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Environmental Dimensions of Biofuels

*Ondrej Benes and Karel Janda **

Abstract

This paper deals with non-economic problems of biofuel development. Firstly we look at a complex of issues surrounding the food-fuel debate, which is concerned mainly with the efficiency of use of land resources for the production of biofuel feedstock rather than for production of food for human consumption. Secondly we look at other environment and health related problems of extensive biofuels production. Lastly we briefly acknowledge the existence of a large block of socio-economic impacts of biofuels.

Key Words: Biofuels; land; food; environment.

JEL codes: Q42, Q55, Q58

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1. Introduction

At the time when the massive support of biofuels started, they looked as a very good alternative regarding transport fuels. However, in reality their production and usage face many challenges on economic and non-economic grounds. In this paper we focus on these non-economic problems of biofuel development.

Firstly we look at a complex of issues surrounding the food-fuel debate, which is concerned mainly with the efficiency of use of land resources for the production of biofuel feedstock rather than for production of food for human consumption. Secondly we look at other environment and health relate problems of extensive biofuels production. Lastly we briefly acknowledge the existence of a large block of socio-economic impacts of biofuels.

2. Land use, environment and social impacts

2.1 The food-fuel debate¹

Amongst other things, food security and energy security are both crucial to the UN's SDGs (Sustainable Development Goals)². However, they share one component, biomass (and its cropland), making their simultaneous achieving complicated. This plays a huge role in renewable energy goal fulfilments. For example, in the EU energy³ from biomass and waste has been, during the last decade, stably accounting for around 60 % of EU's renewables in primary energy sources (PES), which in turn accounted for 29.9 % in 2017 ('Eurostat - Energy Production and Imports' 2019).

The influence of the triggered global food-fuel debate (academic, political, etc.) is surely one of the principle reasons for the policies switch from 1G biofuels to those promoting 2G biofuels. Those findings about the impacts of biofuels on food markets may be illustrated by Mallory et al. (Mallory, Irwin, and Hayes 2012). In their study the authors support the claims of de Gorter et al. (Gorter, Drabik, and Just 2015) regarding the link between biofuel a

¹ Food-Fuel-Feed – The debate spans also into the area of feeding needs. However, this adds many extra concerns to the topic, like that livestock, meet and diary production takes up to 77 % land, it offers only 17 % of global calorie supply and 37 % of protein supply(Ritchie and Roser 2013). Since the food-fuel (-feed) is not the main focus of this thesis, we will concentrate on the food-fuel side of the debate.

² The UN's SDGs are some of the most influential economic, environmental and social drivers currently in place.

³ Includes power, heat and transport fuels derived from biomass and waste.

feedstock prices, therefore on food grain commodity prices. Using corn and ethanol production, the conclusion is the presence of a strong link between ethanol and corn prices, that started in 2007 and continued at least to February 2012 (time of writing of that paper). Furthermore, they claim that the relationship appeared to be strong enough to overpower all other present forces also effecting the corn-ethanol relationship for the given years⁴.

To illustrate the opposing side, the study by Filip et al. (Filip et al. 2019) is used. This study replicates the 2010 study of Zhang et al. (Zhang et al. 2010) and confirms the original findings plus offers a prolonged dataset and evaluation of its own. The authors point out the importance of studying time variation of the relationships in order to properly understand them⁵. With the subject regions being the U.S., Brazil and the EU, and the three time periods (before, after and during the crises), this gives 9 models in total. The study's final position is that *"price series data do not support strong statements about biofuels uniformly serving as main leading source of high food prices and consequently the food shortages"* (Filip et al. 2019).

Given their feedstock 2G biofuels generally do not face this controversy. However, some feedstocks (energy crops, vegetable oil sources) can still compete for land, meaning traces of the food-fuel competition still linger over 2G fuels.

