

A sustainability assessment of biofuel supply chain

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Abstract

This article aims to build sustainability in a biofuel supply chain. Ethanol is chosen to represent the biofuel and is assessed in terms of economic, environmental, and societal benefit feasibility. A unified optimization model of product, process and supply chain and life cycle assessment (LCA) is proposed to give the optimal solutions for sustainability. The decision parameters of process synthesis and logistics as well as raw materials production synthesize a closed loop economy. The techno-economic analysis embedded into the LCA so that the supply chain design achieves technical feasibility. The results show that integrated product and process design in the supply chain could achieve sustainability. Therefore it is proposed to extend further the design towards the SC contribution to energy grid of the local community.

Keywords

Ethanol; LCA; optimization; techno-economic analysis; rice straws; supply chains

1. Introduction

This article aims to build sustainability in a biofuel supply chain (SC). Sustainable SC covers not only sustainable production but also sustainable demand and supply. Sustainable biofuel is chosen since the fuel is necessary in the near future to replace fossil fuel to sustainably produce sustainable goods and services. However, nowadays the processing technology of biofuels SC is far from mature. In supply side, lignocellulose biomass are often used for other needs, for instances, in Indonesia farmers often use rice straws for fertilizer, feeding cattle, or even electricity production (Seabra and Macedo 2011). Therefore, no commercial rice straws to ethanol conversion but sugar cane in Indonesia and even worldwide, can be used as references (Perales et al., 2011). Indeed, the conversion of lignocellulose biomass into bio-fuel is expected reduce the combine-climate-change and health costs from \$469 million to \$208 million (Hill et al., 2009).

An integration of life cycle assessment (LCA) and techno-economic optimization from cradle to grave, is proposed in this article to realize sustainable production that emphasizes on the environmental, societal and economic aspects of a firm's actions (Tseng, 2013). The objective of the integration is to create circular economy that able to 1) reuse its own waste, 2) receive other industrial waste, and 3) generate local economy. In that sense, the assessment includes mass and energy balances, inputs and output analysis that could reduce emission inventory and carbon foot print.

The study starts with a brief introduction to the definition and objective of BET supply chain from rice straw, their principles, and the objectives of this study. The remainder of this study is organized as follows: A theory of LCA is

presented in the beginning, after which the proposed CSC model is presented. A brief analytical model and simulation is presented in the following section. Afterwards, the simulation result is presented and is followed by the highlights of the managerial implications. Finally, this study presents a summary of the findings of the method and recommendations for its further development and practical application.

2. Life cycle assessment (LCA)

The life cycle assessment (LCA) follows four main steps, the setting of goal and scope definition, inventory analysis, impact assessment and results interpretation. Life cycle assessment based on biofuel synthesis from raw materials to end-of-life (EoL) of the fuel. In this article the entire process can be depicted as follows:

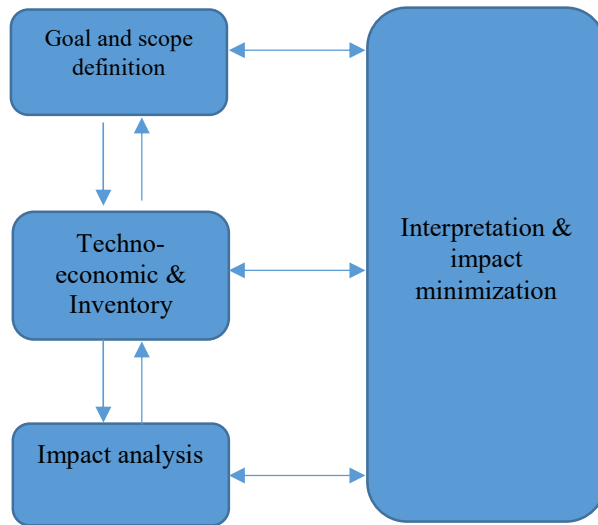


Fig 1. The framework of LCA & Techno-economic analysis

2.1 Goal and scope definition

The goal of this study is to assess environment impacts based on CO₂ and energy performance of production process for ethanol from rice plantation to fuel transfer to vehicle fuel tank. The functional unit is one liter of ethanol. The scope of the study includes rice straw transportation, rice straw storage, and fuel production, intermediate transportation, intermediate storage, liquid fuel transportation and distribution, and fuel combustion in manufacturing operations. Lignin can be used as energy source of BET synthesis and gypsum is dump into landfill.

