Chapter 7
Review of the Impacts on Air Quality and Human Health of Land-Use Changes Induced by Non-food Biomass Production

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Abstract Biomass production has developed significantly in the latest decades to meet the growing needs of the bioeconomy sector. This trend is expected to continue in the near future to substitute dwindling fossil resources. Concerns were recently raised on the consequences of expanding feedstock production on land use worldwide, prompting a surge in scientific publications. These consequences may be analysed through a three-step causal chain relating drivers of feedstock production, changes in land use (LUC), and environmental impacts. Among these, atmospheric pollution or human health impacts, as related to LUC, are rarely evaluated although they are a prime concern for environmental policies and the sustainability of the bioeconomy.

Here, we reviewed current research on the LUC-mediated effects of biomass development on air quality and human health through a systematic survey of literature from 1975 to 2015. Only 17 articles addressing air quality and 9 papers addressing human health were retrieved. Most were published after 2014, implying that these topics only emerged recently. Most studies focused on liquid biofuels (1st and 2nd generation), although bio-materials and bio-electricity were also represented. These studies covered several geographical areas, with an emphasis on Europe and South America. Given the small size of our sample and the diversity of contexts it addressed, it is difficult to evidence clear-cut trends on the impacts of substituting fossil resources with biomass on human health and air quality.. Overall, the benefits of this substitution appeared mixed and dependent on the type of end-product considered. First-generation biofuels were out-performed by their second-generation counterparts, but this trend relies on a low number of references. Life-cycle assessment was the predominant method used to estimate the impacts of biomass development on human health or air pollution. This emerging field warrants further efforts toward more thorough assessments of LUC effects.

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7.1 Introduction

Biomass production has developed significantly in the latest decades to meet the growing needs of the bioeconomy sector (whether for bioenergy, biomaterials, or bio-based chemicals), and this trend is expected to continue in the near future to substitute dwindling fossil resources (Chum et al. 2011). Concerns were recently raised around the consequences of land-use changes (LUC) incurred when expanding feedstock production (e.g., Searchinger et al. 2008), and prompted a surge in scientific publications over the past 10 years (see Réchauchère et al., General Introduction, this volume). Attributing LUC to biomass production requires the elicitation of mechanisms explaining the relationship between feedstock production, changes in land use or land management, and their impacts on the environment. These relationships may be analysed as a three-step causal chain: drivers of feedstock production, LUC occurring in response to this production – whether direct or indirect, and environmental impacts involving various dimensions, such as greenhouse gas (GHG) emissions, biodiversity, water resources, soil quality, or human health.

Although the effects of LUC on the GHG balance of biofuels have been extensively documented in the literature (see eg, Broch et al. 2013; Berndes et al. 2013; Bamiere and Bellassen, Chap. 6, this volume), the impacts on atmospheric pollution or human health – as mediated by LUC – is rarely reported. A recent review of "meta-studies" carried out in the context of "land-use science" (van Vliet et al. 2016) fails to mention these issues, implying they have been little researched in this context, whereas impacts on air quality are clearly high on the environmental policy agenda in general (Molina and Molina 2004). Reducing "the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination" is one of the targets mentioned by the Sustainable Development Goals put forward by the United Nations in 2015. Air pollution and human health are also important issues for bio-based products, concerns having been raised on the actual benefits of substituting fossil fuels with biofuels (Chum et al. 2011). For instance, bio-ethanol blends were shown to increase ozone concentrations the troposphere under low temperatures, and thus adversely impact human health compared to pure gasoline in the US (Ginnebaugh et al. 2010). Most of these studies ignore LUC effects associated with feedstock production, although changes in land use or management are likely to affect emissions of primary air pollutants such as nitric oxide or ammonia (Bouwman et al. 2002), toxic contaminants such as pesticides (Foley et al. 2005), or black carbon emissions from slash-and-burn when converting forests.