2.1.1 Land availability

Since 2G feedstocks are not edible (the assumption being they are therefore not in need of prime agricultural land), use of less productive "marginal land" is promoted as a way to overcome land use controversies. However, the term "marginal land" can be rather vague and so Shortall (using a United Kingdom background) presents three separate definitions:

- 1) land unsuitable for food production,
- 2) ambiguous lower quality land and
- 3) economically marginal land. (Shortall 2013)

In opposition to the last, the first two differ in a couple ways. Mainly by being normatively oriented (Shortall 2013). They simply state that energy crop production *"should"* only take place on land otherwise unsuitable for effective food production. The third is often supported (e.g. (Nalepa and Bauer 2012)) as more realistic. It refers to land where *"cost-*

⁴ Regarding methodology, Mallory et al. used a structural price model and in addition, time-series techniques.

⁵ Regarding methodology, the study follows the procedure of Zhang et al, using the vector error-correction model in order to focus on both long-term relationships (represented by cointegration relationships) and short-term connection (lagged variables in vector autoregression representation).

effective food production is not possible under given circumstances”(Shortall 2013). This makes sense, since it urges us to approach the local land individually by weighing what it can and cannot offer, given the local conditions and overall cost-benefit state of arising opportunities. Also, this definition does not talk about full abandonment of risks and other negative impacts, but rather that use of marginal land will lead to significantly lower risk and sustainability impacts (Shortall 2013). Furthermore, in order to be viable for the cause of 2G feedstock production, all three definitions carry certain assumptions within them (see Tab. 1).

For a 2011 estimate of available agricultural marginal land, see Tab. 2. Based on these, if 2G feedstocks were planted on abandoned and degraded cropland and LIHD perennial energy crops on grassland with marginal productivity, the result could sum up to 26–55 % of current world liquid fuel consumption. Also, without effecting both current pastureland and regular productivity land used for conventional crops. The study ran several scenarios which resulted in Africa holding 1/3 of the available land and if combined with Brazil, the two share more than ½ of the total land in question. Fritz et al. (Fritz et al. 2013) reported the same range, but after further studies, downgraded the estimate to 56–1035 million hectares.

Tab. 1 – Definitions with underlying assumptions

	Assumptions	Reality
Definition 1 & 2	<p>1) Significant amounts of marginal land exist.</p> <p>(We assume enough marginal land is available for the sufficient volumes of biofuel crops.)</p>	<p>Overestimated.</p> <p>Can be true in some developing regions, however due to the definition's normative form, studies have shown that even by definition "marginal land" is often still used for grazing.</p>
	<p>2) Production is possible on marginal land</p> <p>(Technical and economical assumption that production is feasible on such land.)</p>	<p>Scepticity.</p> <p>Some studies and NGOs (see below) focusing on Jatropha yields on marginal land argue for dismissing this assumption. Opposed to this scepticity, support for breeding techniques and genetically modified crops is growing. However, as stated before, such techniques are problematic and carry risks.</p>
	<p>3) Production can be targeted to marginal land</p> <p>(Market/policy assumption, we assume a certain type alone is easily targetable.)</p>	<p>Problematic</p> <p>If no legal framework offers incentive to use such land (positive or negative) what stops rational companies from growing crops on prime land.</p>

Definition 3	<p>1) Using economically marginal land will reduce impacts of energy crops.</p> <p>(Use of such land has <i>the potential</i> to significantly reduce land use controversies.)</p>	<p>Depending on conditions, but strong potential.</p> <p>Assessment can be problematic, since "significant impact" (regarding environmental and social impacts) is a value judgement.</p>
	<p>2) Economically marginal land includes grassland</p> <p>(It is acceptable to use grassland for energy crop production.)</p>	<p>Can help avoid sustainability and food-fuel land competition issues. On the other hand, converting includes soil carbon loss.</p> <p>E.g., Booth et al. (2009) estimate that if put against the emission reduction from the coal to biomass switch, the conversion of grassland to willow would result in a net carbon deficit, meaning soil would lose carbon than it would gain. Due to soil carbon loss from the conversion.</p>
	<p>3) Technology will make up the shortfall in food production.</p> <p>(If food production replaced on marginal land (and other land), yield increases on the remaining land will make up for the losses.)</p>	<p>Unpredictable.</p> <p>Technology improvements can be irregular and furthermore, they do not apply just to marginal land. Also, potential population growth slowdown, changes in diet and many other factors come in play here.</p>

Source: Own processing based on (Shortall 2013).

