A REVIEW OF THE STUDY

"DETERMINING THE ENVIRONMENTAL IMPACTS OF CONVENTIONAL AND ALTERNATIVELY FUELLED VEHICLES THROUGH LCA"

DECEMBER 2020

During the 6th Plenary Meeting of the ART Fuels Forum in February 2020, it was decided to formulate an ad-hoc working group to conduct a review on the Study "Determining the Environmental Impacts of Conventional and Alternatively Fuelled Vehicles through LCA", conducted by Ricardo Energy and Environment, E4TECH and IFEU on behalf of DG CLIMA[1].

The ad-hoc working group consisted of experts from: CONCAWE, EBA, EBB, ENGIE, ePure, IEA Bioenergy, Liquid Gas Europe, NESTE, NGVA, Novozymes, Triple E&M, VTT, Waldheim Consulting, as well as the members of the management team of the Forum.

$(S\&T)^2$ Consultants Inc. were commissioned to prepare the review on behalf of the ART Fuels Forum.

The present review was funded by the following members of the ART Fuels Forum: CONCAWE, EBA, EBB, ePure, Liquid Gas Europe, NESTE, NGVA

The following shows the original report that was endorsed by the ad-hoc working group

[1] https://op.europa.eu/en/publication-detail/-/publication/1f494180-bc0e-11ea-811c-01aa75ed71a1

A REVIEW OF THE STUDY

"DETERMINING THE ENVIRONMENTAL IMPACTS OF CONVENTIONAL AND ALTERNATIVELY FUELLED VEHICLES THROUGH LCA"

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Date: December 16, 2020

EXECUTIVE SUMMARY

The study ‘Determining the environmental impacts of conventional and alternatively fuels vehicles through LCA’ (hereafter the Study) commissioned by the European Commission’s DG Climate Action provides a life cycle analysis of transport sector options. This environmental assessment was to include all stages of the lifecycle.

The stated aim of this study was to improve the understanding of the environmental impacts of road vehicles and the methodologies to assess them in the mid- to long-term timeframe (up to 2050). It covers a selection of light-duty vehicles (LDVs) and heavy-duty vehicles (HDVs) with different types of powertrains (internal combustion engine and/or electric engine powered by fuel cells or batteries) and using different types of energy (of fossil and/or renewable origin). It had two main objectives:

> 1. To develop an approach for a LCA of road vehicles, including the fuels or electricity which powers them, based on a literature review and stakeholder consultation, and combining mainstream elements of vehicle LCAs with novel methodological choices where necessary.
>
> 2. To apply this approach to understand the impacts of methodological choices and data sources on the LCA results for selected vehicle/powertrain/fuel categories expected to be in use over the time period 2020 to 2050.

This review focussed on the fuel chain portion of the Study, where 60 fuel chains ranging from conventional to developing technologies were studied.

The authors of the Study concluded that they had met the objectives of the study. However they included a number of very significant and serious caveats with respect to the results of the work. These caveats are the authors’ words and include;

> *“However, it is not generally valid to compare the results from this study with those of other studies characterised by their own analytical boundaries, different data sources, and specific data processing choices. As a result, this study cannot be considered to provide definitive, absolute results on the environmental impacts of different vehicles.”*
>
> *“For fuels, different methodological approaches, assumptions and data sources are tested in this study, some of which were novel in nature or utilised data with significant underlying uncertainty. This means that the results should not be taken as an accurate, consistent representation of impacts across all of the fuel chains investigated.”*
>
> *“In addition, comparisons should not be made between fuel chains when these are evaluated via different methodological approaches or where data robustness is more limited.”*
>
> *“However, the breadth of the study did not allow for a consistent level of robustness and validation of all data, which, in several instances, were limited, especially for certain more novel energy and fuel chains.”*

The executive summary of the Study reports results for the gasoline, diesel, and electric vehicles almost exclusively. The one exception is for the natural gas supply chain where CNG and LNG vehicles are compared to diesel, battery powered and hybrid vehicles in one figure. None of the other 60 fuel supply chains included in the work are directly mentioned in the Executive Summary or have any results presented in the Executive Summary.

Furthermore, of the 60 fuel chains studied, commercially available fuels such as bioLPG were not considered at all, even though global production is some 250 kilotonnes/year.

The authors made a number of recommendations with respect to future work. For the fuel chains the recommendations were;

1. *Develop improved foreground data-sets for non-conventional natural gas production, hydrogen production from natural gas, and fuel production processes which are currently at an early stage of commercialisation such as e-fuel production.*
2. *Model additional counterfactual and substitution scenarios to provide LCA practitioners with guidance and default values and identify feedstocks or fuel production chains which may be at high risk of causing indirect impacts through their use in fuel production.*
3. *Explore the possibility to model all residues as co-products and allocate a share of the impacts of the primary production process to them.*
4. *Modelling of additional fuel chains, for example to cover new fuel types (e.g. bio-LPG) or variations on existing fuel chains.*
5. *General exploration and improvement to the temporal harmonisation and granularity of data across all areas.*

The authors of the Study acknowledged a significant number of issues with robustness of the results and cautioned the use of the results in making comparisons between fuel chains. The whole purpose for doing an LCA is to allow comparisons to be made. This review has confirmed that there are very significant issues with the robustness of the results and provides numerous examples of the issues with the Study.

This review of the Study focussed on the LCA methodology employed and the quality of the data used. Within the LCA methodology the focus was on the forecasts used to project emissions for all fuel chains through to 2050, the counterfactual cases developed in the Study, the treatment of co-products from systems that produce more than one products, and the land use change emissions. Detailed analyses of some of the methodological issues and a comparison of the data used for some of the fuel chains with other data sources are provided in three appendices to this report.

