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Life-cycle Inventory to Assess and Analyze Bio-diesel Production in South Africa

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Abstract—**Biofuels, just like fossil fuels, are also associated with various environmental impacts along the production-consumption chain. Those impacts need to be attributed to different products, as biofuel production generally yields one or more co-products, like animal fodder or soymeal, or may be a co-product of some other, higher-valued process, like bagasse from sugar cane for heat or electricity production. Life cycle assessments impacts of biofuels are usually studied in a comparative manner, in order to analyse which alternative amongst fossil or bio-based options has the lesser environmental burden.The inventory analysis shows that the inputs and outputs of the farming unit process are sensitive to the type of crop and region of produce. Water usage is a highly variable parameter, which emphasises the importance of rainfall and irrigation to the overall burden of the biodiesel system on water resources. Crop yields may differ by a factor of two, which is a significant difference in terms of land and non-renewable energy resources requirements. The oil and meal/cake content of the seed proves to be the most important parameter that influences the initial unit processes of the value chains.**

Index Terms— **LCA, life-cycle inventory analysis, Biofuels, South Africa**

I. INTRODUCTION BACKGROUND AND JUSTIFICATION

The use of biomass as a source of energy is increasing sharply in countries such as the United States of America, Germany, Brazil and Japan [3].The popularity of the organic fuel comes mainly from its economic and environmental benefits [4], and it can be easily converted into energy for direct heating applications and/or electricity generation systems [3]. Among several sources of biomass residues that can be employed in energy generation, the sugarcane bagasse is one of the most used in the world. Sugarcane is a tall grass with big stems [5], which is largely grown in tropical countries such as Brazil. The sugarcane bagasse is a by-product of the ethanol and/or sugar production composed mostly of fiber and water and generated in the sugarcane milling process [6].The bagasse is a residue applied as input resource in 80 sugarcane producing countries, especially for electricity generation.

Bioethanol is a fuel that can be generated from sugar through fermentation and distillation process [8]. Crops such as maize or sugar molasses require an additional processing step that converts the starch to a sugar. This process is referred to as first-generation bioethanol production and has a long history of successful operation in countries such as Brazil, Malawi and many other countries. South Africa has used bioethanol in fuel in the past (1920s to about 1960), but presently only produces bioethanol for non-fuel purposes. Second generation technologies are being developed that will allow lignin and cellulose to be used as a feedstock and hence enable non-food components of vegetation to be converted into fuel [12].

Biofuels, just like fossil fuels, are also associated with various environmental impacts along the production-consumption chain. Those impacts need to be attributed to different products, as biofuel production generally yields one or more co-products, like animal fodder or soymeal, or may be a co-product of some other, higher-valued process, like bagasse from sugar cane for heat or electricity production. Life cycle assessments impacts of biofuels are usually studied in a comparative manner, in order to analyze which alternative amongst fossil or bio-based options has the lesser environmental burden. Often, the alternatives have different strengths and weaknesses depending on the demand, especially on the case of bio-fuels [7].

The biofuels environmental impact depends on different factors, these include the raw materials used to obtain the biofuels, the different production processes and the final use can determine the environmental balance of biofuels introduction [1]. Several climatology factors (type of soil, weather etc.) have a strong influence on environmental impact. Additionally, other significant factors are the past land-use, the by-products, the technological process path as well as the relative use of the end fuel either in a mixed or in a pure mode [2].

The growing demand for fuel crops may only be supplied through the expansion of cropland. Indirect impacts of biofuel production, like the destruction of natural habitats (e.g. rainforests or savannahs) to expand agricultural land, may have larger environmental impacts than the direct effects. In the worst cases, for example, the greenhouse gas (GHG) emissions from biofuel production may be higher than from an equal amount of fossil fuels [9; 10].

Biofuels may also change the geographical distribution of the environmental burden of feedstock production within a country or a region, across borders, and also from developed countries to developing countries. The extent to

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which the co-products of biofuel production displace other products and their environmental impacts (rather than stimulate additional consumption) depends on the elasticity of demand in the relevant markets (the more inelastic the demand, the greater the substitution), the way in which the co-products affect supply curves, and other market and non-market (i.e. political and regulatory) factors. [13]

The production of Bio-ethanol also results in emissions to the environment such as fertilizers during plantation and emissions from fuel use during oil extraction, transportation, etc [15]. Thus, the environmental implications of biofuel production need to be addressed. Life Cycle Assessment can be used for such an evaluation.

OBJECTIVES OF THE RESEARCH

The study aims on increasing the understanding of the environmental implications of the South African biofuels production. It set out to explain the South African life cycle inventory of biodiesel production as a first step towards comprehensive analyses of biofuels value chains.