Tab. 2 – Availability of marginal agricultural land estimate⁶

Region	Range	Comment
Africa, China, Europe, South America & continental U.S.	320 - 720 million hectares	Only abandoned and degraded crop, mixed crop and vegetation land, usually of low quality.
	1107 - 1411 million hectares	Marginally productive grassland, savanna and shrubland added. The range caused by incl. (or not) pastureland.

Source: (Cai, Zhang, and Wang 2011), (Fritz et al. 2013)

Another study by FAO states that 1.4 billion hectares of prime⁷ and good land is still available (Alexandratos, 2012). This being in addition to currently cultivated land, however, all this free land is very unevenly distributed. 960 million hectares (68 %) are in developing countries and 85 % of these 960 million are located in sub-Saharan Africa and Latin America (Wesseler and Drabik 2016). This is making logistics complicated at best.

⁶ Low-input high-diversity (LIHD) native perennial energy crops are considered for planting.

⁷ Prime being very suitable and good suitable and moderately suitable for crop cultivation.

Globally, area under biofuel crops was estimated at 45 million hectares in 2010 and is expected to double, becoming 3-4.5 % of all cultivated land, by 2030 (UNCCD 2017). All land under food crops, worldwide, accounts for around 30 % (1,5 billion ha, 2017) of all agriculture land (see Tab. 3 below).

Tab. 3 – Various land use types as a share of agriculture land, globally (%)

World; (%)	Arable land	Land under permanent crops	Cropland	Land under perm. meadows and pastures	Land area equipped for irrigation
2003	27.66	2.86	30.42	69.48	6.12
2004	27.95	2.95	30.79	69.11	6.23
2005	27.94	3.00	30.84	69.06	6.28
2006	27.78	3.05	30.73	69.17	6.33
2007	27.79	3.13	30.81	69.08	6.38
2008	27.85	3.16	30.90	68.99	6.43
2009	27.89	3.21	30.99	68.90	6.49
2010	27.87	3.27	31.03	68.86	6.55
2011	28.16	3.33	31.44	68.45	6.63
2012	28.32	3.37	31.64	68.25	6.70
2013	28.42	3.40	31.77	68.12	6.79
2014	28.44	3.41	31.80	68.09	6.81
2015	28.82	3.45	32.20	67.68	6.86
2016	28.91	3.48	32.33	67.55	6.91
2017	28.81	3.48	32.23	67.66	6.88

Source: Own processing; data from FAOSTAT⁸

In summary, there could be sustainable volumes of available prime and marginal land to deal with food-fuel land competition challenges. However, uneven distribution and several partially unrealistic assumptions are still major obstacles.

2.1.2 Land use change

Indirect (ILUC) and direct land use change (DLUC) are still an issue even with the non-edible feedstocks. DLUC occurs when new cropland is created for biofuel feedstock production, whereas ILUC is the process where these feedstocks push out food (feed) crops of current cropland. The “pre-crop” land type – grasslands, forests, etc. – typically captures high

⁸ <http://www.fao.org/faostat/en/#data>

levels of CO₂. By transforming them into arable land for fuel crops, this CO₂ is released and atmospheric GHG levels rise (indirect LUC) (European Technology and Innovation Platform, 2020.). No matter the generation, it has been long established, according to a literature review by Timilsina and Shrestha (Timilsina and Shrestha 2010), that biofuels offer GHG emission reduction compared to fossil fuels. However, this is when LUC is excluded (see Tab. 4). However, once we consider emissions related to LUC, the storyline changes.

Tab. 4– Lifecycle GHG savings from biofuel for fuel substitution, LUC emissions excluded.

Biofuel	Feedstock	GHG saving (gCO ₂ eq/MJ)
Ethanol ^a	Corn	35.58
Ethanol ^a	Sugarcane	59.99
Biodiesel ^a	Rapeseed	41.18
Biodiesel ^a	Soybeans	38.79
Ethanol ^b	Woody biomass	63.10
Methanol ^b	Woody biomass	77.60

^a Calculations based on Renewable Fuels Agency (2009).