Here, we set out to review scientific articles dealing with the relationships between bio-based products, LUC, and their impacts on atmospheric pollution and human health, since both impacts are connected and often jointly addressed. The objective was to assess the current extent and foci of such research, regarding biomass feedstocks, its end-uses, and categories of LUC analysed, and to examine possible trends in the outcomes of these studies. In particular, a key question regarded the effect of including LUC on the conclusion of the assessments of substituting fossil-based products with bio-based equivalents. This overview also aimed at highlighting possible gaps with current research, and potential improvement routes in terms of methodology.

7.2 Literature Survey

In a first step, we surveyed the scientific literature on LUC (whatever the driving factor) between 1975 and February 2015, and retrieved a body of 5730 articles from two databases relevant to this topic (Web of Science and CAB). All references included keywords related to land-use changes, but another constraint was that references should cover the three steps of the following causal chain: driving factors → land-use changes → environmental impacts. They were selected so as to a mention at least one bio-based end-product, one type of biomass feedstock, and one category of environmental impacts – including atmospheric pollution and human health.

An automated textual analysis of the papers' abstracts, titles and keywords evidenced a series of themes structuring this set of references (El Akkari et al., Chap. 2, this volume), and the subset of papers studying the environmental impacts of biomass/bioenergy through LUC effects was selected. It was further screened manually by a dozen of experts in the fields covered by this literature (economics, ecology, agronomy, forestry, sustainability assessment), and winnowed down to 241 references covering all impact categories. The references pertaining to including atmospheric pollution and human health totalled 17 and 9, respectively, making up less 8% and 5% of the overall body of references on LUC mediated impacts. There was an overlap between the two impact categories, with six articles dealing with both. Thus the total number of articles analysed in the following sections was 20.

All the articles were published after 2008, which was a turning point in LUC-related research (Réchauchère et al., General Introduction, this volume). Most papers (13 out of 20) were published in 2014 and 2015 (the latest year surveyed), implying this topic is still in its infancy. All studies involved several scenarios in terms of feedstocks, end-uses and LUC. One article investigated about a hundred of them, corresponding to 20 different possible LUC scenarios in the US (Daystar et al. 2014).

7.3 Feedstock Types and End-Uses Assessed

Arable crops dominated in terms of feedstock types (Fig. 7.1), with first-generation (1G) biofuels as main application, followed by bio-plastics. Lignocellulosic crops came second, with perennial herbaceous species as well as woody ones, in the form

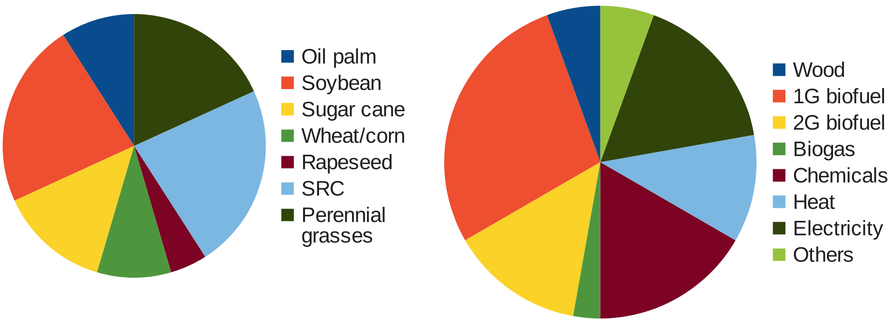

Fig. 7.1 Breakdown of feedstock types assessed in the literature surveyed (right), and end-uses (left). *SRC* short rotation coppice (poplar, willow, eucalyptus)

of short rotation coppice (SRC). Miscanthus, switchgrass, and poplar SRC were the most frequent feedstocks investigated, with a range of end-uses: combined heat and power, bio-plastics, or 2G biofuels. Liquid biofuels dominated in terms of end-uses, with a 45% share overall (Fig. 7.1). Oil palm was assessed in three articles, in the context of 1G biofuels, but also delivering heat and electricity co-products via the anaerobic digestion of palm oil meal effluent. Four studies involved agricultural residues. This was unexpected since residue extraction from agricultural land does not require additional land for production, in principle, and is thus generally considered neutral in terms of LUC. However, these articles tackled the impact of residue removal on soil quality, as opposed to being returned to the soil (eg, Clark et al. 2013), and also compared this feedstock with dedicated biomass plants. One article combined the conversion of an oil crop (*Brassica camelina*) to bio-diesel, with the use of its co-products (straw and cake) to produce chemicals, following a biorefinery approach (Fiorentino et al. 2014). Most studies compared bio-based products and fossil-based equivalents, but some (2/20) simply focused on the effects of establishing biomass plantations on unproductive land (eg marginal soils).

