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A techno-economic evaluation of a biomass energy conversion park

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HIGHLIGHTS

- ▶ This paper presents a biomass energy conversion park.
- ▶ A techno-economic evaluation is performed.
- ▶ From a socio-economic point of view it is more interesting to invest in a multi-dimensional model.
- ▶ From an investor's perspective one should invest solely in the OMSW digester.
- ▶ Economic, energetic and environmental advantages result from multi-dimensional models using biomass residue streams.

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ABSTRACT

Biomass as a renewable energy source has many advantages and is therefore recognized as one of the main renewable energy sources to be deployed in order to attain the target of 20% renewable energy use of final energy consumption by 2020 in Europe. In this paper the concept of a biomass Energy Conversion Park (ECP) is introduced. A biomass ECP can be defined as a synergetic, multi-dimensional biomass conversion site with a highly integrated set of conversion technologies in which a multitude of regionally available biomass (residue) sources are converted into energy and materials. A techno-economic assessment is performed on a case study in the Netherlands to illustrate the concept and to comparatively assess the highly integrated system with two mono-dimensional models. The three evaluated models consist of (1) digestion of the organic fraction of municipal solid waste, (2) co-digestion of manure and co-substrates, and (3) integration. From a socio-economic point of view it can be concluded that it is economically and energetically more interesting to invest in the integrated model than in two separate models. The integration is economically feasible and environmental benefits can be realized. For example, the integrated model allows the implementation of a co-digester. Unmanaged manure would otherwise represent a constant pollution risk. However, from an investor's standpoint one should firstly invest in the municipal solid waste digester since the net present value (NPV) of this mono-dimensional model is higher than that of the multi-dimensional model. A sensitivity analysis is performed to identify the most influencing parameters. Our results are of interest for companies involved in the conversion of biomass. The conclusions are useful for policy makers when deciding on policy instruments concerning manure processing or biogas production.

1. Introduction

Biomass needs to contribute to the European target of 20% renewable energy use of final energy consumption by 2020. Disadvantages of biomass are the competition with food and feed, the high supply cost, low energy density, high conversion cost, and the seasonality [1,2]. Main advantages of biomass are its flexibility, its ability to be stored, and its CO_2 neutrality. It is a versatile energy

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source generating electricity, heat and biofuels [3–5]. Authors in recent studies point to the potential of biomass residue streams and the many benefits they can include [6,7]. These streams do not compete with food or feed and can be regionally collected to avoid high supply costs. For example, Igliński et al. stressed the potential and benefits of using unmanaged biomass such as manure, maize after seed harvest and organic municipal solid waste [8]. Ali et al. showed the potential of green waste from green markets in Thailand [9]. Tonini and Astrup conclude their study with the recommendation to use residual, domestically available biomasses instead of energy crop production [10]. Other authors already investigated the possibilities of using regionally available biomass streams in local decentralized energy generation systems. They concluded that these systems offer many advantages such as more efficient usage of end products (e.g. electricity, heat, cooling, fertilizer), reduction of logistics and regional development [11–13]. Heat for example cannot be transported over large distances and should, preferably, be used locally. Additionally, De Meester et al. pointed out that the utilization of the generated heat is even necessary to achieve an environmentally competitive technology [14]. Heat that results from one process can for example be transported to another process where it can be used beneficially, e.g. for drying biomass [15]. Also Song et al. demonstrated that the integration of CHP plants with other processes represents a big potential in terms of reducing GHG emissions, increasing energy utilization efficiency and replacing conventional power plants [16]. Processes can even be further integrated by using residues, other than heat, in another process [17]. In literature a combination of technologies is often called a biorefinery, which is defined as a facility that integrates biomass conversion processes to produce fuels, power and chemicals from biomass [18]. However, not every nation has already recognized the large potential of biorefineries [19]. Our research aim is to further identify the technical and economic advantages of combining conversion technologies primarily based on regional residue streams into a multi-dimensional plant compared to the separate use of the different conversion technologies and to identify the main drivers of profitability. In this paper a techno-economic assessment is performed on the concept of a biomass energy conversion park (biomass ECP).

