CODEN STJSAO ISSN 0562-1887
ZX470/1412 UDK 620.95:662.75:662.63:504.06

Environmental Impacts of the First Generation Liquid Biofuels Production and Emerging Global Climate Changes

Rok FINK[1)] **and** ***Sašo MEDVED***[2)]

1) University of Ljubljana, Faculty of Health Sciences. Department for Sanitary Engineering. Poljanska 26a, SI-1000, Ljubljana,
Republic of Slovenia

2) University of Ljubljana, Faculty of Mechanical Engineering. Laboratory for Heating, Sanitary and Solar Technology, Aškerčeva 6, SI-1000 Ljubljana,
Republic of Slovenia

saso.medved@fs.uni-lj.si

Original scientific paper

In now days transport relays mostly on liquid fossil fuels, although history of combustion engine started with biofuels. But decreasing reserves of fossil fuels and emerging global changes forced mankind to revived liquid biofuels production.
In this research data from Faostat database and Climate Research Unit were calculated to create models for correlation between yield of feedstock and weather variables like precipitation and temperature are. For assessment of liquid biofuels production on environment, program tool Sima Pro 7.1 and method Eco indicator 99 was used. Results show that yield of feedstock for biofuels production is strongly influenced by temperature and less by precipitation. And that increasing the temperature will decrease yield for most of feedstock, except soybean yield is projected to increase. Some projections show that global air temperature will increase for 1.1 to 1.6 °C regard to baseline scenario 1980-1999. Meanwhile precipitation will decrease for 20 % in some regions, but will increase for the same share in others. Therefore Global projection of biofuels production at expected global changes show decrease up to 40 % by the end of 2100. Results of environmental assessment show much larger environmental load for biodiesel or bioethanol in comparison to fossil diesel, petrol or electricity from various sources.
Therefore can be concluded that first generation liquid biofuels can not represent long term solution, neither from ensuring enough quantities at projected global changes, neither from environmental point of view.

Utjecaj na okolinu kod proizvodnje prve generacije tekućih biogoriva i očekivane globalne klimatske promijene

Izvornoznanstveni članak

U povijesti su bili motori s unutarnjim izgaranjem na biogoriva glavni pogon u prometu, ali danas promet uglavnom ovisi od tekućih fosilnih goriva. Smanjenje rezerva fosilnih goriva i velike globalne promjene su razlog za ponovno oživljavanje upotrebe biogoriva.
Predmetna analiza daje ocjenu utjecaja meteoroloških parametara, kao što su temperatura i oborine, na proizvodnju sirovina za biogoriva. Modeli su izrađeni na osnovi podataka Faostat database i Climate Research Unit. Za ocjenu utjecaja biogoriva na okolinu upotrijebljeni su računalski programi Sima Pro7.1 i metoda Eco indicator 99. Iz rezultata analize možemo vidjeti, da meteorološki parametri imaju važan utjecaj na proizvodnju sirovina za biogoriva. Posebno veliki utjecaj ima temperatura. Rezultati također pokazuju, da povećanje temperature smanjuje proizvodnju većine sirovina. Samo u primjeru soje model pokazuje pozitivan utjecaj više temperature na proizvodnju. Različite analize pokazuju, da će se u budućnosti temperatura zraka u prosjeku povećati za 1,1 do 1,6 °C, ako gledamo prosječne temperature u razdoblju od 1980. – 1999. Projekcije padavina pokazuju interesantan scenarij, tako da će se na nekim područjima povećati padavine za oko 20 %, a međutim na drugim područjima smanjiti za 20 %. Rezultati analize pokazuju, da će se do 2100. godine globalna proizvodnja biogoriva zbog globalnih promjena smanjiti također za 40 %. Provjerili smo i utjecaje na okolinu i rezultati pokazuju, da ima proizvodnja tekućih biogoriva prve generacije puno veći utjecaj na okolinu, nego proizvodnja fosilnih goriva ili proizvodnja električne energije različitih izvora.
Rezultati ove studije pokazuju, da biogoriva prve generacije nisu rješenje za duže vrijeme, jer ne možemo osigurati dovoljne količine a i zbog utjecaja na okolinu.

Keywords
Climate change
Environmental impacts
Liquid biofuels

Ključne riječi
Klimatske promijene
Tekuća biogoriva
Utjecaj na okolinu

Received (primljeno): 2009-07-03
Accepted (prihvaćeno): 2009-10-30

1. Introduction

Energy sources in history of mankind are changing due to intense exploration, technology and development [1, 2]. Although life of combustion engine started by liquid biofuel, it consumption died out due to chipper oil. But in recent years consumption of biofuels become exponential on one hand because climate change concerns and on other because limit resources of fossil [3].

The present energetic paradigm of our society, based on the massive use of fossil fuels, has to be changed rapidly, due both direct problems increase of oil prices, limited of reserves [4] and political instability in the main oil producers and, above all, the serious influence to the climate and environment of large emissions of greenhouse gases (GHG) into the atmosphere [5 – 8].

