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Assessment of the energy and economic performance of second generation biofuel production processes using energy market scenarios

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ABSTRACT

In this paper performance assessment of second generation biofuel production using energy market scenarios and system-level performance indicators is proposed. During biofuel production a number of products and services can be co-generated while import of energy services (e.g. electricity and heat) in addition to the fuel supply may also be needed. This needs to be reflected by a well-defined performance indicator enabling a comparison between different process alternatives. A marginal production perspective is proposed in this study for the definition of a general energy performance indicator, recalculating all services to primary energy on a system level. The Energy Price and Carbon Balance Scenarios (ENPAC) tool developed at Chalmers is used for the definition of the energy system background. Thereby, a scenario-specific comparison of the processes' thermodynamic, economic and carbon footprint performance is possible. The usefulness of the approach is illustrated for production of synthetic natural gas (SNG) from biomass. The shortcomings of common performance indicators are also discussed.

1. Introduction

Significant increase of production of biofuels for transportation has sparked much debate among researchers and policy-makers. On the one hand, biofuels are seen as a powerful option for greenhouse gas (GHG) emission reduction, for reducing fossil fuel dependency, as well as for local job creation in rural areas [1] and their use is promoted by targets for a 20% renewable energy share within the transport sector by 2020 in the European Union [2]. In particular the concept of biorefineries – resulting in a spectrum of products using an integrated upgrading system – has become a promising concept for efficient production of biofuels [3]. On the other hand their impact on food production and prices as well as their climate change mitigation potential is uncertain, as evidenced by a number of studies that present contrasting results (see for example [4,5]). A general consensus is that there is a need for identification of sustainability criteria for biofuel production in order to be able to compare different alternatives on a common basis and to assess their actual potential regarding different aspects [6,7].

Cherubini and Ulgiati [8] illustrate an approach based on life cycle analysis (LCA) with a case study of a biorefinery concept based on crop residues. They show large potential for GHG emission reduction and non-renewable energy saving, but also an increased eutrophication potential compared to a fossil reference system. In addition, sensitivity of the results – in particular for the GHG emission reduction potential – to land use change effects are highlighted by Cherubini and Ulgiati [8]. Another prominent example of a major comparative study that also adopts an LCA perspective within the biomass-based transportation fuel sector is the JRC-EUCAR-CONCAWE well-to-wheel study [9], in which second generation biofuels are recognised to have a high GHG emission reduction potential. The latter study has been analysed by Wetterlund et al. [10] who note that it has a major shortcoming by not taking into account the fact that biomass is not an unlimited resource. Increased use of biomass within the transport sector most likely will cause a deficit of biomass within another energy sector in the future. Covering this deficit with a fossil alternative will cause an increase of CO_2 emissions on the overall system level, thereby drastically reducing the GHG emission reduction potential of several biofuel options within the transportation sector. The concept of system expansion is adopted in Ref. [10] which accounts for alternative use of biomass within an assumed energy system background. Differing assumptions for the background system are also shown to have a major effect on the results of the cost-effectiveness of CO_2 abatement costs for different bioenergy technologies in an Austrian context [11]. Further, Daianova et al. [12] investigate bioethanol and biogas production as transport fuels within a regional context taking into account local conditions. The latter analysis is however restricted to cost optimisation and does not investigate CO_2 consequences and system efficiencies.

Other approaches for taking into account the surrounding system within LCA-based studies include the introduction of exergy based

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Nomenclature

CCS	carbon capture and storage
CHP	combined heat and power
GHG	greenhouse gases
LCA	life cycle analysis
LHV	lower heating value
SNG	synthetic natural gas
NG	natural gas
O&M	operation and maintenance
IO	annual investment opportunity
Symbols	
fuel	fuel
α	power-to-heat ratio
c	energy-specific CO_2 emissions
E	exergy
η	efficiency
n	annual energy use/production
p	energy-specific costs
P	power
$Q/\dot{Q}$	heat energy/thermal duty
Indices/exponents	
–	exported
+	imported
bio	biomass
el	electrical
ex	exergetic
marg	marginal
prod	product
q	heat
ref	reference
sys	system
th	thermal

indicators (e.g. [13]) or the use of system perturbation (e.g. [14]). The latter approach allows adapting LCA to regional conditions.

