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Can farmers mitigate environmental impacts through combined production of food, fuel and feed? A consequential life cycle assessment of integrated mixed crop-livestock system with a green biorefinery

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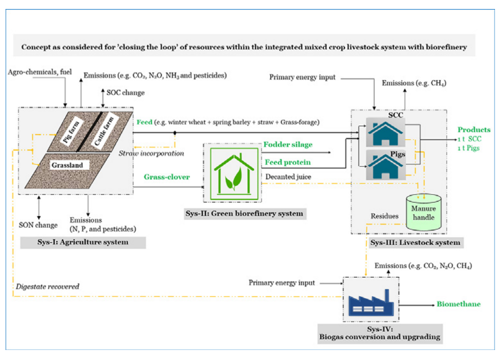
HIGHLIGHTS

- Integrated crop-livestock and biorefinery systems were considered for optimal resource utilizations.
- Combined production of food, feed and fuels were aimed from the integrated farm system.
- Environmental consequences of reducing the import dependency of soymeal are presented.
- Beef and pigs, as the main outputs were considered for the environmental evaluation of the system.

GRAPHICAL ABSTRACT



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ABSTRACT

This study evaluates environmental impacts of an integrated mixed crop-livestock system with a green biorefinery (GBR). System integration included production of feed crops and green biomasses (Sys-I) to meet the demand of a livestock system (Sys-III) and to process green biomasses in a GBR system (Sys-II). Processing of grass-clover to produce feed protein was considered in Sys-II, particularly to substitute the imported soybean meal. Waste generated from the livestock and GBR systems were considered for the conversion to biomethane (Sys-IV). Digestate produced therefrom was assumed to be recirculated back to the farmers' field (Sys-I). A consequential approach of Life Cycle Assessment (LCA) method was used to evaluate the environmental impacts of a combined production of suckler cow calves (SCC) and Pigs, calculated in terms of their live weight (LW). The functional unit (FU) was a basket of two products "1 kg_{LW}-SCC + 1 kg_{LW}-Pigs", produced at the farm gate. Results obtained per FU were: 19.6 kg CO_2 eq for carbon footprint; 0.11 kg PO_4 eq for eutrophication potential, −129 MJ eq for non-renewable energy use and −3.9 comparative toxicity units (CTU_e) for potential freshwater ecotoxicity. Environmental impact, e.g. greenhouse gas (GHG) emission was primarily due to (i) N_2O emission and diesel consumption within Sys-I, (ii) energy input to Sys-II, III and IV, and (iii) methane emission from Sys-III and Sys-IV. Specifically, integrating GBR with the mixed crop-livestock system contributed 4% of the GHG emissions, whilst its products credited 7% of the total impact. Synergies among the different sub-systems showed positive environmental gains for the selected main products. The main effects of the system integration

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were in the reductions of GHG emissions, fossil fuel consumption, eutrophication potential and freshwater ecotoxicity, compared to a conventional mixed crop-livestock system, without the biogas conversion facility and the GBR.

1. Background

Fossil fuel is still one of the principal input to the modern agricultural system and one of the largest commodities produced and consumed (Gielen et al., 2016). Major environmental challenges that human are facing are primarily due to climate change and predicted shortage of fossil fuels. Both fossil fuel shortage and greenhouse gas (GHG) emissions, however can be mitigated through the production of biofuels (FAO, 2012). Moreover, the increasing demand of agricultural biomasses to produce both fuel and non-fuel products is said to exacerbate the issues related to agricultural sustainability (Lin et al., 2006). The 'persistent critique' on the competitive use of biomass for fuel and food is also on the escalation of global food prices (Flammini, 2008). In addition, effects of indirect land use change (iLUC), as claimed for inducing GHG emissions, e.g. due to biofuels production is widely debated (Khanna et al., 2011). Moreover, there are also many critical urgings on iLUC issues, which stressed on the need to delineate a more scientifically robust and consistent method for assessing the impact, if it should be included in the carbon footprint assessments (Finkbeiner, 2013; Langeveld et al., 2014).

