Literature review on biogenic CO_2 emissions from industrial process associated with annual crop

July 21, 2020

Seungdo Kim

Prepared for the Biogenic CO_2 Coalition

Introduction

I have been asked by the Biogenic CO_2 Coalition to review peer-reviewed scientific articles that address biogenic carbon dioxide emissions from annual crop-based product systems and their potential impact on atmospheric greenhouse gases, with a particular focus on how biogenic CO_2 emissions from stationary sources are calculated in greenhouse gas (GHG) accounting schemes. Relevant scientific articles published from 2010 to present were selected for review from the Web of Sciences database using the Boolean search terms below. About 100 articles have been deemed suitable for review, and the majority of articles reviewed here are concerning biofuel or bioenergy.

(biogenic OR CO_2 OR "greenhouse gas" or GHG) AND ("carbon accounting" or "greenhouse gas accounting" or "GHG accounting" or LCA or "life cycle analysis" or "carbon footprint") AND (corn or soybean or cotton or “annual crop”) NOT (wood or tree or "woody material" or forest or animal or dairy or manure or "anaerobic")

Biogenic CO_2 emission sources associated with the annual crop-based product system are: (1) carbon stock loss due to direct land conversion from forest/grassland to cropland, (2) carbon stock loss by indirect land use change (ILUC) (3) soil organic carbon loss, (4) stationary sources (e.g., fermentation, etc.), and (5) combustion of biomass and biofuel. The first three emission sources are out of the scope of this literature review since the focus is on biogenic CO_2 released from stationary sources. Therefore, this review focuses on the last two emission sources.

There are three main approaches to dealing with the biogenic carbon dioxide emissions in GHG accounting: (1) Neutrality, (2) Input-output and (3) Additionality.

Neutrality

In the Neutrality approach, biogenic CO_2 emissions from stationary and mobile sources associated with annual crops are carbon neutral. The biogenic carbon released as CO_2 from any stationary/mobile sources (e.g., fermentation, combustion of annual crop, etc.) does not affect climate change. This is a steady state condition because all biogenic CO_2 released into the atmosphere is absorbed by biomass growth over a short period of time. Therefore, biogenic CO_2 emissions are excluded from GHG accounting. Most of articles reviewed here (83 out of 108 articles) use this Neutrality approach in their GHG accounting without including biogenic CO_2 emissions. Furthermore, the Neutrality approach has been widely used in regulation (EPA, 2010) and international guidelines (UNFCCC, 2006; IPCC 2006).

Input-output

In the input-output approach, carbon flux taken up by biomass and biogenic carbon releases are taken into account in the GHG calculations. Some LCA studies reviewed here (14 articles) use this approach and show that carbon uptake by crops completely offsets biogenic CO_2 emissions associated with annual crops. Articles from Argonne National Laboratory (Wang et al., 2012, Dunn et al., 2012, Cai et al. 2013) also use the input-output approach. These articles subtract the biogenic carbon credit from combustion of biofuel, but do not include biogenic CO_2 emissions from fermentation in their GHG calculations. van der Voet et al. (2010) found that exclusion of biogenic carbon generates the same results when co-products are not produced in the biofuel system. However, for biofuel systems with co-products, excluding biogenic carbon produces different results due to the allocation method. It is clear that the magnitude of carbon uptake by biomass allocated to biofuel is not always the same as the magnitude of biogenic carbon emissions from biofuel, because allocation is usually done by physical (e.g., mass, energy, etc.) or economic properties, not molecular weight. Before the allocation, carbon uptake by biomass is the same as biogenic carbon emissions. Therefore, this is an allocation issue, not a carbon neutrality issue.

Additionality

Currently, several studies (Searchinger, 2010; Haberl et al., 2012; DeCicco, 2015; DeCicco et al., 2016; DeCicco, 2018) have questioned the carbon neutrality of biogenic CO_2 emissions, especially biogenic CO_2 emissions in the bioenergy/biofuel system. "Additional biomass (or additional carbon uptake on cropland)" is the key concept in those studies. They claimed that if no bioenergy were produced, plants for bioenergy would not be harvested and would continue to absorb carbon, helping to reduce CO_2 in the air. In global projections of atmospheric carbon, treating biogenic CO_2 emissions released in the bioenergy system as carbon neutral is a "double-counting error". Atmospheric carbon is absorbed by plants regardless of bioenergy. Therefore, biogenic CO_2 emissions should be offset by additional carbon uptake on cropland. DeCicco et al. (2016) claimed that only 37% of the biogenic CO_2 emissions in corn-based ethanol fuel production systems should be offset by carbon uptake by additional corn production, so only 37% of biogenic CO_2 emissions are carbon neutral. However, this analysis struggles with uncertainties related to inconsistent system boundaries, selection of periods for evaluation, economic conditions and weather dependence (De Kleine et al., 2016; De Kleine et al., 2017; Khanna et al., 2020). De Kleine et al. (2017) pointed out that biogenic carbon in corn grain is released into the atmosphere in a short time, even when used as biofuel or food/feed. As a result, there is no substantial change in net carbon emissions to the atmosphere. Wang et al. (2015) raised two questions about the additional biomass:

- "Would farmers/growers continue to grow biomass if there were no demand for biomass due to bioenergy production? In particular, if there were no cellulosic biofuel industry demanding cellulosic biomass, can one assume that farmers/growers would grow cellulosic biomass anyway?"

- "When bioenergy production results in managed biomass growth, how does the growth rate differ from that of natural biomass growth?"

The additional biomass (or additional carbon uptake on cropland) relies heavily on value-choice and scenario-based modeling. Similar to ILUC, the additionality approach assigns to biofuel/bioenergy all the changes in the crop system in spite of many inter-related factors that also contribute to changes in the crop system. These inter-related factors include local and global economic conditions, weather, national policy, international trade, dietary preferences, biofuel/bioenergy, technology improvements, etc. In other words, the "additionality approach" is oversimplified.

Other approaches

Cherubini et al. (2011) quantified global warming potentials (GWP) for biogenic CO_2 emissions, taking into account the timing of biogenic CO_2 emissions and uptake by biomass regrowth (at the end of the rotation period). Therefore, the modified GWP for biogenic CO_2 emissions depends on the biomass rotation period, as seen in Table 1. The modified GWP for biogenic CO_2 emissions released form one-year rotation biomass (e.g., annual crop, grass, etc.) is zero, implying that biogenic CO_2 emissions associated with one-year rotation biomass have no negative impact on the climate per unit of biogenic CO_2 emitted from stationary/mobile sources associated with annual crops.

Downie et al. (2014) investigated three different GHG accounting methods: 1) the biogenic method, which includes biogenic CO_2 emissions, even though they may be neutral over the timeframe; (2) the stock method, which excludes biogenic CO_2 emissions, but includes credit for biogenic carbon not released for a long-term C cycle (e.g., biochar, etc.); and (3) the simplified method, in which the net biogenic CO_2 flux is neutral over the timeframe. The biogenic method is corrected if the term for carbon uptake by biomass is added. The stock method is the most accurate method to forecast the net change in atmospheric GHG for activities that involve biogenic carbon. When all biogenic carbon is released over a short time of period, results from the simplified method are equal to those from the stock method.

Table 1 Modified GWPs for biogenic CO_2 emissions (Cherubini et al., 2011).

Rotation period (years)	**Modified GWP for biogenic CO_2 emission (time horizon = 100 years)**
1	0.00
10	0.04
20	0.08
50	0.21
70	0.30
100	0.43

Discussion

Brandao et al. (2013) pointed out that biogenic carbon management differs from fossil-fuel carbon management in that biomass can sequester and release carbon into the atmosphere. They were also concerned about the time differences between uptake and release of CO_2, even though CO_2 release is balanced by carbon uptake by biomass. The time lag between uptake and release of CO_2 will lead to different trajectories of atmospheric CO_2 concentrations and thus different cumulative radiative forcing, which have different impacts on climate change. In annual crop-based systems, uptake and release of CO_2 occur within one year. As seen in Cherubini et al (2011), the effects of the time lag in the annual crop-based systems can be negligible. Thus, the time lag issues are not relevant in the annual crop systems.