Since mobility is central to our modern industrialized society [9] and known petroleum reserves are limit resources, consumption is still growing. Various studies put the date of the global peak in oil production between 1996 and 2035 [4, 10]. And apart from a few exceptions, the transport of people and goods is sustained by liquid fuels. The transport sector accounts for more than 30% of final energy consumption in the European Union and is expanding, along with carbon dioxide (CO_2) emissions. By 2010 the transport related CO_2 emissions are estimated to reach 1, 11 billion tonnes. The main culprit is road transport, which accounts for 84 % of those CO_2 emissions [11].

Renewable energy sources, unlike fossil fuels, can be used without ever being used up; since equal amount of CO_2 is burned up as it is used in process of photosynthesis [12 – 15]. There are two global bio renewable liquid transportation fuels that might replace gasoline and diesel fuel. Ethanol is currently produced from sugar or starch crops, while biodiesel is produced from vegetable oils or animal fats [12, 16 – 19].

Some biofuels can lead to substantial GHGs emission reductions when compared to fossil fuels [20, 21], particularly with the development of advanced technologies that rely on agricultural wastes and dedicated cellulosic crops such as switch grass [22]. But there are also other environmental considerations like acidification, eutrophication, photo smog, health hazards, ozone depletion, loss of biodiversity and impact on ground water [1, 12]. These environmental impacts are mainly associated with agriculture and the production process of feedstock. But also impacts of biomass transport, biofuel production, distribution, and consumption have to be considered [12, 23]. Finally biofuels also consume a significant amount of energy that is derived from fossil fuels. Inputs to production include tillage, fertilizers, pesticides, irrigation, operation of machinery for transport, steam and electricity for processing [24-25]. Therefore some concerns appeared that expansion of biofuel market will increase pressure to intensify agriculture and also to expand agriculture into natural habitats [26].

Another concern related to expansion of biofuels production are projected global climate changes. If the temperature and precipitation will change how this will affect production the feedstock for liquid biofuels. IPCC is predicted that average global air temperature will increase by 2100 for 1, 1 to 6.4 °C relatively to baseline average air temperature in period 1980-1999. Expected changes in precipitation have not so high confidence level as temperature does. Therefore is projected that precipitation will decrease in some region for 20 %; meanwhile will increase for 20 % in others [27].

But today the question is not whether renewable biofuels will play a significant role in providing energy for transportation, but rather what the implications of their use will be for economy, for the environment, for global security and for the health of whole mankind [17].

2. Methods

Average yields ($t \cdot ha^{-1}$) for period 1980-2000 were obtained from data base Faostat-Food and Agriculture Organization of United Nations. Average annual air temperature (°C) and precipitation (mm) were obtained from the Climate Research Unit, United Kingdom.

Five the most common used feedstock were selected for biodiesel and bioethanol production assessment [12]. For soybean 25 locations were selected, for maize 38, for sugar beet 23, sugarcane 22 and for rapeseed 22. All locations with missing data for research period were excluded. Also Egypt was excluded, since great yield is due to irrigation from river Nile and not from precipitation. Data were plotted in three dimensional figures in Wolfram Mathematica 7.0 and function was calculated using function FindFit. Also regression was calculated to access statistical correlation between yield and meteorological parameters like precipitation and temperature are.

Verification of models was done by comparing data from Faostat database and models for yield prediction using annova statistical method.