^b Calculations based on CONCAWE/JRC/EUCAR (2007).

Source: (Havlík et al. 2011)

To illustrate and compare 1G and 2G biofuels, results from several studies will be used. Starting with a study using the GLOBIOM model⁹ commissioned by the European Commission aimed to quantify LUC emissions¹⁰ for various feedstock (1G, 2G) and policies and keeping in mind that the results refer only to EU related environments (policies, trade partners, etc.), the results show the following¹¹ (Bauen et al. 2015).

EU 2020 biofuel mandates caused 8.8 Mha¹² of LUC, 8 Mha of which in new cropland (DLUC), the rest by short rotation plantations on existing cropland (ILUC). About 33 % (2.9 Mha, from 8.8 Mha) of the conversion occurs in Europe, resulting in less land abandonment, and 24 % (2.1 Mha) is land converted in Southeast Asia, half of which at the expense of tropical

⁹ For more visit e.g. <https://www.globiom.org/>

¹⁰ Agricultural production and chain emissions - direct emissions from crop cultivation (fertiliser, machinery, etc.), the conversion into biofuels and product transport plus distribution - where not included.

¹¹ All scenarios within the model are for the years 2020 and 2030, with an additional assumption that biofuel use targets from 2020 stay the same up till 2030.

¹² Mha = “million hectares”

forest and peatland, due to palm plantation expansions. For comparison, the 8.8 Mha is about the land area of Austria (0.6 % of total global crop area in 2012).

Bauen et al. (2015) offer an emission values analysis of various first and second generation feedstocks (presented in gCO₂eq/MJ¹³). From their results it is clear that 1G biofuels come up at the shorter end, by far. Conventional feedstock groups, sugar and starch crops have much lower (under 50 gCO₂eq/MJ) LUC emission than their biodiesel counterpart (vegetable oils, 80–300+ gCO₂eq/MJ), since they lead to lesser peatland oxidation and deforestation. If produced from SRC and perennials, advanced biofuels have negative LUC emissions (-29 gCO₂eq/MJ and -12 gCO₂eq/MJ respectively). However, advanced biodiesel from forestry residues can carry significant LUC emissions (17 gCO₂eq/MJ), even though they do not require extra land. The emissions are in reality from lower build-up of soil organic carbon (SOC), making the emissions more a SOC issue than LUC matter (Bauen et al. 2015). Also, overharvesting (here of e.g. cereal as feedstock for ethanol) leads to soil carbon depletion and a small yield loss. According to the study, sustainable (no yield effect, so no LUC observed) straw removal rate is about 33-50 %.

Based on literature, generally, high yield/ha crops tend to have lower indirect impacts on LUC and GHG emissions¹⁴ (Bauen et al. 2015). After the game changing paper by Searchinger et al. (2008) after which including LUC emissions to GHG emissions of biofuels became a habit, the benefits of 1G biofuels are not as certain as before. E.g., instead of producing 20 % GHG savings (compared to gasoline), corn-based ethanol (U.S.) almost doubles greenhouse emissions and increases GHG for 167 years (Janda, Kristoufek, and Zilberman 2012)¹⁵.

It is safe to say that 2G biofuels are a better option regarding LUC. This was proved e.g. Havlík et al. (2011) (see Fig. 9) in their study, using the GLOBIOM model¹⁶ quantifying impacts of both generation of biofuel.