II. LIFE CYCLE ASSESSMENT METHODOLOGY APPLICATION FOR BIODIESEL ASSESSMENT

E-LCA uses tools from many disciplines. Biodiesel projects affect local economies, societies, geography, and anthropology, the psychology of people affected, local management systems, agronomy, forestry and health and safety aspects. These fall within many fields of study and hence the assessment methods have to be multidisciplinary [14]. The analytical, monitoring, communication and reporting tools and used can complement each other. Positive and negative social, potential social and indirect impacts throughout the life cycle of a diesel production are identified in a way that informs incremental improvements of the product's social performance. The assessment methods used are similar to Social LCA (S-LCA) involving goal and scope definition, life cycle inventory analysis, life cycle impacts assessment and interpretation, but focusing of social and socio-economic impacts and information on organization-related aspects along the diesel production, consumption and disposal chain. This extends the assessment methods towards sustainability LCA. Data are collected for stakeholder categories for a specific site, location and lifecycle stage. Subjective data and variables are used and positive and negative social impacts identified for a given geographical location.

Life Cycle Inventory Analysis involves collection and modelling of data to determine how the biodiesel production chain performs throughout its life cycle. Inventory indicators are being still being developed and regularised for biodiesel production in South Africa. Other methodologies employed include document audits, directed and semi-directed interviews

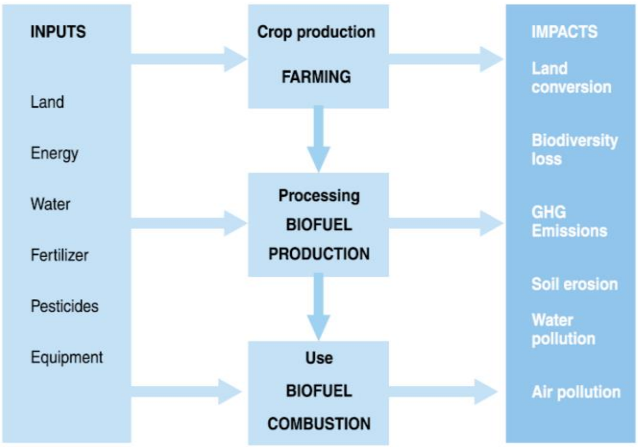

Fig 1. General Biofuel pathway with inputs and environmental impacts

Data verification and triangulation for different stakeholder groups is planned. Information collected includes remuneration levels to classify them as living, minimum or average wages. Co-products are handled by the life cycle inventory phase encloses data collection and calculation in order to quantify inputs (energy, raw and ancillary materials and other physical inputs) and outputs (products, emissions and waste) of a product system.

The government's contribution to the biodiesel industry in South Africa is through the Biofuels Industrial Strategy which was gazetted in 2007 [1]. This outlines policy, regulations and incentives regarding biofuels in South Africa. Areas covered include water limitations, food security (availability and affordability), land prices and land restitution, environmental concerns, biofuels quality, technology choices and crop selection/ choices. The highlight of the strategy is a plan to achieve a 2% biofuel penetration of the transportation fuel market, representing about 400 million litres. The aim is to replace 240 million of petrol by ethanol and 160 million litres of diesel by biodiesel.

The crops proposed for bio-ethanol production, with little impact on human consumption are sugar cane and sugar beet and for biodiesel are sunflower, canola and soybeans. The targeted land for these crops is underutilised. It is estimated about 14% of arable land, mainly in the former homelands, is underutilised. To meet the 2% interim market penetration target, only 10% of this underutilised land is required suggesting that this will have minimal impact on local society and on food production. However still, there is hesitancy by the South African government to approve such projects due to the food-fuel competition issue being brought to the fore by different stakeholders. There is therefore a need to do a full sustainability life cycle assessment of biodiesel production in South Africa. This can be the basis for more favourable policy formulation towards biodiesel promotion that can attract investment

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III. DISCUSSION

The detailed inventory dataset is provided elsewhere (BIOISSAM, 2014: www.biossam.org/wpcontent/ uploads/2014/08/Life-cycle-inventory-datafor-biodiesel-scenarios.pdf). For the farming unit processes, data valuesare provided for the reference flow of the unit process, namely 1 tonne of produced oil seed, and for the functional unit of the complete life cycle, namely 19.5 kt/yr of biodiesel product. Per reference flow, the variations in the data reflect differences between the Provinces, except for canola where country average values were used. Per functional unit, the variations in the data reflect uncertainties throughout the life cycle. For the oil pressing unit processes, which include the transportation from the respective farming unit processes, the data values are again provided for the reference flow of the unit process, namely 1 tonne of processed oil seed, and for the functional unit of the complete life cycle. Variations in the data per reference flow are due to the potential differences in the oil and meal/cake content of the oil seed. Per functional unit, the uncertainties across the value chain are reflected in the variations of the data. Data values are provided for the biodiesel production unit process, which includes the transportation from the oil pressing unit processes, per a reference flow of 1 tonne of biodiesel produced, and per the functional unit of 19.5 kt/yr. Uncertainties are due to the location of the facilities, which has a minor influence, and the interactions between unit processes in the value chain.