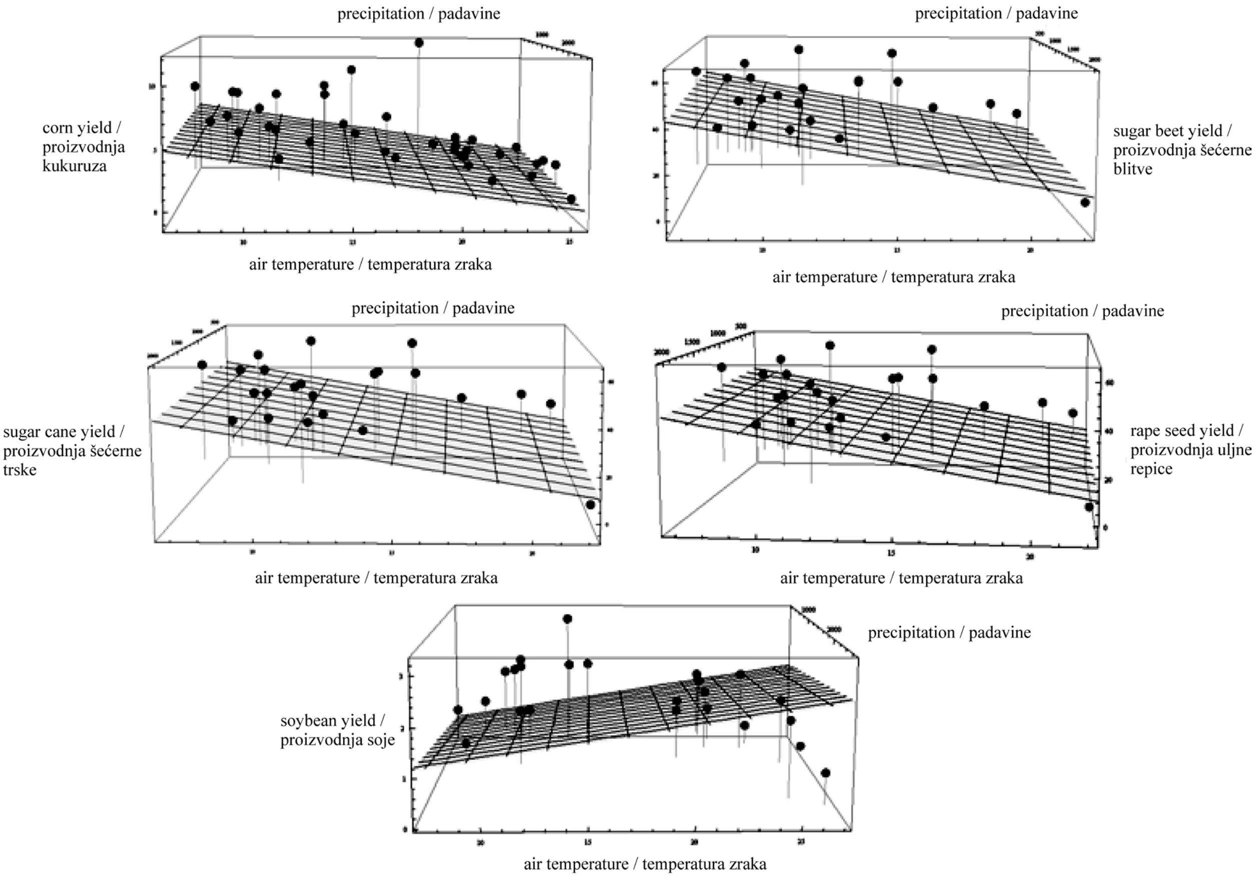
Expected global climate changes were defined as four scenario according to the IPCC projections [27]. Scenario 1 (precipitation increase for 20 %; temperature increase for 1,1 ºC), scenario 2 (precipitation increase for 20 %; temperature increase for 6.4 ºC), scenario 3 (precipitation decrease for 20 %; temperature increase for 1.1 ºC) and scenario 4 (precipitation decrease for 20 %; temperature increase for 6.4 ºC). Change in yield was projected using model (1-5) and scenarios mention above.

For assessment of liquid biofuels production on different aspects of environment, program tool Sima

Pro 7.1 and method Eco indicator 99 was used. Data about material and energy inventories were accessed from scientific articles [28-37]. Results of liquid biofuels assessment were compared to environmental impacts of fossil diesel and petrol production as also to electricity from various sources. Results are presented per functional unit (FU) which means fuel consumption (l) per 100 driven kilometres. Environmental impacts are expressed as Eco indicator point (Pt). The absolute value of the points is not very relevant as the main purpose is to compare relative differences between products or components. The scale is chose in such way that the value of 1 Pt is representative for one thousandth of the yearly environmental load of one average European inhabitant [38].

3. Results

Figure 1 show correlation between yield of selected feedstock and weather variables like temperature and precipitation are. As figure show yield is strongly influenced by temperature and precipitation. In all cases increasing the weather variables, results in decreasing the yield. Only in case of soybean temperature increase have positive effect on yield.



$$\text{yield}_{(corn)} \text{ / proizvodnja}_{(kukuruz)} = -0.000283 \cdot p - 0.248571 \cdot t + 7 \quad (1)$$

$$\text{yield}_{(sugar\ beet)} \text{ / proizvodnja}_{(šećerna\ blitva)} = -0.001589 \cdot p - 2.04763 \cdot t + 59 \quad (2)$$

$$\text{yield}_{(sugarcane)} \text{ / proizvodnja}_{(šećerna\ trska)} = 0.010700 \cdot p - 0.970942 \cdot t + 60 \quad (3)$$

$$\text{yield}_{(rapeseed)} \text{ / proizvodnja}_{(uljna\ repica)} = 0.000312 \cdot p - 0.089961 \cdot t + 2.8 \quad (4)$$

$$\text{yield}_{(soybean)} \text{ / proizvodnja}_{(soja)}\ 0.000257 \cdot p + 0.065377 \cdot t \quad (5)$$

Legend / Legenda:
yield / proizvodnja, $t \cdot ha^{-1}$
p = precipitation / padavine mm
t = temperature / temperatura °C

Figure 1. Selected feedstock yield regard to temperature and precipitation
Slika 1. Proizvodnja odabranih sirovina u ovisnosti od temperature i oborine

Correlation between yield and temperature is statistical significant for all selected feedstock (p<0.05), meanwhile correlation is not significant in case of precipitation. Table 1 also show results of verification, where data from Faostat database were compared to models for yield prediction (1-5) where correlation can be in all cases addressed as linear and statistical significant.

