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Environmental footprint of AFYREN's products via Life Cycle Assessment (14040/14044 standards)

Human wellbeing is closely linked to the health of the environment. Around the world, 24% of deaths can be traced back to avoidable environmental factors, according to the World Health Organization. People need clean air to breathe, fresh water to drink, and places to live that are free of toxic substances and hazards. Environmental sustainability is the responsibility to conserve natural resources and protect global ecosystems to support health and wellbeing, now and in the future.

AFYREN is offering to a wide range of industries replacement molecules that are 100% biobased, thanks to an environmentally friendly technology that uses natural microorganisms, an unique "all-in-one" fermentation technology. Various kinds of biomass can be valued without competing with human food chain and approaching zero waste generation and a real circular bioeconomy business model. AFYREN's innovative use of resources generated from organic raw materials means that it contributes to the quest for the most efficient use of resources. The manufacturing process forms a circular economy that goes from the valorization of biomass in a clean factory back to the earth.

Nevertheless, this environmental sustainability of AFYREN's products has to be measured, especially when these products aimed to be compared to petro-based products and products from the market. AFYREN chose Life Cycle Assessment to quantify the sustainability of its products.

1. What is Life Cycle Assessment?

Life cycle assessment is the most advanced tool for comprehensive and multi-criteria assessment of environmental impacts, and so the evaluation of environmental sustainability. This standardized method (ISO 14040-14044[1]) makes it possible to measure the quantifiable effects of products or services on the environment.

Life cycle assessment (LCA) identifies and quantifies the physical flows of material and energy associated with human activities throughout the life cycle of products. It assesses the potential impacts and interprets the results obtained in accordance with its initial objectives. Its robustness is based on a dual approach:

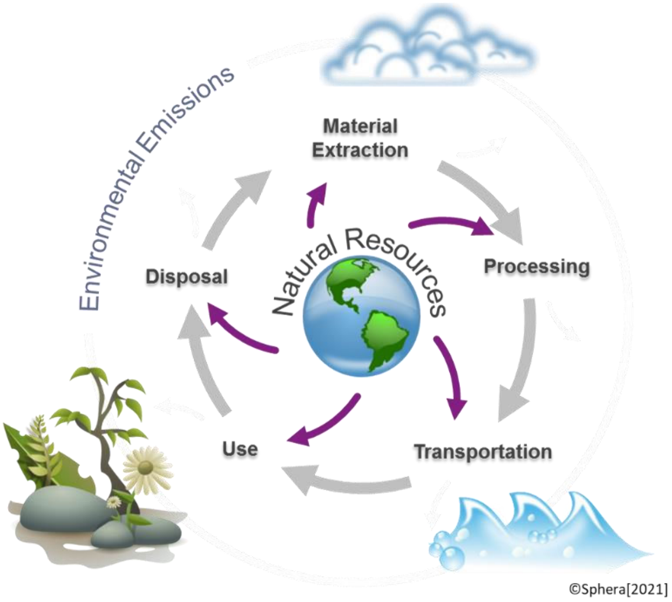
- *A "life cycle" approach:*

Whether it is a good, a service or even a process, all stages of a product's life cycle are taken into account for the inventory of flows, from "cradle to grave": extraction of the energy and non-energy raw materials needed to manufacture the product, distribution, use, collection and disposal to end-of-life channels, as well as all transport phases.

- *A multicriteria approach:*

A LCA is based on several criteria for analyzing incoming and outgoing flows. Everything that goes into the manufacture of the product and everything that goes out in terms of pollution is called "flows". Examples of incoming flows are those of materials and energy: iron resources, water, oil, gas. Outgoing flows may include waste, gaseous emissions, liquid waste, etc.

Collecting information on flows is an important step in LCA. They are quantified at each stage of the cycle and correspond to indicators of potential environmental impacts. The complexity of the phenomena involved and their interactions is a source of uncertainty about the real value of the impacts, which is why they are referred to as "potential".



Life cycle assessment is a decision support tool. The results can be used for the purposes of eco-design or environmental signage. The objective of LCA is to present a global vision of the impacts generated by products (goods, services or processes), based on different simulations.