2.2 Techno-economic and inventory analysis

The analysis needs technical and economic data from literatures, simulation software for LCA, optimization software for techno-economic analysis. The case study is Indonesia bio-ethanol supply chain. A contribution data (Samuel, 2013) is used to calculate the yield of BET per ton rice straw. Bernier et al. (2013) provide data for delignification in pretreatment step. Harding et al. (2007) and Akiyama et al. (2003) provide data for fermentation and post-fermentation process. Aden et al. (2009) provide data for the unit operations of BET.

The analysis of materials and energy flows from rice field to gasoline depot is depicted in Figure 2 below:

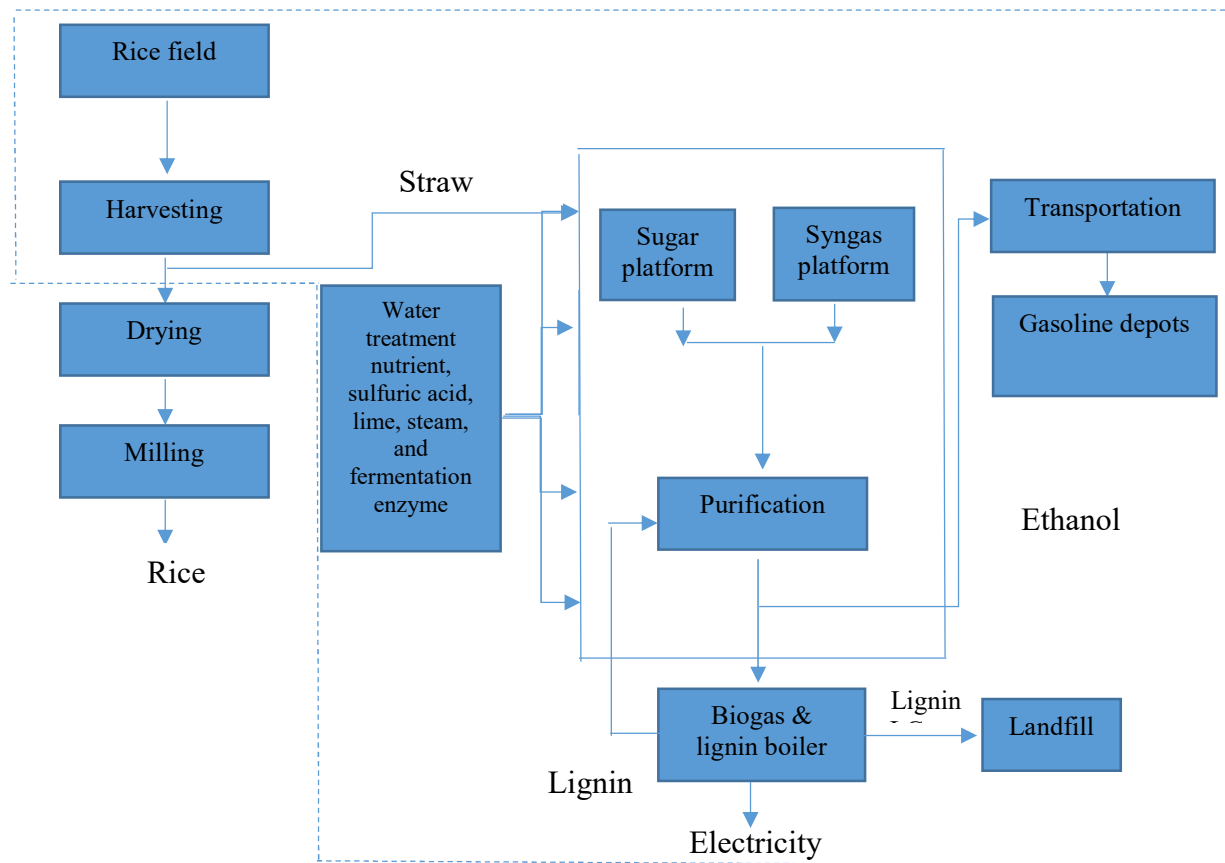


Fig 2. System boundary of BET synthesis from rice straw (sugar and syngas platforms) (Kristianto and Zhu, 2017). In addition to production flows, supply chain network flows is also included in the analysis as depicted in Figure 3.