Table A in the Appendix A lists articles, their feedstock types and the biogenic CO_2 accounting approach. For clarity, the text of each article on biogenic carbon is also quoted in the table if available. Biogenic CO_2 emissions associated with annual crops, perennials and other biomass in 104 articles out of 108 are regarded as carbon neutral regardless of the biogenic carbon accounting approaches (i.e., Neutrality, Input-out approaches and Modified GWP). Note that some articles do not mention biogenic carbon in their text at all, suggesting that biogenic carbon is not taken into account. The 104 articles reviewed here show that biogenic CO_2 emissions from stationary/mobile sources associated with annual crops are completely balanced by biomass regrowth over a short period of time; i.e., carbon neutral.

References

Abraha M, Gelfand I, Hamilton SK, Chen J, Robertson GP. Carbon debt of field-scale conservation reserve program grasslands converted to annual and perennial bioenergy crops. Environmental Research Letters. 2019;14(2).

Acquaye AA, Sherwen T, Genovese A, Kuylenstierna J, Koh SCL, McQueen-Mason S. Biofuels and their potential to aid the UK towards achieving emissions reduction policy targets. Renewable & Sustainable Energy Reviews. 2012;16(7):5414-22.

Adom FK, Dunn JB. Life cycle analysis of corn-stover-derived polymer-grade l-lactic acid and ethyl lactate: greenhouse gas emissions and fossil energy consumption. Biofuels Bioproducts & Biorefining-Biofpr. 2017;11(2):258-68.

Aguirre-Villegas HA, Larson R, Reinemann DJ. Effects of management and co-digestion on life cycle emissions and energy from anaerobic digestion. Greenhouse Gases-Science and Technology. 2015;5(5):603-21.

Akmalina R, Pawitra MG. Life cycle assessment of ethylene production from empty fruit bunch. Asia-Pacific Journal of Chemical Engineering. 2020;15(3).

Bartocci P, Zampilli M, Liberti F, Pistolesi V, Massoli S, Bidini G, et al. LCA analysis of food waste co-digestion. Science of the Total Environment. 2020;709.

Belboom S, Bodson B, Leonard A. Does the production of Belgian bioethanol fit with European requirements on GHG emissions? Case of wheat. Biomass & Bioenergy. 2015;74:58-65.

Bicalho T, Sauer I, Patino-Echeverri D. Quality of data for estimating GHG emissions in biofuel regulations is unknown: A review of default values related to sugarcane and corn ethanol. Journal of Cleaner Production. 2019;239.

Borjesson P, Prade T, Lantz M, Bjornsson L. Energy Crop-Based Biogas as Vehicle Fuel-The Impact of Crop Selection on Energy Efficiency and Greenhouse Gas Performance. Energies. 2015;8(6):6033-58.

Brandao, M.; Levasseur, A.; Kirschbaum, M. U. F.; Weidema, B. P.; Cowie, A. L.; Jorgensen, S. V.; Hauschild, M. Z.; Pennington, D. W.; Chomkhamsri, K., Key issues and options in accounting for carbon sequestration and temporary storage in life cycle assessment and carbon footprinting. International Journal of Life Cycle Assessment 2013, 18 (1), 230-240.

Buchspies B, Kaltschmitt M. A consequential assessment of changes in greenhouse gas emissions due to the introduction of wheat straw ethanol in the context of European legislation. Applied Energy. 2018;211:368-81.

Cai H, Dunn JB, Wang ZC, Han JW, Wang MQ. Life-cycle energy use and greenhouse gas emissions of production of bioethanol from sorghum in the United States. Biotechnology for Biofuels. 2013;6(141):(2 October 2013)-(2 October).

Canter CE, Dunn JB, Han J, Wang Z, Wang M. Policy Implications of Allocation Methods in the Life Cycle Analysis of Integrated Corn and Corn Stover Ethanol Production. Bioenergy Research. 2016;9(1):77-87.

Carvalho M, da Silva ES, Andersen SLF, Abrahao R. Life cycle assessment of the transesterification double step process for biodiesel production from refined soybean oil in Brazil. Environmental Science and Pollution Research. 2016;23(11):11025-33.

Chen R, Qin Z, Han J, Wang M, Taheripour F, Tyner W, et al. Life cycle energy and greenhouse gas emission effects of biodiesel in the United States with induced land use change impacts. Bioresource Technology. 2018;251:249-58.

CHERUBINI, F.; PETERS, G. P.; BERNTSEN, T.; STRØMMAN, A. H.; HERTWICH, E., CO2 emissions from biomass combustion for bioenergy: atmospheric decay and contribution to global warming. GCB Bioenergy 2011, 3 (5), 413-426

Daylan B, Ciliz N. Life cycle assessment and environmental life cycle costing analysis of lignocellulosic bioethanol as an alternative transportation fuel. Renewable Energy. 2016;89:578-87.

Daystar J, Treasure T, Reeb C, Venditti R, Gonzalez R, Kelley S. Environmental impacts of bioethanol using the NREL biochemical conversion route: multivariate analysis and single score results. Biofuels Bioproducts & Biorefining-Biofpr. 2015;9(5):484-500.

De Kleine, R. D.; Anderson, J. E.; Kim, H. C.; Wallington, T. J., Life cycle assessment is the most relevant framework to evaluate biofuel greenhouse gas burdens. Biofuels Bioproducts & Biorefining-Biofpr 2017, 11 (3), 407-416.

De Kleine, R. D.; Wallington, T. J.; Anderson, J. E.; Kim, H. C., Commentary on "carbon balance effects of US biofuel production and use," by DeCicco et al. (2016). Climatic Change 2017, 144 (2), 111-119.

DeCicco, J. M., The liquid carbon challenge: evolving views on transportation fuels and climate. Wiley Interdisciplinary Reviews-Energy and Environment 2015, 4 (1), 98-114.

DeCicco JM. Methodological Issues Regarding Biofuels and Carbon Uptake. Sustainability. 2018;10(5).

DeCicco, J. M.; Liu, D. Y.; Heo, J.; Krishnan, R.; Kurthen, A.; Wang, L., Carbon balance effects of US biofuel production and use. Climatic Change 2016, 138 (3-4), 667-680.

Downie A, Lau D, Cowie A, Munroe P. Approaches to greenhouse gas accounting methods for biomass carbon. Biomass & Bioenergy. 2014;60:18-31.

Dunn JB, Mueller S, Wang M, Han J. Energy consumption and greenhouse gas emissions from enzyme and yeast manufacture for corn and cellulosic ethanol production. Biotechnology Letters. 2012;34(12):2259-63.

Eerhart AJJE, Faaij APC, Patel MK. Replacing fossil based PET with biobased PEF; process analysis, energy and GHG balance. Energy & Environmental Science. 2012;5(4):6407-22.

EPA (2010) Regulation of fuels and fuel additives: changes to renewable fuel standard program; final rule. US Environmental Protection Agency, Washington, DC, Federal Register 75(58): 14669ff

Eranki PL, Manowitz DH, Bals BD, Izaurralde RC, Kim S, Dale BE. The watershed-scale optimized and rearranged landscape design (WORLD) model and local biomass processing depots for sustainable biofuel production: Integrated life cycle assessments. Biofuels Bioproducts & Biorefining-Biofpr. 2013;7(5):537-50.

Fazio S, Monti A. Life cycle assessment of different bioenergy production systems including perennial and annual crops. Biomass & Bioenergy. 2011;35(12):4868-78.

Feng H, Rubin OD, Babcock BA. Greenhouse gas impacts of ethanol from Iowa corn: Life cycle assessment versus system wide approach. Biomass & Bioenergy. 2010;34(6):912-21.

Garba NA, Duckers LJ, Hall WJ. Climate change impacts on life cycle greenhouse gas (GHG) emissions savings of biomethanol from corn and soybean. International Journal of Life Cycle Assessment. 2014;19(4):806-13.

Gonzalez-Garcia S, Teresa Moreira M, Feijoo G. Comparative environmental performance of lignocellulosic ethanol from different feedstocks. Renewable & Sustainable Energy Reviews. 2010;14(7):2077-85.

Grau B, Bernat E, Rita P, Jordi-Roger R, Antoni R. Environmental life cycle assessment of rapeseed straight vegetable oil as self-supply agricultural biofuel. Renewable Energy. 2013;50:142-9.

Guzman-Soria D, Taboada-Gonzalez P, Aguilar-Virgen Q, Baltierra-Trejo E, Marquez-Benavides L. Environmental Impact of Corn Tortilla Production: A Case Study. Applied Sciences-Basel. 2019;9(22).

