Environmental evaluation of innovative biorefinery process

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Introduction

Cheese whey (CW) is an agro-industrial liquid effluent generated by the precipitation and removal of the milk casein during the cheese-making process, being the main by-product of the dairy industry (Zotta et al., 2020). In the European Union (EU), the dairy industry plays an important role in the agro-industrial economy, and the high specific production, around 9-10 L of CW per kg of produced cheese (Prazeres et al., 2012), generated about 40 x 106 t per year (Eurostat, 2018). CW is one of the most difficult agro-industrial organic waste streams to be properly processed (Asunis et al., 2019; Zotta et al., 2020) also because of the high organic load of 50-100 g COD/L, which is quite hazardous for the environment (Asunis et al., 2020). However, the CW has quite good qualitative homogeneity, which is an important preliminary characteristic when processes more complex than composting or anaerobic digestion are intended to be applied (Asunis et al., 2021). For this reason, CW can be fed to an integrated biorefinery process, (Alibardi et al, 2020), as it has been proposed and studied within the BBCircle project[1], funded by the Lazio Region (IT).

Basing on some already available laboratory test results, a preliminary environmental evaluation, by Life Cycle Assessment (LCA) approach, was performed aimed at comparing two options proposed for the studied biorefinery.

Materials and methods.

The focus of this work is on the first part (Figure 1) of the proposed biorefinery wider scheme (Costa et al., 2022). The CW is fed to a first step base either on dark fermentation (DF) or integrated bio-electrochemical system (IBES), to produce a gas mainly composed by H_2 and CO_2. The H_2/CO_2 gas is processed by physical/chemical absorption, with the aim of producing an almost pure H_2 stream for further use. The fermentate, exiting the DF/IBES as well, is still rich in organic content and can be further exploited by other steps. Here hydrothermal carbonization (HTC) is considered for producing hydrochar, to be used as biofuel. HTC process water is assumed to be disposed of.

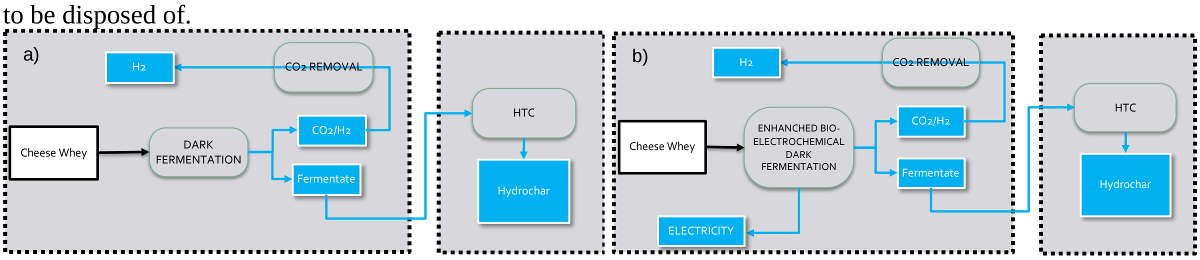

Figure 1. Schematic of the considered processes: a) DF based schematic; b) IBES based schematic.

The LCA is developed according to the phases identified by ISO 14040:2006 (ISO, 2006) and ISO 14044:2006 (ISO, 2006).

The goal of this study is to compare the environmental performances of two biorefinery process:

- DF based schematic: the first step consists of conventional DF process
- IBES based schematic: the first step consists of innovative IBES process

The functional unit adopted for the study is 1 t of CW. System boundaries of the biorefinery include the DF or IBES, the HTC process, the HTC process water treatment and disposal, the H_2/CO_2 separation.

The production processes for utilities, fuels, chemicals, and manufactured materials entering the processes and the generated emissions are included within the system boundaries. Impacts caused by the construction of the plants are not included within the system boundaries (Evangelisti et al., 2015, 2017). The multi-functional issues of the system are addressed by system expansion (Clift et al., 2000; Finnveden et al., 2009), which is the most common choice in LCA applied to waste management (Laurent et al., 2014), considering the substitution of market

[1] BBCircle - Biomateriali, Biocombustibili, Sequestro della CO_2 e Circolarità. Studio sull'implementabilità di Bioraffinerie nella Regione Lazio - Avviso Pubblico "Gruppi di Ricerca 2020" di cui alla Determinazione n. G08487 del 19/07/2020 U e modificato con Determinazione n. G10624 – POR FESR LAZIO 2014 – 2020 – Progetto n. A0375-2020-36701
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mix products, i.e. referring to average data. Indeed, the system function is to process 1 t of CW, while useful outputs are produced: H_2 and hydrochar. The produced H_2 is assumed to replace H_2 available on the market from fossil origin. Hydrochar is assumed to replace lignite in solid fuel power plants. Inventories for the utilities, fuels, chemicals and manufactured materials entering the processes, for substituted products (hydrogen and lignite), and wastewater treatment are retrieved from Ecoinvent 3.0 (Steubinget al., 2016; Wernet et al., 2016).

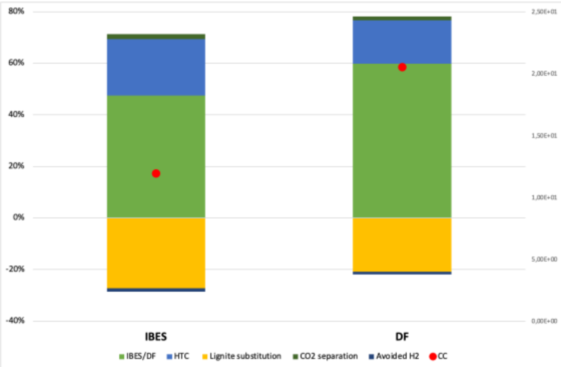

Figure 2. Contributions of sub-processes to CC indicator and total value in kg CO_2 eq/t CW.

The Environmental Footprint (EF) 3.0 method, developed by the Joint Research Centre of European Commission, is used to perform the Life Cycle Impact Assessment (LCIA). However, for the sake of conciseness, only Climate change (CC) indicator – expressed in in kg CO_2 eq. – is discussed in this paper.

Results

The Climate change indicator results favourable for the IBES case, thanks to the reduced impacts of the biological process.

Conclusions

Based on the discussion above, the biorefinery results appear to be promising. However, further aspects need to be investigated to derive a better understanding of the processes.

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