Europe was the most frequent continent for biomass expansion (40% of the articles), followed by South America (30%) and North America (20%). Most studies were done at national scale, with regional differentiations for about a third of them.

7.4 Categories of Land-Use Changes Analysed

A total of 38 scenarios of LUC were reported by the experts who analysed the 20 articles selected in this review. Seven of those were seemingly neutral (e.g., cropland to cropland), and were zeroed by convention in the corresponding matrix (Table 7.1) to focus on more radical shifts such as forest to cropland. This leads to a total of 31 LUC scenarios overall. These involved mostly the conversion of cropland or grassland to perennial biomass plants (14 scenarios out of a total of 31), and the conversion of cropland to grassland, or vice-versa (10 scenarios). Conversion to

Table 7.1 Matrix of direct land-use changes reported in the 20 articles reviewed

To from	Forest	Cropland	Perennial crop	Grassland	Wetland
Forest	–	3	4	0	0
Cropland	1	–	7	6	0
Perennial crop	0	0	–	0	0
Grassland	1	4	7	–	0
Wetland	0	0	1	0	–

forest was only mentioned twice, while wetlands were affected only once. Only 14 scenarios (out of 31) reported indirect LUC as such in the articles. These mostly pertained to the conversion of forests into cropland, grassland or perennial crops (8 scenarios), and that of grassland (4 scenarios; not shown here). Besides LUC, some changes in land management practices were also reported: intensification and extensification of cropland were mentioned once each, and the conversion to organic farming was mentioned in a fourth of the articles. This emphasizes the importance of this potential shift in terms of environmental impact mitigation, despite its low acreage overall (only 5% of the Uttilizable Agricultural Area was organic in 2010 in Europe; Bellora and Bureau (2013). Note that the impacts of shifting to organic production in terms of land use per se, due to the lower yields itentails in general (Seufert et al. 2012) was beyond the scope of these articles, although this may generate significant LUC effects (see Bellora and Bureau 2013).

In terms of methodology to assess LUC in response to increasing biomass demand, simple methods such as 'basic calculations' dominated, along with the absence of an identifiable methods in a quarter of the articles. Economic models, which are one the major options to assess LUC (Gabrielle et al., Chap. 3, this volume) were only used in one article (or 5% of the studies), while bio-physical models were mentioned in only 3 articles.

7.5 Air Pollution, Biomass and LUC: Mixed Outcomes and an Overwhelming Effect of End-Product Types and System Boundaries

Life-cycle assessment (LCA) was the single most used method to assess impacts on air pollution, with an occurrence of 85%. Air pollution was actually reduced to so-called the photo-chemical ozone creation potential (POCP), a commonly-used mid-point impact of LCA. It was calculated with characterization methods such as CML, Impact2002+, and EDIP (see Dreyer et al. 2003) for a comparison of these methods). In the other cases, either no particular methodology was reported, or a simple calculation. LCA was often combined with biophysical models to simulate crop yields and/or emissions of air pollutants, such as nitrogen oxides. Chemistry-transport models, which are heavily used in the investigation and prediction of air

Table 7.2 Contingency table of the impact of developing biomass on air pollution, depending on the type of end-product generated

End-product	Counter-factual	Impact on air quality				Total
		Positive	Negative	Neutral	Variable	
1G biofuel	Fossil fuel	1	2	1	5	9
2G biofuel	Fossil fuel	4	0	1	2	7
Heat	Fossil fuel	2	1	0	1	4
Electricity	Fossil fuel	4	3	0	0	7
Bio-plastic	Petro-chemical plastic	4	2	0	0	6
Development of biomass crops	Marginal land; current electricity mix and cropland	0	1	0	1	2
Total		15	9	2	9	35

The total number of cases exceeds the number of articles because the latter consider more than one end-product

pollution were never mentioned, although they have been used in combination with LCA in the past (Labouze et al. 2004). Only 2 papers out of 17 included information on the accuracy of impact estimates.

