Comments on

Avoiding Bioenergy Competition for Food Crops and Land by Searchinger and Heimlich

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The report by Searchinger and Heimlich expresses concern that bioenergy cannot contribute significantly to the fuel supply for the transportation and power sectors without compromising food availability and cost. Further, the report discusses perceived errors in greenhouse gas (GHG) accounting that cause incorrect claims that adoption of biofuels reduces emissions of CO_2 and therefore is an important technology to reduce climate change. We offer the below comments on the key topics in that report.

In the section *Biofuels and Food*, the authors maintained that world agriculture needs to benefit poor farmers and address climate, water, and ecosystems (the first paragraph on p. 6). However, the authors failed in the section to elaborate how agriculture should be designed to accomplish these aims. Some other authors have elaborated that in poor regions, such as Africa, bioenergy can indeed enable the introduction of agricultural technologies, the building of necessary agricultural infrastructure, and increases in farmers' income (Lynd et al. 2015).

Searchinger and Heimlich defined "the dedicated use of land for bioenergy" as the production of bioenergy that sacrifices alternative outputs from land (the third paragraph on p. 6). This narrow definition treats bioenergy production in isolation. For instance, some feedstocks (such as soybeans and rapeseed) for biofuel production would not fit into this definition because the land produces protein as animal meal as the main product and, secondarily, oil (either as cooking oil or a biofuel feedstock as biofuel products). That is, biofuel production from oil would not cause "dedicated use of land for bioenergy production." The authors certainly did not promote bioenergy production from those feedstocks. Also, "land" can be very different in terms of suitability and productivity for different vegetation types. Land that may not be suitable for row crops could be suitable for growth of other vegetation types because of differences in nutrients, water, climate, and other requirements. Throughout the report, the authors did not offer a detailed differentiation of various land types in the estimation of their biomass production potentials. Further, the authors treated marginal/degraded lands as not existing.

Searchinger and Heimlich rightly stated that the demand for land to produce bioenergy feedstock can cause shifts in land use patterns that can affect agricultural land. Land use change (LUC) impacts of biofuels have been a concern since Searchinger first published a paper in 2008 (Searchinger et al. 2008) investigating LUC associated with bioenergy crop production and subsequent GHG emissions. Since that time, understanding of biofuel-associated LUC has improved greatly because better land use data are available and economic models for modeling LUC have been improved significantly. Recent LUC GHG results indicate that Searchinger originally over-estimated LUC GHG emissions significantly (Dunn et al. 2013).

U.S. Department of Agriculture (USDA) data (USDA 2014) for U.S. farm acres for different crops including corn, soybeans, wheat, and other lands illustrate that while corn acreage has increased in parallel with the build-up of the corn ethanol industry between 2004 and 2013, total principal crop acreage has remained fairly constant and constituted 311 million acres in 2013 (see Wang et al. 2014). These observed trends are consistent with Taheripour and Tyner (2013), who analyzed land cover data from the Food and Agriculture Organization of the United Nations. These authors, in line with the trend in the USDA data, did observe crop shifting (e.g., wheat fields converted to corn agriculture) in the United States in this time period as a key mechanism for additional corn production. Another mechanism is likely the conversion of grasslands, wetlands, and other lands. In particular, the USDA data show that between 2008 and 2012, corn acreage increased by 11.2 million acres (together with 1.48 million acres for soybeans), while wheat acreage decreased by 7.8 million acres, hay acreage by 3.8 million acres, sorghum acreage by 2 million acres, barley acres by 609,000 acres, and oats acreage by 487,000 acres. The key point is that agricultural acreage in the United States has not significantly increased despite a dramatic biofuel boom. Additionally, the U.S. Renewable Fuel Standard states that biofuel feedstocks must come from land that was not forested before 2007. This provision limits the expansion of agricultural land into forested lands for biofuel production. In the case of woody feedstocks, the forests from which they derive must have been managed plantations before 2007.

The above observed increased acres for corn farming are driven by the significant increase in corn prices since 2005. However, several key factors cause increases in corn price, including U.S. corn ethanol production, weather events, recent grain demand increases, and diet changes in emerging economies (Trostle et al. 2011).

Concerns over the role of food crops in the energy sector are well-founded, and for this reason (among others), the Renewable Fuel Standard caps corn ethanol volumes at 15 billion gallons. In 2013, the United States produced 13.3 billion gallons and in 2014 had the capacity to produce nearly 15 billion gallons. In short, for biofuels to expand their role in the transportation sector in the United States, they must be produced from cellulosic feedstocks, such as energy grasses, short rotation woody crops, crop residues, wastes, and other sources. Searchinger and Heimlich correctly pointed out that directing wastes like crop residues and municipal solid waste to biofuel production is a good use of these resources. They raised concerns, however, that dedicated cellulosic crops are not a promising option for a biofuel feedstock because they require land and do not have sufficiently high yield. This conclusion contradicts recent studies that see an important role for cellulosic crops, including that of Werling et al. (2014) and the U.S. Department of Energy's Billion Ton Study (Oak Ridge National Laboratory 2011). Reliable reports indicate that significant areas of marginal lands exist that could be used to produce cellulosic crops that are currently underutilized (Cai et al. 2010).