Haberl, H.; Sprinz, D.; Bonazountas, M.; Cocco, P.; Desaubies, Y.; Henze, M.; Hertel, O.; Johnson, R. K.; Kastrup, U.; Laconte, P.; Lange, E.; Novak, P.; Paavola, J.; Reenberg, A.; van den Hove, S.; Vermeire, T.; Wadhams, P.; Searchinger, T., Correcting a fundamental error in greenhouse gas accounting related to bioenergy. Energy Policy 2012, 45, 18-23.

Hajjaji N, Pons M-N, Renaudin V, Houas A. Comparative life cycle assessment of eight alternatives for hydrogen production from renewable and fossil feedstock. Journal of Cleaner Production. 2013;44:177-89.

Han D, Yang X, Li R, Wu Y. Environmental impact comparison of typical and resource-efficient biomass fast pyrolysis systems based on LCA and Aspen Plus simulation. Journal of Cleaner Production. 2019;231:254-67.

Han J, Elgowainy A, Dunn JB, Wang MQ. Life cycle analysis of fuel production from fast pyrolysis of biomass. Bioresource Technology. 2013;133:421-8.

Heng L, Xiao R, Zhang H. Life cycle assessment of hydrogen production via iron-based chemical-looping process using non-aqueous phase bio-oil as fuel. International Journal of Greenhouse Gas Control. 2018;76:78-84.

Heng L, Zhang H, Xiao J, Xiao R. Life Cycle Assessment of Polyol Fuel from Corn Stover via Fast Pyrolysis and Upgrading. Acs Sustainable Chemistry & Engineering. 2018;6(2):2733-40.

Hums ME, Cairncross RA, Spatari S. Life-Cycle Assessment of Biodiesel Produced from Grease Trap Waste. Environmental Science & Technology. 2016;50(5):2718-26.

IPCC (Intergovernmental Panel on Climate Change) 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 1: General Guidance and Reporting. Hayama, Kanagawa, Japan: Institute for Global Environmental Strategies.

Iriarte A, Rieradevall J, Gabarrell X. Life cycle assessment of sunflower and rapeseed as energy crops under Chilean conditions. Journal of Cleaner Production. 2010;18(4):336-45.

Jeswani HK, Falano T, Azapagic A. Life cycle environmental sustainability of lignocellulosic ethanol produced in integrated thermo-chemical biorefineries. Biofuels Bioproducts & Biorefining-Biofpr. 2015;9(6):661-76.

Kaliyan N, Morey RV, Tiffany DG. Reducing life cycle greenhouse gas emissions of corn ethanol by integrating biomass to produce heat and power at ethanol plants. Biomass & Bioenergy. 2011;35(3):1103-13.

Kauffman N, Hayes D, Brown R. A life cycle assessment of advanced biofuel production from a hectare of corn. Fuel. 2011;90(11):3306-14.

Kaufman AS, Meier PJ, Sinistore JC, Reinemann DJ. Applying life-cycle assessment to low carbon fuel standards-How allocation choices influence carbon intensity for renewable transportation fuels. Energy Policy. 2010;38(9):5229-41.

Khanna M, Wang W, Wang M. Assessing the Additional Carbon Savings with Biofuel. Bioenergy Research. 2020.

Khoshnevisan B, Rafiee S, Tabatabaei M, Ghanavati H, Mohtasebi SS, Rahimi V, et al. Life cycle assessment of castor-based biorefinery: a well to wheel LCA. International Journal of Life Cycle Assessment. 2018;23(9):1788-805.

Kim S, Dale BE, Jin M, Thelen KD, Zhang X, Meier P, et al. Integration in a depot-based decentralized biorefinery system: Corn stover-based cellulosic biofuel. Global Change Biology

Bioenergy. 2019;11(7):871-82.

Kim S, Dale BE, Zhang XS, Jones CD, Reddy AD, Izaurralde RC. The Renewable Fuel Standard May Limit Overall Greenhouse Gas Savings by Corn Stover-Based Cellulosic Biofuels in the US Midwest: Effects of the Regulatory Approach on Projected Emissions. Environmental Science & Technology. 2019;53(5):2288-94.

Kim S, Dale BE. A distributed cellulosic biorefinery system in the US Midwest based on corn stover. Biofuels Bioproducts & Biorefining-Biofpr. 2016;10(6):819-32.

Kim S, Dale BE. All biomass is local: The cost, volume produced, and global warming impact of cellulosic biofuels depend strongly on logistics and local conditions. Biofuels Bioproducts & Biorefining-Biofpr. 2015a;9(4):422-34.

Kim S, Dale BE. Comparing alternative cellulosic biomass biorefining systems: Centralized versus distributed processing systems. Biomass & Bioenergy. 2015b;74:135-47.

Kim S, Zhang XS, Dale B, Reddy AD, Jones CD, Cronin K, et al. Corn stover cannot simultaneously meet both the volume and GHG reduction requirements of the renewable fuel standard. Biofuels Bioproducts & Biorefining-Biofpr. 2018;12(2):203-12.

Kim S, Zhang XS, Dale BE, Reddy AD, Jones CD, Izaurralde RC. EISA (Energy Independence and Security Act) compliant ethanol fuel from corn stover in a depot-based decentralized system. Biofuels Bioproducts & Biorefining-Biofpr. 2018;12(5):873-81.

Knoope MMJ, Balzer CH, Worrell E. Analysing the water and greenhouse gas effects of soya bean-based biodiesel in five different regions. Global Change Biology Bioenergy. 2019;11(2):381-99.

Krohn BJ, Fripp M. A life cycle assessment of biodiesel derived from the "niche filling" energy crop camelina in the USA. Applied Energy. 2012;92:92-8.

Kumar D, Murthy GS. Life cycle assessment of energy and GHG emissions during ethanol production from grass straws using various pretreatment processes. International Journal of Life Cycle Assessment. 2012;17(4):388-401.

Kusiima JM, Powers SE. Monetary value of the environmental and health externalities associated with production of ethanol from biomass feedstocks. Energy Policy. 2010;38(6):2785-96.

Lienhardt T, Black K, Saget S, Costa MP, Chadwick D, Rees RM, et al. Just the tonic! Legume biorefining for alcohol has the potential to reduce Europe's protein deficit and mitigate climate change. Environment International. 2019;130.

Liptow, C.; Janssen, M.; Tillman, A.-M., Accounting for effects of carbon flows in LCA of biomass-based products—exploration and evaluation of a selection of existing methods. The International Journal of Life Cycle Assessment 2018, 23 (11), 2110-2125.

Liu C, Huang Y, Wang X, Tai Y, Liu L, Liu H. Total environmental impacts of biofuels from corn stover using a hybrid life cycle assessment model combining process life cycle assessment and economic input-output life cycle assessment. Integrated Environmental Assessment and Management. 2018;14(1):139-49.

Liu H, Ou X, Yuan J, Yan X. Experience of producing natural gas from corn straw in China. Resources Conservation and Recycling. 2018;135:216-24.

Mahmud N, Rosentrater KA. Life-Cycle Assessment (LCA) of Different Pretreatment and Product Separation Technologies for Butanol Bioprocessing from Oil Palm Frond. Energies. 2020;13(1).

Martinez-Hernandez E, Campbell GM, Sadhukhan J. Economic and environmental impact marginal analysis of biorefinery products for policy targets. Journal of Cleaner Production. 2014;74:74-85.

Martinez-Hernandez E, Ibrahim MH, Leach M, Sinclair P, Campbell GM, Sadhukhan J. Environmental sustainability analysis of UK whole-wheat bioethanol and CHP systems. Biomass & Bioenergy. 2013;50:52-64.

Melamu R, von Blottnitz H. 2nd Generation biofuels a sure bet? A life cycle assessment of how things could go wrong. Journal of Cleaner Production. 2011;19(2-3):138-44.

Michailos, S., Process design, economic evaluation and life cycle assessment of jet fuel production from sugar cane residue. Environmental Progress & Sustainable Energy 2018, 37 (3), 1227-1235.

Moller F, Slento E, Frederiksen P. Integrated well-to-wheel assessment of biofuels combining energy and emission LCA and welfare economic Cost Benefit Analysis. Biomass & Bioenergy. 2014;60:41-9.

