



# Corrigendum: Indirect Effects Negate Global Climate Change Mitigation Potential of Substituting Gasoline With Corn Ethanol as a Transportation Fuel in the USA

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**Keywords:** indirect land use change (iLUC), corn ethanol, climate change mitigation, life cycle assessment, carbon footprint

## A Corrigendum on

### Indirect Effects Negate Global Climate Change Mitigation Potential of Substituting Gasoline With Corn Ethanol as a Transportation Fuel in the USA

by Brandão, M. (2022). *Front. Clim.* 4:814052. doi: 10.3389/fclim.2022.814052

In the published article, there was an error. Poor grammar/language construction and incomplete information.

A correction has been made to **Abstract**. This sentence previously stated:

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“... or by the indirect land requirements (iLUC) that compensate for the diversion of food/feed crops into biofuels, both cases leading to greenhouse gas emissions. We investigated data over the last 20-year period to estimate the magnitude of the effects ethanol production in the USA has had on land use domestically and abroad. The data analyzed suggests that, over the period, the use of corn for ethanol increased by 118 Mt per year, most of it coming from displacement of other uses of corn, mainly feed, which were compensated by increased feed production elsewhere. Results suggest a relatively low dLUC but a significant iLUC effect, mainly due to the compensation for the foregone feed production as a result of diverting corn into ethanol production. The resulting 18.0 Mt CO<sub>2</sub>-eq. associated with meeting the renewable-energy target of 15 billion gallons of corn ethanol more than negates the climate benefits from avoided use of gasoline, indicating that promoting corn ethanol for global climate change mitigation may be counter-productive as, despite decreasing domestic emissions, global emissions increase.”

The corrected sentence appears below:

“... or by the indirect land requirements (iLUC) that compensate for the diversion of crops from food/feed into fuel, both cases potentially leading to emissions of greenhouse gases. We investigated official data over the last 20-year period to estimate the magnitude of the effects ethanol production in the USA has had on land use domestically and abroad. The data analyzed shows that, over the period, the use of corn for ethanol increased by 118 Mt per year. According to our model, most of it came from the displacement of other uses of corn, mainly feed, which was compensated for by increased feed production elsewhere. Results indicate a relatively low dLUC but a significant iLUC effect, mainly due to the compensation for the foregone feed production as a result of diverting corn into ethanol production. Meeting the renewable-energy target of 15 billion gallons of corn ethanol more than negates the climate benefits from avoided use of gasoline (by 18.0 Mt CO<sub>2</sub>-eq.), suggesting that promoting corn ethanol for global climate change mitigation may be counter-productive as, despite decreasing domestic emissions, global emissions increase.”

A correction has been made to **Introduction**. This sentence previously stated:

“However, when a life cycle approach is taken, it is clear that there are a range of indirect emissions that cannot be excluded from robust assessments, e.g., those from fertilizer production and land-use change (LUC). Most crops require land on which to grow; converting land from a natural state to cropland almost always entails a decrease in the terrestrial carbon stock between the two steady states prior and after conversion, the difference between those is what is emitted to the atmosphere as carbon dioxide (CO<sub>2</sub>), although there are exceptions such as biochar or long-lived wood products.”

The corrected sentence appears below:

“However, when a life cycle approach is taken, it is clear that there are a range of indirect emissions that cannot be excluded from robust and comprehensive assessments, such as those from fertilizer production and land-use change (LUC). Most crops require land on which to grow; converting land from a natural state to cropland almost always entails a decrease in the terrestrial carbon stock between the two steady states prior and post conversion, the difference between those is what is emitted to the atmosphere as carbon dioxide (CO<sub>2</sub>).”

A correction has been made to **Introduction**. This sentence previously stated:

“...it now appears that they may be a net source of GHGs to the atmosphere (Tian et al., 2016). Consequently, an increase in demand for crops is expected to put pressure on land which, in turn, may result in CO<sub>2</sub> emissions from conversion of natural ecosystems to cropland.”

“...that compensate for the diversion of crops from food or feed uses into fuels (e.g., Searchinger et al., 2008), both cases leading to both emissions and avoided emissions, the net effect being positive or negative depending on the particular case under study. This issue has been considered and established in both scientific and policy contexts, and ways to measure it have been put forward.”

The corrected sentence appears below:

“...it now appears that they may be a net source of greenhouse gases (GHGs) to the atmosphere (Tian et al., 2016). Consequently, an increase in demand for crops is expected to put pressure on land which, in turn, may result in CO<sub>2</sub> emissions from conversion of natural ecosystems to cropland.