This review of the Study considered two fundamental questions related to the report from the Study.

1. Are the summary and introduction compatible with the content and focus of the study?
2. What are the risks of comparing the results and even giving policy advice based on this "wide" collection of different data and models?

With respect to the first question, the fact that of all of the alternative fuel chains analyzed only the CNG and LNG fuel chains are mentioned in the executive summary. There is **no mention of any of the other fuel chains**, not which ones were included in the study, or any of the results. A reader of only the executive summary would have no idea of how many fuel chains are included in the report, which ones they are, or any of the results for those alternative fuel chains.

The executive summary and the report clearly states several times that there is a **high risk of comparing the results** between this study and other studies and even comparing the results between the different fuel chains in this study due to concerns about the quality and robustness of the data used for many of the fuel chains.

The authors of the Study expressed a higher degree of satisfaction with vehicle aspects of the work including the vehicle manufacturing, battery manufacturing, vehicle operation, the vehicle and battery end of life, and the electricity production chains than they do with respect to the fuel chain analysis.

In the executive summary of the Study report the authors make a number of recommendations with respect to improvements in the modelling of the fuel chains that should be made to the model including better quality datasets, additional counterfactual scenarios and substitution scenarios. The findings of this review fully support all of those recommendations as the Study has serious shortcomings in all of those aspects.

The Study encompasses a number of what the authors called novel aspects. However there are issues with most of the novel aspects of the Study. These include.

1. The forecasts of future emissions would appear to only include changes in the emission intensity of electricity. There are no changes in agricultural production despite this being a major objective of a new CAP. There do not appear to be any changes in alternative fuel production technologies even though new technologies are being adopted and there are incentives for industry to reduce emissions, with emissions already being clearly lower currently than 5 to 10 years ago.

2. The counterfactual cases (one for each secondary feedstock) do not reflect the range of current use of these feedstocks in most cases and thus the counterfactual results have little validity.

3. Using the substitution method for dealing with co-products, which is the ISO preferred approach, produces lower emissions for oilseed based fuels and similar results for starch based fuels. The issue of the implications of one co-product allocation method compared to another is very poorly understood by most people other than LCA practitioners. It can have a significant impact on the results and the Study has not done anything to explain the reasons for the differences.

4. There have been changes to the GLOBIOM model since the 2015 work was done that has resulted in lower land use change values. The GTAP model also generally produces lower land use change values that GLOBIOM, particularly for oilseed based fuels. The availability of lower land use emissions from newer modelling frameworks is not acknowledged in the Study report.

5. The simple addition of values from an attributional analysis and a partial consequential analysis provides a distorted view of the emission profile. The resulting product almost certainly overstates the results from a proper consequential analysis.

The development of a LCA model is a data driven exercise. High quality data is a prerequisite to a high quality outcome or model. The Study authors acknowledge that there is a lack of robustness of the data used for some of the fuel chains.

We would suggest that improved data sets are required for almost all of the alternative fuel chains that were included in the report. The variance between the Study results and the REDII typical values, the JEC version 5 results, and in the case of ethanol, the audited industry performance is very troublesome. It is almost always possible to improve the quality of data used in models. As more attention is placed on climate change, more and higher quality data is being released. This new, high quality data needs to be incorporated into the LCA model. Modelling that relies on data that is 20 years old or older, as is the case with many of the fuel chains included in the Study, is just not acceptable in a modern LCA model.

Finally we have strong reservations about the quality of some of the data that have been used in the Ricardo study. The model output is only as strong as the quality of the data that goes into the model. Every year new and better quality data sources become available for LCA practitioners. Some of this is because of stronger reporting requirements that governments have placed on companies and other actors in society. Some of it is because some companies are becoming more transparent with respect to their performance to maintain their social licenses to operate. The academic community is developing better tools to help understanding some of the process that generate emissions so that more accurate reporting can happen.

The development of new datasets should be guided by the data quality matrix. The data should be updated at least every 6 years so that it ranks as a 1 or 2 in the quality matrix. Data that is not verified or based on estimates should not be acceptable. The data used for modelling should be taken from a representative sample of sites over a period long enough to remove seasonal variations. The data should be from a region with similar production practices as the study is investigating and finally the data should be representative of all of the technologies employed in the region to produce the product under study.

It is clear that the report and the findings are not sound enough to serve as a roadmap for policy makers considering options to reduce the environmental impacts of transports systems over the next 30 to 50 years.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

The study 'Determining the environmental impacts of conventional and alternatively fuels vehicles through LCA' (hereafter the Study) commissioned by the European Commission's DG Climate Action commissioned provides a life cycle analysis of transport sector options. This environmental assessment was to include all stages of the lifecycle. The study and supporting documentation has been published on DG Climate Action's website https://ec.europa.eu/clima/policies/transport/vehicles_en#tab-0-1).

The stated aim of this study was to improve the understanding of the environmental impacts of road vehicles and the methodologies to assess them in the mid- to long-term timeframe (up to 2050). It covers a selection of light-duty vehicles (LDVs) and heavy-duty vehicles (HDVs) with different types of powertrains (internal combustion engine and/or electric engine powered by fuel cells or batteries) and using different types of energy (of fossil and/or renewable origin). It had two main objectives:

> 1. To develop an approach for a LCA of road vehicles, including the fuels or electricity which powers them, based on a literature review and stakeholder consultation, and combining mainstream elements of vehicle LCAs with novel methodological choices where necessary.
>
> 2. To apply this approach to understand the impacts of methodological choices and data sources on the LCA results for selected vehicle/powertrain/fuel categories expected to be in use over the time period 2020 to 2050.

