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Global perspectives on first generation liquid biofuel production

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Abstract: Transport today is mostly sustained by liquid fossil fuels, despite the fact that the invention of the combustion engine started with biofuels. However, known environmental impacts and the instability of the fossil-fuel market have revived the status of biofuels. Some concerns have appeared regarding how emerging global climate changes will affect biofuels' feedstock production, since agriculture is strongly dependent on climate variables. Therefore, numerical models were introduced to calculate how temperature and precipitation could affect crop production for biodiesel and bioethanol production. Furthermore, 4 scenarios projected by the Intergovernmental Panel on Climate Change were put into the calculations. The results show that temperature has significant impact on feedstock production in all cases ($P < 0.05$), while precipitation seems to be less significant. If the temperature increases by 6.4 °C as the Intergovernmental Panel on Climate Change predicts, production of bioethanol made from sugar beets will decrease by as much as 70%. For other feedstocks, the share of production decrease will be smaller. Only biodiesel made of soybean will be positively affected by a temperature increase. Since global climate change will have negative impacts on feedstock for biofuel production, it is a challenge to meet the projected increases in biofuels' share in the fuel market.

Key words: Biofuels, climate change, fuel security, transport energy

Introduction

Energy sources have changed throughout history due to intense exploration, technology and development. Some evidence exists showing that humanity learned to control fire more than 500,000 years ago. The evolution of energy sources is followed by coal use and petrol fuel consumption (Azar et al. 2003; Demirbas et al. 2008). The current energy paradigm of our society is therefore based on massive use of fossil fuels, limited oil reserves, increase of oil prices, and political instability, as well as on other indirect problems, such as the impacts on the climate and environment (Stern 2007; Baruch 2008; Pin-Koh and Ghazoul 2008).

Mobility has crucial importance to our modern industrialised society. Apart from a few exceptions, the transport of people and goods is sustained by liquid fuels. Despite the known fact of limited petroleum resources, consumption is still growing and, therefore, a number of various studies put the date of the global peak in oil production between 1996 and 2035 (Pimentel et al. 2007; Demirbas

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2008). However, renewable energy sources, unlike fossil fuels, are theoretically infinite. It is important to note that the renewable energy sources release the equal amount of CO_2 when burned as it is used in process of photosynthesis (Clair et al. 2008; Chauhan et al. 2009). There are 2 global bio-renewable liquid transportation fuels that might replace gasoline and diesel fuel: ethanol and biodiesel. Ethanol is produced from sugar or starch crops, while biodiesel is produced from vegetable oils or animal fats (Demirbas 2008).

Although the diesel engine began with biofuels, their consumption decreased due to less expensive oil. However, in recent years the consumption of biofuels has grown exponentially (Antoni et al. 2007). Therefore, the use of liquid biofuels has revived for 2 reasons: to mitigate expected climate changes that are caused by massive fossil fuel use and to reduce concerns related to limited oil reserves (Charles et al. 2007). Nevertheless, there are also some concerns based on liquid-biofuel security, such as whether the production of biofuels will meet the projected consumption. This is especially relevant when taking into account projected climate changes. The IPCC (Intergovernmental Panel on Climate Change) has made projections that the average global air temperature will increase by the end of 2100 from 1.1 to 6.4 °C relatively to baseline average in the period 1980-1999; meanwhile, precipitation will increase by 20% in some areas, but will decrease by 20% in others (IPCC 2007). According to the recent observed trends it is expected that the highest temperature rise will occur over the land. The peak of the air temperature rise will occur in the area of northern latitudes. The minor air temperature rise is expected to be in the area of Southern Ocean and northern North Atlantic. At lower latitudes, especially in seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (IPCC, 2007). The concurrent increase in surface temperature with carbon dioxide and other greenhouse gases during the past century is one of the main indications that our climate is changing. Climate change will have multiple effects on ecosystems as changes in precipitation patterns, global air temperature, droughts, and floods. In general, the larger and faster the changes in climate are, the more difficult it will be for human and natural systems to adapt (Stern, 2007). Since crop production depends on climate, the sector most affected by climate change will be agriculture (Motha and Baier 2005; Salinger 2005). Seasonal temperature is an important climatic factor that can have profound effects on the yield of crops. Changes in seasonal temperature affect grain yields, mainly through phenological development processes (Kalra et al. 2008). Today's question is no longer whether renewable biofuels will play a significant role in providing energy for transportation, but rather what are the implications of their use and how will it be reflected in the economy, environment, global security, and in the health of the whole of humanity (Bernard and Prieur 2007).