Comparison of products or services

Environmental assessment is frequently used in a comparative way: comparing two technical options for a designer, comparing two products for a buyer, comparing two political orientations for a decision-maker. **The strength of LCA is that it restores the complexity of the environment and avoids choices that would result in degrading environments that had not been considered, or shifting impacts from one stage of the life cycle to another.** LCA accounts for potential pollution transfers by comparing two alternative scenarios. Thus, with LCA, it is possible to compare two products with the same function (e.g. a conventional razor and a disposable shaver); two different products with the same function (a car and a bus) or a "dematerialized" good and service (a letter and an e-mail).

Avoiding the risk of impact transfer

The interest of LCA is to evaluate several types of environmental impacts and all stages of the life cycle. In a comparison, it can show that a product has less impact than another on one criterion (greenhouse gas emissions, for example), but has more on another criterion (air acidification, for example). LCA can also show that a gain at one life cycle stage can have consequences that degrade another stage! For example, improving the insulation of a refrigerator reduces energy consumption in the use phase, but may require the use of more materials or more toxic materials (hence a greater impact of the production phase in terms of resource depletion or toxicity). In this case, by decreasing the environmental impact at the level of raw materials, it has been increased at the level of manufacture and use.

LCA results reflect the complexity of the systems studied: they make it possible to identify their strengths and weaknesses, but it is difficult to propose an absolute hierarchy in terms of ecological quality. It is in this sense that LCA should only be considered as a decision-making tool.

Methodology

The LCA methodology is based on four steps:

- **Goal and scope definition of the study**[2], where the foundations of the study are laid, as well as the functional unit to which the results will relate (1 km travelled by a vehicle, 1 kg of product manufactured, etc.).
- **Inventory of data**[3]: analytical accounting of the input and output flows of the system considered (resources needed for manufacturing the product, materials, energy, emissions, etc.).

- **Life cycle impact assessment**[4]: calculations of LCA results through several indicators like climate change impact (or carbon footprint), or damages on human health, quality of ecosystems (biodiversity loss), resources depletion.
- **Interpretation**[5]: discussion of the results obtained according to the selected objectives of the study.

2. AFYREN's products environmental benefits compared to fossil-based products

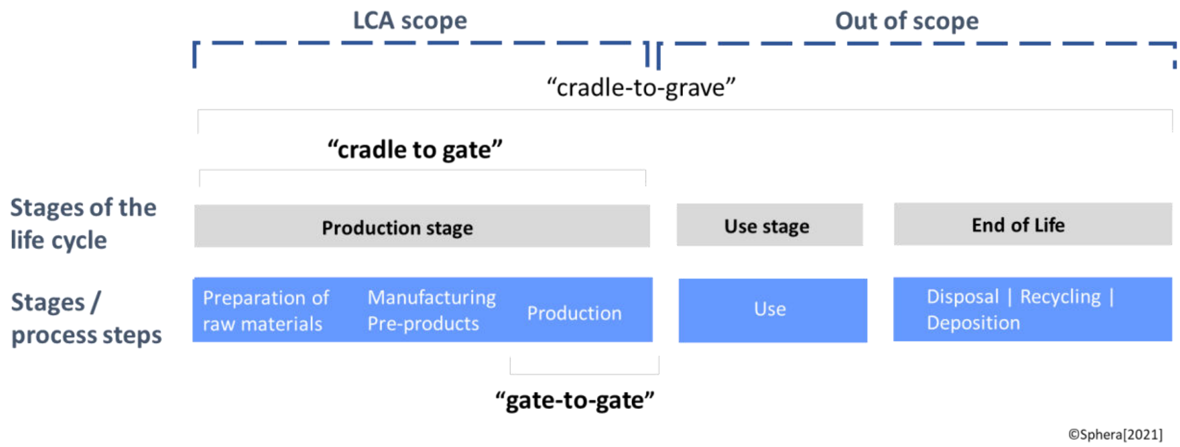
SPHERA has conducted a first environmental balance of AFYREN's products through LCA in the 2018-2019 period, based on pre-industrial data for AFYREN's process[6]. **Thanks to its iterative approach, and with updated pre-industrial data due to improvements in the process design, the LCA was updated in 2020 and prefigure the environmental assessment of the future Carling biorefinery.**

The goal of the study was multiple:

- **To evaluate the environmental performance of AFYREN's products** (acids and fertilizer), in order to identify the main contributors to the impacts, and the potential levers of improvement, in order to place AFYREN's process in an ecodesign approach, while the process is under industrialization.
- **To compare the balance of AFYREN's products with products of the market:** fossil acids and caproic acid available on the market.