The paper is built up as follows. The second section covers the concept of a biomass ECP. The third section explains the development process of the techno-economic evaluation method. The fourth section contains a techno-economic evaluation of a biomass ECP using a case study. The fifth and final section holds the conclusions and discussion.

2. The concept of a biomass energy conversion park

A biomass ECP is defined as a synergetic multi-dimensional biomass conversion site with a highly integrated set of conversion technologies in which a multitude of regionally available biomass (residue) sources are converted into energy and materials. It can, therefore, be regarded as a specific form of a biorefinery in which the focus lies on the use of regional waste streams. As such, a biomass ECP answers to the questions raised by authors to focus on an integrated approach using regional residue streams, as mentioned in the introduction. Further advantages derived from the regional nature of the input are: (1) the reduction of environmental impact due to the possible saving of fossil energy with related greenhouse gas savings or decreased water usage, (2) the shortening of the transport distance resulting in lower costs, pollution and traffic burden, and (3) the creation of economic value for the local community by valorizing residual streams that do not yet have an economically interesting destination. Fig. 1 provides a general overview of the potential biomass inputs and technologies that can be combined to form ECP routes and their potential outputs. Every combination of inputs, technologies, and outputs that is feasible, fits the definition above. Typically in an ECP, combinations are made of technologies that exchange energy and materials in an intelligent and efficient way resulting in valuable synergies. Smart combining and linking of biomass processes contributes to effective biomass valorization. Other papers have previously offered an overview of biomass conversion routes with a specific goal. For example Bram et al. give an overview of the most important biomass conversion routes for transport, heat an power production [20], Demirbas reviews biofuel valorization facilities and biorefineries [18] and Srirangan et al. give a summary of conversion routes associated with biorefinery [21].

For the development of a biomass ECP first a macro-screening is used to determine potential interesting locations [22]. Secondly, available regional biomass residue types are inventoried and the most important stakeholders such as suppliers of biomass, investors, government, and heat customers are consulted [23,24]. This stakeholder participation contributes to the likelihood of acceptance and eventual realization of the concepts [23]. Finally, each design is evaluated: technically, economically as well as environmentally. The different uni-dimensional processes of the concept are evaluated separately. Afterwards, the biomass ECP is assessed and synergies identified. The techno-economic feasibility analysis of the different concepts will be discussed further in the remainder of the paper. An analysis of the social context and the multi-stakeholder approach falls beyond the scope of this paper.

3. Techno-economic evaluation method

A techno-economic spreadsheet model is developed. The model consists of two data input sheets, one with mass- and energy balance data and one with information concerning the economic parameters. Furthermore, the model consists of one output sheet for every ECP concept that is evaluated. These sheets include a material flow diagram (MFD) of the concept, the mass- and energy balance calculations and a cost benefit analysis (CBA) with calculation of net present value (NPV), internal rate of return (IRR) and discounted payback period (DPBP) [25–29]. In the technical analysis part a MFD is generated per ECP design. This diagram describes the ECP inputs and outputs and the material and energy flows between individual processes. Using Material Flow Analysis (MFA) modeling, the mass- and energy balances are calculated for each concept, including mutual exchanges and synergies between the individual concepts. Outcomes of the analyses include:

- A quantification of the synergies such as increase in resource valorization and reduction of energy and water need through mutual connections and reduction of waste;
- The properties of residues per individual process and an evaluation of suitability as input for other processes;
- An evaluation of the technical feasibility of the proposed connections.

The technical part is integrated with the economic part in which scale advantages are taken into account when calculating NPV, IRR and DPBP. The NPV gives an indication of the profitability of the biomass ECP using equation [1], where T is the life span of the investment, CF_n the difference between revenues and costs in year n, I_0 the initial investment in year 0, and i the discount rate. A biomass ECP is considered interesting when the NPV is positive [26,30]. When one has to choose between more than one biomass ECP concept (i.e. alternatives), the NPV ranking is mostly preferred over the IRR ranking [28].