Table 1 on p. 7 in Searchinger and Heimlich is an example that aspiration and speculation were combined to form the authors' opinions. At a high level, the five criteria for sustainable food future appear to be great aspirations. However, the effects of bioenergy on these five criteria are created on the basis of speculation without considering the dynamics of farming and farmers in the world's poor regions. Bioenergy could enable farmers in poor regions to introduce agricultural technologies and improve infrastructure to increase farm productivity and thus to raise farmers' income (Lynd et al. 2015). Thus, bioenergy could help, not hinder, some of the criteria in Table 1. Also, bioenergy and food production can co-exist and enhance each other by advancing technologies and increasing yields (Dale et al. 2014), thus complementing each other instead of competing against each other.

Estimations of the food crop calorie gap in the section *Biofuels and the Food Gap* assumes a unit energy of fuel produced from biomass displaces a unit of energy in food, decreasing the food supply (see Endnote 11 of the report). This simple conversion fails to address different human nutrition requirements and the fact that certain bioenergy production can co-produce certain nutrients (such as protein production from first-generation biofuels). Together with the simplistic conversion, Figure 2 gives readers a false impression that energy MJ and food calories are simply interchangeable.

Figure 3 in Searchinger and Heimlich was developed on the basis of Endnote 21 in which calculations were based on the current global mix of corn and sugarcane ethanol. In the calculations, the authors ignored potential energy supplies from corn stover produced together with corn grains and bagasse together with sugarcane juice. Since the authors were to calculate potential energy supplies, these two sources, which can supply a large amount of energy, should have been included in the authors' calculations. Furthermore, the authors again ignored by-products of biofuel production that supply food or feed. In the case of corn ethanol, this is a significant omission because one-third of corn entering a dry mill leaves as animal feed, not as corn ethanol.

The section *What about Fast-Growing Grasses or Trees for Cellulosic Biofuels* was based on the authors' assertion that "growing trees and grasses will require fertile land, resulting in potential land competition with food production" (the second paragraph on p. 12). Many studies, including that for the Department of Energy (Oak Ridge National Laboratory, 2011), have identified land where cellulosic biomass can be grown to avoid competition between cellulosic biomass and food production. The authors simply ignored those studies.

The statement, "For cellulosic ethanol production to match this figure (corn plant biomass yield), the grasses and trees must achieve almost double the national cellulosic yields estimated by the U.S. Environmental Protection Agency" cites Plevin (2010) (Endnote 25 on p. 35). Many studies, however, report or review biomass yields. The authors should have conducted a complete literature review of available studies rather than citing a single study. To the contrary of what the authors stated, some of the studies on this topic indeed indicate that doubling of currently low cellulosic biomass yields is achievable (see Lynd et al. 2009).

In the same paragraph, the authors maintain that two to four times of current biomass yields are probably needed on the basis of their calculation in Endnote 26 on p. 35. Endnote 26 was based on a biomass yield of 16 metric tons per hectare or 7.1 dry tons/acre. This yield is indeed achievable in the near future. Further, the authors assumed an ethanol yield of 100 gallons per metric ton (91 gallons per ton) that represents a yield for the near future and did not take into account potential electricity co-produced with ethanol in cellulosic ethanol plants. The authors maintained that biomass yields could be much lower by citing Plevin (2010) and Schmer et al. (2010). Schmer et al. studied switchgrass yield variation in Nebraska, North Dakota, and South Dakota (the Northern Great Plains) during 2000–2005. Switchgrass yields are not optimal in this region relative to other U.S. regions, such as the Southern United States. Schmer et al. intended to study variation in switchgrass yield in the Northern Great Plains, not potential switchgrass yields in various U.S. regions where switchgrass may be grown in the future. The results of Schmer et al. were used out of context by Searchinger and Heimlich in their report.

The statement of “displacing a hectare of food crops to grow trees or grasses for biofuels in one place would just lead to the conversion of a hectare (or more) of land elsewhere to grow those food crops” (the third paragraph on p. 12) was based on the false premise that trees and grasses will be grown on the same land where food crops are grown, which the authors erroneously assumed throughout the report.

The authors asserted that coarse satellite maps often overestimated “marginal” or “degraded” lands (the sixth paragraph on p. 12). But the authors did not provide evidence to support their assertion. To the contrary, studies have identified the land that statistics and satellite images often missed (and underestimated) land availability (see Mueller and Copenhaver 2009). Ground truthing of land availability and agricultural land use is needed to accurately assess land available for food and bioenergy production. The results may not be what the authors asserted.