“... that compensate for the diversion from other uses into fuels (e.g., Searchinger et al., 2008), leading to both emissions and avoided emissions, the net effect being positive or negative depending on the particular case under study. This issue has been documented and is well established in scientific and policy contexts, and ways to measure it have been proposed.”

A correction has been made to **Introduction**. This sentence previously stated:

“The United States of America (USA) is the world’s leading producer of ethanol, producing around half of its global output.”

“...One of the provisions in RFS2 is that the biofuels adopted must emit lower levels of greenhouse gases (GHGs) ... to around 40% in 2020 [9], which raises concerns over whether this share increase came via cropland expansion (resulting in dLUC), diversion from other corn uses (possibly resulting in iLUC) and/or came via intensification (i.e., increased production per ha), all of which incurring GHG emissions.”

The corrected sentence appears below:

“The USA is the world’s leading producer of ethanol, producing around half of the global output.”

“... One of the provisions in RFS2 is that the biofuels adopted must emit lower levels of GHGs ... to around 40% in 2020 (USDA, 2021), which raises concerns over whether this share increase came via cropland expansion (resulting in dLUC), diversion from other corn uses (resulting in iLUC) and/or came via intensification (i.e., increased production per ha), all of which incurring GHG emissions.”

A correction has been made to **Introduction**. This sentence previously stated:

“Direct land use change (dLUC) entails converting land into arable land. Previous land uses range from natural ecosystems to forest, grassland, or permanent cropland. Indirect land use change (iLUC) refers to the conversion of land to make way for the crops that were used for food but that are now being used for fuel. For example, if corn is diverted from feed to fuel in the USA and thereby decreasing global supply of feed while feed demand remains unchanged, the underprovided feed market may trigger production and, in turn, land-use change elsewhere so that the feed gap is compensated for and the feed market balances (i.e., maintains the same level of supply). The third way of increasing production is not to use more land as an additional factor of production, but more N fertilizer, other agrochemicals, mechanization and breeding (see Edgerton, 2009).”

The corrected sentence appears below:

“Direct land use change (dLUC) entails converting land from one use into another. Land uses range from natural ecosystems to forest, grassland, permanent cropland or arable land. Indirect land use change (iLUC) refers to the conversion of land to make way for the crops that compensate those that were used for food but that are now being used for fuel. For example, if corn is diverted from feed to fuel in the USA, thereby decreasing global supply of feed while feed demand remains unchanged, the now underprovided feed market will trigger production and, in turn, LUC elsewhere so that the feed gap is compensated for and the feed market balances (i.e., maintains the same level of supply). An alternative way of increasing production without land as an additional factor of production is achieved via increased use of N fertilizer, other agrochemicals, mechanization and breeding (see Edgerton, 2009).”

A correction has been made to **Methodological Framework—Theory**. This sentence previously stated:

“As the aim of the research is to compare the changes in land use and associated climate-change impacts from the production of corn ethanol, we used the amount of land used by the different corn uses at the beginning of the period (year 1999) as the counterfactual against which the actual land use at the end of the period is measured (year 2018). We have thus assumed that the counterfactual corresponds to the land dedicated to the different uses of corn in the absence of policy support for ethanol, and is represented by the corn land use for food, feed, ethanol, etc. at the start of the period. We used official data to estimate how additional demand for corn ethanol may be met. Meeting demand for corn can take place in a variety of ways. The possible sources of supply are:

(i) **Diversions:** use of corn from land currently devoted to corn but for non-ethanol uses, such as food and feed, which may result in indirect land use change (iLUC) when the assumption of *ceteris paribus* in adjacent markets (e.g., food and feed) is adopted, such as the markets for food and feed, which are assumed to remain unchanged, i.e., supply and demand remain at constant levels;”

“Subsequently, we estimated the indirect effects from each of the sources, such as land use.”... “The carbon footprint refers to the life cycle GHG emissions of products/services.”

“... LCA comprehensively compares alternative systems with the same functionality so provides an appropriate basis to inform policy to support transition toward more sustainable production and consumption.”... “The application of environmental systems analysis tools, such as LCA, has elucidated that the assumed climate benefit of biofuels is not always realized (e.g., Brandão et al., 2021).”