The aim of this study was to create numerical models based on retrospective data that can predict how the global changes will affect yield of feedstock for biofuel production.

Materials and methods

Five of the most commonly used feedstocks were selected for biodiesel (BD) and bioethanol (EtOH) production assessment. Average yields for each feedstock (t ha^{-1}) were obtained from the Faostat Database of the Food and Agriculture Organization of the United Nations (Faostat, 2010).

From the annual temperatures (°C), annual average air temperature ($\overline{Ta}$) was calculated as follows for each location:

$$\overline{Ta}_i = \frac{\sum_{j=1}^{99} T_i}{99} \qquad (1)$$

where i denotes years from 1901 to 2000, i = 1-99 represents years of temperature measurement, and Ti denotes year temperature.

Moreover, from the annual precipitation (mm) average annual precipitation ($\overline{pa}$) was calculated as follows for each location:

$$\overline{pa}_i = \frac{\sum_{j=1}^{99} p_i}{99} \qquad (2)$$

where i denotes years from 1901 to 2000, i = 1-99 represents years of precipitation measurement, and pi denotes year precipitation.

For soybeans 25 locations were selected, for corn 38, for sugar beet 22, for sugarcane 23, and for rapeseed 22 (Table 1). Data were plotted in 3-dimensional figures in Wolfram Mathematica 7.0 and the polynomial function was calculated using the function FindFit. Since the yield of feedstock is a function of temperature and precipitation, the calculated models were named climate yield prediction (CYP) models. In addition, regression was performed to obtain the statistical correlation between yield and meteorological parameters such as precipitation and temperature.

Verification of CYP models was done by comparing models' results to yields assessed from publications published in research articles. For each location where yield was calculated with CYP models, yield was also obtained from scientific journals and compared. Correlation was evaluated using linear regression. For all CYP models, at least 3 reference values of yield were obtained and compared. Expected global changes by the end of 2100 were defined as 4 scenarios according to the IPCC projections: Scenario 1 (precipitation increase by 20%; temperature increase by 1.1 °C), Scenario 2 (precipitation increase by 20%; temperature increase by 6.4 °C), Scenario 3 (precipitation decrease by 20%; temperature increase by 1.1 °C), and Scenario 4 (precipitation decrease by 20%; temperature increase by 6.4 °C). Change in EtOH/BD production was projected using CYP models and the scenarios mention above. From this point of view, all 4 combination scenarios were taken into account for estimating influences of global climate change on yield for selected feedstock.

Results

We calculated numerical models for EtOH and BD production due to weather variables, i.e. temperature and precipitation. The equation in bracket represents the yield of feedstock for biofuel production, while the factor after the brackets is the conversion factor for fuel production (d) obtained from the literature

Table 1. Locations of EtOH and BD feedstock production.

Bioethanol		Biodiesel	
Feedstock	*Location*	*Feedstock*	*Location*
Corn	Afghanistan, Algeria, Angola, Argentina, Austria, Bangladesh, Bolivia, Botswana, Brazil, Bulgaria, Chile, China, Congo, Cuba, Ecuador, France, Germany, Greece, Hungary, Iran, Iraq, Israel, Italy, Japan, Kenya, Mexico, Morocco, Pakistan, Paraguay, Poland, Portugal, Romania, Spain, Turkey, Uruguay, Venezuela, Zambia, Zimbabwe.	Rapeseed	Algeria, Argentina, Austria, Brazil, Chile, China, Denmark, France, Germany, Hungary, India, Ireland, Italy, Japan, Mexico, New Zealand, Pakistan, Poland, Romania, Spain, Turkey, United Kingdom
Sugar beet	Afghanistan, Albania, Austria, Bulgaria, Chile, China, Denmark, Ecuador, France, Germany, Greece, Hungary, Iran, Iraq, Ireland, Italy, Japan, Pakistan, Poland, Romania, Spain, Turkey	Soy bean	Albania, Argentina, Bolivia, Brazil, Bulgaria, China, Colombia, France, Hungary, India, Indonesia, Iraq, Italy, Japan, Mexico, Nepal, Nigeria, Pakistan, Paraguay, Peru, Romania, Spain, Turkey, Zambia, Zimbabwe
Sugarcane	Afghanistan, Angola, Bolivia, Brazil, Cuba, Ecuador, India, Iran, Iraq, Jamaica, Japan, Mexico, Niger, Nigeria, Pakistan, Panama, Papua New Guinea, Paraguay, Philippines, Spain, Uganda, Venezuela		

Table 2. Equation factors for specific feedstock.