Moreno J, Iglesias J, Blanco J, Montero M, Morales G, Melero JA.1 Life-cycle sustainability of biomass-derived sorbitol: Proposing technological alternatives for improving the environmental profile of a bio-refinery platform molecule. Journal of Cleaner Production. 2020;250.

Munoz I, Flury K, Jungbluth N, Rigarlsford G, Canals LMI, King H. Life cycle assessment of bio-based ethanol produced from different agricultural feedstocks. International Journal of Life Cycle Assessment. 2014;19(1):109-19.

Murphy CW, Kendall A. Life cycle analysis of biochemical cellulosic ethanol under multiple scenarios. Global Change Biology Bioenergy. 2015;7(5):1019-33.

Nguyen L, Cafferty KG, Searcy EM, Spatari S. Uncertainties in Life Cycle Greenhouse Gas Emissions from Advanced Biomass Feedstock Logistics Supply Chains in Kansas. Energies. 2014;7(11):7125-46.

Obnamia JA, Dias GM, MacLean HL, Saville BA. Comparison of US Midwest corn stover ethanol greenhouse gas emissions from GREET and GHGenius. Applied Energy. 2019;235:591-601.

Oliveira MdCTBE, Rosentrater KA. An Environmental and Economic Analysis of Flocculation Technology Applied to a Corn-Based Ethanol Plant. Processes. 2020;8(3).

Olukoya IA, Ramachandriya KD, Wilkins MR, Aichele CP. Life cycle assessment of the production of ethanol from eastern redcedar. Bioresource Technology. 2014;173:239-44.

Patrizi N, Caro D, Pulselli FM, Bjerre AB, Bastianoni S. Environmental feasibility of partial substitution of gasoline with ethanol in the Province of Siena (Italy). Journal of Cleaner Production. 2013;47:388-95.

Pecanha Esteves VP, Vaz Morgado CdR, Fernandes Araujo OdQ. Regional and temporal sustainability assessment of agricultural-based biodiesel. Clean Technologies and Environmental Policy. 2020;22(4):965-78.

Pellegrino Cerri CE, You X, Cherubin MR, Moreira CS, Raucci GS, Castigioni BdA, et al. Assessing the greenhouse gas emissions of Brazilian soybean biodiesel production. Plos One. 2017;12(5).

Pourhashem G, Adler PR, Spatari S. Time effects of climate change mitigation strategies for second generation biofuels and co-products with temporary carbon storage. Journal of Cleaner Production. 2016;112:2642-53.

Prieler M, Lindorfer J, Steinmueller H. Life-cycle assessment of green biorefinery process options. Biofuels Bioproducts & Biorefining-Biofpr. 2019;13(6):1391-401.

Rathnayake, M.; Chaireongsirikul, T.; Svangariyaskul, A.; Lawtrakul, L.; Toochinda, P., Process simulation based life cycle assessment for bioethanol production from cassava, cane molasses, and rice straw. Journal of Cleaner Production 2018, 190, 24-35.

Reinhard J, Zah R. Consequential life cycle assessment of the environmental impacts of an increased rapemethylester (RME) production in Switzerland. Biomass & Bioenergy. 2011;35(6):2361-73.

Roy P, Tokuyasu K, Orikasa T, Nakamura N, Shiina T. A Review of Life Cycle Assessment (LCA) of Bioethanol from Lignocellulosic Biomass. Jarq-Japan Agricultural Research Quarterly. 2012;46(1):41-57.

Sanscartier D, Dias G, Deen B, Dadfar H, McDonald I, MacLean HL. Life cycle greenhouse gas emissions of electricity generation from corn cobs in Ontario, Canada. Biofuels Bioproducts & Biorefining-Biofpr. 2014;8(4):568-78.

Sastre CM, Gonzalez-Arechavala Y, Santos AM. Global warming and energy yield evaluation of Spanish wheat straw electricity generation - A LCA that takes into account parameter uncertainty and variability. Applied Energy. 2015;154:900-11.

Scacchi CCO, Gonzalez-Garcia S, Caserini S, Rigamonti L. Greenhouse gases emissions and energy use of wheat grain-based bioethanol fuel blends. Science of the Total Environment. 2010;408(21):5010-8.

Schumacher B, Oechsner H, Senn T, Jungbluth T. Life cycle assessment of the conversion of Zea mays and x Triticosecale into biogas and bioethanol. Engineering in Life Sciences. 2010;10(6):577-84.

Searchinger, T. D., Biofuels and the need for additional carbon. Environmental Research Letters 2010, 5 (2).

Semba T, Sakai Y, Sakanishi T, Inaba A. Greenhouse gas emissions of 100% bio-derived polyethylene terephthalate on its life cycle compared with petroleum-derived polyethylene terephthalate. Journal of Cleaner Production. 2018;195:932-8.

Sharara MA, Sahoo K, Reddy AD, Kim S, Zhang XS, Dale B, et al. Sustainable feedstock for bioethanol production: Impact of spatial resolution on the design of a sustainable biomass supply-chain. Bioresource Technology. 2020;302.

Shuai W, Chen N, Li B, Zhou D, Gao J. Life cycle assessment of common reed (Phragmites australis (Cav) Trin. ex Steud) cellulosic bioethanol in Jiangsu Province, China. Biomass & Bioenergy. 2016;92:40-7.

Smullen E, Finnan J, Dowling D, Mulcahy P. The environmental performance of pretreatment technologies for the bioconversion of lignocellulosic biomass to ethanol. Renewable Energy. 2019;142:527-34.

Song S, Liu P, Xu J, Chong C, Huang X, Ma L, et al. Life cycle assessment and economic evaluation of pellet fuel from corn straw in China: A case study in Jilin Province. Energy. 2017;130:373-81.

Souza SP, Seabra JEA. Integrated production of sugarcane ethanol and soybean biodiesel: Environmental and economic implications of fossil diesel displacement. Energy Conversion and Management. 2014;87:1170-9.

Staples MD, Malina R, Suresh P, Hileman JI, Barrett SRH. Aviation CO2 emissions reductions from the use of alternative jet fuels. Energy Policy. 2018;114:342-54.

Su M, Huang C, Lin W, Tso C, Lur H. A Multi-Years Analysis of the Energy Balance, Green Gas Emissions, and Production Costs of First and Second Generation Bioethanol. International Journal of Green Energy. 2015;12(2):168-84.

Tabatabaie SMH, Tahami H, Murthy GS. A regional life cycle assessment and economic analysis of camelina biodiesel production in the Pacific Northwestern US. Journal of Cleaner Production. 2018;172:2389-400.

Tsang M, Fox-Lent C, Wallace S, Welp T, Bates M, Linkov I. Life-cycle impacts of soybean and algae biodiesel: Case study of US marine vessels. Biofuels Bioproducts & Biorefining-Biofpr. 2015;9(5):567-80.

Ukaew S, Shi R, Lee JH, Archer DW, Pearlson M, Lewis KC, et al. Full Chain Life Cycle Assessment of Greenhouse Gases and Energy Demand for Canola-Derived Jet Fuel in North

Dakota, United States. Acs Sustainable Chemistry & Engineering. 2016;4(5):2771-9.

UNFCCC (United Nations Framework Convention on Climate Change) 2006, Updated UNFCCC reporting guidelines on annual inventories following incorporation of the provisions of decision. 14/CE.11. FCCC/SBSTA/2006/9, Aug. 18.

Valli L, Rossi L, Fabbri C, Sibilla F, Gattoni P, Dale BE, et al. Greenhouse gas emissions of electricity and biomethane produced using the Biogasdoneright system: four case studies from Italy. Biofuels Bioproducts & Biorefining-Biofpr. 2017;11(5):847-60.

van der Voet, E.; Lifset, R. J.; Luo, L., Life-cycle assessment of biofuels, convergence and divergence. Biofuels-Uk 2010, 1 (3), 435-449.

Vargas-Ramirez JM, Wiesenborn DP, Ripplinger DG, Pryor SW. Carbon footprint of industrial-beet sugars stored as raw thick juice for use as a fermentation feedstock. Journal of Cleaner Production. 2017;162:1418-29.

Viskovic M, Djatkov D, Martinov M. Corn stover collection prior to biogas production - Evaluation of greenhouse gas emissions. Journal of Cleaner Production. 2018;199:383-90.