The outcomes of biomass development were highly variable overall: 7 articles concluded to a decline in air pollution, 5 to an increase, and 5 to a variable effect. The outcomes depended on the type of end-product considered (Table 7.2), but also on the types of comparison pursued by the studies. While most of them focused on the substitution of fossil-based products by bio-based equivalent, two compared agricultural biomass and forest feedstocks. One of them concluded to the superiority of forest resources over their agricultural counterparts for the supply of lignocellulose. Another examined the interest of replacing imported palm oil by locally-sourced agricultural products in Canada, and showed import substitutes to be less detrimental to air quality.

In terms of end-products, 2G biofuels and bio-plastics were generally associated with a decrease in air pollution compared to fossil fuels (Table 7.2), while the impact of 1G biofuels was mostly variable. Electricity from biomass generated mixed results, with 4 cases increasing air pollution and 3 cases producing the opposite result. While electricity from biomass is generally ascribed a detrimental impact on air quality because of particle emissions when burning the feedstock (Chum et al. 2011), some cases in our sample involved biogas generation from the co-products of 1G palm oil-based biofuels. Power generation from biogas is less prone to these emissions, and may out-perform electricity generated by the combustion of fossil resources in terms of air pollution (Poeschl et al. 2012).

Two studies lead to conflicting outcomes regarding the substitution of petroleum-based material with bio-plastics (Alvarenga et al. 2013; Liptow and Tillman 2012), although based on the same case study (plastic manufacturing from ethanol produced from the sugar cane in Brazil), and the same category of LUC (grassland converted to sugar cane for the direct part, conversion of Amazonian forests or savannas to grassland or cropland for the indirect effects). Since none of the studies accounted for air pollutants emissions in relation to indirect LUC, the major difference between them lies in the transport of bio-plastic, which is consumed in Europe in the article concluding to the superiority of fossil-based plastic (Liptow and Tillman 2012). The authors also compared the attributional and consequential approaches for the LCA – the second being more favourable to bio-plastics than the first, due to an emission credit granted by the generation of electricity at the end of life of bio-plastics (in Europe).

7.6 Human Health Impacts: Scant Data and Exposure Pathways

Only 9 articles dealt with the impacts of bio-based products of human health, with 6 of them being also part of the above-described set of references on air pollution. Thus, there are strong similarities with the latter set in terms of methodologies: LCA was predominant again, being present in all the articles but one (Larsen et al. 2014), which involved a qualitative survey of stakeholders impacted by the development of the oil palm mill in a region of Indonesia. On the other hand, half of the studies involved uncertainty analyses, which were thus more frequent than with the air pollution theme. In terms of scope, most of these studies compared bio-based products (whether liquid fuels, electricity, chemicals or bio-materials) with fossil equivalents. Two exceptions involved the cultivation of camelina, an oil crop, on contaminated soils (Fiorentino et al. 2014), and the development of oil palm in Indonesia (Larsen et al. 2014). It is important to single out these two studies in the analysis of the outcomes since they involve different system boundaries and scope.

Out of the 7 studies comparing fossil and bio-based products, two concluded that the substitution by biomass lead to an improvement in human health, two to detrimental effects, one to neutrality, and two to variable effects. The breakdown was similar regardless of the end-product considered (Table 7.3), with only 2G biofuels presenting an absence of adverse effects, although it is hard to conclude based on only 20 end-product cases overall. There are currently very few literature reviews on the health impacts of bio-based products available. An early article focusing on 1G bioethanol concluded that results on human toxicity “were more often unfavourable than favourable” to this biofuel (von Blottnitz and Curran 2007), due to emissions occurring during the feedstock cultivation and harvesting phases. These studies did not factor in LUC effects, but revealed a similar pattern to that observed here. A more recent review encompassing lignocellulosic biofuels concluded that reliance on herbaceous feedstocks resulted in higher impacts on human health compared to fossil fuels, but that wood or flax shives (an agricultural co-product) had positive effects (Borrion et al. 2012). The way LUC was handled in these studies is not clear from the review, which suggests that variations in LCA outcomes across studies mostly depended on allocation methods (for co-products) and system boundaries. Another study mentioned in this review concluded that bio-materials always