The LCA approach used in this study covered a broad range of environmental impacts caused by the manufacturing, use and end-of-life phases of selected vehicle categories.

The authors claimed that;

1. The methodological choices were consistently applied across the entire different vehicle, fuel/electricity chain and powertrain types.
2. However, the breadth of the study did not allow for a consistent level of robustness and validation of all data, which, in several instances, were limited, especially for certain more novel energy and fuel chains.
3. There were also some fuel chains where alternative or more novel methodological options were explored in order to understand their impacts. The impacts of these alternative methodological options were explored through sensitivity analyses, and results for fuel chains were not included in the overall vehicle LCA analysis where data or methodological choices were judged insufficiently robust.
4. Overall vehicle LCA outputs from this study provide robust and internally consistent indications on the relative life-cycle performance of the different options considered, particularly for vehicle powertrain comparisons, electricity chains, and conventional fuels.
5. The study also provides good evidence on how temporal and spatial considerations influence lifecycle performance and how potential future developments (in technology or electricity supply) are likely to affect these powertrain comparisons.

Note the inconsistency in these claims particularly with respect to the fuel chains; in point 1 the claim is that the methodological choices were consistently applied but point 2 states that there was an inconsistent level of robustness and validation of all of the data. Point 3 states that **some** fuel chains had different methodological options employed. This work elaborates on the inconsistencies in the report and cautions against accepting the report findings.

1.1 SCOPE OF WORK

The focus of this work will be on the Well to Tank (WTT) GHG impacts of Liquid and Gaseous Fuels chains and the LCA methodology. Some of the specific questions to be addressed are:

- Are the summary and introduction compatible with the content and focus of the study?
- What are the risks of comparing the results and even giving policy advice based on this wide collection of different data and models?
- What is the new model developed like? Is it on the same level as the known and widespread models?
- Given that some conclusions on biofuels/waste are clearly debatable, which is the analysis needed on the counterfactual?
- Which model and which data banks have been used for which power train and which fuels? Considering all these differences in the calculation, is it acceptable to compare the emission of the different fuels in the various vehicles on a 1:1 basis to each other?
- Is it acceptable to mix data from different data banks?

In section 2 of this report the first question is addressed. Section 3 of this report deals with the LCA methodology used in the Study including the approach used for forecasting, the suitability of the counterfactual case assumptions, the approach to dealing with co-products, and the treatment of land use change emissions. Section 4 of this report addresses the issues of data quality. Section 5 reports on the findings of this review. There are also three appendices with more detail on the shortcomings with respect to forecasting, the counterfactual cases, and the data used in the Study.

1.1.1 Fuel Chains of Interest

The 60 fuel chains that have been examined in more detail are the following.

Gasoline, and diesel fuel

- Conventional Crude, Non-conventional Crude

Ethanol

- Sugar beet, sugarcane, corn, wheat, agricultural residues, forestry residues, sawdust, short rotation wood, waste industrial gases

FAME

- Rapeseed, sunflower, used cooking oil, palm oil

HVO

- Rapeseed, sunflower, used cooking oil, palm oil

Synthetic gasoline and Synthetic diesel

- Municipal solid waste, short rotation wood, agricultural residues, forestry residues, saw dust, electricity + CO_2

LPG

- Conventional Crude, Non-conventional Crude

CNG and LNG

- Conventional Natural Gas, Unconventional Natural Gas

- Municipal Solid Waste, manure, agricultural residues (via gasification and anaerobic digestion), short rotation wood, sawdust, electricity + CO_2

Hydrogen and Liquid Hydrogen

- Conventional and unconventional natural gas (SMR with and without CCS)
- Electricity

While there could be a long list of feedstocks and fuels that could be examined, the notable exceptions to the list of fuels in the study were LPG produced from natural gas and renewable LPG that is a co-product of the HVO process. Both of these fuels are commercially important fuels in Europe today and both offer environmental benefits to conventional gasoline and diesel fuels and they were not considered in the study.

1.1.2 Critical Review

The study authors did commission a critical review by a single reviewer. Critical reviews by a single reviewer are allowed under the ISO 14044 standard and the ISO Technical Specification 14071, although a panel of three or more reviewers is discussed in ISO 14044 and often used for large and important projects.

The reviewer, Dr. Andrea Del Duce, did produce a review report. The review report does include a statement regarding the independence of the reviewer; however it does not include a statement of competence of the reviewer as suggested in ISO TS 14071. The review report does generally cover the review requirements identified in the ISO standards.

2. REPORT FINDINGS

The report and the appendices to the report total over 500 pages and there is a separate Excel file that can be used to review the results (Results Viewer). It is unlikely that decision makers will read and fully comprehend the report in its entirety. It is therefore critical that the report does meet the objectives of the study as reported in the Introduction and that the Executive Summary properly reflects the findings and conclusions of the study, including any limitations that the authors reported.

While the authors of the Study concluded that they had met the objectives of the study, they acknowledged a significant number of issues with robustness of the results and cautioned the use of the results in making comparisons between fuel chains. The whole purpose for doing an LCA is to allow comparisons to be made. This review has confirmed that there are significant issues with the robustness of the results and provides numerous examples of the issues with the Study.

