Proceedings of the 11th International Conference on Manufacturing Research (ICMR2013), Cranfield University, UK, 19th – 20th September 2013, pp 549-554

IMPACT OF CLIMATE CHANGE ON FIRST GENERATION BIOFUELS PRODUCTION IN THE 21ST CENTURY

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ABSTRACT

This study assessed the potential (near, medium, and long term) impacts of climate change on first generation corn bioethanol and soybean biodiesel production in Gainesville, Florida, USA. The Decision Support System for Agrotechnology Transfer-Cropping System Model (DSSAT-CSM) was used to simulate biomass and grain yield under climate change scenarios in the 21st century with direct effect of CO_2. Weather projection was made for each scenario using the 10 year weather data for the baseline period (1981–1990). Precipitation is projected to increase by +20, +10, -10, and -20% every month throughout the growing season. Daily minimum and maximum air temperatures are projected to increase by +1.5, +3, and +5^{o}C. Atmospheric CO_2 is projected to increase by +70 and +350$_{ppm}$. Simulated yields (grains/seeds and by-products) were then used as inputs into the LCA models. Results show that while bioethanol from corn and biodiesel from soybean offers some potential for GHG emissions savings per cultivated ha of set-aside land, this is tempered by rising air temperature. However, increased atmospheric levels of CO_2 relative to current condition would reduce the severe impact of warming. Only soybean biodiesel will be positively affected by climate changes.

Keywords: climate changes, biomass, biofuel

1 INTRODUCTION

Sustainability of global energy systems is an important prerequisite for sustainable development. About 81% of the world's energy demand is currently supplied by conventional fossil-based fuels such as crude oil, coal, and natural gas. However, as concern grows about the twin challenges of energy security and climate change from the burning of these fossil-based fuels, the potential for producing agricultural crop-based liquid transportation biofuels is attracting anxious interest (Sims *et al.,* 2006). Conventional bioethanol and biodiesel primarily produced from starch and edible vegetable oil respectively are the most common form of biofuels (Börjesson *et al.,* 2011). These biofuels have been shown to contribute significantly towards climate change mitigation due to reduction of combustion emissions when they are use as potential substitutes for fossil-based fuels in the transportation sector (Grau *et al.,* 2013; Renouf *et al.,* 2013). The benefits of using crop-based liquid transportation biofuels are strongly debated in recent literature and several different life cycle assessment (LCA) studies have been conducted by many researchers regarding the sustainability of agricultural crop-based biofuels in terms of energy balance and greenhouse gas (GHG) reductions.

For instance, while researchers such as Searchinger *et al.* (2008) are of the opinion that there is no benefit from production of crop-based transportation biofuels, a recent study by Gelfand *et al.* (2013) shows that crop-based biofuels from marginal lands can have positive environmental outcomes, and also according to Sims *et al.* (2006), biofuels could make a substantial proportion of future energy portfolios. However, the resulting GHG emissions reduction from these biofuels remains uncertain as there are growing concerns about how emerging global climate change will affect energy crops for biofuels production, since agricultural production of these crops tends to be more sensitive to weather and climate variables (Fischer *et al.,* 2002). LCA studies that use crop system models (CSM) coupled with LCA models to analyse the possible effects of climate change on energy crops for biofuels production have also been reported in recent literature (e.g. Persson *et al.,* 2009; Wang *et al.,* 2012). Nevertheless, most of these studies limit their research on the energy balance of biofuels grown on agricultural arable lands. Reliable projection of how climate change will affect the resulting GHG emissions savings of crop-based biofuels grown on set-aside lands would be of real benefit to policymakers for the deployment of large scale agricultural crop-based biofuels. This paper investigate the impacts that climate change will have on the GHG emissions savings of corn bioethanol and soybean biodiesel from set-aside lands in the near, medium and long-term future.

2 METHODOLOGY

The methodology is underpinned by life cycle thinking. Crop system models (CSM) and LCA models are integrated and used as tools for assessing the carbon footprint of corn bioethanol and soybean biodiesel when they are used as alternatives to conventional fossil-based gasoline and diesel respectively.

2.1 Crop models and inputs

Corn and soybean dry biomass yields (grain/seed and stover/stalk) were simulated for current (baseline) and projected climate change scenarios and used as inputs into the LCA analyses. Process based crop model simulations were run with the CERES-Maize (Ritchie *et al.,* 1998) and CROPGRO-Soybean (Jones *et al.,* 2003) of the DSSAT-CSM model v4.0.2 Software (Hoogenboom *et al.,* 2003) for corn (*Zea mais L.*) and soybean (*Glycine max*) respectively. The models simulates physiological crop responses on a daily basis as a function of climate factors (daily maximum and minimum temperature, precipitation, and solar radiation), soils, and crop management practices (cultivar, planting date, row spacing, plant population, and planting depth). The models have been applied extensively in many different parts of the world for climate change applications (e.g. Gungula *et al.,* 2003; Rötter *et al.,* 2012). Gainesville, Florida, USA, meteorological weather station data were used in the study because of readily available and reliable data in a suitable format required by the DSSAT-CSM model.