Biofuel type	a	b	c	d
Corn EtOH production	0.000283	–0.248571	7	0.32
Sugar beet EtOH production	-0.001589	-2.04763	59	0.08
Sugarcane EtOH production	0.010700	–0.970942	60	0.58
Rapeseed BD production	0.000312	–0.089961	2.8	0.42
Soybean BD production	0.000257	0.065377	/	0.17

(WorldWatch Institute, 2007). The conversion factors represent the amount of fuel that can be obtained from each type of feedstock (tonnes of fuels per tonne of feedstock). Since impacts of weather variables vary to the type of feedstock, numerical models were calculated for all selected feedstocks. For single specific feedstock that EtOH or BD is produced from, equation factors (a, b, c, d) can be obtained from Table 2.

$$\text{Biofuel production} = (a \times + b \times (\overline{Ta}) + c) \times d \qquad (3)$$

Table 3 presents the results of correlati on between meteorological variables and feedstock for biofuel production. Correlation between average air temperature and feedstock production is strongly significant for most feedstocks; the confidence level is 99.9. However, precipitation has a less significant impact on yield for feedstock production (Table 3).

Verification was done by comparing yields for specific locations calculated with CYP models and yields assessed from publications in research journals (Table 4). The results of the statistical analysis show significant correlation ($P < 0.05$) between CYP models and yields in research articles.

Using the CYP models (3) and predicted climate change by the IPCC, changes in EtOH and BD production have been calculated. Figure shows that a change in weather variables will have important impacts on biofuels production. In particular, Scenario 2 and 4, in which increases of temperature by 6.4 °C are projected, will be devastating. Production of biofuels is projected to decrease up to 70% by the end of 2100 relatively to the baseline average in the period 1980-1999. Sugar beet and corn ethanol production will be particularly affected by climate change. Only soybean production will have some benefits from temperature increase (Figure).

Table 3. Results of statistical analysis.

Feedstock	Meteorological variables	Statistical parameters	
		P value	significance
corn, n = 38	$\overline{pa}$ (mm)	0.694	NS
	$\overline{Ta}$ (°C)	0.000054	***
sugar beet, n = 23	$\overline{pa}$ (mm)	0.817	NS
	$\overline{Ta}$ (°C)	0.00018	***
sugarcane, n = 22	$\overline{pa}$ (mm)	0.104	NS
	$\overline{Ta}$ (°C)	0.00035	***
rapeseed, n = 22	$\overline{pa}$ (mm)	0.895	NS
	$\overline{Ta}$ (°C)	0.000059	***
soybean, n = 25	$\overline{pa}$ (mm)	0.444	NS
	T (°C)	0.005	**

$\overline{Ta}$ average air temperature; $\overline{pa}$ average precipitation; n number of observation; *** highly significant $P \leq 0.001$; ** very significant $P \leq 0.01$; * significant $P \leq 0.05$; NS not significant $P > 0.05$.

Discussion

Since 1906, global air temperature has increased on average by 0.74 °C ± 0.2, and for the next 2 decades it is expected that the air temperature will rise by about 0.2 °C per decade (IPCC 2007).

There have been numerous studies carried out to analyse the possible impacts of temperature change on crop productivity. These results indicated that the sector most affected by climate change and its

Table 4. Verification of CYP models.