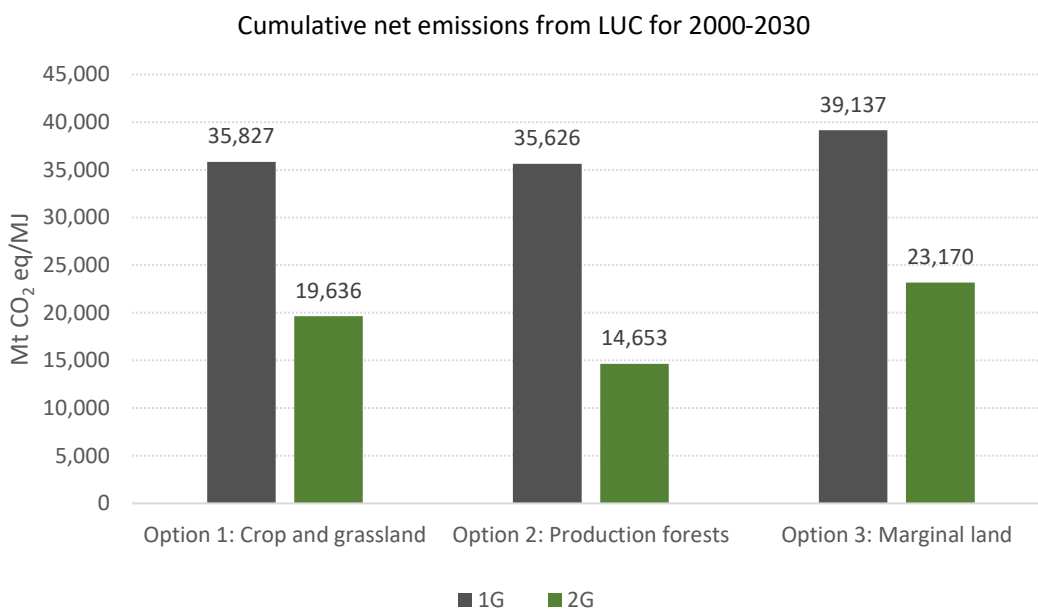
¹³ gCO₂eq/MJ = Grams of CO₂ equivalent per megajoule of biofuels

¹⁴A notable exception is palm oil, a high yielding crops whose performance is strongly impacted by emissions from deforestation and peatland conversion, as explained above.

¹⁵ Later downgraded to 28 years in a study by Hertel et al. (2010) (Janda, Kristoufek, and Zilberman 2012).

¹⁶ Using global data from FAO, JRC, ISRIC, NASA, IFA, etc.

Fig.1 – Cumulative net emissions from LUC for 2000-2030



Source: Own processing based on (Havlík et al. 2011).

If we wish to compare effects of biofuels production on fuel and food prices, we may again use Havlík et al.'s model (see Tab. 5). As we can see in the table, 2G biofuels affect crop prices minimally (peaks reached on crop and grassland) and in some feedstock options, not at all. However, their price can almost triple if we consider feedstock from traditional forests, but still, regarding crop price, they outperform 1G fuels. As most price-prominent (crop & fuel) appear 2G fuels from marginal land plantations and with the additional available land (see above), further progress is possible.

Tab. 5 - Impact of different production options on fuel and crop prices in 2030 relative to 2000 prices.¹⁷

Scenario names	Option 1: Crop and grassland		Option 2: Production forests		Option 3: Marginal land	
	Fuel Price	Crop price	Fuel Price	Crop price	Fuel Price	Crop price
Baseline	1.18	1.29	1.35	1.25	1.12	1.21
1G	1.14	1.27	1.14	1.27	1.14	1.24
2G	1.38	1.30	2.84	1.23	1.21	1.23
No biofuels	1.10	1.23	1.10	1.23	1.09	1.21

Source: (Havlík et al. 2011)

Regarding policies, the most prudent way to reduce land use emission would be a price on carbon (Melillo et al. 2009) or broadening the range of regulation on land emissions beyond biomass production on energy (T. D. Searchinger et al. 2009). According to Witcover et al. (Witcover, Yeh, and Sperling 2013), if such policies were used globally, the necessity for LUC related policies would vanish. However, neither solution will probably come into effect during the current policies horizon. There are also some efforts currently in place trying to deal with LUC like RED-II in the EU or RFS in the U.S.. Also, recent findings seem to prefer DLUC in front of ILUC, as it can be better monitored and holds less uncertainties (Daioglou et al. 2017).