Table 1. Results of statistical analysis for correlation between yield, temperature and precipitation and verification of model

Tabela 1. Rezultati statističke analize za usporedbu između proizvodnje, temperature, te oborine i verifikacija modela

feedstock / sirovina	weather variables / meteorološke varijable	correlation factor / korelacijski faktor	p- value / p- vrijednost	range of model / područje modela	verification / verifikacija	
					R2	p-value / p- vrijednost
corn / kukuruz	*p* (mm)	- 0,856	0,694	87-2690	0,70	4,43•10-8 *
	t (°C)		5,490•10-7 *	7-25		
sugar beet / šećerna blitva	*p* (mm)	- 0,832	0,817	208-2066	0,64	9,11•10-4 *
	t (°C)		1,819•10-4 *	7-22		
sugarcane / šećerna trska	*p* (mm)	- 0,867	0,104	143-3056	0,62	8,25•10-4 *
	t (°C)		3,598•10-4 *	11-27		
rapeseed / uljna repica	*p* (mm)	- 0,814	0,895	87-1722	0,73	2,57•10-5 *
	t (°C)		1,595•10-5 *	7-25		
soybean / soja	*p* (mm)	- 0,833	0,444	208-2704	0,61	1,50•10-3 *
	t (°C)		0,005*	7-27		

Legend / Legenda:
p-precipitation / padavine
t-temperature / temperatura
*statistical significant / statistička karakteristika $p < 0.05$

is projected to increase for 6,4 °C and precipitation will increase for 20 % (scenario2) or decrease for scenario 4. Figure also shows that change in precipitation will have minor impact according to temperature. The most vulnerable is sugar beet, which yield could decrease up to 70 %, followed by corn and rapeseed. The least affected will be sugarcane with yield reduction less than 20 %.

Projected climate changes will result in yield decrease for biofuels production can be seen on Figure 2. The most affecting are scenario 2 and 4 where temperature According to models in this research only soybean can be influenced positive by temperature increase.

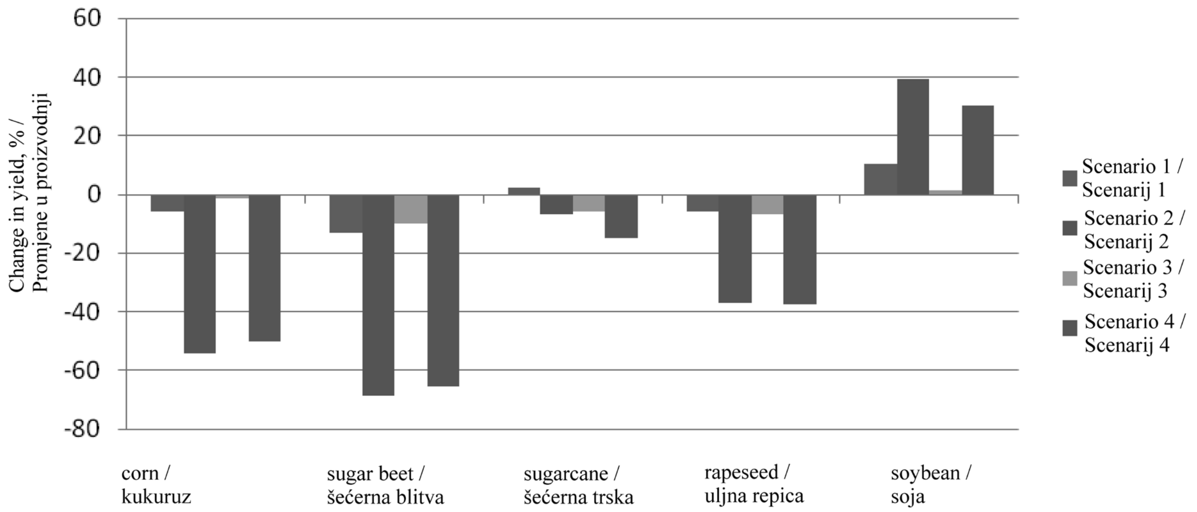


Figure 2. Change in yield (%) for selected feedstock regard to projected global climate changes

Slika 2. Promjena proizvodnje (%) odabranih sirovina u ovisnosti od očekivanih globalnih klimatskih promjena

Projected global changes show that temperature will increase in average for 1.1 to 6.4 and that precipitation will increase or decrease for 20 % relatively to baseline 1980-1999. Such scenarios will decrease production of biodiesel and bioethanol almost to 40 % according to average production in baseline period.

Figure 4 show comparison of environmental impacts for biodiesel and bioethanol made of selected feedstock. Data are also compared to other sources of energy for road transport, like fossil diesel, petrol and also electricity from various sources. Results show that production of biodiesel and bioethanol causes large environmental impacts regard to reference fuels. The reason lies in fact that first generation liquid biofuels consume large amount of fossil fuels in farm operations and also in processing stage. Also use of fertilizers is not negligible.

