Renewable and Sustainable Energy Reviews 94 (2018) 38–48

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Technical and economic assessment of food waste valorization through a biorefinery chain

Francesca Demichelis[a], Silvia Fiore[a,*], Daniel Pleissner[b], Joachim Venus[c]

[a] DIATI, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy
[b] Sustainable Chemistry (Resource Efficiency), Institute of Sustainable and Environmental Chemistry, Leuphana University of Lüneburg, C13, 21335 Lüneburg, Germany
[c] Leibniz Institute for Agricultural Engineering and Bioeconomy Potsdam, Max-Eyth-Allee 100, 14469 Potsdam, Germany

ARTICLE INFO

Keywords:
Integrated biorefinery
Economic assessment
Energy balance
Food waste
Lactic acid
Biogas

ABSTRACT

This work presents the economic assessment of an integrated biorefinery process for sequential fermentative production of lactic acid and biogas from food waste. The integrated biorefinery process was compared to single processes for either lactic acid or biogas production. The economic assessment, considering catchment areas from 2000 to 1 million inhabitants, was based on data from real biorefinery plants and carried out using SuperPro Designer® 8.0. The consistency of the approach was evaluated through a set of composite indicators. The integrated biorefinery process was investigated for its economic feasibility of producing lactic acid and biogas, the impact of process scale as well as energy use. Outcomes revealed that an integrated biorefinery process contributes more to optimal use of energy and material flows than single processes. Profitability was confirmed for catchment areas larger than 20,000–50,000 inhabitants.

1. Introduction

The global amount of food waste (FW) generated annually was estimated as 1.3–1.6 billion tons. This amount is associated to 990 billion USD [1] and 3.3 billion tons of CO_2 eq. emissions [2] FW composition depends strongly on dietary habits, however 20–50 wt% cereals, 25–60 wt% fruit and vegetables, 6–12 wt% meat and fish, 8–35 wt% milk and eggs were identified to be the main constituents [1]. Currently, prevalent technical options for FW management in EU (90 Mt produced in 2012, 52 wt% from households) are composting and anaerobic digestion [3]. Composting is mainly challenged by the composition of FW, which heavily influences the final product quality, gaseous emissions and the management of non-biodegradable impurities [4]. Anaerobic digestion of FW allows the production of 0.10–0.25 m^3 CH_4/kg_{VS} [1]. Even though the anaerobic digestion of FW results in lower environmental impacts compared to composting [5], it requires co-digestion and pre-treatment of organic residues [1,6]. It further requires an intensive processes monitoring and control [7] in order to achieve process stability and highest energy conversion efficiency.

The composition of FW, consisting of carbohydrates, lipids, proteins, sugars and fibres, however, makes it a suitable feedstock for more advanced biorefineries [7,8]. Biorefinery is defined as a route to convert organic substrates, in accordance to the principle of cascade use, first into added-value products followed by energy generation [9]. Biorefineries improve industrial competitiveness and wealth, provide biobased products and energy through economically, socially and environmentally sustainable processes, and they are fully consistent with EU circular economy policy [10]. The combination of cascade use in one biorefinery, a so called integrated biorefinery, provides the opportunity to responsibly exploit FW and to contribute to a circular bioeconomy [7].

Among biorefineries, FW conversion into lactic acid (LA) through fermentative routes is a well-established technical solution [11–13]. The technical feasibility of sequential production of LA and biogas from FW through fermentative biorefinery processes was already assessed [14,15]. However, technical feasibility and the use of waste biomass as feedstock are insufficient to guarantee the readiness and sustainability of the process at industrial scale [16]. Compared to a previous study [14], which focused exclusively on technical aspects of an integrated LA and biogas production, this work validates the readiness through economic and energy assessments. The here-presented economic analysis analysed capital and operational costs, market values of LA and biogas, net present value (NPV), return of investment (ROI), payback time and economic costs as well as incomes per ton of treated FW. The energy evaluation considered energy required and recovered. The combination of economic and energy assessments with the already proven technical feasibility can validate the readiness of the process at industrial scale

* Corresponding author.
E-mail address: silvia.fiore@polito.it (S. Fiore).

https://doi.org/10.1016/j.rser.2018.05.064
Received 22 February 2018; Received in revised form 17 May 2018; Accepted 28 May 2018