2.1 INTRODUCTION

The objectives of the study are detailed in the Introduction to the report. The Study report states that;

> *"A key objective of this study is to combine past knowledge from the literature, as well as the knowledge and expertise from the project team and stakeholders to propose a comprehensive methodology filling past data and methodological gaps, as well as developing and applying more novel aspects to further enhance the analysis."*

The authors of the report state that: (emphasis added)

> "*The methodological choices made in this study, including the specific modelling of environmental impacts and use of datasets, were primarily based on available datasets and literature.* ***The breadth of the study did not allow for a consistent level of robustness and validation of all data, which, in several instances, were limited*** *(especially for certain energy/fuel chains). The* ***study outcomes primarily intend to show the consequences of methodological choices and key assumptions used in LCA*** *on the resulting environmental impacts of vehicle and energy chains, and to identify potential hotspots and areas of uncertainty and potential future improvement.* ***With due regards to the novel nature of some of these methodological choices and the limited robustness underlying some of the data used in this study for certain fuel production chains, it is important to take the results of this study with caution to avoid any definitive judgement on the environmental impacts in absolute and relative terms in these areas****. Nevertheless, the outputs from this study do provide robust indications on relative performance of the different options* ***particularly for vehicle powertrain comparisons, electricity chains, and conventional fuels****, and on how temporal and spatial considerations (e.g. due to variations in electricity mix) lead to different situations and potential future developments likely to affect these comparisons."*

The emphasised portions of the preceding paragraph are all extremely important**. It is clear that the report and the findings are not sound enough to serve as a roadmap for policy makers considering options to reduce the environmental impacts of transports systems over the next 50 years.**

Later in the Introduction the objectives are expanded and clarified as:

1. To develop an approach for a LCA of road vehicles, including the fuels or electricity which powers them, based on a literature review and stakeholder consultation, and combining mainstream elements of vehicle LCAs with novel methodological choices where necessary.

2. To apply this approach to understand the impacts of methodological choices and data sources on the LCA results for selected vehicle/powertrain/fuel categories expected to be in use over the time period 2020 to 2050.

The first objective has been at least partially met in that a new LCA methodology has been developed and it has some relatively novel choices, although the degree of originality and scientific veracity for the fuel supply chains is debateable. It is not apparent from the report that there was sufficiently thorough stakeholder involvement, at least from the alternative fuels sector. There were only two workshops for stakeholders and some information requests with no follow-up, for a study of this scope and magnitude this is not sufficient collaboration.

One aspect of the work that does differentiate this work from other transportation LCA models or well to wheels studies is the inclusion of additional environmental mid points beyond greenhouse gases, air pollution and energy balances. This study and model also produces results for acidification potential (AP), particulate matter formation potential (PMFP), photochemical ozone formation potential (POFP), human toxicity potential (HTP), water and terrestrial eco-toxicity potential (ETP), eutrophication potential (EP), ionizing radiation (IR), land use change, water consumption, abiotic resource depletion potential (ADP), and costs.

The second objective of applying the methodology to selected vehicles/powertrain/fuels has been partially met, however as noted above the authors state some significant caveats that apply to many of the alternative fuel chains. The report does not provide a comparison of the LCA results for different data sources as they might relate to the fuel chains. There has only been a single set of data used for the fuel chains. Furthermore the data choices that have been made for the fuel chains are not based on the most up to date information available.

2.2 Executive Summary

The authors of the study concluded that they had met the objectives of the study. They reported that;

> *The methodological choices made in this study, including the specific modelling of environmental impacts and the choice of datasets, are transparent and build on available literature and datasets. The choices made are based on fulfilling the specific objectives of the study, and have been (as far as feasible) consistently applied across all of the different vehicle, fuel/electricity chain and powertrain types.*

However they then go on to state

> *However, the breadth of the study did not allow for a consistent level of robustness and validation of all data, which, in several instances, were limited, especially for certain more novel energy and fuel chains.*

The transparency claim with respect to the data used in the modelling is questionable; while the source of the data is usually identified, for most of the sources there are multiple options with respect to geography and technology that are not specified. This makes it difficult for an independent reviewer to replicate the results.

With only one exception, the results presented in the Executive Summary are for the gasoline, diesel, and electric vehicles exclusively. The one exception is for the natural gas supply chain where CNG and LNG vehicles are compared to diesel, battery powered and hybrid vehicles in one figure. None of the other 60 fuel supply chains are directly mentioned in the Executive Summary or have any results presented in the Executive Summary.

The Executive Summary does identify the key limitations and uncertainties with respect to the study. These are copied directly from the report and include:

> *However, it is not generally valid to compare the results from this study with those of other studies characterised by their own analytical boundaries, different data sources, and specific data processing choices. As a result, this study cannot be considered to provide definitive, absolute results on the environmental impacts of different vehicles.*
>
> *For fuels, different methodological approaches, assumptions and data sources are tested in this study, some of which were novel in nature or utilised data with significant underlying uncertainty. This means that the results should not be taken as an accurate, consistent representation of impacts across all of the fuel chains investigated.*
>
> *In addition, comparisons should not be made between fuel chains when these are evaluated via different methodological approaches or where data robustness is more limited.*

The **conclusions and recommendations** that are presented in the Executive Summary highlight the success of the work but they are **mostly related to the analysis of the vehicles themselves and the electricity supply chains, not the liquid and gaseous fuel chains.** In this section of the Executive Summary there are again **many caveats reported with respect to the fuel chains**. These include the following conclusions.