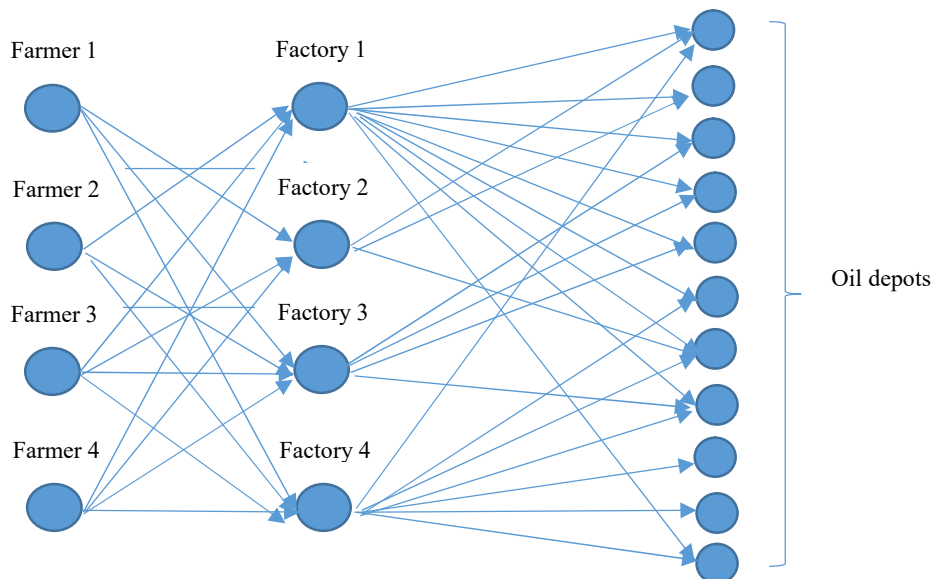


Fig. 3 ethanol supply chain networks from rice straws system boundary (Kristianto and Zhu, 2017).

While materials and energy balances necessary to include each steps that the energy and mass conversion occurs, Figure 4 shows the detail process of ethanol synthesis from lignocellulose biomass as follows:

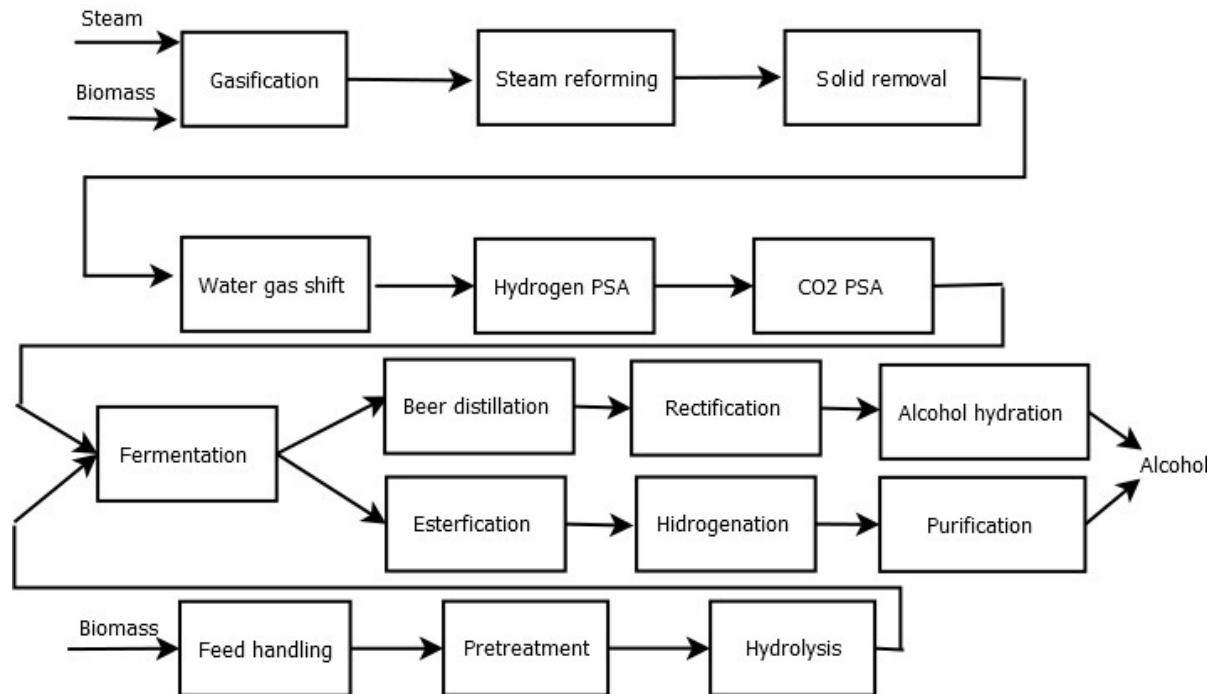


Fig 4. Process flow diagram of ethanol synthesis from rice straws (Kristianto and Zhu, 2017).

