: 1 ton of material at the factory gate in Thailand.

|  |  |
| --- | --- |
|  | Carbon footprintKg CO2-eq/kg plastic |
|  | Production | Production and incineration |
| PMMA | 6 | 7.8 |
| Polyethylene (PET) | 3 | 5.2 |
| Polystyrene (PS) | 2 | 5.1 |
| PLLA\* | 0.5 | 2.2 |
| \* PLLA belongs to the polymer family of polylactic acids (PLAs). |

Supplementary Table . Carbon footprint for five main plastic scenarios, adapted from (Posen et al., 2017). Functional unit: set of services provided by the U.S. national production of commodity thermoplastics.

|  |  |  |
| --- | --- | --- |
|  | Carbon footprintKg CO2-eq/kg plastic | Carbon footprint with low carbon energy, e.g., wind and renewable natural gasKg CO2-eq/kg plastic |
| PS | 3.1 | 1.6 |
| PET | 2.4 | 1.0 |
| PVC | 2.2 | 0.63 |
| PLA | 1.9\* | 0.09 |
| Bio-PVC | 1.9 | 1.3 |
| \* This figure considers that PLA is landfilled and acts as a carbon sink. If PLA was to be composted, it would release an additional 1.6 kg CO2-eq/kg plastic. |

Cherrett, N., 2005. Ecological footprint and water analysis of cotton, hemp and polyester. Stockholm Environmental Institute, Stockholm.

Groot, W.J., Borén, T., 2010. Life cycle assessment of the manufacture of lactide and PLA biopolymers from sugarcane in Thailand. Int J Life Cycle Assess 15, 970–984. https://doi.org/10.1007/s11367-010-0225-y

Guinée, J.B. (Ed.), 2002. Handbook on life cycle assessment: operational guide to the ISO standards, Eco-efficiency in industry and science. Kluwer Academic Publishers, Dordrecht ; Boston.

Posen, I.D., Jaramillo, P., Landis, A.E., Griffin, W.M., 2017. Greenhouse gas mitigation for U.S. plastics production: energy first, feedstocks later. Environ. Res. Lett. 12, 034024. https://doi.org/10.1088/1748-9326/aa60a7

Rosenboom, J.-G., Langer, R., Traverso, G., 2022. Bioplastics for a circular economy. Nat Rev Mater 7, 117–137. https://doi.org/10.1038/s41578-021-00407-8

Schmutz, M., Hischier, R., Som, C., 2021. Factors Allowing Users to Influence the Environmental Performance of Their T-Shirt. Sustainability 13, 2498. https://doi.org/10.3390/su13052498

Walker, S., Rothman, R., 2020. Life cycle assessment of bio-based and fossil-based plastic: A review. Journal of Cleaner Production 261, 121158. https://doi.org/10.1016/j.jclepro.2020.121158