The global agenda of sustainable development has also urged to investigate on the options to meet the demand of food, feed and chemicals to the growing population (IEA, 2011). Identified new value chains in the biomass conversion pathways have unavoidably demanded to optimize agricultural productivity and the biomass conversion systems (Kremen et al., 2012). The increasing demand of agricultural biomasses in multifold sectors is also said to put additional pressure on livestock sector (Thornton, 2010). Livestock sector is one of the world's largest consumers of natural resources (Steinfeld et al., 2006). The European Union (EU) livestock sector is the largest producer of the world's meat, milk and eggs. It contributed around 40% of the EU's agricultural production values (Eurostat, 2012). It has also supported to the rural development and to a better functioning of agro-ecosystem (Lutzeyer, 2014). On the other hand, in EU countries, such as France, Germany, the UK and Denmark the cattle population is decreasing (European Commission, 2012). Likewise, Danish Ecological Council (2008) reported that the pig production in Denmark is high, but for a more sustainable agriculture scenario, it stressed on the need to reduce 30% of annual pigs production by 2020. Agronomic-consequences resulting due to the changes in the population density of livestock production, e.g. cattle, are on the management of grassland, which has importance for nature conservation and biodiversity (Isselstein et al., 2005). Systemic synergies between the crop and livestock systems that can provide solutions to increased demand of agricultural commodities without compromising the productivity and with minimum environmental damages is thus relevant.

Most of the impacts on livestock production are expected to be indirect, due to variations in feed availability, indicating on the need of holistic sustainability assessments of a mixed crop-livestock system, i.e. involving both crop and livestock activities (Thornton et al., 2009). In general, farmers pursuing a mixed crop-livestock system are producing about half of the world's food (Herrero et al., 2010). Hence, integrating decentralized technologies to a conventional livestock system not only can add new value chains to the sector, but is also important at mitigating the prevailing environmental problems of the sector. This has been realized also in the form producing cascades of biobased products through biorefinery so that multiple demands of agricultural and other commodities can be met (Parajuli et al., 2015b). Nonetheless, it is imperative to identify whether an agricultural sector can be a principal driver for sustainable supply of green energy and other products demanded in different production sectors. Combination of different biomass conversion technologies in the form of an integrated biorefinery has great potential for a combined production of fuels, chemicals, materials and power (Fatih Demirbas, 2009). Furthermore, green biorefinery (GBR) technology is considered as one of the noble solutions for the optimal utilization of the grassland biomass and to produce alternative biobased products (Kamm et al., 2009). In a GBR technology, green biomass is separated into a fibre-rich press cake and a nutrient-rich press juice. The bulk chemical content contained in the press cake (e.g. cellulose, starch, and dyes) and green juice (e.g. proteins, free amino acids, organic acids, enzymes, and minerals) are argued for having good economic values, as they can be used as raw materials to produce high-quality fodder and cosmetic proteins, human nutrition, chemicals (e.g. lactic acid and lysine). The technology also facilitates the conversion of the co-produced substrates to biogas (Kamm and Kamm, 2004). Production of green protein from a GBR is important, particularly in a situation, where the livestock sector is highly reliant on imported protein sources (such as soybean and soymeal), e.g. in European countries (FAOSTAT, 2013). Likewise, management of biodegradable waste generated from GBR can be a sustainable option to maximize the resource use efficiency, e.g. in the form of producing biogas and its upgrading.

A Life cycle assessment (LCA) method is widely used as a tool to assess environmental performance of different products and services (European Commission, 2015; ISO, 2006). In LCA studies, whenever, a product system yields multiple products, choices on the approach to handle the co-products are unavoidably connected (Thomassen et al., 2008). Generally, such issue is handled either by: sub-dividing the multi-functional processes, system expansion and allocation (European Commission, 2010; ISO, 2006). Attributional and consequential approaches of LCA method were evolved along with the methodological debates over the allocation problems and carrying over the arguments for the choice of data (Thomassen et al., 2008). Within attributional approach, allocation can be avoided by using system expansion, but the products' allocation method is widely used (Thomassen et al., 2008). Assessments relying on attributional LCA approach are most often seeking to quantify the environmental impact potentials associated with a given product or service. Typically, attributional assessments rely on allocation for cutting of data demanding background systems to simplify the modelling and assessment. When applying the consequential approach assessors are generally seeking to identify and quantify the changes within a product system caused by provision of a given product or service under various circumstances. As is obvious, the two approaches are intended for providing answers to quite different questions. Nevertheless, the two approaches are mixed, by e.g. avoiding all or selected allocations in attributional assessments by inclusion of background systems to account for such issues as avoided impacts (Curran, 2015). In a consequential approach, the co-products are substituted with the related alternative products, preferably the marginal products (Schmidt, 2008).

The current study aims at evaluating environmental performance of an ideal mixed crop-livestock system, within which, a green biorefinery technology is also integrated. The system was designed in such a way to bring together, the farmers pursuing two different livestock farms-cattle and pig, e.g. in a form of "farmers-cooperative", so that the local resources can be optimally utilized and shared. The special focus of