The farming unit process showed significant sensitivity to the type of crop and region of production. For example, the inputs and outputs of sunflower, except for water usage, do not differ much between the Provinces, but due to yield differences in soybean production, the values may differ by a factor of two. Such variability has also been reported elsewhere (Landis *et al.,* 2007). The availability of data, and how it is reported, also plays a significant role. For example, energy usage on the farm is often reported per hectare and emissions, in international databases, per tonne produced. The consequence is that emissions may not seem sensitive to feedstock production yields, although, of course, they should. The water usage ranges by a factor of two for soybean and canola, and by a factor of nearly three for sunflower, which highlights the importance of rainfall in a region in terms of the requirement to extract water from a catchment. The oil and meal/cake content of the seed produce influences the elementary flows associated with the transportation requirements to the oil pressing unit process, although the South African field trip data suggests that it is not a very important factor in terms of energy usage at the oil pressing facilities. However, the oil and meal/cake content proves to be the most important parameter that influences the unit processes in the initial life cycle phases. Almost all the inputs and outputs of the farming unit processes, for all the crops, range in the order of a factor of two due to variations in this parameter. Section 3.2 indicates that, at present, the meal/cake co-product has an economic value, often more than the fuel product. However, should there not be an offset market, the production system would face a significant waste stream; between 27 and 120 kilo tonnes for 19.5 tonnes of biodiesel. This, together with the other waste streams, most notably KCl (around 200 tonnes) and glycerol (2 kilo tonnes), would necessitate a separate waste management systems in the economy. The uncertainties associated with the logistic system in the value chain have major implications. For example, should the distances from the farming activities to the oil pressing unit process, and to the biodiesel production unit process, increase by a factor of two, then the energy balance may be negative (with soybean as feedstock). Indications are that average distances should not exceed 300 km in the product value chain. Very little uncertainties were detected in the biodiesel production unit process. However, the energy efficiency of the overall system needs due consideration. On average, the 19.5 kilo tonnes biodiesel product has an energy-content in the order of 800 TJ; the energy demand of the system is in the order of 400 to 1100 TJ. This means that the nearly half of all the production may be an energy sink, which is clearly unsustainable.

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Interpretation and Limitations

There are, however, a number of limitations with the inventory. The geographical representation of available data remains a problem for most of the elementary flows and for the initial unit processes of value chains, especially in the South African context. Farming practices were not captured in the flows of such a simplified inventory. For example, crop rotation is vital to preserve soil quality in most regions of South Africa, and the chemicals used may differ significantly between regions. The potential requirement to transform land to meet the requirements for bio-fuels production is not captured, which, in turn, may have a significant influence on ecosystems’ structure and functioning.

The inventory dataset also highlight the challenge with deriving comprehensive impact assessment profiles for bio-fuels production. Much emphasis has been placed on energy balances and air emissions of life cycle systems, but a number of issues still remain outstanding. Land use flow and water usage flow, in life cycled assessment terms, is deemed inadequate to reflect changes in the quantity and quality of land and water resources. However, biodiversity indexes have been proposed to evaluate land use changes that could be used to define appropriate land usage flows and the diversity at microbial level has been proposed as an index that can be utilised to define water usage and release flows respectively.

There is currently no documented approach to handle the solid waste streams of biofuel value chains. With respect to the air emissions, the life cycle inventory compares reasonably to other studies.

IV. CONCLUSIONS

The inventory reflect that the inputs and outputs of the farming unit process are sensitive to the type of crop and region of produce. Water usage is a highly variable parameter, which emphasises the importance of rainfall and irrigation to the overall burden of the biodiesel system on water resources. The oil and meal/cake content of the seed proves to be the most important parameter that influences the initial unit processes of the bio-fuels value chains.

It was also noted that there are generally a few relatable LCA databases on biodiesel production making it difficult to screen for hotspots and a desk screening using literature is proposed. Emphasis is also to be placed on data status, quality, reliability and relevancy. A combination of on-site data collection and statistical methods is proposed.

There is a need for creating databases of social, socio-economic information and data on all biodiesel production and unique tools also need to be developed to help in conducting S-LCA studies. The following laws and regulations that promote the rights of farm workers need to be effectively enforced: The Basic Conditions of Employment Act (BCEA); Sectorial Determination for Farm Workers and; Extension of the Security of Tenure Act. The data used needs to be complemented with more data collection from primary and secondary sources to enable a more complete social life cycle assessment. The information collected show how difficult it is to develop such studies. However the main hotspots identified are the social conditions of farm workers, the exploitation of immigrants, and the need for economic empowerment of previously disadvantaged groups in the process of biodiesel development.

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