2.2 Environmental impacts

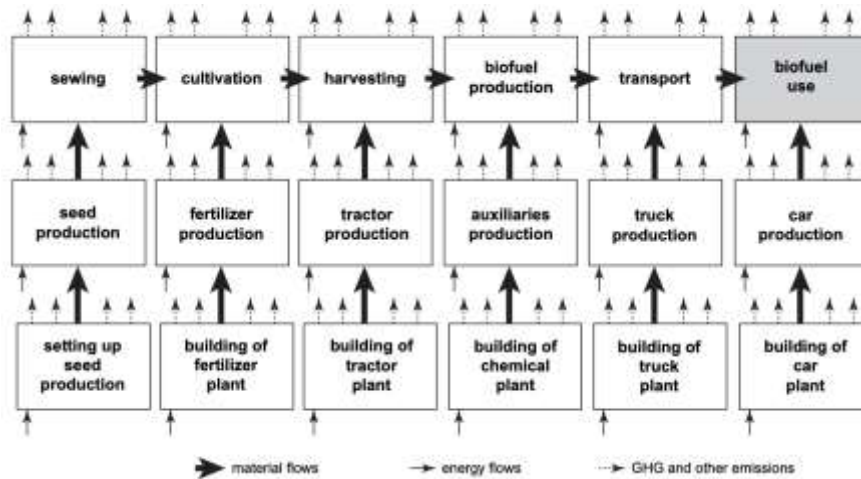
GHG emissions from LUC and land availability concerns are not the only environmental questions in play. Still, with the above two being probably the largest current dilemmas, we will touch the remaining only briefly. The other externalities being overall GHG emission life cycle assessments, water footprint, soil erosion, deforestation and air pollution.

The LCA of biofuel related emission is a tricky task at best. Many pollutants arise at each step of the value chain, the most occurring and voluminous being CO₂ (Zah et al. 2009). Fig. 2 shows the flows of materials, energy and pollutants in the biofuel production chain.

Fig. 2 – A schematic flow diagram of materials, energy and pollutants¹⁸

¹⁷ In the model, prices of both first and second generation feedstock start in the simulations at some USD 700 per toe.

¹⁸ In LCA all flows are related to the reference flow, in this case one unit of biofuel use (grey box), e.g. 1 vehicle km.



Source: (Zah et al. 2009)

Daioglou et al. (Daioglou et al. 2017) come with a novel approach to life cycle analysis (LCA). In their study they deal with spatial heterogeneity, which is supposedly causing the differences in emission factor (EF) ranges in various studies. In their comparison of grass methanol, wood methanol and sugarcane ethanol LUC accounted for up to 50 % (in boreal forests, grassland and savannas), the rest going to e.g. conversion (approx. 20 kgCO₂eqGJ_{biofuel}). In Tab. 6 we can see the mean EF₈₅ (85y horizon emission factor) with a 10th–90th percentile range for the three fuels in comparison to gasoline. If we abstract from all other positive 2G externalities, based on the listed values, we would probably choose to keep producing sugarcane ethanol. The large spread is caused by spatial variations in carbon stock as well as crop yield differences (Daioglou et al. 2017).

Tab. 6 – Mean estimates for grass wood and sugarcane fuels in an EF₈₅

Global (kgCO ₂ eq. GJ ⁻¹)	Grass methanol	Wood methanol	Sugarcane ethanol	Gasoline
Mean EF ₈₅ (10th-90th percentile range)	72 (37-127)	59 (37–81)	58 (33–78)	87
Lowest mean (percentile range) from grassland	45 (20–71)	51 (18–80)	36 (24–50)	-

Source: Based on (Daioglou et al. 2017)

This narrow insight is meant to show the complexity of LCA and at least an example of some biofuels. Lowering carbon emissions throughout the whole process will be a constant challenge in biofuels production.

Biofuel feedstock and food-crops compete not only for land, but also natural resources, especially, water. A study by Mathioudakis et al. (2017) focuses on the water footprint (WF,

in m³/t) on 2G bioenergy from feedstock to conversion process and comes to certain conclusions. Firstly, after evaluating ten crop residue types and a couple 2G bioenergy feedstocks, the main takeaway would be that from the water perspective, using the potential of crop residues would be most efficient (under 200 m³/t), although, sunflower straw can carry a WF of 600 m³/t). Regarding conversion, pyrolysis oil has a lower WF than bioethanol from fermentation and gasification with combustion both hold similar, lower than the other, WF values. The worst outcome arises from eucalyptus and pine, both over 1200 m³/t of purely green (rain) water footprint.