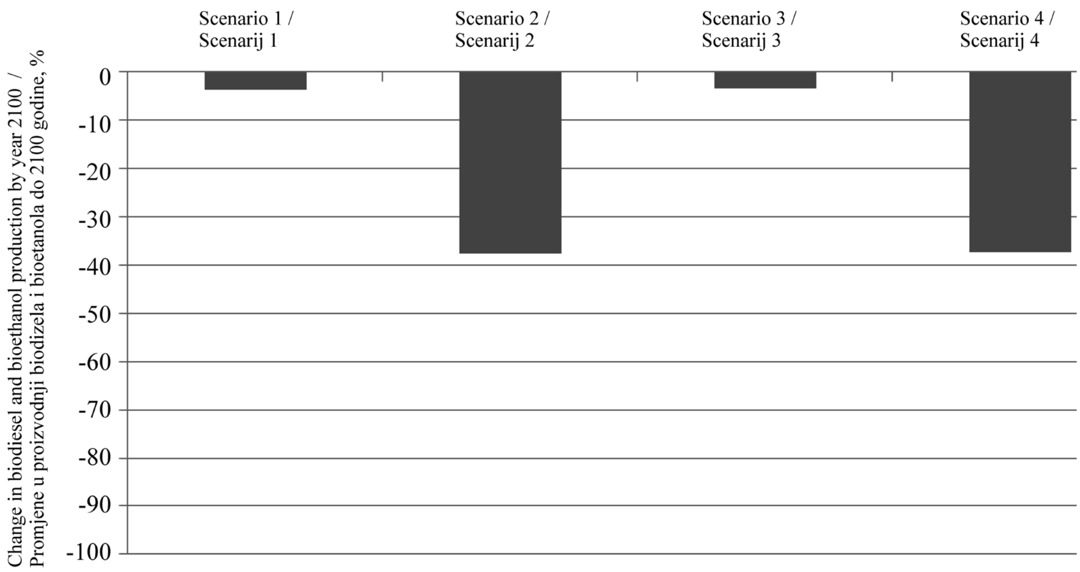


Figure 3. Change in biodiesel and bioethanol production by year 2100.

Slika 3. Promjene u proizvodnji biodizela in bietanola do godine 2100.

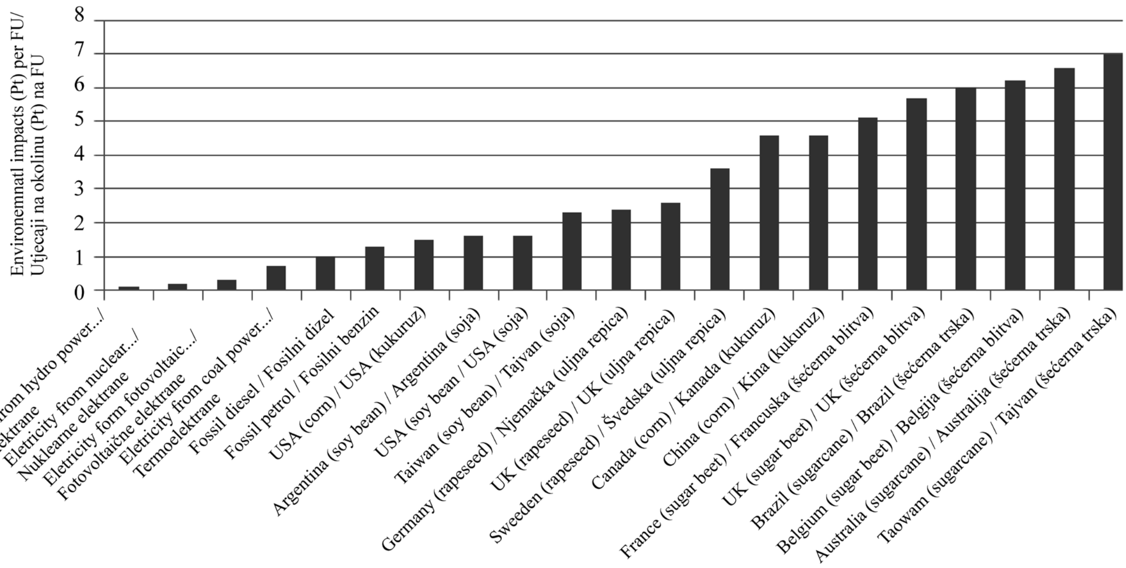


Figure 4. Environmental impacts of liquid biofuels production made of selected feedstock in comparison to other sources of energy per FU

Slika 4. Utjecaj na okolinu kod proizvodnje tekućih biogoriva iz odabranih sirovina u usporedbi sa drugim izvorima energije na funkcionalno jedinicu

Figure 5 show correlation between environmental impacts (mPt) and yield for each feedstock. As figure shows there are two groups of feedstock. First are sugarcane and sugar beet, where correlation is weak, and second are corn, rapeseed and soybean where correlation can be address as linear. Correlation between yields of selected feedstock and environmental impacts are not statistical significant. Detailed analysis show that in first group differences upon energy and material inventories are minor and is therefore predicted that change in environmental impacts is result of meteorological conditions and in second group where there are large differences in fertilizer and fossil fuel use inside the same group, reasons for changes are agro technical procedures. Therefore environmental impacts in biofuels production and yield of feedstock cannot be correlated.