2.2 Baseline climate data and climate change scenarios

Historical ten – year daily observed climate data from 1981 to 1990 for the station were used in this study. Farm level management practices with most optimal yield were chosen for the corn cultivar, McCurdy 84aa and soybean cultivar, PIO332. Simulations were run under rain fed conditions. Table 1 depicts the climate variables used in the generation of the climate change scenarios. Here we used the "environmental modification" section of the XBuild module in DSSAT-CSM model to generate climate change scenarios using variable combinations of temperature, precipitation, and atmospheric CO_2 levels. Daily changes in the climate variables were applied to the observed daily climate records. Projections were made throughout the crops growing season.

Table 1: Climate change parameters range and values used to create climate change scenarios.

Climate Parameters	Values
Daily maximum temperature	+1.5, +3.0 and +5.0^{o}C
Daily minimum temperature	+1.5, +3.0 and +5.0^{o}C
Precipitation	+20, +10, -10 and -20%
Atmospheric carbon dioxide (CO_2) concentration	+70 and +350*ppm*.

2.3 LCA analysis: GHG emissions calculation

The GHG kg CO_2-eq. ha^{-1} yr^{-1} for CO_2, N_2O and CH_4 emissions were calculated using a life cycle assessment approach. This methodology was used to analyse and compare the Carbon Footprint of bioethanol produced from corn and biodiesel produced from soybean with petroleum based fossil fuels – petrol (gasoline) and diesel respectively according to ISO 14044 standard (ISO, 2006). This method advocates the system boundary expansion method – "displacement method" or "substitution method" for LCAs (Börjesson *et al.,* 2011) (Figure 1). Models were developed using the GaBi v4.4. The crop yields are based on simulated model outputs from the DSSAT-CSM model and were used as inputs for the LCA models. In this study, average energy crop yields over 10 years were taken to smooth out annual variations due to temperature and precipitation differences. The LCA steps are described in the subsequent sections.

2.4 System boundary and functional unit

The system boundary in this study as shown in Figure 1 included energy crop (feedstock) production and transportation, biofuels processing, and biofuels distribution to service station. Direct land use was also included in the study (Searchinger *et al.,* 2008). Upstream activities such as manufacturing of equipments/machines and chemicals were taken into account. The average 100 km feedstock transportation data was considered in the study (González-García *et al.,* 2010). The functional unit is 1 ha of cultivated land. All annual GHG emissions savings kg CO_2-eq. are calculated per ha.

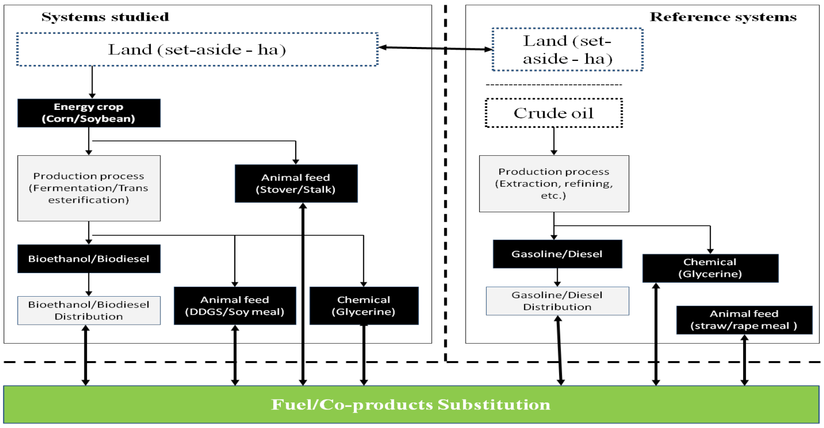

Figure 1: System description/system boundaries of bioethanol from corn (CBE) and biodiesel from soybean (SBD) displacing fossil-based fuels

2.4.1 Life cycle inventory (LCI)

The model representation of the physical processes inventory for bioethanol and biodiesel are constructed in GaBi v4.4 LCA software using ecoinvent v2.0 database unit process raw data that has been incorporated into the Software. The datasets were preferentially selected from the USA (based in the USA) which represents the study site. However, limited availability of data has always been one of the critical issues in LCA studies, where data is not available, data from RER (based in Europe) and the CH (Europe specific) were used in the analysis.