> *The comparability of individual fuel chains is more limited because of methodological complexity and robustness of data sources.*
>
> *For fuel production chains, this study has highlighted numerous challenges for developing a consistent and harmonised methodology and dataset to evaluate all types of fuel chains through LCA. This has proved difficult in the context of complex methodological considerations and limited data availability for some newer fuel/process types. The results also highlight the importance of methodological choices with regards to the treatment of co-products, as the consistent implementation of a substitution approach shows significant differences, compared to the implementation of an energy allocation approach. Similarly, the inclusion of counterfactual scenarios in the assessment significantly affects the modelling of impacts of secondary fuels. Future research should further explore the modelling of counterfactual scenarios and the building of robust datasets to evaluate them.*

With respect to recommendations for future work the authors of the Study made a number of recommendations made with respect to the fuel chains. These were;

- *Develop improved foreground data-sets for non-conventional natural gas production, hydrogen production from natural gas, and fuel production processes which are currently at an early stage of commercialisation such as e-fuel production.*
- *Model additional counterfactual and substitution scenarios to provide LCA practitioners with guidance and default values and identify feedstocks or fuel production chains which may be at high risk of causing indirect impacts through their use in fuel production.*

- *Explore the possibility to model all residues as co-products and allocate a share of the impacts of the primary production process to them.*
- *Modelling of additional fuel chains, for example to cover new fuel types (e.g. bio-LPG) or variations on existing fuel chains.*
- *General exploration and improvement to the temporal harmonisation and granularity of data across all areas.*

2.3 KEY FINDINGS

With respect to the Introduction and the Executive Summary of the Study report there were two fundamental questions that were to be addressed by this review.

3. Are the summary and introduction compatible with the content and focus of the study?
4. What are the risks of comparing the results and even giving policy advice based on this "wide" collection of different data and models?

The answer to both questions is actually found either in the executive summary itself or by omission, that what is not stated in the executive summary.

With respect to the first question, the fact that of all of the alternative fuel chains analyzed only the CNG and LNG fuel chains are mentioned in the executive summary. There is **no mention of any of the other fuel chains**, not which ones were included in the study, or any of the results. A reader of only the executive summary would have no idea of how many fuel chains are included in the report, which ones they are, or any of the results for those alternative fuel chains.

The executive summary clearly states several times that there is a **high risk of comparing the results** between this study and other studies and even comparing the results between the different fuel chains in this study due to concerns about the quality and robustness of the data used for many of the fuel chains.

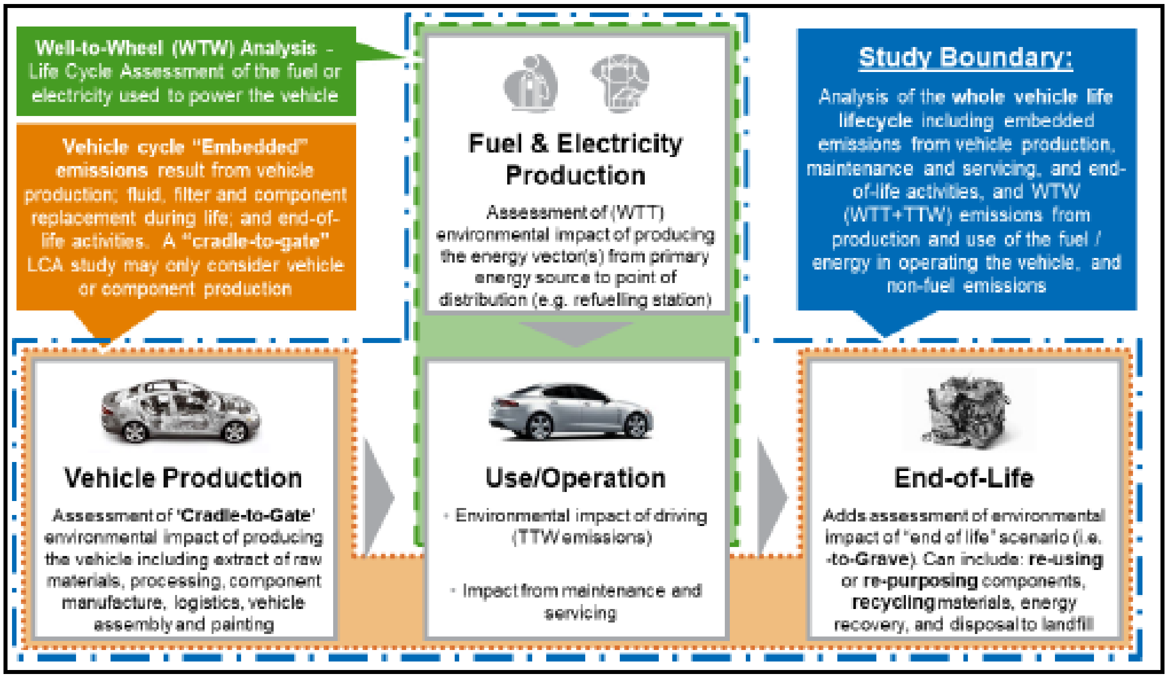
The authors of the Study expressed a higher degree of satisfaction with vehicle aspects of the work including the vehicle manufacturing, battery manufacturing, vehicle operation, the vehicle and battery end of life, and the electricity production chains than they do with respect to the fuel chain analysis.

In the executive summary of the Study report the authors make a number of recommendations with respect to improvements in the modelling of the fuel chains that should be made to the model including better quality datasets, additional counterfactual scenarios and substitution scenarios. The findings of this review fully support all of those recommendations as the Study has serious shortcomings in all of those aspects.

3. LCA METHODOLOGY

The first step in undertaking a life cycle assessment is to define the goal and scope of the study. The stated goal of this work was "to explore the environmental impact of a representative selection of road vehicle configurations in a holistic manner." The scope was to cover vehicle production, use/operation of vehicles including fuel and electricity production, as well as vehicle end-of-life. The system boundaries are shown in the following figure. It can be seen that the fuel production chains are just one portion of the entire system.