The perimeter of the study was double:

- First, a "gate-to-gate" analysis, from the biomass supply entering AFYREN's process to the products outgoing AFYREN's plant, revealed the AFYREN's own assessment. The biomass entering AFYREN's process in this study consists in non-food byproducts of sugar industry (molasses, sugar beet pulps…).
- Then, the study was enlarged to take into account the upstream processes and represent a "cradle-to-gate" analysis (including the agricultural and biomass processing stages of sugar beet into products and byproducts).
- **The use phase of AFYREN's products and the end of life** (in a "cradle-to-grave" approach) **were not considered in this study.**



The functional unit chosen for this study was the ton of AFYREN's product as an output of the industrial chain. A mass allocation was considered between the different products, as the LCA model was built for one year of production for AFYREN's plant.

Various LCA indicators were used to have a complete environmental balance of AFYREN's products like Global Warming, Acidification, Eutrophication, Photochemical Ozone Creation, Fossil Resources Depletion[7] or Water use. In this publication we focus on Global Warning and more specifically Carbon footprint, which is the most relevant indicator for AFYREN's products.

A carbon footprint in favor of biobased products

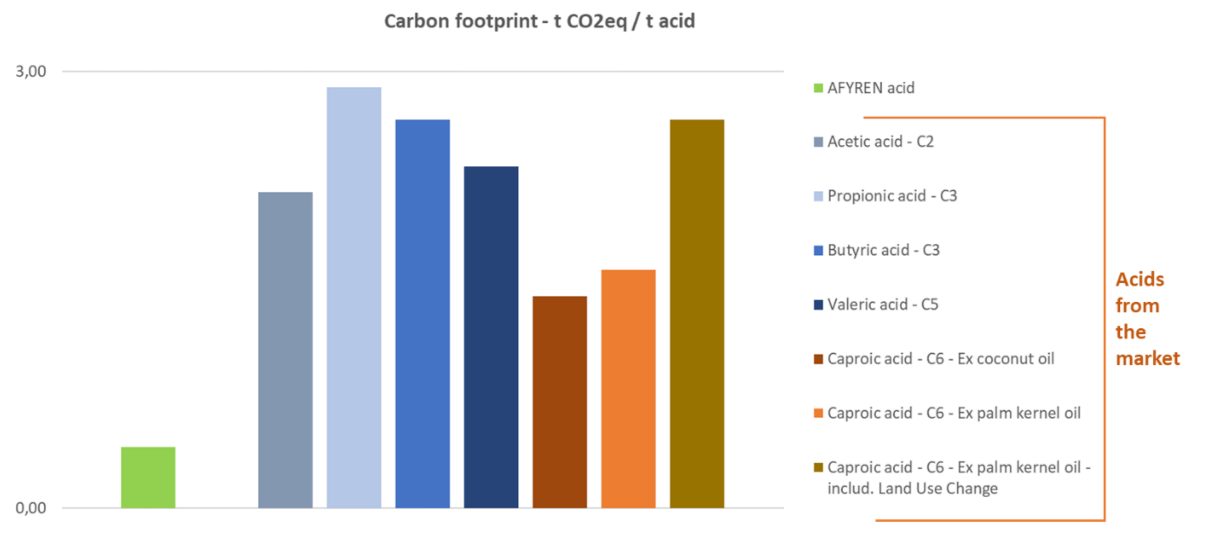
Based on the cradle-to-gate analysis the **carbon footprint of AFYREN's acids is in average 0,42 t CO_2 eq/ t of product**[8]**.**

This data includes the impact of the upstream activity and the activity within AFYREN. If we focus on the production part more precisely (gate to gate), where AFYREN has a proper responsibility, much of the impact comes first from the energy used in AFYREN's process and secondly from reagents used. The rest is negligible, like transport of biomass inputs and reagents to AFYREN's plant as well as outputs like emissions or waste or utilities in minor quantities.