The corrected sentence appears below:

“As the aim of the research is to compare the changes in land use and associated climate-change impacts induced by the production of corn ethanol, we used the areas of land under the different corn uses at the beginning of the period (year 1999) as the counterfactual against which the actual land use at the end of the period is measured (year 2018). We have thus assumed that the counterfactual corresponds to the land dedicated to the different uses of corn in the absence of policy support for ethanol, and is represented by the corn land use areas for food, feed, ethanol, etc. at the start of the period. We used official data from the (USDA, 2021) to estimate how additional demand for corn ethanol may be met which, as mentioned above, can take place in a variety of ways. The possible sources of additional supply are:

(i) **Diversions:** use of corn from land already devoted to corn but for non-ethanol uses, such as food and feed, which may result in iLUC when the assumption of *ceteris paribus* in adjacent markets is adopted, i.e., supply and demand in the markets for food and feed are assumed to remain at constant levels;”

...  
“Subsequently, we estimated the indirect effects from each of the sources, such as land use requirements.”... “The carbon footprint of products/services refers to their life cycle GHG emissions.”

“... LCA comprehensively compares alternative systems with the same functionality, thereby providing an appropriate basis to inform policy that aims at supporting transitions toward more sustainable production and consumption systems.”... “Published applications of environmental systems analysis tools, such as

LCA, to biofuel systems has elucidated that the assumed climate benefit of biofuels is not always realized (e.g., Brandão et al., 2021)”

A correction has been made to **Methodological Framework—Balancing Markets**. This sentence previously stated:

“As feed energy and protein and co-produced jointly” ... “(more DDGS but less corn in the feed market) by solving multiple equations simultaneously. The use of this by-product in the feed market implies that a similar amount of feed energy and feed protein will be displaced if the market is to balance.”

...  
“Assuming that the demand for feed is both global and independent from the fuel market cereal grain is identified as the marginal source for feed energy and soybean meal as the marginal source for feed protein (Schmidt and Weidema, 2008). We have adopted Schmidt and De Rosa (2020) estimates for the marginal supply mix for feed energy and feed protein, which is based on the countries’ largest share of change over the period 2012–2016.”

The corrected sentence appears below:

“As feed energy and protein are co-produced jointly” ... “(i.e., more DDGS but less corn in the feed market) by solving multiple equations simultaneously. The use of this by-product in the feed market implies that the exact amounts of feed energy and feed protein be displaced if the market is to balance.”

...  
“Assuming that the demand for feed is both global and independent from the fuel market, cereal grain is identified as the marginal source for feed energy while soybean meal as the marginal source for feed protein (Schmidt and Weidema, 2008). We have adopted Schmidt and De Rosa (2020) estimates for the marginal supply mix for feed energy and feed protein, which is based on the suppliers’ largest share in global production increase over the period 2012–2016.”

A correction has been made to **Methodological Framework—System Boundary Delimitation**. This sentence previously stated:

“...we calculated emissions for the LUC in those counties” ... “for producing the marginal crops or the marginal feed crops and associated land displaced by the co-production of DDGS.”

The corrected sentence appears below:

“...we calculated emissions for the LUC in those countries” ... “for producing the marginal feed crops and associated land displaced by the co-production of DDGS.”

A correction has been made to **Methodological Framework—Characterizing GHG Emissions**. This sentence previously stated:

**“Characterizing GHG Emissions**

Emissions of carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O) were included in the assessment by using GWP-derived characterization reflecting cumulative radiative forcing over 100 years.”

The corrected sentence appears below:

**“Characterizing GHG Emissions**

Emissions of carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O) are included in the assessment by using IPCC GWP-derived characterization reflecting cumulative radiative forcing over 100 years.”

A correction has been made to **Results—Estimating Supply Changes**. This sentence previously stated:

“... but this increase was not constant among all uses” ... “which corresponds to a share increase from 6 to 37%” ... “from 60 to 39% of total production...”

The corrected sentence appears below:

“...but this increase was not equal among all uses”... “which corresponds to a share increase from 6% to 37%” ... “from 60% to 39% of total production...”

A correction has been made to **Results—Estimating Displacement Effects**. This sentence previously stated:

“Assuming that the corn land used for other purposes would have remained unchanged in the absence of policy support for biofuels”

...

“Despite the production of corn increasing considerably over the two decades, we estimated that, of the 134 Mt used for ethanol, 56 Mt (48%) came from additional production, while 60 Mt (52%) came from diversion from other uses, particularly 44 Mt (38%) was diverted from feed use, 9 Mt (8%) was diverted from food use, and 7 Mt (6%) from exports.”

The corrected sentence appears below:

“Assuming that the corn land used for non-ethanol purposes would have remained unchanged (i.e., continue being dedicated to non-ethanol purposes) in the absence of policy support for biofuels”

...