Figure 3-1 Study System Boundaries



3.1 NOVEL ASPECTS

It is stated throughout the report that the authors developed a novel methodology. This raises the question of what is novel about the methodology. While the term "novel methodological" is frequently used in the report there is no summary of what that actually means. The term is used in the report to describe the following aspects;

- End of life accounting for materials,
- A highly systematic approach was applied to accounting for future changes in the impacts of key materials and energy chains due to decarbonisation of the energy system and process improvement,
- Counterfactual scenarios (consequential LCA) in the case of secondary fossil and biogenic feedstocks,
- Impacts from co-products modelled via substitution, and
- Global land use-use change (both direct and indirect) impacts of primary biogenic fuels.

A discussion of these novel aspects is discussed below.

3.2 FORECASTS

Results for all of the fuel chains are presented in the Results Viewer for every tenth year between 2020 and 2070, but it does not appear that there are any changes after 2050.

From the results reported it would appear that there is **very little process improvement taken into account in the forecasts, contrary to the claims of a novel methodology**. Those fuel chains that have significant amounts of electricity consumption certainly have lower emissions through the 2020 to 2050 time period but many other portions of the fuel chains show no change in emissions through the 2020 to 2050 time period as shown for the corn ethanol pathway in the following table. The first table are the corn ethanol results, where it can be seen that there is no change in feedstock emissions through the study period. There is a small reduction in processing emissions but this most likely due to just the reduced emissions related to electricity consumption. There is a reduction in transport emissions which could reflect increased penetration of lower emission fuels in the transportation fuel mix.

Table 3-1 Corn Ethanol Results over Time

	2020	2030	2040	2050	2060	2070
	g CO_2eq/MJ					
Feedstock	34.2	34.2	34.2	34.2	34.2	34.2
Processing	29.6	28.4	27.8	27.4	27.4	27.4
Transport	1.5	1.3	1.2	1.1	1.1	1.1
LUC	14.0	14.0	14.0	14.0	14.0	14.0
Counterfactual	0.0	0.0	0.0	0.0	0.0	0.0
Total WTT	79.3	77.9	77.2	76.7	76.7	76.7
Gasoline	88.7	88.5	88.4	88.3	88.3	88.3

There are so many opportunities for employing technologies to reduce the emissions of corn ethanol production such as the use of biomethane to displace natural gas, or increased adoption of combined heat and power systems, and increased electrification to replace the use of fossil fuels in the production system. It is not conceivable that none would be adopted by the industry in the next 30 years.

The assumption of no change in feedstock production emissions is completely inconsistent with the historical data and emerging potential for precision agriculture. More detail on some of the historical trends is presented in Appendix 2. In an October 2020 press release the European Council published its negotiating position (general approach) on the post-2020 common agricultural policy (CAP) reform package. This agreed position puts forward some strong commitments from member states for higher environmental ambition with instruments like mandatory eco-schemes (a novelty compared to the current policy) and enhanced conditionality. (European Council, 2020). Some concrete examples of how member states will fulfil higher environmental standards, which were debated and agreed during the two-day Council, include:

- Farmers would receive financial support under the condition that they adopt practices beneficial for the climate and the environment, to make the CAP even greener than before.
- Farmers going beyond the basic environment and climate requirements would get additional financial support through the introduction of "eco-schemes". Indicative examples of eco-schemes include practices like precision farming, agroforestry, and

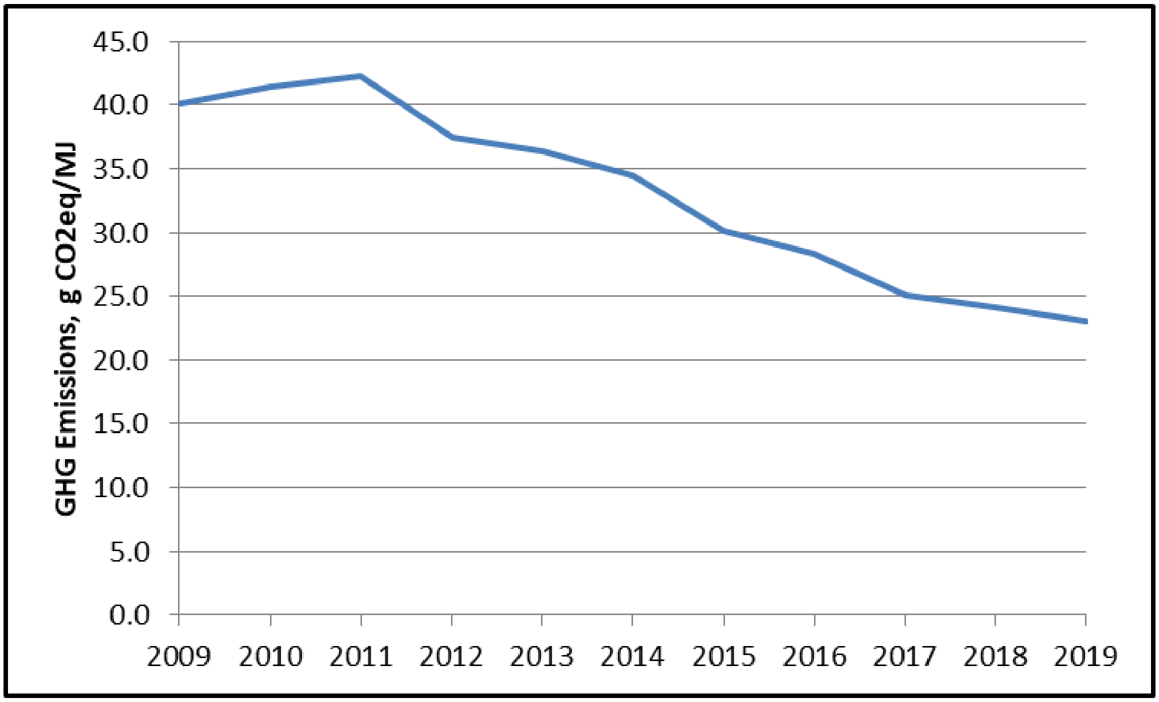
organic farming, but member states would be free to design their own instruments on the basis of their needs.