Thus, energy is the major lever of improvement of the process, noting that electricity coming from French electricity grid mix (industrial voltage), having a low carbon footprint and steam is produced from natural gas.

➔The energy optimization of the process is therefore the first area of work identified with LCA for AFYREN.

Comparing the biobased acids of AFYREN to homologous products on the market, shows that AFYREN's products have a reduced carbon footprint by 81% in average.



LUC: Land Use Change[9]

With a production capacity of 16 957 tons per year, the production of biobased carboxylic acids will generate 7 119 tons of CO2 eq emitted to the atmosphere per year. The products having a carbon footprint 81% lower than the equivalent products on the market, AFYREN production will offer to the market low carbon solutions, allowing to save more than 30 000 tons of greenhouse gases emissions per year.

Taking into account the progressive ramp up of the factory, we can expect a total amount of near 90 ktons of greenhouse gases emissions avoided by 2025 thanks to AFYREN technology.

Taking the average mileage emissions of new vehicles registered in France for the period between January and October 2020 (98,1 g CO2 / km according to the ADEME)[10], these avoided emissions would be equivalent to 306 millions of kilometers travelled by a vehicle over one year and up to 891 millions of km travelled until 2025.

Regarding the other impacts, preliminary LCA results are variable compared with fossil or biobased alternatives and more investigations will be conducted on these indicators in a second time.

Further iterations of the LCA and sensitivity analysis, as well as LCA assessments with a cradle-to-grave perspective will be required to cover the entire knowledge regarding the environmental performance of AFYREN's products.

3. Perspectives of work

LCA of AFYREN's carboxylic acids will be completed by other sustainability assessments, through the European project AFTER-BIOCHEM (2020-2024)[11].

The main aim of the work will be to help in investigating sustainability of the flagship biorefinery regarding the three sustainability pillars: environmental performance (using an LCA approach), economic feasibility (using a Life-Cycle Costing approach) as well as societal impact (using the WBCSD social impact metrics approach).

A set of metrics - all based on life cycle thinking – will be developed to assess the performance of the products derived from the new bio-refinery in comparison to their fossil-based alternatives:

- *New iteration of the LCA of the biorefinery and the bio-products.* Investigation will be conducted on other LCA indicators than climate change, including indicators on ecosystems quality and biodiversity. A critical review will be done for this LCA, as recommended by the LCA ISO standards.
- *Life-cycle Costing (LCC)* for the assessment of Total Cost of Ownership. As cost competition between bio-based and fossil-based products is dominating customer behaviour (for example: at higher oil prices bio-based products are more competitive), this approach will answer some following challenges: identification of the break-even point of the bio-based approach vs. the fossil-based approach in relation to different feedstock and oil prices, respectively; or identification of the economic drivers of the bio-based approach such as options to improve the handling, disposal and/or potential valorization of by-products and bio-process effluent which are major cost factors of bio-based products.
- *Material Circularity Indicator to assess circularity of the products.* Making products and value chains more circular will be a prerequisite for successful economic as well as sustainable business practices. The Material Circularity Indicator (MCI) has been developed by Granta Design and the Ellen Macarthur Foundation to measure how restorative the material flows of a product or company are. Coupling the two approaches of LCA and MCI, an evaluation of the environmental impact as well as the circularity of the products coming from the bio-refinery can be done hand-in-hand and the value chain be optimized towards both sustainability and circularity.
- *Social Life-Cycle Metrics* according to WBCSD[12] to assess relevant social aspects. Beyond reducing the environmental impact, improving resource use and biorefinery cost efficiency, some social criteria such as impacts on competitivity, territory integration and employment regionally near the production site in Carling (France) are also major criteria to assess in order to have a holistic view of bio-based products and industry along the principles of people, planet and profit. The social impact assessment will provide a hot-spot analysis of the relevant social aspects (like basic rights and needs, employment, health and safety, skills and knowledge, well-being) of the various production alternatives across their life cycles (from feedstock to consumer).

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[1] ISO 14040:2006 - Environmental management - Life cycle assessment - Principles and framework and ISO 14044:2006 - Environmental management - Life cycle assessment – Requirements and guidelines.