Table 7.3 Contingency table of the impact of developing biomass on human health, depending on the type of end-product generated

End-product	Counter-factual	Impact on human health				Total
		Positive	Negative	Neutral	Variable	
1G biofuel	Fossil fuel	1	3	0	1	5
2G biofuel	Fossil fuel	1	0	0	1	2
Heat	Fossil fuel	2	0	0	0	2
Electricity	Fossil fuel	2	1	1	1	5
Bio-plastic	Petro-chemical plastic	2	1	0	1	4
Development of biomass crops	Current land use	0	1	0	0	1
Total		8	6	1	4	19

The total number of cases exceeds the number of articles because the latter consider more than one end-product

had lower impacts on human health than their petrochemical counterpart, which was not so clear-cut here.

As could be expected, the two studies examining the expansion of biomass production per se pointed to a detrimental effect on human health, due to increased pressure on otherwise unmanaged land. In the absence of a counterfactual scenario for delivering the service provided by biomass, the value of such results is hard to fathom in practice, other than pointing out at the need to carefully select the land on which bioenergy crops should be established, and to prevent detrimental effects as much as possible by an appropriate management of the plantations.

7.7 Conclusion

The impacts of bio-based products on air quality and human health, as mediated by land-use changes are rarely addressed, and represented less than 10% of the body of references addressing the full drivers to impacts chain of biomass development analysed in a recent review (Réchauchère et al., Chap. 1, this volume). Still, the 20 articles retrieved in this article covered a significant range of feedstock types, end-uses, and geographical regions. Liquid biofuels were predominant, but other end-uses such as bio-plastics or electricity were also represented. As a result, arable crops and dedicated lignocellulosic species (perennial grasses and short rotation coppice) were the most frequent feedstocks analysed. Environmental impacts were almost exclusively evaluated by means of life-cycle assessment (or its variant, life-cycle impact assessment), which does not reflect the diversity of assessment methods used to investigate either atmospheric pollution or human health impacts (Steinemann 2000).

Given the small size of our sample and the diversity of contexts it addressed, it is difficult to evidence clear-cut trends. Overall, the benefits of substituting fossil resources with biomass appeared mixed. Despite the fact that only one assessment method was used, which could lead to some degree of bias, it is also clear that the reliability of these estimates is rather low and uncertain, given that this framework is ill-equiped to address air pollution or human health (Hauschild et al. 2008; Bessou et al. 2011). Relying on more commonly-used methods to deal with atmospheric pollution or human toxicity impacts, such as air pollution modeling and epidemiology (Schwartz et al. 2017), or environmental impact assessment (Steinemann 2000), respectively, would be relevant to complement LCA and provide benchmarks. Effects related to indirect LUC – ie occurring outside of the region where the biomass was produced are also difficult to deal with, leading some of the experts who reviewed these articles to question the robustness of their conclusions. This emerging field warrants further efforts toward sounder methodologies and more thorough assessments of LUC effects.

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References

Bamiere L, Bellassen V (this volume) Review of the impacts on greenhouse gas emissions of land-use changes induced by non-food biomass production. In: Réchauchère O, Bispo A, Gabrielle B, Makowski D (eds) Sustainable agriculture reviews, vol 30. Springer, Cham

Bellora C, Bureau JC (2013) The indirect trade and virtual land effects of a greener EU agriculture. 7èmes Journées de Recherche en Sciences Sociales dans le domaine de l'agriculture INRA-SFER-CIRAD, Angers, December 12–13, 2013

Berndes G, Ahlgren S, Borjesson P, Cowie AL (2013) Bioenergy and land use change-state of the art. WIREs 2(3):282–303. https://doi.org/10.1002/wene.41

Bessou C, Ferchaud F, Gabrielle B, Mary B (2011) Biofuels, greenhouse gases and climate change. A review. Agron Sustain Dev 31(1):1–79. https://doi.org/10.1051/agro/2009039