In the section *the Implications of Broader Bioenergy Targets*, the authors present Figure 4, which shows that even if all crops, crop residues, and harvested wood are used for bioenergy production, the contribution of bioenergy to global total energy consumption would be small. Unfortunately, the chart and the conclusion of this section was based on an erroneous calculation sourced to Endnote 32 on p. 36. Endnote 32 cited Haberl et al. (2007) as the source for total bioenergy from all the crops, plant residues, and wood harvested. Haberl et al. estimated 15.6 Pg carbon/year as the human appropriation of net primary energy production (HANPP), which is 2.4×10^{10} tonnes of biomass (when we assume that the carbon content of primary biomass is 65%). With the energy content of 18.5 GJ/tonne as presented in Endnote 32, the total amount of energy available in this harvested biomass is 440 EJ/year, not 225 EJ as presented by Searchinger and Heimlich. The erroneous estimate by the authors is from the authors’ omission of converting carbon in Haberl et al. to biomass. With the corrected total amount of energy from crops, plant residues, and harvested wood, the hypothetical conversion of all these to energy can contribute to 40% of total global primary energy use in 2050, not 24% as authors erroneously presented in Figure 4. This result even assumes no increase in production of food, plant residues, and harvested wood between now and 2050.

In the section *Bioenergy vs. Solar Energy,* the authors estimated that solar energy conversion of solar photovoltaics (PVs) was 30 times more than bioenergy solar energy conversion per unit of land (the fourth paragraph on p. 14). But three paragraphs after that (the fifth paragraph on p. 14), they maintained the PV energy conversion is at least 100 times more efficient than bioenergy per unit of land. The latter number was based on calculations in Endnote 44 on p. 36. The calculations there were done on an unrealistic basis. In particular, the authors assumed that solar PVs and bioenergy feedstocks will be grown globally on all available lands (except those permanently covered by ice and the driest deserts). This implies that the authors assumed that bioenergy feedstocks would be grown on a large amount of lands, some of which may not be suitable for biomass growth. In addition, the authors assumed an ethanol conversion of 100 gallons per dry tonne of biomass (91 gallons per ton) that only represents the near-term yield and did not consider any energy in co-produced electricity. The co-produced electricity can increase total energy yield of cellulosic ethanol plants by 12%.

The authors presented a simplistic comparison between bioenergy and solar energy in this section. A fair, comprehensive comparison for land-based energy harvest could have been done to reflect the potential of each energy system on suitable lands. For example, a comparison could have been done for solar PV energy vs. bioenergy from a farm that integrates wind turbines. Many U.S. Midwest farms already adopt this practice. Furthermore, one could evaluate an integrated renewable energy system with bioenergy and wind turbines on the lands that are suitable for biomass growth and with wind resources and solar PV energy on the lands that are not suitable for biomass growth but are suitable for PV installation. This integrated renewable energy system can be compared with the existing fossil energy systems for carbon reductions. That is, bioenergy, wind electricity, and solar PV energy can be designed to be complementary to each other for the best use of lands instead of a hypothetical competition of land between solar PVs and bioenergy.

While Searchinger and Heimlich explained how advances in PV technology will bring down its costs, they did not describe how cellulosic biofuel research, both in the feedstock production and conversion arenas, will also drive down the cost of cellulosic biofuels. These fuels include not only ethanol but also the so-called drop-in hydrocarbons that could be direct replacements for petroleum-derived fuels and therefore not subject to ethanol blending limitations. One example of technology development is the dramatic reduction in enzyme loadings required in processes that biologically convert biomass to fuels and chemicals (Emelfarb 2014). These enzymes are expensive, and industry, academia, and government continue to collaborate to drive down their impact on biofuel cost (Mohanram et al. 2013). One indication of the state of technology of energy from solar PV as compared to corn ethanol (a mature technology) and cellulosic ethanol (a developing technology) is the cost per unit energy. Corn ethanol is approximately $0.017/MJ (U.S. Energy Information Administration 2015), cellulosic ethanol is estimated to cost $0.027/MJ (Humbird et al. 2011), and solar PV energy is estimated to cost the most of these technologies at $0.033/MJ (U.S. Energy Information Administration 2014). The cost of both solar PV and cellulosic biofuels will continue to decline with technology advancements. Even though solar PV and electric vehicle technologies that may use PV electricity to power batteries are promising technologies, electrification is currently not a viable solution for the aviation sector or long-distance travel, both of which rely on energy-dense liquid fuels. The solar efficiency of producing energy from biofuels or from solar PV is not a useful indicator of the relative performance of these technologies because solar energy, a limitless resource, does not need to be conserved.