[2] This stage makes it possible to define the objectives of the LCA, specifying how it will be applied: ecodesign, comparison or environmental declaration. The target of the study (internal or external to the company) is specified at this stage, as well as the way in which the results will be disclosed (for comparative claims, for example). The scope of the study must also specify the functions of the product under study, the functional unit chosen, the boundaries of the system under study and the limits of the study. It is also at this stage that the various rules for the calculations applied to the study will be decided. The functional unit is the unit of measurement used to evaluate the service provided by the product. In the same way that to compare the price of two fruits a consumer brings back the prices per kilo, to compare the environmental impacts of two products, the impacts will be brought back to a common unit of measurement.

[3] This step consists of drawing up an inventory of the incoming and outgoing flows of materials and energy associated with the stages of the life cycle in relation to the functional unit selected. The inventory is therefore an analytical accounting of the flows. Two types of data are collected: activity factors (kWh consumed, km travelled, toes transported, etc.) and emission factors (g of NOx emitted into the air, g of PO4 emitted into water, etc.). These specific (or primary) data can be supplemented by generic (or secondary) data, taken from the bibliography, from calculations or from LCA databases, when the former are not sufficient or when they are not accessible.

[4] Based on the material and energy flows identified, and according to the indicators and the selected characterization method, the potential impacts will be assessed. Different ways exist to characterize the inventoried flows into environmental impact indicators at different levels. The most widely recognized and used today characterize flows as potential impact indicators (or "midpoint"), like Global Warming Potential, Acidification Potential, Eutrophication Potential, etc. Others go to a second level of characterization to obtain indicators of potential damage (or "endpoint"). These methods facilitate the understanding and use of

results because of the smaller number of indicators, generally four in number (e.g. damages to human health, damages to ecosystems, etc.), but are less recognized due to their lower scientific robustness.

[5] This step is iterative with the previous three, so as to always validate that the results obtained meet the study's objectives (for example, the unavailability of certain data may lead, in the course of the study, to restricting the scope of the study). It is also here that the robustness of the results will be assessed.

[6] The LCA model was created in Sphera GaBi LCA software tool (http://www.gabi-software.com/international/index/) and based on GaBi databases.

[7] LCA results calculated with LCIA methodology CML 2001 – August 2016.

[8] In 2019, first LCA results gave a carbon footprint for AFYREN's acids of 0,77 t CO2 eq / t of product, representing a reduction of 66% compared to petrobased acids or caproic acid on the market. This improvement in the carbon footprint is due to improvements in the process design.

[9] Land Use Change (LUC): Land use, land-use change, and forestry (LULUCF), also referred to as Forestry and other land use (FOLU), is defined by the United Nations Climate Change Secretariat as a "greenhouse gas inventory sector that covers emissions and removals of greenhouse gases resulting from direct human-induced land use such as settlements and commercial uses, land-use change, and forestry activities. LULUCF has impacts on the global carbon cycle and as such, these activities can add or remove carbon dioxide (or, more generally, carbon) from the atmosphere, influencing climate. LULUCF has been the subject of two major reports by the Intergovernmental Panel on Climate Change (IPCC). Additionally, land use is of critical importance for biodiversity.

[10] From https://carlabelling.ademe.fr/

[11] https://after-biochem.eu/ The AFTER-BIOCHEM project is aiming to develop the first all-in-one biorefinery within the «CHEMESIS» chemical platform sited in Carling Saint-Avold, France. It will create multiple value chains based on the transformation of sugar industry's co-products as well as other non-food biomass feedstocks into bio-based and natural molecules for various applications. AFTER-BIOCHEM brings together at different stages of the value chain teams 12 partners from 5 European countries, including AFYREN and SPHERA. The project will be carried out over 48 months, from May 2020 to April 2024, with an overall budget of € 33M including € 20M funding from the European Union's Horizon 2020 research and innovation programme and the Bio Based Industries Consortium.

[12] https://www.wbcsd.org/ World Business Council for Sustainable Development (WBCSD) is a global, CEO-led organization of over 200 leading businesses working together to accelerate the transition to a sustainable world.