Borrion AL, McManus MC, Hammond GP (2012) Environmental life cycle assessment of lignocellulosic conversion to ethanol: a review. Renew Sust Energ Rev 16(7):4638–4650. https://doi.org/10.1016/j.rser.2012.04.016

Bouwman AF, Boumans LJM, Batjes NH (2002) Modeling global annual N2O and NO emissions from fertilized fields. Glob Biogeochem Cycles 16(4):28-1–28-9. https://doi.org/10.1029/2001gb001812

Broch A, Hoekman SK, Unnasch S (2013) A review of variability in indirect land use change assessment and modeling in biofuel policy. Environ Sci Pol 29:147–157. https://doi.org/10.1016/j.envsci.2013.02.002

Chum H, Faaij A, Moreira J, Berndes G, Dhamija P, Dong H, Ribeiro S, Gabrielle B, Goss Eng A, Lucht W, Mapako M, Masera Cerutti O, McIntyre T, Minowa T, Pingoud K (2011) Bioenergy. In: Edenhofer O, Pichs-Madruga R, Sokona Y, Seyboth K, Matschoss P, Kadner S, Zwickel T, Eickemeier P, Hansen G, Schlömer S, Stechow Cv (eds) IPCC special report on renewable energy sources and climate change mitigation. Cambridge University Press, Cambridge, pp 209–332

Dreyer LC, Niemann AL, Hauschild MZ (2003) Comparison of three different LCIA methods: EDIP97, CML2001 and eco-indicator 99 – does it matter which one you choose? Int J Life Cycle Assess 8(4):191–200. https://doi.org/10.1065/lca2003.06.115

El Akkari M, Sandoval M, Le Perchec S, Réchauchère O (this volume) Textual analysis of published research articles on the environmental impacts of land-use change. In: Réchauchère O, Bispo A, Gabrielle B, Makowski D (eds) Sustainable agriculture reviews, vol 30. Springer, Cham

Fiorentino G, Ripa M, Mellino S, Fahd S, Ulgiati S (2014) Life cycle assessment of Brassica carinata biomass conversion to bioenergy and platform chemicals. J Clean Prod 66:174–187. https://doi.org/10.1016/j.jclepro.2013.11.043

Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, Chapin FS, Coe MT, Daily GC, Gibbs HK, Helkowski JH, Holloway T, Howard EA, Kucharik CJ, Monfreda C, Patz JA, Prentice IC, Ramankutty N, Snyder PK (2005) Global consequences of land use. Science 309(5734):570–574. https://doi.org/10.1126/science.1111772

Gabrielle B, Barbottin A, Wohlfahrt J (this volume) The environmental impacts of non-food biomass production through land-use changes: scope, foci and methodology of current research. In: Réchauchère O, Bispo A, Gabrielle B, Makowski D (eds) Sustainable agriculture reviews, vol 30. Springer, Cham

Ginnebaugh DL, Liang JY, Jacobson MZ (2010) Examining the temperature dependence of ethanol (E85) versus gasoline emissions on air pollution with a largely-explicit chemical mechanism. Atmos Environ 44(9):1192–1199. https://doi.org/10.1016/j.atmosenv.2009.12.024

Hauschild MZ, Huijbregts M, Jolliet O, MacLeod M, Margni M, van de Meent DV, Rosenbaum RK, McKone TE (2008) Building a model based on scientific consensus for life cycle impact assessment of chemicals: the search for harmony and parsimony. Environ Sci Technol 42(19):7032–7037. https://doi.org/10.1021/es703145t

Labouze E, Honore U, Moulay L, Couffignal B, Beekmann M (2004) Photochemical ozone creation potentials – a new set of characterization factors for different gas species on the scale of Western Europe. Int J Life Cycle Assess 9(3):187–195. https://doi.org/10.1065/lca2004.04.155

Larsen RK, Jiwan N, Rompas A, Jenito J, Osbeck M, Tarigan A (2014) Towards 'hybrid accountability' in EU biofuels policy? Community grievances and competing water claims in the Central Kalimantan oil palm sector. Geoforum 54:295–305. https://doi.org/10.1016/j.geoforum.2013.09.010