Voet Evd, Lifset RJ, Luo L. Life-cycle assessment of biofuels, convergence and divergence. Biofuels. 2010;1(3):435-49.

Wang C, Chang Y, Zhang L, Chen Y, Pang M. Quantifying uncertainties in greenhouse gas accounting of biomass power generation in China: System boundary and parameters. Energy. 2018;158:121-7.

Wang M, Han J, Dunn JB, Cai H, Elgowainy A. Well-to-wheels energy use and greenhouse gas emissions of ethanol from corn, sugarcane and cellulosic biomass for US use. Environmental Research Letters. 2012;7(4).

Wang MQ, Tyler WE, Williams D, Dunn JB (2015) Comments on and discussion of 'the liquid carbon challenge: evolving views on transportation fuels and climate.' Manuscript, March 30. Argonne National Laboratory, https://greet.es.anl.gov/publication-comments-liquid-carbon.

Weinberg J, Kaltschmitt M. Greenhouse gas emissions from first generation ethanol derived from wheat and sugar beet in Germany - Analysis and comparison of advanced by-product utilization pathways. Applied Energy. 2013;102:131-9.

Yan X, Boies AM. Quantifying the uncertainties in life cycle greenhouse gas emissions for UK wheat ethanol. Environmental Research Letters. 2013;8(1).

Yang Y, Ni J-Q, Bao W, Zhao L, Xie GH. Potential Reductions in Greenhouse Gas and Fine Particulate Matter Emissions Using Corn Stover for Ethanol Production in China. Energies. 2019;12(19).

Yang Y, Suh S. Marginal yield, technological advances, and emissions timing in corn ethanol's carbon payback time. International Journal of Life Cycle Assessment. 2015;20(2):226-32.

Zamboni A, Murphy RJ, Woods J, Bezzo F, Shah N. Biofuels carbon footprints: Whole-systems optimisation for GHG emissions reduction. Bioresource Technology. 2011;102(16):7457-65.

Zhang X, Witte J, Schildhauer T, Bauer C. Life cycle assessment of power-to-gas with biogas as the carbon source. Sustainable Energy & Fuels. 2020;4(3):1427-36.

Zhang Y, Kendall A. Life Cycle Performance of Cellulosic Ethanol and Corn Ethanol from a Retrofitted Dry Mill Corn Ethanol Plant. Bioenergy Research. 2017;10(1):183-98.

Zhao L, Ou X, Chang S. Life-cycle greenhouse gas emission and energy use of bioethanol produced from corn stover in China: Current perspectives and future prospectives. Energy. 2016;115:303-13.

Appendix A. Table A. List of articles

	Approach	Biomass	*Quotation*/Remark
Zhang X, Witte J, Schildhauer T, Bauer C. (2020)	Neutrality	anaerobic digestion of sewage sludge and green waste	*"Biogenic CO_2 emissions are not accounted for assuming a closed carbon circle."*
Sharara MA, Sahoo K, Reddy AD, Kim S, Zhang XS, Dale B, et al. (2020)	Neutrality	corn stover	not explicitly mentioned
Pecanha Esteves VP, Vaz Morgado CdR, Fernandes Araujo OdQ. (2020)	Neutrality	soybean and livestock	not explicitly mentioned
Oliveira MdCTBE, Rosentrater KA. (2020)	Neutrality	corn	not explicitly mentioned

Moreno J, Iglesias J, Blanco J, Montero M, Morales G, Melero JA. (2020)	Neutrality	corn	*"… sorbitol production starting from corn starch has been evaluated using a cradle-to-gate life cycle assessment (LCA) approach* *including biogenic carbon for calculations makes that CO_2 fixed during corn cultivation almost compensates the emissions of the rest of the process steps, highlighting the importance of using autotrophic biomass as raw materials."*

	Approach	Biomass	*Quotation*/Remark

Mahmud N, Rosentrater KA. (2020)	Neutrality	oil palm frond	*"According to the IPCC, only non-biogenic* CO_2 *emissions should be considered as greenhouse gas (GHG) emissions, which eventually contribute towards an increase in global warming potential (GWP). The biogenic* CO_2 *is not considered as GHG emission, because, throughout plants' life, they are conducting a photosynthesis process by taking* CO_2 *from the atmosphere (49). The biogenic CO2 emissions fractions in most of the simulated models were higher than that of non-biogenic, because of the large fraction of* CO_2 *generated during the fermentation process and the waste fibers burning in the CHP generation system."*
Khanna M, Wang W, Wang M. (2020)	Additionality	corn	Criticize uncertainty associate with selecting time frame for evaluation, economic conditions, and weather dependency

Bartocci P, Zampilli M, Liberti F, Pistolesi V, Massoli S, Bidini G, et al. (2020)	Neutrality	food waste	not explicitly mentioned
Akmalina R, Pawitra MG. (2020)	Neutrality	empty fruit bunch	*"Carbon dioxide released from the biomass-based process can be considered as biogenic carbon. It is the carbon contained in biomass during plant growth, involving photosynthetic process. In other words, this substance is possibly to be removed from the atmosphere through a carbon cycle."*

	Approach	Biomass	*Quotation*/Remark

Yang Y, Ni J-Q, Bao W, Zhao L, Xie GH. (2019)	Neutrality	corn stover	*"It was assumed that carbon in the form of CO_2 from vehicular ethanol combustion originated from biogenic carbon that was derived from corn stover because more than 96% of all carbon in the process entered as biomass feed, with only small amounts of additional carbon coming from glucose (for enzyme production) and fermentation nutrients such as corn steep liquor 33). Thus, CO_2 emissions from ethanol in the vehicle-use stage were negligible in this study."*
Smullen E, Finnan J, Dowling D, Mulcahy P. (2019)	Neutrality	switchgrass	not explicitly mentioned
Prieler M, Lindorfer J, Steinmueller H. (2019)	Neutrality	grass silage	*"The GWP excludes biogenic carbon so the bound carbon in the grass silage is not included."*

Obnamia JA, Dias GM, MacLean HL, Saville BA. (2019)	Neutrality	corn stove	*“The LCA software packages apply this approach by determining total emissions in the fuel use stage and then subtracting* CO_2 *emissions traceable to the fuel’s biogenic carbon component. This leads to net zero GWP for CO2 from the fuel’s biogenic carbon content (i.e., biofuel fraction) while* CO_2 *from the fuel’s fossil carbon fraction and all other non-*CO_2 *GHGs emitted in the fuel use stage are still accounted for.”*
Lienhardt T, Black K, Saget S, Costa MP, Chadwick D, Rees RM, et al. (2019)	Neutrality	pea and wheat	not explicitly mentioned
Knoope MMJ, Balzer CH, Worrell E. (2019)	Neutrality	soybean	not explicitly mentioned

	Approach	Biomass	*Quotation*/Remark
Kim S, Dale BE, Zhang XS, Jones CD, Reddy AD, Izaurralde RC. (2019)	Neutrality	corn stover	*“Biogenic carbon dioxide emissions released from combusting ethanol fuel are not included as GHG emissions.”*
Kim S, Dale BE, Jin M, Thelen KD, Zhang X, Meier P, et al. (2019)	Neutrality	corn stover	not explicitly mentioned

Han D, Yang X, Li R, Wu Y. (2019)	Input-output	corn stover	*"For GWPs, the percentage of absorption of carbon in the biomass production is higher than its release in the production process; thus, the net GWP is negative, and that the entire life cycle is absorbing GHGs."*
Guzman-Soria D, Taboada-Gonzalez P, Aguilar-Virgen Q, Baltierra-Trejo E, Marquez-Benavides L. (2019)	Neutrality	corn	not explicitly mentioned
Bicalho T, Sauer I, Patino-Echeverri D. (2019)	Neutrality	sugarcane and corn	not explicitly mentioned

Abraha M, Gelfand I, Hamilton SK, Chen J, Robertson GP. (2019)	Neutrality	switchgrass, restored prairie, and corn	*“We present a whole-system LCA of the global warming impact (GWI) of all converted fields over eight years by measuring GHG fluxes (CO_2, N_2O and CH_4), farming operations, agronomic inputs and a fossil fuel offset credit that include co-products.* *A fossil fuel offset credit for ethanol was computed from the dry mass yield (kg m^{-2} yr^{-1}), its ethanol production potential (L kg^{-1}), and its ethanol energy content (MJ L−1) compared to the equivalent energy and CO2 emissions for the gasoline use the ethanol would offset (table S6).*
	Approach	Biomass	*Quotation*/Remark