In this study the ENPAC tool [15] developed at Chalmers within the EU Pathways project [16] is used for the necessary energy system background definition. The tool can be used to generate consistent scenarios depicting possible cornerstones of future energy markets. Based on these scenarios a systematic evaluation of biofuel production processes is possible as the background energy system is specified with corresponding reference technologies for the different energy services, including appropriate conversion efficiency values for these technologies. Energy and economic efficiency, as well as CO_2 emission consequences, of the introduction of second generation biofuel processes can be analysed as illustrated in this paper for production of synthetic natural gas (SNG) from biomass feedstock. The capability of the energy market scenario tool is thereby extended to allow a multifaceted scenario-specific evaluation of different processes, enabling identification of robust alternatives not only from an economic, but also from a thermodynamic and environmental viewpoint.

2. Methodology

In order to be able to evaluate the performance of a new process that is to be introduced to an existing background energy system, it is important to clearly define the system boundaries and the underlying assumptions for the evaluation. The life-cycle-perspective for this study is a well-to-tank perspective meaning that no specific application for the produced biofuel is considered. This is different to other studies investigating biofuel process alternatives [9,10], but the idea with this study is to not limit the application to biofuels for the transport sector but rather to adopt a general view on system energy efficiency based on the underlying scenarios. The case of SNG production that is used for illustration of the methodology in this paper might be such an example as SNG is not limited to transport applications but might also replace fossil natural gas in any of its other applications within the power or chemical sector.

The approach applied in this study is illustrated in Fig. 1. Possible by-products from a new process such as heat and electricity compete with reference technologies within the existing energy system and thereby indirectly influence the overall performance of a new process considering energy efficiency and CO_2 emission consequences. Even the feedstock used for the new process is subject to competition with a reference user since biomass is not an infinite resource. Replacing biomass with an alternative – most

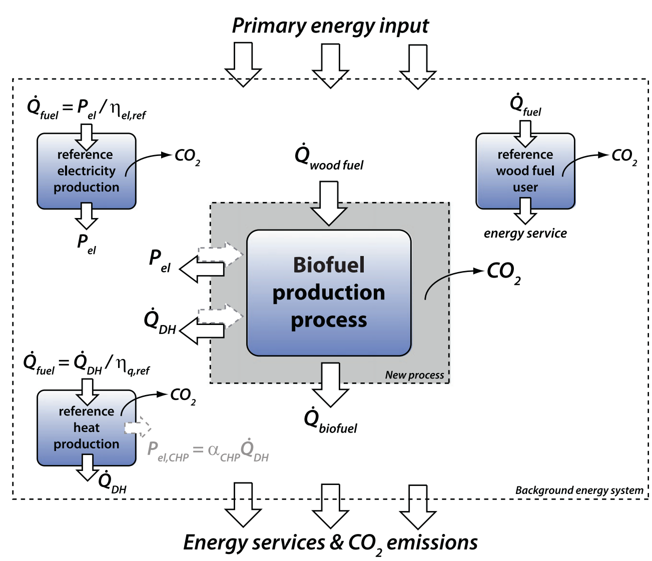

Fig. 1. Schematic representation of the methodology accounting for reference services of the background energy system the new process is to be integrated into.

likely fossil – feedstock in the process defined as the reference user in the background energy system has a non-negligible impact on the CO_2 balance of the new process. For defining the energy system background an energy market scenario tool (ENPAC) is used as explained in more detail in Section 2.5. The time perspective of the study (and the scenario tool) is medium to long term. The different system aspects investigated in this study – energy performance, CO_2 emission consequences and economic performance – are discussed in more detail in the following paragraphs.

2.1. Energy efficiency calculation

The energy efficiency evaluation of a process can be done in various ways. The most commonly used performance indicators are the overall energy (η_{th}) and exergy efficiency (η_{ex}). The definition of these two performance indicators may vary depending on system boundary definitions and conventions, but follows the general form of