Liptow C, Tillman AM (2012) A comparative life cycle assessment study of polyethylene based on sugarcane and crude oil. J Ind Ecol 16(3):420–435. https://doi.org/10.1111/j.1530-9290.2011.00405.x

Molina MJ, Molina LT (2004) Megacities and atmospheric pollution. J Air Waste Manage Assoc 54(6):644–680. https://doi.org/10.1080/10473289.2004.10470936

Poeschl M, Ward S, Owende P (2012) Environmental impacts of biogas deployment – part I: life cycle inventory for evaluation of production process emissions to air. J Clean Prod 24:168–183. https://doi.org/10.1016/j.jclepro.2011.10.039

Réchauchère O, El Akkari M, Le Perchec S, Makowski D, Gabrielle B, Bispo A (this volume) An innovative methodological framework for analyzing existing scientific research on land-use change and associated environmental impacts. In: Réchauchère O, Bispo A, Gabrielle B, Makowski D (eds) Sustainable agriculture reviews, vol 30. Springer, Cham

Schwartz J, Bind MA, Koutrakis P (2017) Estimating causal effects of local air pollution on daily deaths: effect of low levels. Environ Health Perspect 125(1):23–29. https://doi.org/10.1289/ehp232

Searchinger T, Heimlich R, Houghton RA, Dong FX, Elobeid A, Fabiosa J, Tokgoz S, Hayes D, Yu TH (2008) Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change. Science 319(5867):1238–1240. https://doi.org/10.1126/science.1151861

Seufert V, Ramankutty N, Foley JA (2012) Comparing the yields of organic and conventional agriculture. Nature 485(7397):229–232

Steinemann A (2000) Rethinking human health impact assessment. Environ Impact Assess Rev 20(6):627–645. https://doi.org/10.1016/S0195-9255(00)00068-8

van Vliet J, Magliocca NR, Buchner B, Cook E, Benayas JMR, Ellis EC, Heinimann A, Keys E, Lee TM, Liu JG, Mertz O, Meyfroidt P, Moritz M, Poeplau C, Robinson BE, Seppelt R, Seto KC, Verburg PH (2016) Meta-studies in land use science: current coverage and prospects. Ambio 45(1):15–28. https://doi.org/10.1007/s13280-015-0699-8

von Blottnitz H, Curran MA (2007) A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life cycle perspective. J Clean Prod 15(7):607–619. https://doi.org/10.1016/j.jclepro.2006.03.002

Annex: References in the Study Corpus Addressing Impacts on Air Quality and Human Health

Alvarenga RAF, Dewulf J, De Meester S, Wathelet A, Villers J, Thommeret R, Hruska Z (2013) Life cycle assessment of bioethanol-based PVC. Part 2: consequential approach. Biofuels Bioprod Biorefin-Biofpr 7(4):396–405. https://doi.org/10.1002/bbb.1398

Bottcher H, Frank S, Havlik P, Elbersen B (2013) Future GHG emissions more efficiently controlled by land-use policies than by bioenergy sustainability criteria. Biofuels Bioprod Biorefin-Biofpr 7(2):115–125. https://doi.org/10.1002/bbb.1369

Cavalett O, Chagas MF, Seabra JEA, Bonomi A (2013) Comparative LCA of ethanol versus gasoline in Brazil using different LCIA methods. Int J Life Cycle Assess 18(3):647–658. https://doi.org/10.1007/s11367-012-0465-0

Cherubini F, Ulgiati S (2010) Crop residues as raw materials for biorefinery systems – a LCA case study. Appl Energy 87(1):47–57. https://doi.org/10.1016/j.apenergy.2009.08.024

Clark CM, Lin Y, Bierwagen BG, Eaton LM, Langholtz MH, Morefield PE, Ridley CE, Vimmerstedt L, Peterson S, Bush BW (2013) Growing a sustainable biofuels industry: economics, environmental considerations, and the role of the Conservation Reserve Program. Environ Res Lett 8(2):025016. https://doi.org/10.1088/1748-9326/8/2/025016