One of the sectors more affected by climate change and its variability will be agriculture, since crop development depends directly on climate [39-40]. Simulation models have suggested that climate change will bring benefits for some crops but not for others. Growing season length should increase in all agricultural areas [41-42]. Yields of soybean, winter wheat and potato would increase in a warmer and wetter climate, but corn yield would decrease [43]. Similar results showed also results of this research. All feedstock production for liquid biofuels will decrease if the temperature and precipitation keep rising, only in case of soybean results are pointing that global changes will affect yield positively (Figure 1). IPCC [27] projected that global air temperature will increase for 1.1 to 6.4 °C relatively to average baseline 1980-1999. Projection about precipitation change are

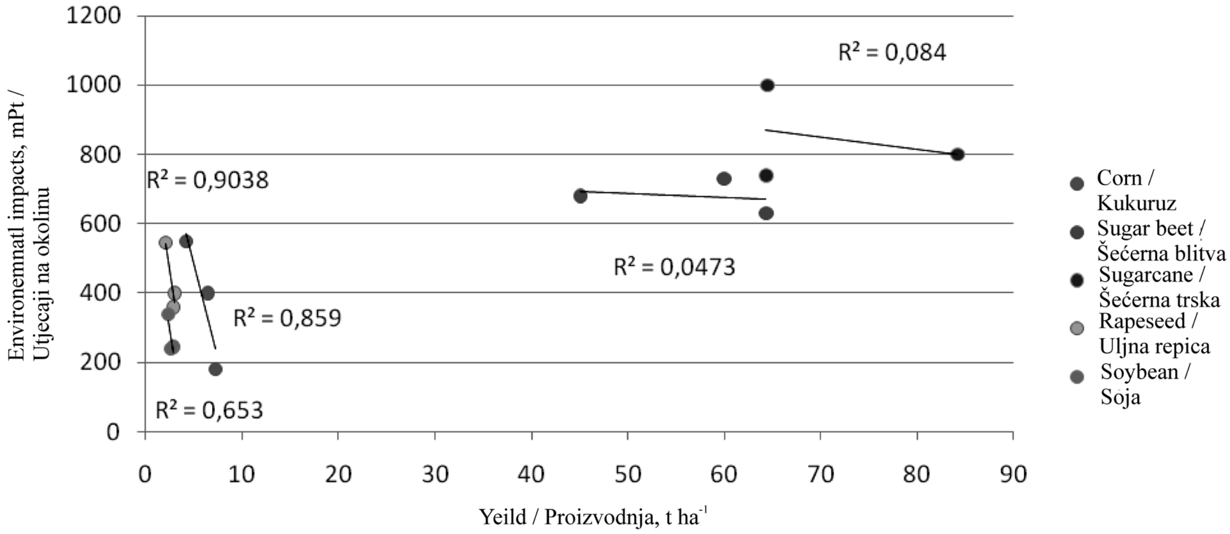


Figure 5. Correlation between environmental impacts (Pt) and yield (t ha^{-1})

Slika 5. Usporedba između utjecaja na okolinu (Pt) i proizvodnje (t ha^{-1})

4. Discussion

Emerging global changes and limited reserves of fossil fuels expanded the market with biofuels. There are many fields of concerns implementing the liquid biofuels for substituting the fossil one. One of them is environmental sustainability of biofuels, especially when projected climate changes are taken into the consideration.

Since 1906 in average global air temperature has increased for 0.74ºC ± 0.2 and for the next two decades a warming of about 0.2 ºC per decade is projected. Warming is expected to be greatest over land and at most high northern latitudes, and least over the Southern Ocean and northern North Atlantic, continuing recent observed trends [27].

not as confidence as for temperature; therefore it is projected that precipitation will decrease for 20 % in some region, meanwhile in other will increase for the same share. At lower latitudes, especially in seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases [27]. Results of this research show that weather variables, especially temperature has important impact on yield and therefore also indirect impact on first generation liquid biofuels production. Especially scenario 2 and 4 will have devastating impacts (Figure 2). Therefore it can be assumed that for the same share that yield will be reduce, harvested area will have to be increased to sustain the same quantity of biofuels, not to take into account projected increase in biofuels consumption. Expected climate changes will have according to models in this research large impact on biofuels production. In the worst case scenario production can be reduced up to 40 % (Figure 3). Therefore is questionable if the global production will meet the biofuels consumption needs. Some authors [44] attempt to estimate CO_2 affects on yield, but sizes of CO_2 increment were too small to results in a measured yield signal.

One of the aims of this study was to make extensive research on bioethanol and biodiesel impacts on environment; compare impacts inside the same feedstock and compare between feedstock. In comparison as reference value fossil diesel and petrol were used, since biofuels should replace them and also electricity from coal, nuclear, hydro power station and photovoltaic as another source of energy for cars in future. All fuels were compared per FU since efficiency of internal combustion engine and electric motors are different (Figure 4). Results show that biofuels production have much larger environmental impact that production of reference fuels. For first generation liquid biofuels large amount fertilizers are used and fossil fuels consumed in agricultural operations and in processing phases. Corn bioethanol from USA show the greater potential, meanwhile sugarcane bioethanol made in Taiwan have the largest impacts according to this research.

Therefore meeting the goals to increase the share of biofuels by facing emerging global changes on one hand while reducing the environmental impacts on other is a challenge.