2.4.2 Life cycle impact assessment (LCIA)

The cumulative impact assessment results from ecoinvent (LCIA) for GHG global warming potential (GWP) were taken by applying the CML2001, 100 years Global Warming Potential (GWP) methodology (Renó *et al.,* 2011) due to its relevance to current legislative goals (IPCC, 2007). Our analysis accounts for the GHG emissions from energy crops cultivation (farm operations), biofuel conversion process, and distribution to regional storage (equation 1).

$$GHG_{biofuels} = GHG_{farm} + GHG_{process} + GHG_{distribution} \qquad (1)$$

2.4.3 GHG emissions reduction due to fossil fuels replacement

GHG emissions reduction (GHG emissions savings) from fossil gasoline and diesel displacement due to use of corn bioethanol and soybean biodiesel respectively were calculated as the difference between emissions from the production, distribution and combustion (use) of fossil gasoline/diesel and the crop cultivation, production and distribution of bioethanol/biodiesel (equation 2).

$$GHG_{savings} = \left(GHG_{fossilprod} + GHG_{fossildist} + GHG_{fossilcomb}\right) - \left(GHG_{biofuel}\right) \tag{2}$$

Where $GHG_{fossilprod}$, $GHG_{fossildist}$ and $GHG_{fossilcomb}$ are the fossil-derived GHG emissions from fossil fuels production (including extraction of crude oil), fossil fuel extraction and combustion of the displaced fossil fuel equivalent $(fossil_{equiv.})$, which is the amount (kg) of the displaced fossil reference system defined as:

$$fossil_{equiv.} = biofuel_{produced} \times S_r \tag{3}$$

Where $biofuel_{produced}$, is the amount of biofuel produced per ha, and S_r is the substitution ratio between the biofuel and the conventional fossil fuel (equation 4).

$$S_r = \frac{CV_{biofuel}}{CV_{fossil\ fuel}} \tag{4}$$

Where $CV_{biofuel}$, is the calorific value of the biofuel produced (MJ/kg), and $CV_{fossil\ fuel}$, is the calorific value of the displaced fossil reference system (MJ/kg).

3 RESULTS AND DISCUSSIONS

Models calculations show that production of CBE and SBD per ha substituting for equivalent quantity of fossil-based reference fossil-based fuels would result in potential GHG emissions savings of -4743.32 kg CO_2-eq. ha^{-1} yr^{-1} and -2655.41kg CO_2-eq. ha^{-1} yr^{-1} respectively in the current – baseline scenario. Our result for CBE, agree well with that of Gelfand *et al.* (2013) and Larson (2006) who reported GHG emissions savings capacity of -4290 and about -4900 kg CO_2-eq. ha^{-1} yr^{-1} respectively from corn-based bioethanol. Similarly, for SBD GHG emissions savings potential for the baseline results corresponds with that of Larson (2006) who reported about -2100 kg CO_2-eq. ha^{-1} yr^{-1}. For projected climate change scenarios which include a combinations of increased surface air temperatures, changes in seasonal distribution of precipitation, and elevated atmospheric CO_2 concentration, the potential impacts of these changes are complex, and include not implications for energy corn and soybean dry biomass yields per ha, but also the biofuels produced and the resulting potential GHG emissions savings that could be achieved. This demonstrates that climate change will have serious implications not only the agronomy of these crops, but also and their Carbon Footprint.

As depicted in Figure 2, for the near (+1.5°C temperatures increase), medium (+3°C temperature increase), and long term (+5°C temperature increase) we can expect GHG emission savings to decrease between 9 to 46% for CBE in all the scenarios assessed compared to the baseline scenario. The overwhelming trend of the impacts of all projected climate change scenarios on CBE was negative, the more the temperature increases the more the GHG emissions savings per ha declines. However, the magnitude of the impacts varied with scenario. The impact of precipitation change on GHG emissions savings from CBE is less noticeable compared to SBD. A rise in atmospheric CO_2 concentration to 680 ppm (+350 ppm) would lead to a CO_2 fertilization effect on the corn thereby raising plant yield and potential GHG emissions savings per ha. With respect to the dynamic of change in GHG emissions savings for CBE between +70 and +350 ppm CO_2 gains in GHG emissions savings due to CO_2 enrichment are going to rise by 10%.