2.3 Impact analysis

Impact analysis measures collective economic, environment and societal benefit from ethanol supply chains. The analysis follows input output model

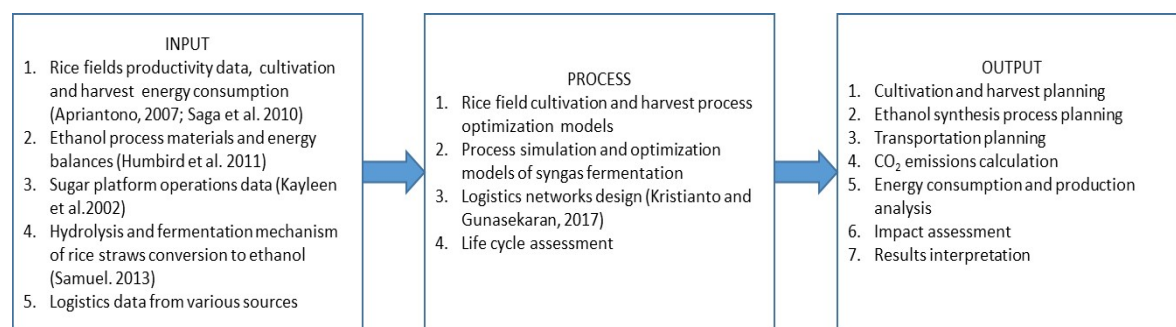


Fig 5. Process input output of ethanol synthesis from rice straws (Kristianto and Zhu, 2017)

2.4 Interpretation

The decision includes 1) farmers decisions on whether selling the rice straws or re-consume it for cattle feed, 2) ethanol factory decisions on production capacity of each BET factory. Ethanol factory location should be coordinated with regard to the locations of rice fields that can supply the demands, and paddy harvest capacity in

each province. In addition 3) the demand of fuels in each depot determine the amount of carbon emissions from logistics. There are four chosen areas of rice straw collection, West Java, Central Java, East Java and Bone.

The impact minimization is formulated into mixed integer programming (MIP) and non-linear programming (NLP). The problem is solved by using an algorithm as proposed by Kristianto and Gunasekaran (2018). The result is tabulated in Table 1 as follows:

Table 1. Operations variables of the syngas fermentation platform (Kristianto and Zhu, 2017)

Variables	Value
T gasifier (K)	1375
T mix (K)	561.562
CO ₂ in syngas (% mol)	0.724
H ₂ in syngas (% mol)	0.211
CO in syngas (% mol)	0.288
H ₂ O in syngas (% mol)	0
CH ₄ in syngas (% mol)	0.049
CO uptaking rate mmol/gr enzyme.h)	0.376
Ethanol yields mM/h)	1.121
Acetic acid yields (mM/h)	18.814
Clostridium Ljunhdahlia bacteria growth rate (h ⁻¹)	0.87
Ethyl acetate conversion to ethanol	0.991

Table 2. Energy generated from syngas fermentation platform (Kristianto and Zhu, 2017)

Sources	per mole biomass	
gasification	54.955	W/mole
Reformer	63.5	W/mole
Acetic acid hydrogenation	44.87953	W/mole
Ethyl acetate hydrogenation	739.64	W/mole
Total generated energy	902.9745	W/mole

Table 3. Utility consumptions for syngas fermentation and sugar platforms (Kristianto and Zhu, 2017)

Utilities	Syngas fermentation model	Reference (Kayleen et al., 2011)
Heating steam (MMBtu/ton rice straws)	0.00E+00	3.46E+00
Cooling water (gallons/ton rice straws)	2.55111E+03	1.03E+04
Injection steam (MMBtu/ton rice straws)		3.34E+00
Process water (gallons/ton rice straws)	0.52E+02	3.24E+02

Tables 1,2 and 3 listed a suggested operating conditions of syngas fermentation that minimizes the total energy consumptions as well as carbon emissions. Similarly, ethanol purification suggests the following operating conditions:

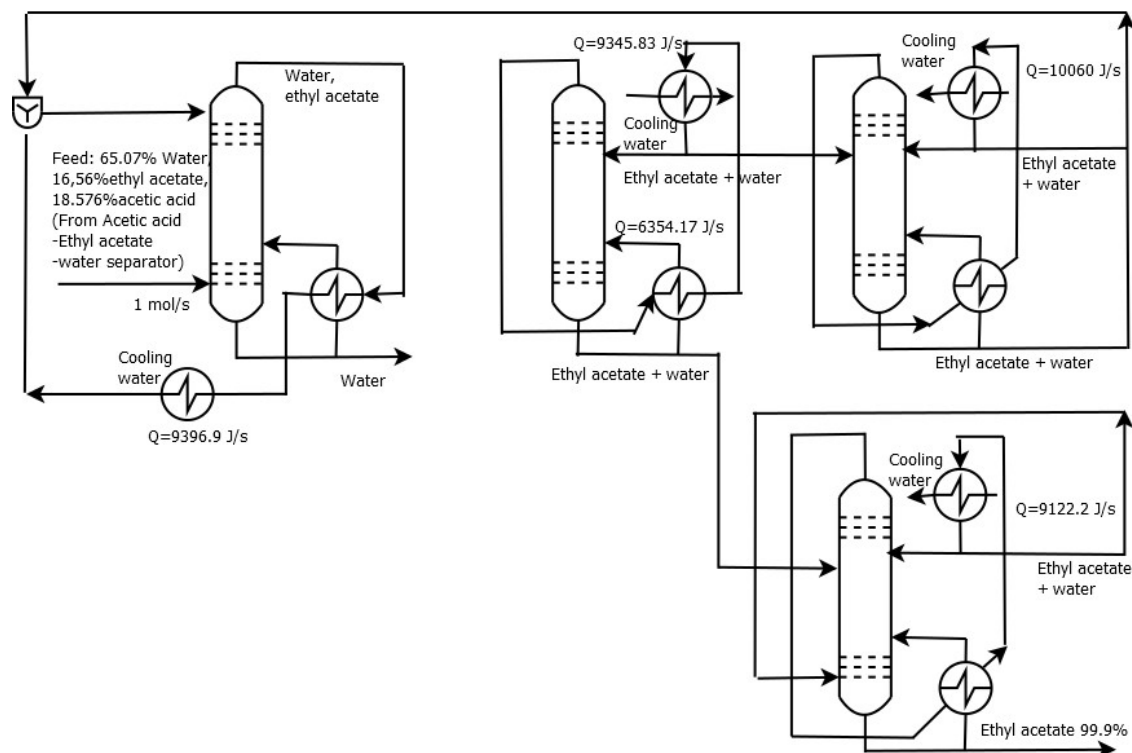


Fig 6. Heat integration of Ethyl Acetate purification section (Kristianto and Zhu, 2017)