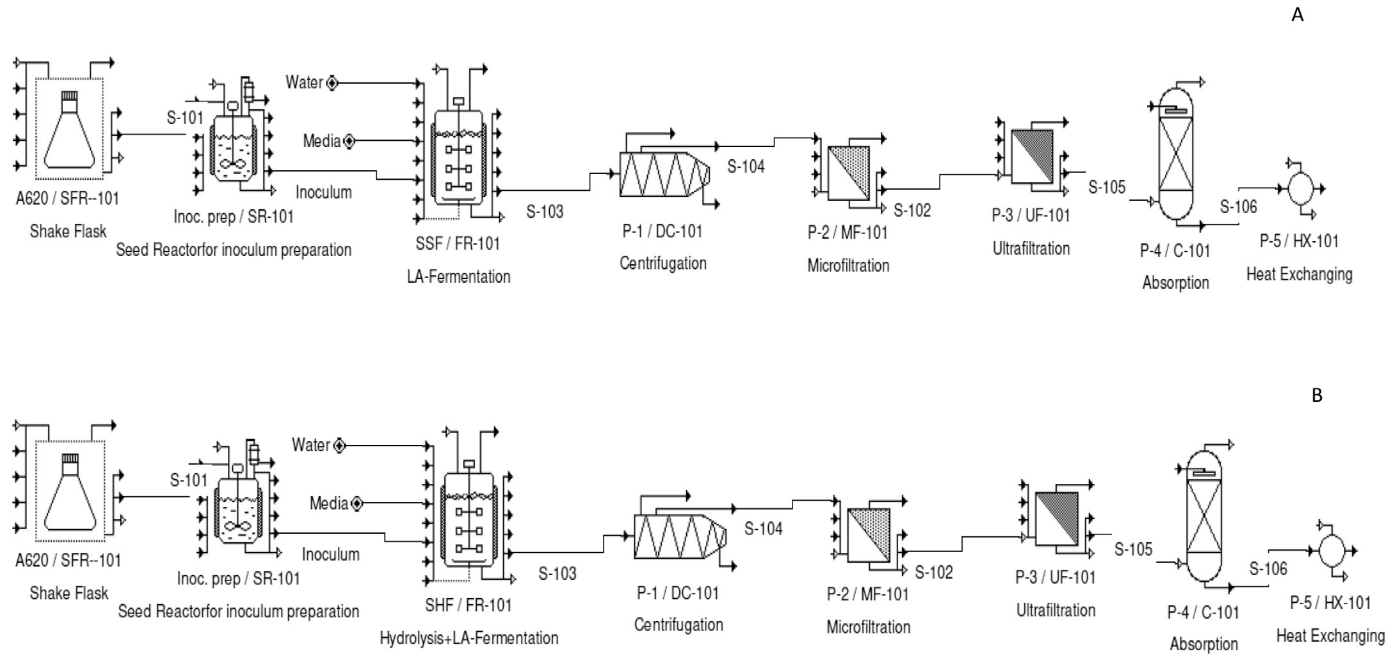

Fig. 1. Process scheme of Scenario Ia (1A), Scenario Ib (1B).

[17].

The aim of the present study was to compare three different scenarios to evaluate advantages and disadvantages of LA and biogas productions from FW. Productions were considered as single processes or as a two-step chain for investigating hierarchical and sequential design approaches [18]. The chosen scenarios were: 1) LA fermentation, 2) biogas production and 3) sequential LA fermentation and biogas production from fermentation residues.

In order to be adaptable to the whole EU, the three scenarios were not geo-referred, and thus an environmental assessment was not included in this study. The novelty of the presented approach is the economic and energy analyses based on experimental data from existing biorefinery plants. Those data were subsequently verified using SuperPro Designer® 8.0 software.

Previous studies about economic and energy assessments of biorefineries (fungal hydrolysis and LA fermentation, LA production, biogas and other bio-based products generation), were based on software simulations through SuperPro Designer® 8.0 [19,20] and Aspen Plus® [21,22], and on stochastic models as Monte Carlo statistical simulation [23]. Compared to the above-cited literature, exclusively focused on the economic analysis of a single process and on the market value of the products, this work takes into account a two-step chain (sequential production of a platform chemical and of biogas, according to the general hierarchy assumed by biorefineries) [9] and the management of the waste flows deriving from the chain, endorsing the crucial and versatile role of biogas in single and sequential biorefinery processes [24]. The consistency of the present study was assessed through: 1. Implementing the three above-mentioned scenarios in catchment areas from 2000 to 1 million inhabitants; 2. A final evaluation through composite indicators of the most promising scenario based on net-incomes after 5 years of amortization, NPV, ROI, payback time and economic incomes per ton of treated FW.

2. Methodology

2.1. Modeling approach and boundary conditions

The processes were studied and designed through an empirical model rather than a stochastic one. A stochastic model provides as output probable distribution with uncertainty based on the chosen random variables and model, which generally has to be inferred from prior experimental data collected from real plants [25]. Contrarily, an empirical model describes exactly how processes work under different boundary conditions and is validated through simulation models [26].

In the present study, the process configurations were based on data gained from previous works of the authors [14,27] and then simulated using SuperPro Designer® 8.0 to verify mass and energy balances as well as costs. Mass balance data was scaled-up with a 0.8 conservative factor to full-scale plants. Economic and energy data was derived from literature and existing plants [28]. Batch and continuous operations were considered for LA and biogas production, respectively, with 300 days per year operation time and 90% working capacity. Extra time was accounted for filling, emptying and cleaning of the fermenter in batch mode. According to previous studies [19,29] a plant lifetime of 20 years was assumed. Since the task of the study was the evaluation of process profitability according to a catchment area between 2000 and 1 million inhabitants without any influence of location, the three scenarios were not geo-referred.

2.2. Biorefinery processes description

The present study compares three different scenarios to evaluate advantages and disadvantages of LA and biogas productions from FW. Productions were considered as single processes or as a two-step chain for investigating hierarchical and sequential design approaches [18]:

- Scenario I: Production of LA from FW through two fermentative routes, simultaneous saccharification and fermentation (SSF) or separate hydrolysis and fermentation (SHF);
- Scenario II: Generation of biogas from FW by means of *meso*philic anaerobic digestion;
- Scenario III: Sequential LA production from FW through SSF or SHF and biogas generation from fermentation residues through *meso*philic anaerobic digestion.

The three scenarios were based on processes already investigated at laboratory (2 L) and technical scales (72 L) [14,27]. FW from households (i.e. organic fraction of municipal solid waste, OFMSW) was