5. Conclusion

Several countries have created favourable framework for biofuels implementation, on one hand because limited fossil fuel reserves, but on other because of reduction of GHGs. Projected global climate changes will decrease yield for most of feedstock for liquid biofuels production, but some crops can be effected also positive. Nevertheless, environmental impacts assessment shows that production of liquid biofuels is not sustainable when compared to other sources of energy. Therefore can be concluded that first generation liquid biofuels can not represent long term solution for fossil fuel substitution from emerging climate change point of view, or from environmental sustainability.

6. Limitations of research

Predictions of yields for future climate scenarios always have some degree of uncertainty since studies are based on average meteorological data, not to take into consider extreme weather events like drought, floods and hails that will also decrease yield production of feedstock.

This research is assessing 5 most common feed stocks for first generation feedstock production at three different locations. There is potential that from other feedstock in some other location affects could be smaller.

REFERENCES

[1] RAJAGOPAL, D.; ZILBERMAN, D.: *Review of Environmental, Economic and Policy Aspects of Biofuels*. Policy Research Working Paper. The World Bank Development Research Group Sustainable Rural and Urban Development Team. 2007, 11-13.

[2] DEMIRBAS, M.F.; BALAT, M.; BALAT, H.: *Potential contribution of biomass to the sustainable energy development*, Energy Conversion and Management 50 (2009) 17, 1746-1760.

[3] BROWN, R.C.: *Biofuels*. Handbook of Energy Efficiency and Renewable Energy, New York 2007, 51-65.

[4] DEMIRBAS, A.: *Biodiesel: A Realistic Fuel Alternative for Diesel Engines*. Springer 2008, 87-114.

[5] STERN, N.: 2007. *The Economic of Climate Change. The Stern Review*, Cambridge University Press 2007, 4-24.

[6] BARUCH, J.J.: *Combating global warming while enhancing the future*, Technology in Society 30 (2008) 111-121.

[7] PIN-KOH, L.; GHAZOUL, J.: *Biofuels, biodiversity, and people: Understanding the conflicts and finding opportunities*, Biological Conservation (2008)141, 2450-2460.

[8] NOVAK, P.; MEDVED S.: *Energija in okolje: izbira virov in tehnologij za manjše obremenjevanje okolja: energija – gibalo razvoja, vplivi energetskih pretvorb na okolje, proizvodnja in varčna raba elektrike, promet in okolje, energetska prihodnost*. Svet za varstvo okolja Republike Slovenije 2000.

[9] LOMBORG, B.: *The sceptical environmentalist. Measuring the real state of the world.* Cambridge university press, United Kingdom 2001, 119-136.

[10] PIMETEL, D.; PATZEK, T.; GERALD, C.: *Ethanol Production: Energy, Economic, and Environmental Losses*, Reviews of Environmental Contamination and Toxicology (2007) 189, 25-41.

[11] Council Directive 2003/30/EC of the European Parliament and the Council of 8 May 2003 *on the promotion of the use of biofuels or other renewable fuels for transport*. Official Journal of the European Brussels 2003.

[12] RUTZ, D; JANSSEN, R.: *BioFuel Technology Handbook*. WIP Renewable Energies, Munchen 2007.

[13] CHAUHAN, S.K.; GANGOPADHYAY, S.; SINGH, N.: *Environmental aspects of biofuels in road transportation*, Environmental Chemistry Letters (2008) 3653-3661.

[14] STEPHARD, W.: *Energy Studies*. 2nd edition. Imperial College Press 2003, 431-440.

[15] CLAIR, S.; HILLIER, J.; SMITH, P.: *Estimating the pre-harvest greenhouse gas costs of energy crop production*, Biomass and Bioenergy (2008) 32, 442 – 452.

[16] HAMELINCK, C.; BROEK, R.; RICE, B.; GILBERT, A.; RAGWITZ, M.; TORO, F.: *Liquid Biofuels Strategy Study for Ireland*, Dublin 2004, 22-74.

[17] WORLDWATCH INSTITUTE.: *Biofuels for transportation. Global potential and implications for sustainable agriculture and energy in the 21st century*, Washington D.C., 2006.

[18] MEDVED, S.: *Ekološke sledi neposredne rabe energije in mobilnost v MOL*. Poročilo raziskovalnega projekta. Okoljska analiza in presoja prostorskega razvoja MOL v obdobju 1990-2015. Ljubljana 2006.

[19] MEDVED, S.: *Present and future footprint of Slovenia: the influence of energy demand scenarios*, Ecological Modelling (2006) 192, 25-36.

[20] ZAH, R.; HISCHIER, R.; GAUCH, M.; LEHMANN, M.; BÖNI, H.; WÄGER, P.: *Life Cycle Assessment of Energy Products: Environmental Impact Assessment of Biofuels*. Bundesamt für Energy, Bundesamt für Umwelt, Bundesamt für Landwirtschaft 2007.

[21] WORLDWATCH INSTITUTE.: *Biofuels for transport: global potential and implications for sustainable energy and agriculture*. Washington D.C., 2007.