Also as shown in Figure 3, GHG emissions savings for SBD are predicted to decline for all climate change scenarios with +70 ppm CO_2 concentration. However, under double CO_2 concentration (+350 ppm) GHG emissions savings are predicted to increase higher that the baseline condition in some scenarios probably due to CO_2 fertilization effect which tends to reduce the impacts of increased temperature and decreased precipitation. The direct beneficial effect of atmospheric CO_2 enrichment offset the GHG emissions savings decrease in some of the scenarios considered. For instance, at +1.5°C temperature increase coupled with a 20% increase in precipitation and +350 ppm CO_2 increase in GHG emissions savings higher than the baseline scenario is predicted (+27%).

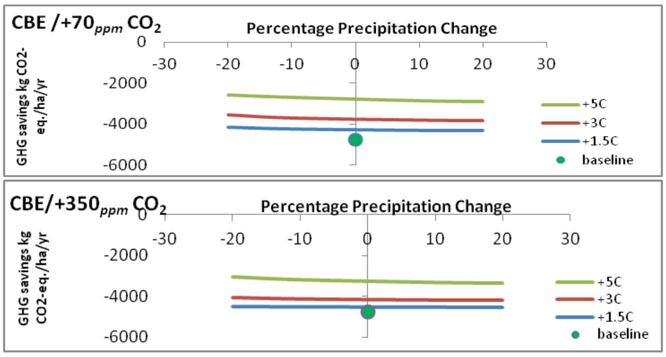

Figure 2: Impact of climate variables on GHG emissions savings of Corn bioethanol (CBE) under current (baseline) scenario and different climate change scenarios by the end of 21st century at different atmospheric levels of CO2.

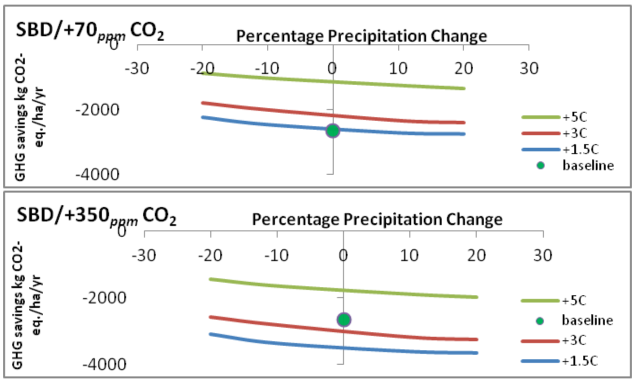

Figure 3: Impact of climate variables on GHG emissions savings of Soybean biodiesel (SBD) under current (baseline) scenario and different climate change scenarios by the end of 21st century at different atmospheric levels of CO2.

With respect to the dynamic of change in GHG emissions savings for SBD between +70 and +350 ppm CO_2 gains in GHG emissions savings due to CO_2 enrichment are going to rise by 23%. In contrast, as the climate gets warmer in the long term future (+5°C temperature increased), the GHG emissions savings for SBD are projected to decline in all climate change scenarios even under doubled CO_2 (+350 ppm) enrichment. For instance, at +5°C temperature increase, and 20% precipitation decrease, there is substantial declines in the GHG emissions savings (-46%). This demonstrated that SBD production would be equally well if not better, in a warmer (milder temperatures increase) and CO_2 enriched future. This might not be unconnected with the photosynthetic advantage that that soybean (a typical C3 crop) has over corn (a typical C4 crop) at considerably high temperatures and elevated atmospheric CO_2 than today's condition (Oliver *et al.*, 2009).

4 CONCLUSION

The impact of climate change on the life cycle GHG savings of CBE and SBD were undertaken using LCA methodology. The approach relies on LCA models in combination with CSM models. GHG savings per ha per annum varies from feedstock types and climate change scenarios. CBE can generate GHG emissions savings of -4743.32 kg CO_2-eq. per ha per annum and SBD can generate -2655.41 kg CO_2-eq. per ha^{-1} yr^{-1}. Therefore, bioethanol from corn and biodiesel from soybean grown on marginal lands could present very good opportunities for reduced GHG emissions when compared with fossil-based fuels. However, these would be affected by changes in future climate. CBE would suffer serious decline in the net GHG emissions savings per ha per year in all the near, mid, and long term future. While SBD would also be negatively affected by climate change in some scenarios, and under double CO_2 concentration (+350 ppm) and at temperatures lower than +5°C coupled with increased precipitation, the net GHG emissions savings are predicted to increase higher than that of the baseline condition probably due to CO_2 fertilization effect. A temperature rise of +5°C will have a devastating effect for both CBE and SBD even with doubled CO_2 concentration. Climate change will affects energy crops production differently. Care must therefore, be taken by farmers, policy makers, and all stake holders in chosen which crop to grow and under which condition in the future.

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