Wang C, Chang Y, Zhang L, Chen Y, Pang M. (2018)	Neutrality	corn stover	*" The GHG emissions of the CSPGS were categorized into two parts: 1) onsite emissions, including N_2O emission from the nitrification and denitrification processes in the soil, CO_2 emission from the soil tilling and erosion processes, CH_4 and N_2O emitted by biomass burning, and GHG emitted by fossil energy combustion; and 2) supply-chain emissions derived from material (building materials, fertilizers, pesticides, and water) production, power-plant equipment manufacturing, services provision (including transport, installation, and repair services), and fossil energy production and supply."*
Viskovic M, Djatkov D, Martinov M. (2018)	Neutrality	corn stover	*"Global warming potential (GWP 100 years) excluding biogenic carbon."*
Tabatabaie SMH, Tahami H, Murthy GS. (2018)	Neutrality	camelina	not explicitly mentioned

Staples MD, Malina R, Suresh P, Hileman JI, Barrett SRH. (2018)	Neutrality	soybean, rapeseed, jatropha and oil palm; maize grain, sorghum grain and cassava; sugarcane and sugar beet; switchgrass, miscanthus and reed canary grass	not explicitly mentioned

	Approach	Biomass	*Quotation*/Remark
Semba T, Sakai Y, Sakanishi T, Inaba A. (2018)	Neutrality	sugarcane and corn	*"It was assumed that PET was incinerated at the disposal stage and that biomass derived GHG emissions were carbon neutral.* CO_2 *emissions from biomass were assumed to be carbon neutral."*
Rathnayake, M.; Chaireongsirikul, T.; Svangariyaskul, A.; Lawtrakul, L.; Toochinda, P. (2018)	Neutrality	cassava, cane molasses, and rice straw	*"The carbon neutral rule is applied for biogenic* CO_2 *emissions (Neamhom et al., 2016)."*

Michailos, S. (2018)	Input-output	sugarcane	*"the amount of CO2 absorbed by photosynthesis during the sugarcane growth is subtracted from the total emissions of the system. The equivalent amount of CO2 stored in the sugarcane is estimated using the stoichiometric relationship of CO2 to carbon of 3.66 kg/kg 38."*
Liu H, Ou X, Yuan J, Yan X. (2018)	Neutrality	corn stover	not explicitly mentioned
Liu C, Huang Y, Wang X, Tai Y, Liu L, Liu H. (2018)	Input-output	corn stover	Carbon uptake (CO_2 absorption): 0.12 kg/MJ) Biogenic CO_2 emissions: 0.07 kg/MJ But before allocation, carbon uptake equals to biogenic CO_2 emissions

Liptow, C.; Janssen, M.; Tillman, A.-M., (2018)	Modified global warming potential	wood; sugarcane	*"In the case of boreal wood, this re-growth takes around 100 years, causing an impact of 3–4 t CO_2,eq/t PE using the GWPbio and the WF methods. In contrast, the sugarcane grows very fast, leading to an almost instantaneous uptake of emissions and hence an impact close to 0 t CO_2,eq/t PE."*

	Approach	Biomass	*Quotation*/Remark
Kim S, Zhang XS, Dale BE, Reddy AD, Jones CD, Izaurralde RC. (2018)	Neutrality	corn stover	not explicitly mentioned
Kim S, Zhang XS, Dale B, Reddy AD, Jones CD, Cronin K, et al. (2018).	Neutrality	corn stover	not explicitly mentioned

Khoshnevisan B, Rafiee S, Tabatabaei M, Ghanavati H, Mohtasebi SS, Rahimi V, et al. (2018)	Neutrality	castor	*"The origin of biomass, i.e., plants, absorbs atmospheric CO_2 during photosynthesis. This CO_2 is approximately equal to the amount of CO_2 released during their subsequent conversion and combustion (Naik et al. Osamu and Carl 1989). Therefore, biofuels not only can alleviate world's dependence on fossil-based fuels but also can simultaneously reduce global CO_2 production.* *... the CO_2 released from castor biodiesel was considered to be completely biogenic as the ethanol and methanol used for biodiesel production were assumed to be of biomass origin (ethanol was completely supplied internally by the biorefinery)."*

Heng L, Zhang H, Xiao J, Xiao R. (2018)	Neutrality	corn stover	*"The reduction in GHG emissions is mainly attributed to the biogenic CO_2 credit from the uptake of atmospheric CO_2 during growth of biomass. The biogenic CO_2 credit can offset the biogenic carbon emissions from biomass pyrolysis, bio-oil upgrading, biofuel consumption, and the disposal of carbonaceous organics in wastewater. Obviously, if the atmospheric CO_2 absorbed by biomass is returned to the atmosphere, the net greenhouse effect is nearly zero."*

	Approach	Biomass	*Quotation*/Remark

Heng L, Xiao R, Zhang H. (2018)	Neutrality	corn stover	*"The corn stover plays a role of carbon fixation via the uptake of atmospheric CO_2 during its growth. The biogenic carbon credit from CO_2 uptake can cancel out all the biogenic CO_2 emission from various unit processes including the disposal of carbonaceous organics in waste water."*
DeCicco JM. (2018).	Additionality	corn	Additional carbon uptake
Chen R, Qin Z, Han J, Wang M, Taheripour F, Tyner W, et al. (2018)	Input-output	soybean	accounting biodiesel combustion and biogenic carbon credit of the same scale
Buchspies B, Kaltschmitt M. (2018)	Neutrality	wheat straw	*"Emissions originating from the combustion of biofuels are considered to be carbon neutral due to the biogenic origin of carbon."*
Zhang Y, Kendall A. (2017)	Neutrality	corn grain and corn stover	not explicitly mentioned

Vargas-Ramirez JM, Wiesenborn DP, Ripplinger DG, Pryor SW. (2017)	Neutrality	Sugar beet	*“Carbon dioxide emitted during ethanol combustion was excluded from this analysis because it is biogenic and does not contribute to global warming potential (Muñoz et al., 2013).”*
Valli L, Rossi L, Fabbri C, Sibilla F, Gattoni P, Dale BE, et al. (2017)	Neutrality	cattle slurry, potato scraps, cereal by-products, corn silage, poultry droppings, sorghum silage, triticale silage, citrus pulp, olive and whey	not explicitly mentioned

	Approach	Biomass	*Quotation*/Remark
Song S, Liu P, Xu J, Chong C, Huang X, Ma L, et al. (2017)	Neutrality	corn stover	*“we first assume that biomass utilization is carbon neutral, which means that the CO_2 fixed by photosynthesis in the biomass equals the CO_2 emissions from burning the biomass.”*

Pellegrino Cerri CE, You X, Cherubin MR, Moreira CS, Raucci GS, Castigioni BdA, et al. (2017).	Neutrality	soybean	*"Our study did not mention the emissions from the final stage (i .e ., combustion) of the life cycle, because the combustion of soybean biodiesel emits biogenic CO_2, which is covered in the agriculture stage, and was considered as zero in this study."*
De Kleine, R. D.; Anderson, J. E.; Kim, H. C.; Wallington, T. J., (2017)	Additionality	corn	Criticize inconsistent system boundary
Adom FK, Dunn JB. (2017)	Input-output	corn stover	Biogenic carbon was treated as stored within the bioproduct in cradle-to-gate analyses. acconting CO_2 uptake during feedstock growth and CO_2 release upon degradation of the same scale
Zhao L, Ou X, Chang S. (2016)	Neutrality	corn stover	Subtracting biogenic CO2 from overall CO_2 emissions associated with E10 fuel
Ukaew S, Shi R, Lee JH, Archer DW, Pearlson M, Lewis KC, et al. (2016)	Neutrality	canola	*"The CO_2 emission from HEFA fuel combustion is considered as carbon neutral; therefore, this emission is not counted in the GHG analysis."*

Shuai W, Chen N, Li B, Zhou D, Gao J. (2016)	Neutrality	common reed	*“Because biogenic GHG emission was climate neutral, only GHG emissions from fossil fuel and other non-renewable resources were counted in calculation.”*