- All farmers would be bound to higher environmental standards; even the smaller ones. To help them in this greening transition, small farmers would be subject to more simplified controls, reducing administrative burden while assuring their contribution to environmental and climate goals.

Many of the fuel chains that are included in the study are novel and are not yet commercial. It is inconceivable that there will be no technological learning for these systems as they are developed and deployed between 2020 and 2050 (Ganter et al, 1992).

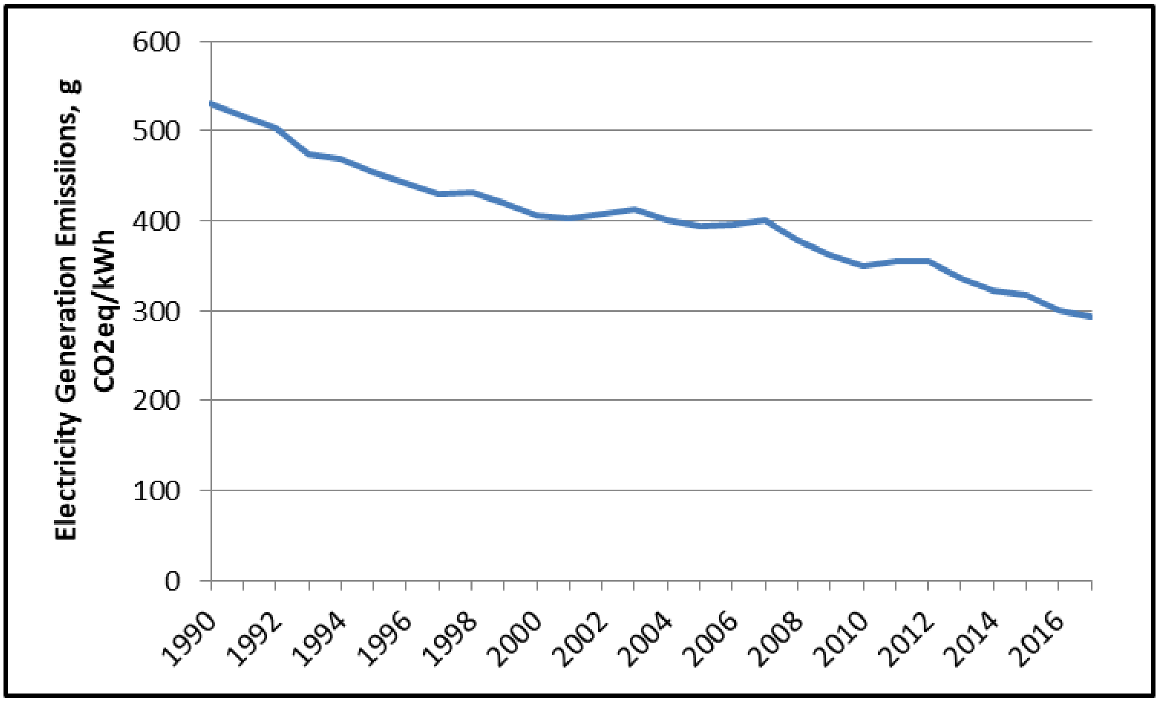
The evidence for GHG emission reductions from the commercial biofuels is also clear. The following figure shows the change in the GHG emission reductions for European produced ethanol in the past decade (ePURE, 2020).

Figure 3-2 Trends in GHG Emissions for Ethanol



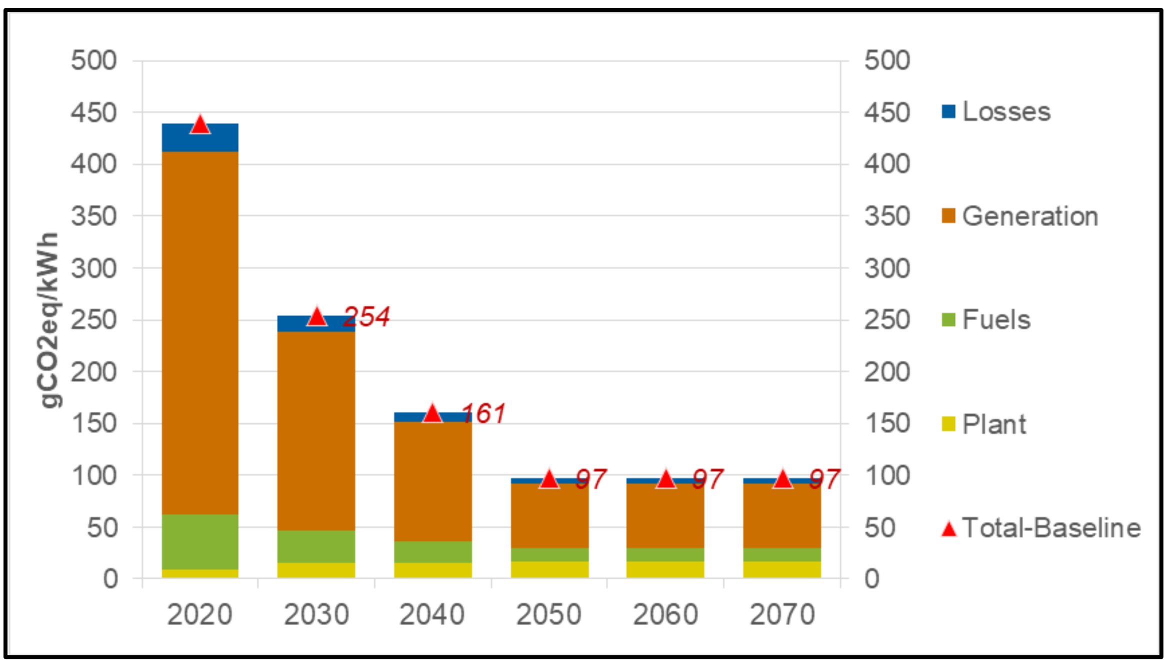
In contrast to the lack of change in fuel production emissions resulting from the adoption of innovations, the change in the emission intensity of electricity through the study period is for a 78% reduction in the GHG emissions for electricity between 2020 and 2050.The historical change in electricity generation is shown in the following figure (European Environment Agency, 2020). These are not lifecycle emissions as they exclude fuel production, plant construction emissions, and distribution losses.