Daystar J, Gonzalez R, Reeb C, Venditti R, Treasure T, Abt R, Kelley S (2014) Economics, environmental impacts, and supply chain analysis of cellulosic biomass for biofuels in the Southern US: Pine, eucalyptus, unmanaged hardwoods, forest residues, switchgrass, and sweet sorghum. Bioresources 9(1):393–444

Falano T, Jeswani HK, Azapagic A (2014) Assessing the environmental sustainability of ethanol from integrated biorefineries. Biotechnol J 9(6):753–765. https://doi.org/10.1002/biot.201300246

Fiorentino G, Ripa M, Mellino S, Fahd S, Ulgiati S (2014) Life cycle assessment of Brassica carinata biomass conversion to bioenergy and platform chemicals. J Clean Prod 66:174–187. https://doi.org/10.1016/j.jclepro.2013.11.043

Gabrielle B, Gagnaire N, Massad RS, Dufosse K, Bessou C (2014) Environmental assessment of biofuel pathways in Ile de France based on ecosystem modeling. Bioresour Technol 152:511–518. https://doi.org/10.1016/j.biortech.2013.10.104

Larsen RK, Jiwan N, Rompas A, Jenito J, Osbeck M, Tarigan A (2014) Towards 'hybrid accountability' in EU biofuels policy? Community grievances and competing water claims in the Central Kalimantan oil palm sector. Geoforum 54:295–305. https://doi.org/10.1016/j.geoforum.2013.09.010

Liptow C, Tillman AM (2012) A comparative life cycle assessment study of polyethylene based on sugarcane and crude oil. J Ind Ecol 16(3):420–435. https://doi.org/10.1111/j.1530-9290.2011.00405.x

Panichelli L, Dauriat A, Gnansounou E (2009) Life cycle assessment of soybean-based biodiesel in Argentina for export. Int J Life Cycle Assess 14(2):144–159. https://doi.org/10.1007/s11367-008-0050-8

Reinhard J, Zah R (2011) Consequential life cycle assessment of the environmental impacts of an increased rapemethylester (RME) production in Switzerland. Biomass Bioenergy 35(6):2361–2373. https://doi.org/10.1016/j.biombioe.2010.12.011

Shonnard DR, Williams L, Kalnes TN (2010) Camelina-derived jet fuel and diesel: sustainable advanced biofuels. Environ Prog Sustain Energy 29(3):382–392. https://doi.org/10.1002/ep.10461

Silalertruksa T, Gheewala SH (2012) Environmental sustainability assessment of palm biodiesel production in Thailand. Energy 43(1):306–314. https://doi.org/10.1016/j.energy.2012.04.025

Styles D, Jones MB (2008) Life-cycle environmental and economic impacts of energy-crop fuel-chains: an integrated assessment of potential GHG avoidance in Ireland. Environ Sci Pol 11(4):294–306. https://doi.org/10.1016/j.envsci.2008.01.004

Suwanmanee U, Varabuntoonvit V, Chaiwutthinan P, Tajan M, Mungcharoen T, Leejarkpai T (2013) Life cycle assessment of single use thermoform boxes made from polystyrene (PS), polylactic acid, (PLA), and PLA/starch: cradle to consumer gate. Int J Life Cycle Assess 18(2):401–417. https://doi.org/10.1007/s11367-012-0479-7

Tsao CC, Campbell JE, Mena-Carrasco M, Spak SN, Carmichael GR, Chen Y (2012) Biofuels that cause land-use change may have much larger non-GHG air quality emissions than fossil fuels. Environ Sci Technol 46(19):10835–10841. https://doi.org/10.1021/es301851x

Turconi R, Tonini D, Nielsen CFB, Simonsen CG, Astrup T (2014) Environmental impacts of future low-carbon electricity systems: detailed life cycle assessment of a Danish case study. Appl Energy 132:66–73. https://doi.org/10.1016/j.apenergy.2014.06.078

van Dam J, Faaij APC, Hilbert J, Petruzzi H, Turkenburg WC (2009) Large-scale bioenergy production from soybeans and switchgrass in Argentina Part B. environmental and socio-economic impacts on a regional level. Renew Sust Energ Rev 13(8):1679–1709. https://doi.org/10.1016/j.rser.2009.03.012