	Approach	Biomass	*Quotation*/Remark
Pourhashem G, Adler PR, Spatari S. (2016)	Neutrality	residue of corn, wheat and barley	*“Biogenic carbon released by biofuel production and combustion is assumed to be captured again by annual cropping.”*
Kim S, Dale BE. (2016)	Neutrality	corn stover	not explicitly mentioned
Hums ME, Cairncross RA, Spatari S. (2016)	Neutrality	grease trap waste	*“The CO_2 credit for biodiesel was represented in the fuel’s combustion. The CO_2 produced from biogenic sources was considered zero because of the recent sequestration of carbon from the atmosphere.”*
DeCicco JM, Liu DY, Heo J, Krishnan R, Kurthen A, Wang L. (2016)	Additionality	corn	Additional carbon uptake

Daylan B, Ciliz N. (2016)	Neutrality	corn stover	*"Biofuels have a large reduction potential for CO_2 emissions throughout their life cycle, since the vehicle combustion of biofuels does not contribute to net emissions of CO_2, which is absorbed by the biomass feedstock through photosynthesis."*
Carvalho M, da Silva ES, Andersen SLF, Abrahao R. (2016)	Neutrality	soybean	not explicitly mentioned
Canter CE, Dunn JB, Han J, Wang Z, Wang M. (2016)	Neutrality	corn and corn stover	*"We treat CO_2 emissions from ethanol combustion during vehicle operation as offset by carbon uptake during feedstock growth, which in the case of corn grain and corn stover occurred in the recent past."*
Yang Y, Suh S. (2015)	Neutrality	corn	not explicitly mentioned

	Approach	Biomass	*Quotation*/Remark

Tsang M, Fox-Lent C, Wallace S, Welp T, Bates M, Linkov I. (2015)	Neutrality	soybean and algae	*"The burning of biodiesel is a closed loop carbon system, meaning that the carbon dioxide emissions during fuel combustion originate from carbon consumed from the atmosphere during growth of the feedstock. Such carbon is considered biogenic and their resulting release into the atmosphere during combustion does not add to the global greenhouse gas burden."*
Su M, Huang C, Lin W, Tso C, Lur H. (2015)	Neutrality	corn, rice straw, switchgrass, sweet potato, sweet sorghum and sugarcane	Not including biogenic CO_2 emissions
Sastre CM, Gonzalez-Arechavala Y, Santos AM. (2015)	Neutrality	wheat straw	*"The emissions of carbon dioxide from straw combustion have not been accounted because CO_2 was previously fixed from the air by the crop no more than one year before being burned."*

Murphy CW, Kendall A. (2015)	Neutrality	corn stover and switchgrass	*"All CO_2 emitted from combusting process byproducts is biogenic and assumed to not to contribute to changing atmospheric CO_2 and, in accordance with widely accepted carbon accounting methods, is not included in calculations."*
Kim S, Dale BE. (2015a)	Neutrality	barley straw, corn stover, oat straw, sorghum stubble, wheat straw, energy sorghum, switchgrass and willow	not explicitly mentioned

	Approach	Biomass	*Quotation*/Remark
Kim S, Dale BE. (2015b)	Neutrality	corn stover	*"Biogenic carbon dioxide emissions are released from the fermentation and the cogeneration facilities."*

Jeswani HK, Falano T, Azapagic A. (2015)	Neutrality	wheat straw, poplar, miscanthus and forest residue	*"As per standard LCA practice, biogenic CO_2 emissions are excluded from the GWP as they are part of the natural carbon cycle. Similarly, biogenic carbon storage in the products is not considered as this carbon will be released during the use of ethanol in vehicles* *for ethanol the biogenic CO_2 emitted during its use is not taken into account as that is equivalent to the amount of CO_2 sequestered from the atmosphere by the feedstocks during their growth."*
Daystar J, Treasure T, Reeb C, Venditti R, Gonzalez R, Kelley S. (2015)	Input-output	pine, eucalyptus, natural hardwood, switchgrass, and sweet sorghum	Carbon uptake and biogenic CO_2 emissions are accounted.
Borjesson P, Prade T, Lantz M, Bjornsson L. (2015)	Neutrality	hemp; sugar beet; maize; triticale; ley crops; wheat (grain)	*"The calculation of life cycle emissions of GHGs includes carbon dioxide (CO_2) of fossil origin and based on changes in soil organic carbon (SOC) content, methane (CH_4) and nitrous oxide (N_2O)."*

Belboom S, Bodson B, Leonard A. (2015)	Neutrality	wheat	*“During crop cultivation, carbon dioxide from atmosphere is converted by the plant into biomass. In this study, we do not take this benefit into account as recommended by the Annex V of the RED (3) neither the emissions of biogenic CO_2 released during combustion phase.”*
	Approach	Biomass	*Quotation*/Remark
Aguirre-Villegas HA, Larson R, Reinemann DJ. (2015)	Neutrality	manure, corn stover and switchgrass	*“ …to account for the CO_2(b) recycling process that takes place during plant growth as it is assumed that the carbon contained in biomass has been previously captured as CO_2”*
Souza SP, Seabra JEA. (2014)	Neutrality	sugarcane and soybean	not explicitly mentioned
Sanscartier D, Dias G, Deen B, Dadfar H, McDonald I, MacLean HL. (2014)	Neutrality	corn cobs	*“.. . biogenic CO_2 emitted during the combustion of the pellets is not counted in calculations as it does not have a net contribution to the global warming effect.”*
Olukoya IA, Ramachandriya KD, Wilkins MR, Aichele CP. (2014)	Neutrality	red cedar	not explicitly mentioned

Nguyen L, Cafferty KG, Searcy EM, Spatari S. (2014)	Input-output	corn stover	Carbon uptake by biomass and Biogenic CO_2 emission are accounted. Biogenic carbon uptake: −234 gCO_2/MJ Fermentative CO_2: 34 gCO_2/MJ Boiler: 122 gCO_2/MJ Ethanol combustion: 71 gCO_2/MJ
Munoz I, Flury K, Jungbluth N, Rigarlsford G, Canals LMI, King H. (2014)	Neutrality	maize corn stover sugarcane wheat and sugar beet	*"… global warming potentials (GWP) from carbon dioxide (CO_2) and methane were used as proposed by Muñoz et al. (2013) for a 100-year period, accounting for methane oxidation in the atmosphere and considering biogenic CO2 emissions as neutral, with the exception of those resulting from land use change (LUC)."*
Moller F, Slento E, Frederiksen P. (2014)	Neutrality	rapeseed	*"RME consists of 100% renewable carbon and therefore its CO_2 emissions are considered neutral."*
	Approach	Biomass	*Quotation*/Remark

Martinez-Hernandez E, Campbell GM, Sadhukhan J. (2014)	Neutrality	jatropha seeds	*“CO_2 emissions from the processing and end use (e.g. combustion) were considered as balanced as they originate from the carbon contained in Jatropha seeds.”*
Garba NA, Duckers LJ, Hall WJ. (2014)	Neutrality	corn and soybean	*“Biofuels are considered ‘carbon neutral’ because they are produced within the short-term carbon cycle, and their combustion only returns as much CO_2 to the atmosphere as that is captured during plant growth.*
Downie A, Lau D, Cowie A, Munroe P. (2014)	Neutrality, Input-output	wheat straw, animal manures, forestry residue	biogenic method (input-output); stock method (neutrality); simplified method (neutrality)
Yan X, Boies AM. (2013)	Neutrality	wheat	*“we assume complete combustion whereby the CO_2 emitted is initially absorbed from the atmosphere during wheat growing.”*
Weinberg J, Kaltschmitt M. (2013)	Neutrality	wheat and sugar beet	not explicitly mentioned

Patrizi N, Caro D, Pulselli FM, Bjerre AB, Bastianoni S. (2013)	Neutrality	wheat, barley and oat straw	*"The combustion of bioethanol by transportation is considered "carbon neutral", since the combustion of biomass releases the same amount of* CO_2 *as was captured by the straw during its growth."*
Martinez-Hernandez E, Ibrahim MH, Leach M, Sinclair P, Campbell GM, Sadhukhan J. (2013)	Neutrality	wheat	*"The biogenic carbon capture is not affected by these parameters and therefore* CO_2 *binding and carbon emissions from end use of products are not changed."*