In the section *the Greenhouse Gas Implications of Using Biomass from Dedicated Land for Energy*, the authors maintained that additional biomass for bioenergy is the key for bioenergy-derived GHG reductions. They further asserted that double counting of carbon occurs in analyses of bioenergy because the biomass additionality issue is not addressed. The concept of additionality for GHG reductions really asks what the counterfactual scenario is when bioenergy does not exist or exists only at current levels. While the authors pointed out a few key factors to determine additionality, the authors did not address differences in land productivity of biomass between the two scenarios. Land biomass productivity differences could be caused by biomass yields, changes from single cropping to double cropping (or even triple cropping) because of bioenergy production (see Babcock and Iqbal 2014), and the ability to use marginal/degraded lands for bioenergy production. Comprehensive modeling needs to be conducted for considering these factors, as well as those listed by the authors, in order to accurately assess biomass additionality. Instead, the authors simply concluded that any dedicated biomass growth would result in double counting of biomass by assuming that biomass for bioenergy is grown on the lands where biomass would be grown anyway and with the same yields.

Searchinger and Heimlich raised concerns about the treatment of biogenic carbon in GHG accounting schemes that find a GHG reduction for biofuels. One difficulty with the approach taken by Searchinger and Heimlich is that it does not account for the release of carbon long-stored underground when fossil fuels are combusted. Compared to this injection of fossil carbon into the atmosphere, the rapid cycling of biogenic carbon between the atmosphere and biomass has a much smaller GHG impact. This advantage diminishes when the biofuel feedstock has a long growth cycle—for example, purpose-grown woody feedstocks like pine. Many life-cycle analyses (LCAs) of biofuels, especially those produced from annual crops, consider that the uptake of atmospheric carbon during biomass growth offsets carbon release at biofuel combustion. GHG emissions occur throughout the additional steps of the biofuels life cycle (e.g., emissions from tractors and biorefineries), so biofuels are not automatically considered carbon-free. In addition to these direct GHG emissions, many LCAs of biofuels include indirect emissions associated with land use change (Dunn et al. 2013). Even in that case, biofuels are routinely shown to have lower life-cycle GHG emissions than conventional fuels, like gasoline. Recent analysis from Argonne National Laboratory estimates a reduction of approximately 34% for corn ethanol as compared to gasoline and potentially larger reductions for cellulosic ethanol (Wang et al. 2012).

The biomass additionality issue has been raised and addressed by many researchers. Careful characterization of counterfactual scenarios and bioenergy scenarios—or the so-called marginal analysis of bioenergy scenarios—has been conducted to address the additionality issue. In fact, some analyses point to the need to compare biofuels to marginally produced, high-GHG-intensity fossil fuels (Ecofys 2014). Further analyses are still needed to address this important issue. Such analysis should give careful considerations to such factors as changes in land productivity in different land types, changes from one biomass type to another (for example, prairie grass to switchgrass) and resulting yield changes, use of less fertile lands for bioenergy, carbon dynamics of biomass growth and harvest in a land type, changes in soil carbon caused by biomass harvest, and avoided fossil energy GHGs.

The U.S. EPA has ruled that passenger vehicles of model year 2001 and beyond can use the E15 blend. The authors' statement of "few cars can use more than a 10 percent blend of ethanol" (the fourth paragraph on p. 27) is incorrect. Also, it is odd that the authors proposed that the E10 blend wall should be artificially maintained for the authors' purpose of controlling ethanol use, even though E15 has already approved by EPA for use.

In Appendix B, the authors presented six illustrative bioenergy production cases:

1. Bioenergy production in marginal/degraded land
2. Bioenergy production from crop residues
3. Bioenergy production from cropland without any productivity increases
4. The case where bioenergy production causes reduction in food demand
5. Bioenergy production from land intensification, such as yield increases and double cropping
6. Bioenergy production from land extensification with significant soil carbon loss

While Case 4 is not a bioenergy production case, the other five cases are. Of the five cases, Case 3 may result in no-net GHG reductions and Case 6 may result in GHG increases. The other three cases can result in GHG reductions. Constructive communications and comprehensive evaluations should be carried out to design sensible bioenergy policies so that Case 6 is avoided; Case 3 is discouraged; and Cases 1, 2, and 5 are encouraged. The authors failed to develop or describe such rational approaches to energy policy.

It is indisputable that land is a resource that must be well managed to provide sufficient food, fiber, and energy for society. Analyses that assess the use of land for energy production must (1) take into account recent and likely future technology advancements, historical land use pattern data, and regulatory approaches that limit undesirable indirect effects and (2) adopt a comprehensive basis for estimates of GHG implications. Such analyses will help develop sound bioenergy policies. Instead, Searchinger and Heimlich bluntly denied a role that bioenergy may play in the future for sustainable environmental development and energy supply.

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