“Despite the production of corn increasing considerably over the two decades, we estimated that of the 134 Mt used for ethanol:

- 18 Mt came from land already under ethanol corn,
- 56 Mt came from expansion of land for corn, while
- 60 Mt came from diversion from other uses, particularly
  - 44 Mt was from feed,
  - 9 Mt was from food, and
  - 7 Mt from exports.”

A correction has been made to **Results—Estimating how the Feed, Food, Export, and Vegetable Oil Markets Balance**. This sentence previously stated:

“Estimating How the Feed, Food, Export and Vegetable oil Markets Balance.”

The corrected sentence appears below:

“Estimating **how** the Feed, Food, Export and Vegetable **Oil** Markets Balance.”

A correction has been made to **Results—Estimating how the Feed, Food, Export and Vegetable Oil Markets Balance**. This sentence previously stated:

“5.2 Mha is required” ... “Total direct and indirect land use change amounts to 3.8 Mha.”

The corrected sentence appears below:

“5.2 Mha are required”... “Total LUC (direct and indirect) amounts to 3.8 Mha.”

A correction has been made to **Results—Estimating Land-Use Change**. This sentence previously stated:

“dLUC emissions were included by estimating the carbon-stock changes between the reference land use and the land used for the production of the crop, and amortized it over 20 years.”... “The resulting values are consistent with the methodological guidance given in RED (European Union, 2009) and its amendment (European Union, 2015), PAS2050 European Commission (2010), Carré et al. (2010), [BSI, 2011], Blonk (2014), Novaes et al. (2017), ecoinvent (Moreno Ruiz et al., 2019; Donke et al., 2020).”

The corrected sentence appears below:

“dLUC emissions are included by estimating the carbon-stock changes between the reference land use and the land used for the production of the crop, and amortized over 20 years.” ... “The resulting values are consistent with the methodological guidance given in RED (European Union, 2009) and its amendment (European Union, 2015), PAS2050 (BSI, 2011), European Commission (2010), Carré et al. (2010), Blonk (2014), Novaes et al. (2017), ecoinvent (Moreno Ruiz et al., 2019; Donke et al., 2020)”

A correction has been made to **Results—Estimating the Carbon Footprint of the Policy Shock**. This sentence previously stated:

“... including the emissions at different stages of the ethanol life cycle: cultivation, processing, transport, use, as well as substitution effects such as land-use change.”

The corrected sentence appears below:

“... representing the emissions at different stages of the ethanol life cycle: crop cultivation, processing, transport, use, as well as substitution effects and land-use change.”

A correction has been made to **Discussion**. This sentence previously stated:

- “• Malaysia and Indonesia (South-East Asia) would see its emissions going up significantly (by 72.6 Mt CO<sub>2</sub>-eq.),
- Brazil and Argentina (South-East America) would decrease emissions by 40.3, and”

corrected sentence appears below:

- Malaysia and Indonesia (South-East Asia) would see their emissions increase significantly (by 72.6 Mt CO<sub>2</sub>-eq.),
- Brazil and Argentina (South-East America) would decrease emissions by 40.3 Mt CO<sub>2</sub>-eq, and”

A correction has been made to **Discussion**. This sentence previously stated:

“... and has given rise to disparate carbon-footprint estimates (Pereira et al., 2019; Brandão et al., 2021).” ... “The exclusion of LUC considerations may lead to contradicting insights (e.g., Lee et al., 2021).”

The corrected sentence appears below:

“... and giving rise to disparate carbon-footprint estimates (Pereira et al., 2019; Brandão et al., 2021).” ... “Standardization is welcomed since the exclusion of LUC considerations may lead to contradicting insights (e.g., Lee et al., 2021).”

A correction has been made to **Conclusions**. This sentence previously stated:

“in the USA, both directly and indirectly, via cropland expansion and intensification, as well as those associated with the balancing of the various markets (food, feed, vegetable oil, and export) when diverting corn from other uses and co-producing DDGS which is subsequently used as animal feed.”

The corrected sentence appears below:

“in the USA, including direct and indirect effects, such as emission associated with cropland expansion and intensification, as well with the balancing of the various markets (food, feed, vegetable oil and export) that occurs when diverting corn from other uses and when co-producing DDGS that is subsequently used as animal feed.”

A correction has been made to **Conclusions**. This sentence previously stated:

“What appears to be universally recognized is to not shift burdens between different impacts”

The corrected sentence appears below:

“What appears to be universally recognized is the need to not shift burdens between different impacts”

The authors apologize for these errors and state that this does not change the scientific conclusions of the article in any way. The original article has been updated.

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