	Approach	Biomass	*Quotation*/Remark
Hajjaji N, Pons M-N, Renaudin V, Houas A. (2013)	Neutrality	wheat and cattle manure	*"The biological CH4 reforming systems contribute less to the global warming potential impact.* CO_2 *emissions from biogenic sources (biomethane and bioethanol reforming processes) are not included in this paper."*

Grau B, Bernat E, Rita P, Jordi-Roger R, Antoni R. (2013)	Neutrality	rapeseed	*"CO_2 emissions for SVO (straight vegetable oil) have been considered null because they are compensated by the amount of this gas absorbed during the growth of the rapeseed plant (CO_2 neutral balance)*
Eranki PL, Manowitz DH, Bals BD, Izaurralde RC, Kim S, Dale BE. (2013)	Neutrality	corn stover	not explicitly mentioned
Cai H, Dunn JB, Wang ZC, Han JW, Wang MQ. (2013)	Input-output for combustion of biomass and biofuel (not for CO_2 emissions from fermentation)	sorghum	*"WTW GHG emissions are separated into WTP, PTW, and biogenic CO2 (i.e., carbon in bioethanol) emissions. Combustion emissions are the largest GHG emission source for all fuel pathways. However, in the bioethanol cases, the uptake* *of CO2 during feedstock production almost entirely offsets ethanol combustion GHG emissions."*

Han J, Elgowainy A, Dunn JB, Wang MQ. (2013)	Input-output	corn stover and forest residue	*"The large observed reduction in WTW GHG emissions for all pyrolysis pathways are mainly due to the biogenic CO2 credit (CO2 absorbed during growth of biomass that is converted into fuel) that cancels out the GHG emissions from the vehicle's operation. Note that pyrolysis, stabilization and upgrading generate large biogenic carbon emissions (CO2, CO, VOC and CH4). These emissions are offset, however, by the uptake of atmospheric carbon during feedstock growth."*
	Approach	Biomass	*Quotation*/Remark
Wang M, Han J, Dunn JB, Cai H, Elgowainy A. (2012)	Input-output for combustion of biomass and biofuel (not for CO_2 emissions from fermentation)	corn, sugarcane, corn stover, switchgrass and miscanthus	*"...biogenic CO2 in ethanol offsets ethanol combustion GHG emissions almost entirely."*
Dunn JB, Mueller S, Wang M, Han J. (2012)	Input-output for combustion of biomass and biofuel (not for CO_2 emissions from fermentation)	corn, corn stover and switchgrass	*"...biogenic CO2 emissions from the cellulosic ethanol plant are not included."*

Roy P, Tokuyasu K, Orikasa T, Nakamura N, Shiina T. (2012)	Neutrality	corn stover	*"Biomass combustions are assumed to be carbon neutral."*
Kumar D, Murthy GS. (2012)	Neutrality	grass straw	*"The CO_2 released during ethanol fermentation and lignin burning was sequestered from environment by photosynthesis process during grass straw production. Hence, CO_2 emissions produced during fermentation process and lignin residue burning were not accounted into calculations."*
Krohn BJ, Fripp M. (2012)	Neutrality	soybean and canola	not explicitly mentioned

	Approach	Biomass	*Quotation*/Remark

Eerhart AJJE, Faaij APC, Patel MK. (2012)	Neutrality	corn	*"When comparing PEF with PET, it is important to distinguish between fossil and biogenic GHG emissions. For petrochemical products, such as PET, the method for determining GHG emissions is broadly accepted. Accounting for CO_2 emissions arising from biobased products is more complex as there are two concepts which can be considered, i.e. carbon neutrality or carbon storage***. However, these two methods yield the same result for the system cradle-to-grave which has been chosen in this paper; therefore, we do not discuss here possible further implications and instead refer the reader to Pawelzik and Patel."*

Acquaye AA, Sherwen T, Genovese A, Kuylenstierna J, Koh SCL, McQueen-Mason S. (2012)	Input-output	rapeseed, corn, soybean, and sugarcane	*"The carbon released through combustion of biofuels is biogenic CO_2; this was captured in the process LCA ecoinvent data (39). It was calculated using the principle of carbon balance (input of carbon=output of carbon); that is, the uptake of carbon during plant growth plus all inputs of biogenic carbon with all pre-products minus biogenic carbon emissions should equal the biogenic carbon content of the biofuel or the product after all allocations have been done."*
Zamboni A, Murphy RJ, Woods J, Bezzo F, Shah N. (2011)	Neutrality	corn and soybean	not explicitly mentioned

	Approach	Biomass	*Quotation*/Remark

Reinhard J, Zah R. (2011)	Neutrality	rapeseed	*"We have not considered the biogenic CO_2 uptake of the biofuels. Thus, we did not take account of its release but rather added the combustion of diesel in the baseline scenario in order to account for the full differences in the emissions of the analysed systems."*
Melamu R, von Blottnitz H. (2011)	Neutrality	sugarcane bagasse	*"… biogenic carbon dioxide emissions from burning bagasse are taken not to contribute to global warming."*
Kauffman N, Hayes D, Brown R. (2011)	Neutrality	corn	*"Given that bio-oil is composed of biogenic carbon, there are thus no GHG emissions associated with hydroprocessing."*
Kaliyan N, Morey RV, Tiffany DG. (2011)	Neutrality	corn	*"Combustion emissions of CO_2 are not included for biomass fuels because the CO_2 released by biomass fuel was removed from the atmosphere during photosynthesis."*

Fazio S, Monti A. (2011)	Neutrality	miscanthus, giant reed, switchgrass, cynara, fibre sorghum , maize, wheat, rapeseed, and sunflower	*"The amount of emitted CO_2 during combustion of biomass crops was considered equal to that absorbed by crops through photosynthesis."*
CHERUBINI, F.; PETERS, G. P.; BERNTSEN, T.; STRØMMAN, A. H.; HERTWICH, E., (2011)	Modified global warming potential		GWP_{bio} = 0 for annual crop

	Approach	Biomass	*Quotation*/Remark
Voet Evd, Lifset RJ, Luo L. (2010)	Input-output		*"In chains where coproducts are not important, exclusion of biogenic carbon generates the same results. However, Luo and colleagues show that, in cases of chains with coproducts, it does make a difference. Allocation may put the credits for extracted CO_2 in a different part of the multiproduct chain than the debits for emitted CO_2, while ignoring biogenic CO_2 would not have this effect."*
Schumacher B, Oechsner H, Senn T, Jungbluth T. (2010)	Neutrality	corn and triticale	not explicitly mentioned

Scacchi CCO, Gonzalez-Garcia S, Caserini S, Rigamonti L. (2010)	Neutrality	wheat	*"… the amount of carbon dioxide released in the combustion step is the same as the amount stored during the growing phase of the wheat. Therefore the carbon dioxide emissions counted come from the combustion of only the fossil fraction contained in the fuel."*
Kusiima JM, Powers SE. (2010)	Neutrality	corn, corn stover, switchgrass and forest residue	*"The CO_2 released during lignin combustion is considered biogenic carbon that was sequestered during feedstock growth. This biogenic carbon is treated as an additional credit. Biogenic carbon credits could also be assigned for the combustion of ethanol in an automobile."*
Kaufman AS, Meier PJ, Sinistore JC, Reinemann DJ. (2010)	Neutrality	corn-grain and corn-stover	*"The CO_2 released during stover combustion is negated by the CO2 captured during plant growth, resulting in no net CO_2 impact."*

	Approach	Biomass	*Quotation*/Remark

Iriarte A, Rieradevall J, Gabarrell X. (2010)	Neutrality	rapeseed	*"... The flows of CO_2 associated with the capture of atmospheric carbon in photosynthesis during crop growth and its release by oxidation are considered neutral. As a result, these flows are not included in the analysis of greenhouse gases, in agreement with the standard approach related to the carbon cycle in agriculture ..."*
Gonzalez-Garcia S, Teresa Moreira M, Feijoo G. (2010).	Neutrality	alfalfa stems, flax shives, hemp hurds, poplar and ethiopian mustard	*"... the carbon released as CO_2 from combustion and production of the fuel would be incorporated into the re-growth of the plant."*
Feng H, Rubin OD, Babcock BA. (2010)	Neutrality	corn	*"The emissions from the burning of ethanol are cancelled by the absorption of carbon as corn grows and therefore are not considered."*