[22] SMEETS, M.W.E.; LEWANDOWSKI, I.M.; FAAIJ, A.P.C.: *The economical and environmental performance of micanthus and switchgrass production and supply chains in a European setting*, Renewable and Sustainable Energy Reviews (2009) 13, 1230-1245.

[23] LAL, R.: *Carbon emission from farm operations*, Environmental International (2004) 30, 981-990.

[24] PIMETEL, D.; PATZEK, T.: *Ethanol Production Using Corn, Switch grass, and Wood; Biodiesel Production Using Soybean and Sunflower*, Natural Resources Research (2005) 14, 65-76.

[25] FARREL, A.E.; PLEVIN, R.J.; TURNER, B.T.; JONES, A.D.; O'HARE, M.; KAMMEN, D.M.: 2006. *Ethanol Can Contribute to Energy and Environmental Goals*, Science 311 (2006) 560, 506-508.

[26] *Are Biofuels Sustainable*.: House of Commons Environmental Audit Committee. First Report of Session 2007–08. United Kingdom 2008.

[27] IPPC-Intergovernmental Panel on Climate Change.: *Climate Change 2007. Synthesis Report*, Spain 2007, 26-53.

[28] RENOUF, M.A.; WEGNER, M.K.; NIELSEN, L.K.: *An environmental life cycle assessment comparing Australian sugarcane with US corn and UK sugar beet as producers of sugars for fermentation*, Biomass and Bioenergy (2008) 32, 1144-1155.

[29] YANG, H.; ZHOU, Y.; LIU, J.: 2009. *Land and water requirements of biofuel and implications for food supply and environment in China*, Energy policy (2009) 37, 1876-1885.

[30] HALLEUX, H.; LASSAUX, S.; RENZONI, R.; GERMAIN, A.: *Comparative Life Cycle Assessment of Two Biofuels Ethanol from Sugar Beet and Rapeseed Methyl Ester*, International Journal of LCA 13 (2008) 3, 184-190.

[31] MALÇA, J.; FREIRE, F.: *Renewability and life-cycle energy efficiency of bioethanol and bio-ethyl tertiary butyl ether (bioETBE): Assessing the implications of allocation*, Energy (2006) 31, 3362-3380.

[32] MACEDO, I.C.; SEABRA, J.E.A; SILVA, S.E.A.R.: *Greenhouse gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020*, Biomass and Bioenergy (2008) 32, 582-595.

[33] CHIUNG-LUNG, S.; YUH-MING, L.: *Development status and life cycle inventory analysis of biofuels in Taiwan*, Energy Policy (2009) 37, 754-758.

[34] KALTSCHMITT, M.; REINHARDT, G.A.; STELZER, T.: *Life cycle analysis of biofuels under different environmental aspects* Biomass and Bioenergy (1997) 12, 121-134.

[35] HOVELIUS, K.; HANSSON, P.: *Energy and exergy analysis of rape seed oil methyl ester (RME) production under Swedish conditions*, Biomass and Bioenergy (1999) 17, 179-290.

[36] STEPHENSON, A.L.; DENNISS J.S.; SCOTT S.A.: *Improving the sustainability of the production of biodiesel from oilseed rape in the UK*, Process Safety and Environment Protection (2008) 86, 427-440.

[37] PIMETEL, D.; PATZEK, D.: *Ethanol Production Using Corn, Switch grass and Wood, Biodiesel Production Using Soybean*. Biofuels, Solar and Wind as Renewable Energy Systems. Springer Science +Business Media B.V. 2008, 373-388.

[38] GOEDKOOP, M.; SPRIENSMA, R.: *The Eco-indicator 99. A damage oriented method for Life Cycle Assessment*. Methodology Report, Amersfoort 2001.

[39] SALINGER, M.J.: *Climate variability and change: Past, present and future-an overview*. Climate Change (2005) 70, 9-29.

[40] MOTHA, R.P; BAIER W.: *Impacts of present and future climate change and climate variability on agriculture in the temperate regions: North America*, Climate Change (2005) 70, 137-164.

[41] DE JONG, R.; LI, K.Y.; BOOTSMA, A.; HUFFMAN, T.; ROLOFF, G.; GAMEDA, S.: *Crop yield variability under climate change and adaptative crop management scenarios*. Final Report for Climate Change Action Fund Project A080. Eastern Cereal and Oilseed Research Centre (ECORC). Agriculture and AgriFood, Canada 2001.

[42] BOOTSMA, A.; ANDERSON, D.; GAMEDA, S.: *Potential impacts of climate change on agro climatic indices in Southern regions of Ontario and Quebec*. Technical Bulletin ECORC Contribution No. 03-284. Eastern Cereal and Oilseed Research Centre. Agriculture and AgriFood Canada, Ottawa, Ontario 2004.

[43] ALMARAZ, J.J.; MABOOD, F.; ZHOU, X.; GREGORICH, E.G.; SMITH, D.L.: *Climate change, weather variability and corn yield at higher latitude scale: South western Quebec*, Climate Change 88 (2008), 187-197.

[44] LOBELL, D.B.; ASNER, G.: *Climate and management contributions to recent trends in U.S. agricultural yields, Science* (2003) 299, 1032.