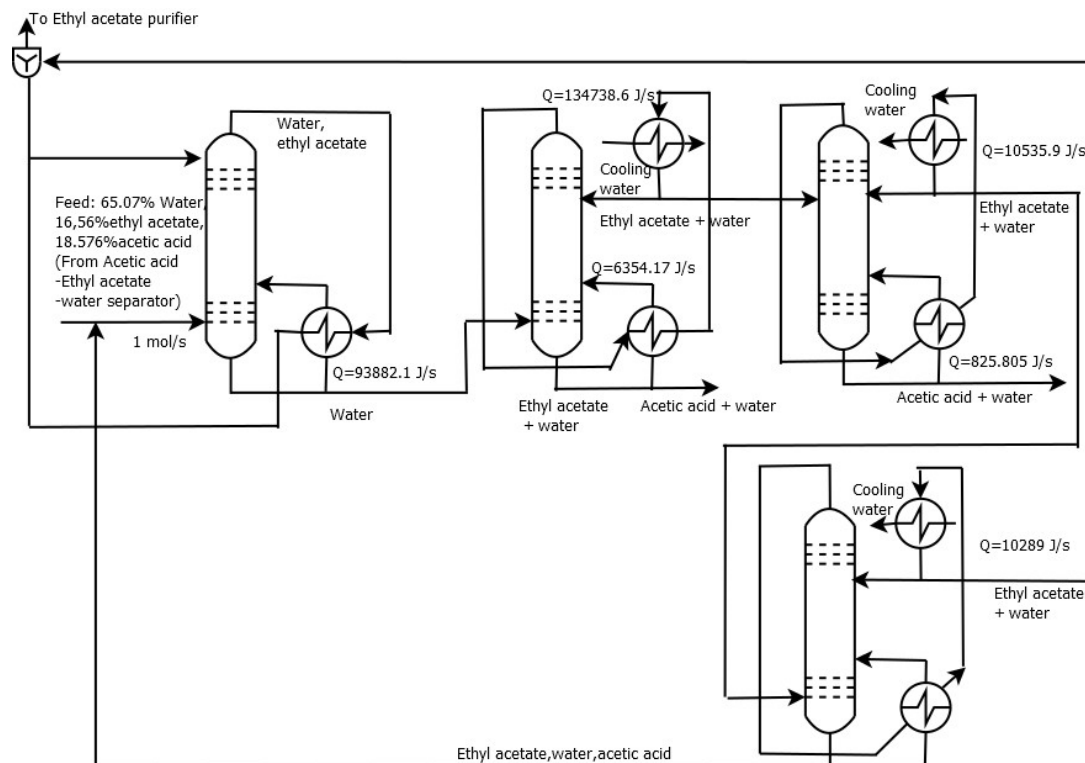


Fig 7. Heat integration of Acetic Acid purification section (Kristianto and Zhu, 2017).

From Figures 6 and 7, Cooling water requirements for 1 mole of inputs are 37.925.8 kW and 32.453 kW for ethyl acetate and acetic acid purification processes respectively.

Considering carbon emissions, the article benchmarks the emissions against literatures. It is shown in Figure 8 that the techno-economic analysis that is embedded into LCA is capable of reducing emissions significantly.

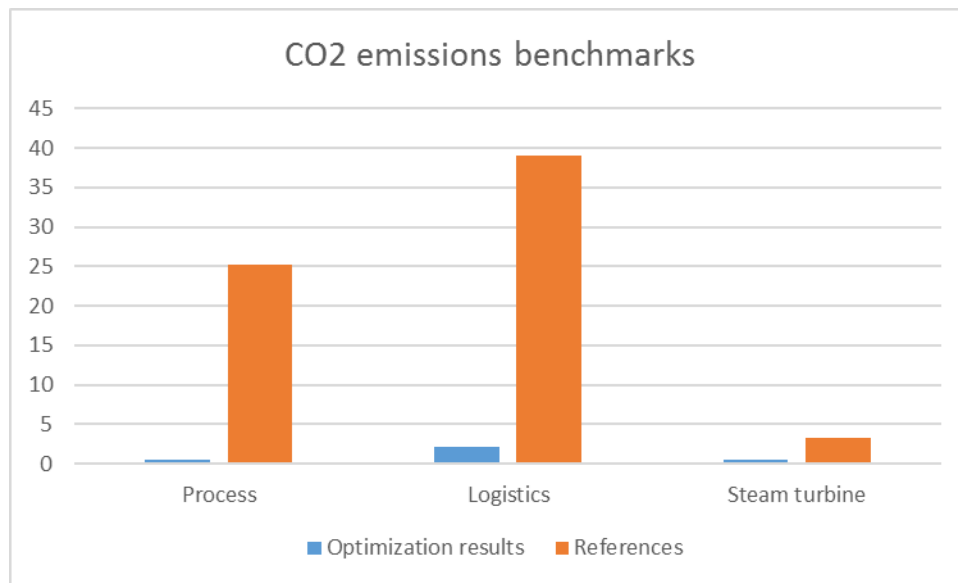


Fig 8. CO2 emissions benchmarks against literatures (Plant^a, logistics^b) (Kristianto and Zhu, 2017)

^a Humbird et al., 2011 ^b McKinnon, 2007.

3. Conclusion

This article combines techno-economic optimization and LCA in order to get an optimum solution towards sustainable supply chain. The integration needs a detail process design from raw materials extraction to final product end-of-life. Due to the complexity of production and supply chain networks, the article proposes a solution method that could address the computational challenge. A case study from a developing country is taken into consideration. The outputs of the analysis is interpreted in terms of its usability in real applications. Therefore, this article suggests standard operations of ethanol production from syngas fermentation technology.

For future recommendations, the analysis could be extended further by looking forward of energy integration between the proposed technology and other green production technology to meet local community energy demand so that the supply chain support local community sustainability.

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Biographies

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