CYP model	statistical parameters				reference
	R^2	standard error	P value	significance	
corn	0.920	0.239	0.009	**	Malvar et al. 2007; Dağdelen et al. 2006. Ines and Hansen 2006.
sugar beet	0.763	0.153	0.012	*	Halleux et al. 2006; Kenter et al. 2006; Malça and Freire 2006; Tzilivakis et al. 2005.
rapeseed	0.853	0.157	0.032	*	Stephenson et al. 2008; Hovelius and Hanssen 1999; Al-Jaloud et al. 1996.
sugarcane	0.598	0.188	0.043	*	Macedo et al. 2008; Inman-Bamber et al. 2002; Singh et al. 2008.
soybean	0.862	0.166	0.022	*	Daroub et al. 2003; Chiung-Lung and Yuh-Ming 2009; Bhati et al. 2008; Daroub et al. 2003; Singh et al. 2003; Dogan et al. 2007.

Legend:
*** highly significant $P \le 0.001$; ** very significant $P \le 0.01$; * significant $P \le 0.05$; NS not significant $P > 0.05$.

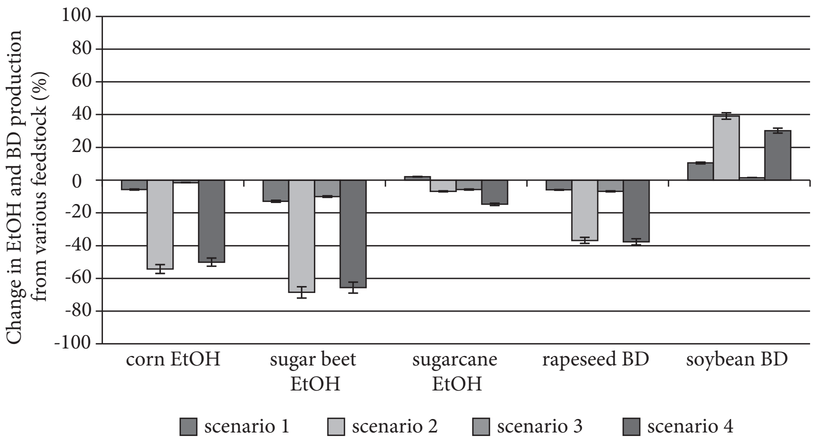

Figure. Impacts of weather variables on security of EtOH and BD production by the end of 2100.

variability will be agriculture. This is due to the crop-production dependence on climate (Motha and Baier 2005; Salinger 2005; Almaraz et al. 2008; Kalra et al. 2008).

According to the simulation models (Kenter et al. 2006; Lobell and Field 2007; Lobell et al. 2007; Baker and Griffis 2009; Tao et al. 2009; You et al. 2009), climate change will bring benefits for some crops, but not for others. It is expected that the length of the growing season for crops in agriculture will be extended. According to the expected changes, it is predicted that yields of soybean, winter wheat, and potato will increase in a warmer climate with higher humidity; meanwhile, corn yields will decrease (Almaraz et al. 2008). It is questionable if biofuel production will meet projected quantities, since production is directly connected to agriculture. The results of the present research imply that feedstock production for liquid biofuels will decrease if temperature and precipitation keep rising; only in the case of soybean results is there some indication that global changes will affect yield in a positive way (Figure). A similar conclusion was also reached by Almaraz et al. (2008). At lower latitudes, especially in seasonally dry and tropical regions, crop productivity is projected to decrease with even small local temperature increases (IPCC 2007). Results show that sugar beet and corn will be the most affected. It is projected that production of EtOH made of corn or sugar beet will be reduced by up to 70% by the end of 2100 (Figure). The most devastating will be Scenarios 2 and 4 in which average air temperature is expected to rise by up to 6.4 °C. Meanwhile, according to the present research, sugarcane will be the less vulnerable for EtOH and soybean for BD (the latter is also positively affected). A mitigation action plan for global climate change should not only discuss liquid biofuels for fossil fuel substitution, but also take into the account that climate change will affect feedstock for its production.

Conclusion

Weather variables needs to be studied in detail and linked with the future climate change scenarios so that they can subsequently be used for evaluating the impact of climate change. At the same time, agronomic management practices have to adjust to the changed environment. Weather variables like temperature have significant impact on feedstock productivity for biofuel production; therefore, meeting the goals to increase its share in the fuel market is an unenviable task.

Limitations of research

Predictions of yields for future climate scenarios always have some degree of uncertainty, since studies are based on average meteorological data. It is important to take into consideration extreme conditions, like drought, floods, and hail that will also decrease the yield of feedstock.

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