A sustainable way of producing carbon fiber reinforced plastic: LCA of recycled carbon fiber

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Carbon fibers are widely used in numerous sectors of the manufacturing industry due to their peculiar qualities as a lightweight material with excellent mechanical strength and electrical and thermal conductivity (Huang X et al., 2009). To date, the most widely used raw material in the production of fibers is polyacrylonitrile (PAN), a polymer derived from acrylonitrile, a compound of petroleum nature, which, however, is particularly expensive, accounting for 53% of the total fiber production cost (Le et al., 2022). Furthermore, since the beginning of the 21st century, there has been a major increase in the global demand for carbon fiber, from 43,500 tons in 2012 to 82,400 tons in 2017, and reaching 112,000 tons in 2020 (Zhu et al., 2019). This has led to a focus on the starting compound of carbon fiber production, known as the precursor, from both an economic and environmental point of view, looking for alternatives to the traditional process, and investigating different options, including the possibility of producing recycled carbon fiber.

The recycling of carbon fibers takes place through the treatment of the waste of the composites in which the fibers are used, the 'carbon fiber reinforced plastics' (CFRP). Such a composite is a material consisting of carbon fiber and an epoxy polymer matrix, and has numerous advantages such as high strength, high stiffness, low density, and corrosion resistance (Morgan, 2005) (Park and Novel, 2018). The life cycle of CFRPs is short at around 15-20 years (Chen et al., 2023), and the total amount of composites to be disposed of in 2020 was 62,000 tons (Pimenta and Pinho, 2011). Furthermore, an average of 60% of CFRP can be recovered in carbon fiber (Chen et al., 2023). The CFRP scrap can be treated mechanically, thermally, chemically, or simply incinerated. The energy ranges per kg of treated CFRP for the various disposal methods obtained from the literature are always around 20% of the energy required for the carbon fiber process from PAN (183-594 MJ/kg) (Chen et al., 2023). Generally, chemical treatment is the process with the highest performance in terms of separating resin from recycled carbon fiber, but it also has higher energy costs due to the use of solvents. Among thermal treatments, gaseous pyrolysis represents an intermediate solution, as it offers an acceptable degradation of the resin, returning a carbon fiber with good mechanical properties (70-85% compared to the characteristics of virgin carbon fiber). Moreover, it is less restrictive in terms of CFRP waste input and can be conducted in plants with an elevated level of automation. At present, it is the technology with the highest technological readiness level (Chen et al., 2023)

The aim of the present study is to assess the environmental impact of the production of recycled carbon fibers used in CFRP applied to automotive components and the identification of bottlenecks and proposals for their abatement through eco-design.

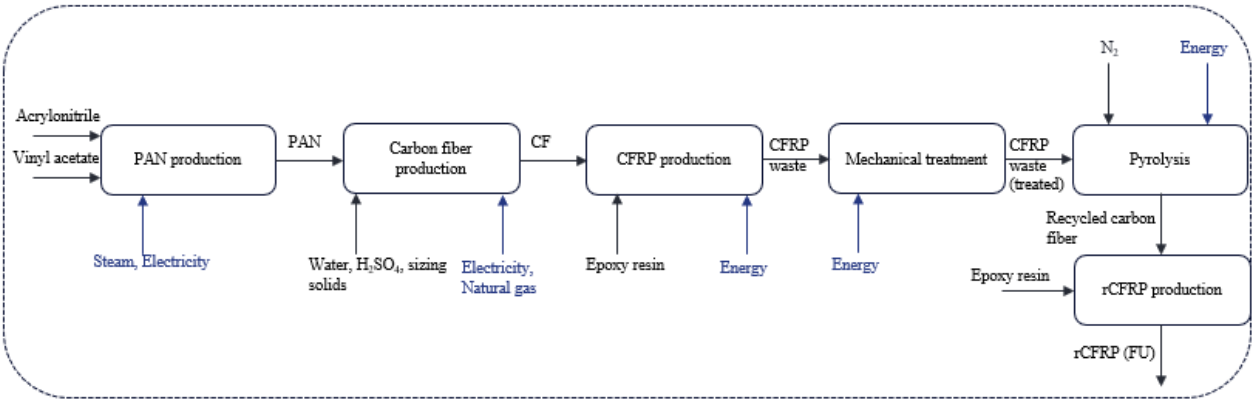
The adopted method to develop the study is Life Cycle Assessment (LCA), which is a tool used to determine and estimate the possible environmental impacts of a product during all the phases of its life cycle, i.e., production, use phase, and waste management. According to the International Organisation of Standardisation (ISO), ISO140040-ISO140044, any LCA must follow four stages: goal and scope, inventory analysis, impact assessment, and interpretation of results.

The inventory, concerning the set of inputs and outputs related to the process under consideration, is made up of secondary data, information obtained by consulting the literature of studies related to the topic studied. Some input data relating to raw materials and energy come from Simapro 9.5.0.2 internal databases such as Ecoinvent, European life cycle database (ELCD), and United States life cycle inventory (USLCI).

Concerning impact assessment, the calculation of environmental impact indicators will be conducted according to different methods such as IMPACT World+, the most recent IPCC GWP 100a according to Akbar and Liew (2021), Meng et al. (2017), Das (2011).

The interpretation of results will be done through the calculation of environmental indicators according to the above-mentioned methods and sensitivity analysis, by varying parameters identified as interesting for environmental assessment purposes, such as the ratio between the amount of resin and carbon fiber input to the composite production step.

Figure 1. Process diagram with system boundaries, inputs, and outputs.



A preliminary result is the choice of functional unit, as represents a fundamental parameter in LCA analysis as it is the unit to which the various environmental indicators calculated according to different environmental impact models refer. In this study, it is 1 kg of rCFRP, an acronym that defines a composite in which recycled carbon fiber is present. Further preliminary results are the definition of the system boundary and the various process steps (Figure 1). The study is currently under analysis.

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