Dark fermentation as an environmental-sustainable win-win solution for bioenergy production

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Keywords: Dark fermentation; Life Cycle Assessment (LCA); resource recovery; environmental solutions

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Abstract

The population increase, urbanization, economic growth and rising societal living standards has fostered industrialization in the last decades (Zhao and Wang, 2015). Manufacturing processes have tried to meet the increasing demand but, so far, this has occurred at the cost of overexploitation of natural resources. However, this non-circular economy strategy adopted has not only led to a situation where resource depletion jeopardizes sustainability. Rejected materials are traditionally discarded instead of being recovered as raw materials with energy-intensive techniques or with associated devastating environmental consequences (Usman et al., 2020). Moreover, and apart from process optimization, the imminent world energy crisis has driven the rapid emergence in the last few years of bio-based processes for energy production (Ani, 2016). Greener technologies such as anaerobic digestion and dark fermentation have proven to be viable options for producing biogas and biohydrogen from waste streams highly concentrated in organic matter. In this regard, dark fermentation has been highlighted as a potential technology for bioenergy production due to its low treatment costs, simplicity of operation and variety of substrates (Ding et al., 2016). Vinasses, molasses, and cheese whey are examples of residual streams from wine, sugar and cheese production processes. The valorisation of these waste streams offers the opportunity to recover materials with different compositions in sugars and N and P compounds (Chojnacka et al., 2020). High value-added products such as bio-hydrogen, electricity, heat, biofertilizers and reclaimed water can be obtained. This leads to a win-win situation for two main reasons: the life cycle of materials is closed (circular economy) and the waste management processes reduce their carbon dioxide emissions (partial decarbonization).

In this context, this study addresses a joint techno-environmental analysis of a conceptually designed valorisation process in which dark fermentation is considered the key common technology. The process was designed and scaled up for three food industry co-products (named above) and biohydrogen was considered as the main target product. The decision-making framework for the selection of the most environmentally friendly solution was built around the internationally standardized Life Cycle Assessment (LCA) methodology. Critical points were identified. Extraction of raw materials from nature and waste production were addressed as background processes from the Ecoinvent database, while biohydrogen production in dark fermentation, anaerobic digestion of downstream liquid effluent, energy transformations and downstream treatment were modelled as foreground processes. The impact assessment stage of the LCA has been carried out with the SimaPro software with the ReCiPe 2016 Hierarchist Midpoint V1.03 World (2010) and ReCiPe 2016 Hierarchist Endpoint V1.03 World (2010) H/H as characterization methods.

Figure 1 shows the environmental differences in the valorisation process in relation to the substrate fed to the system. The role played by each production stage has been analysed. The dominant environmental burden comes from the contribution associated with the waste generated in the food industry for each scenario. The overall load varies from one to the other within the range of 13 to 97%. The rest of the environmental impacts come from the valorisation process itself in which dark fermentation, despite being the key technology, makes the largest contribution (up to a maximum of 40% of the treatment process). However, this impact is partially offset by the production of biohydrogen and other co-products: electricity and heat (from cogeneration) and compost and liquid fertilizer (from post-treatment of effluents). The impact categories that were most influenced are FE, LU and WC with impact reductions of 41-67%, 13-99% and 17-82%. On the other hand, the difference in the environmental impact of substrate modifications has been studied with the endpoint characterization method. The results obtained through the Recipe Endpoint methodology show that the Human Health damage category is the most affected in the vinasses (V) and molasses (M) scenarios (1270 and 400 mPt), whilst the Ecosystem damage category is the most affected using cheese whey (W) (5930 mPt), where the generation of the side flow represents the greatest burden. As a result, the scenario using M provides a better overall environmental impact (660 mPt) than the alternatives with V and W: 1970 and 7220 mPt, respectively.

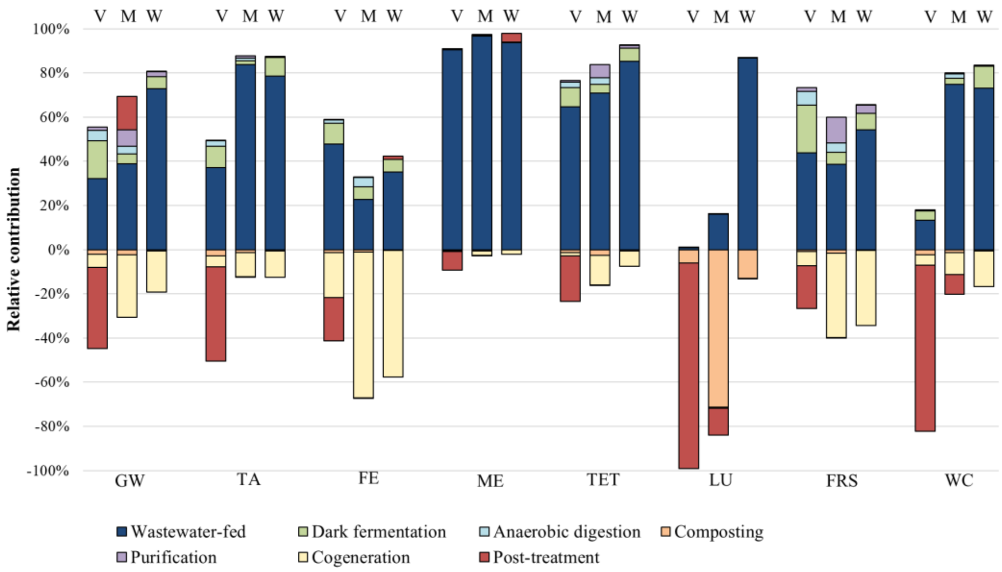

Figure 1. Benchmark comparison of the environmental profile of the bio-based valorisation processes analysed. (V) From vinasses; (M) from molasses and (W) from whey. Acronyms: global warming (GW), terrestrial acidification (TA), freshwater eutrophication (FE), marine eutrophication (ME), terrestrial ecotoxicity (TET), land use (LU), fossil resource scarcity (FRS) and water consumption (WC).

Acknowledgments

The authors belong to the Galician Competitive Research Groups (GRC) ED431C-2021/37, to CRETUS (Interdisciplinary Centre for Research in Environmental Technologies) and to the department of chemical engineering of the University of Santiago de Compostela. S. Estévez thanks to the Spanish Ministry of Science, Innovation and Universities for financial support (Grant reference PRE2020-092074) and C. I. Camacho would also like to express their gratitude to CRETUS for her research scholarship.

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Topic

Anaerobic digestion; Recycling & Resources Recovery; Solid waste prevention techniques; Energy from waste; Waste valorisation; Recovery of materials from wastewater & sludge; Food waste management & bioeconomy; Biorefineries

Type of presentation

ORAL