In addition, Havlík et al. (2011) offer a water irrigation comparison (using the GLOBIOM model) for 1G and 2G fuels. As we can see (Tab. 7), least irrigation water use arises from a “No biofuels” scenario, followed by 2G and 1G biofuels. However, in Option 1 (2G on crop and grassland), 2G biofuels record for the highest need of irrigation.

Tab. 7 – Impact of different production options on irrigation water use in 2030 relative to 2000.

Scenario names	Option 1: Crop and grassland	Option 2: Production forests	Option 3: Marginal land
Baseline	1.37	1.34	1.30
1G	1.36	1.36	1.34
2G	1.38	1.32	1.34
No biofuels	1.32	1.33	1.30

Source: (Havlík et al. 2011)

All the above mentioned effects are also often accompanied by soil erosion and oxidation, due to the changes in herbage and deforestation, thanks to need for excess land (Janda, Kristoufek, and Zilberman 2012). Furthermore, extensive crop¹⁹ production can lead to loss in biodiversity, and in the case of burning biomass also increases risks of air pollution (Janda, Kristoufek, and Zilberman 2012). However, the range of these externalities depends on the regional set up of the production process, conditions and also counter effect policies (afforestation). In some cases biofuels even improve the respective environment or at least come in neutral (Janda, Kristoufek, and Zilberman 2012).

¹⁹ Not only biofuel crops though. This goes for all agricultural products.

2.3 Social and economic impacts

All environmental impacts spill over, in some way, into social and economic challenges. Even though the debate has two sides, 1st generation biofuels have been proven to affect food markets, e.g. being responsible for a quarter (on average) of food price inflation on corn and soy markets in 2007 and 2008 (Janda, Kristoufek, and Zilberman 2012). On the other hand, advanced biofuels do in fact tend to be, to some degree, free of this problem. Moreover, government support of biofuels can only serve as an indirect way to lower fossil fuel use in transport and so battle GHG emissions and climate change (Janda, Kristoufek, and Zilberman 2012). Also based on given production possibilities in various regions, in many cases, the ideal actions may simply be economically unattainable.

Subsidy-wise, the question lies in who should be the main benefactor of the support programs. While R&D projects are currently supported, to what extent is it prudent to support farmers who chose 2G feedstock instead of 1G, or refineries which specialize on sustainable, advanced biofuels. Since the goal still being for advanced fuels to be cost-efficient on their own, building this cost-efficiency on subsidy programs may be reckless in the long-term.

In relation to this is the risk of political “lock-in” on certain generations of biofuels. A paper published by Eggert and Greaker in 2014 (Eggert and Greaker 2014) raised a finger to government support of infant industries which can create powerful lobbies that later effect political decisions, like e.g. the scaling down of an industry (1G biofuels) that didn’t turn out to be so beneficial as originally thought. Also, the role of robust and well-functioning financial markets showed to be crucial for bioenergy development (Al Mamun et al. 2018). Through those, the government can e.g. offer tax credits to investors who chose sustainable investment schemes, instead of heavily subsidising parties directly.

3. Conclusions

While there exists a number of issues on which the biofuels supports are criticised over the last 20 years, the food-fuel controversy was arguable the most discussed one. This wide criticism of using valuable land and other resources for production of biofuel feedstock rather than for production of food for human consumption was a subject of intense debates in many circles: among activists, among policymakers, among experts and academicians and in all biofuels related networks. It lead to important changes in biofuels policies and regulations.

Besides the food-fuel discussion there are other environment related issues connected with biofuels development. Important example are pollutants and other health related risk. These issues are usually investigate through some variant of life cycle analysis.

The least investigated group of negative features of biofuels development are social impacts of biofuels. In this paper we just acknowledge an existence of these issues without investigating them in detail.

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