Figure 3-3 Historical Electricity Generation GHG Emissions



The following figure shows the forecast lifecycle GHG emissions developed in the Study. The 2020 generation emissions in the Study were 351 g CO_2eq/kWh compared to the reported value of 297

Figure 3-4 Electricity GHG Emission Forecast



The inconsistent approach to forecasting seriously skews the future results for the various pathways and renders the future year results meaningless, particularly for any comparison between the pathways. This reinforces the Study's recommendation that comparisons should not be made between fuel chains where data robustness is limited.

In Appendix 1 we present some time series of data to illustrate how systems that the Study assumes won't change over time have changed in the past.

3.3 COUNTERFACTUAL CASES

A counterfactual scenario should account for what would happen if a new technology comes into use or if a shift occurs in how technology is used. Introducing a counterfactual scenario can be difficult because the evolution of technology and technology usage over time in both the new technology and the business-as-usual case must be projected, often with significant uncertainty. This is essentially the definition of a consequential LCA.

One of the ISO principles for life cycle assessment is that of comparability. Two systems must perform the same functions or provide the same service or set of services before a valid comparison can be made compared. The system boundaries are often adjusted to ensure that the systems are in fact comparable. Throughout the LCA literature there is confusion between counterfactual cases and efforts made to ensure that the systems are comparable. In fact in some of the literature the counterfactual case is also called the reference system (ETI, 2018).

The Study makes the case that introducing the counterfactual cases introduces consequential aspects to the attributional approach for most of the LCA.

Single counterfactual cases are presented for secondary feedstocks (waste and residues). For all secondary feedstocks except for animal manure the counterfactual case assumes that the feedstock would have been combusted to produce electricity. In the case of manure the counterfactual assumes the manure is used as fertiliser on a field.

There is some biomass used to produce electricity in the electric power production mixes during the study period but by 2050 the Study finds that power produced from biomass is actually above the grid average carbon intensity.

The inclusion of the counterfactual results is an option in the Results Viewer; that is the results can be calculated with and without these emissions. The Study has also recommended that additional counterfactual cases should be considered in the future.

Since the study assumed that the GHG emissions of electricity generation decline between 2020 and 2050, the counterfactual emissions for the fuels that use secondary feedstocks also decline over time.

There are several issues with the counterfactual cases that are presented in the Study report and these are discussed below.

3.3.1 Existing Uses

The counterfactual case requires an accurate assessment of the current situation since it is meant to determine the consequences of the change from the current situation to a future situation. For most of the secondary feedstocks there are a multitude of existing uses or disposal practices. More detailed information on the current uses of the secondary biogenic feedstocks is presented in Appendix 2.

For example, only 27% of the MSW generated in Europe is incinerated with energy recovery (Eurostat, 2020). Twenty four percent is landfilled where avoided landfill gas emissions would generate a credit instead of an emissions debit.

The material that is currently landfilled or incinerated without energy recovery would be available for use for fuel production without any counterfactual emissions. In fact there may be a reduction in methane emissions from landfilling as most landfill gas capture systems are not 100% effective.

Some straw is used for energy production in some EU member states and some is used for animal bedding but the most often it is incorporated into the soil. Many studies (Monforti et al, 2015, Scarlat et al, 2010) show that significant quantities of crop residues are available beyond existing needs and could be used for energy production without impact soil carbon levels. A more accurate counterfactual would be to consider the impact on soil carbon if the residue is removed rather than incorporated into the soil.

Forest residue availability in Europe has also been recently assessed (Verkerk et al, 2019). They concluded that 357 to 551 million tonnes of dry matter per year could be available. The paper did not fully investigate the sustainability of all of the available biomass but the change in the GHG emissions between using this material for energy versus letting it decompose in the forest would be the more appropriate counterfactual case to investigate rather than assuming that it is all used for the production of electricity.

Clearly the assumption that the secondary feedstocks are used for electricity production is not an appropriate counterfactual case to evaluate for all of the secondary feedstocks.

3.3.2 Comparable Systems or Counterfactual?

In the case of manure used for anaerobic digestion there is a large counterfactual emission credit for avoided methane emissions from not spreading the manure on the fields. In many attributional LCA studies these emissions are included as a credit to the biomethane system (Bacenetti et al, 2016). These LCA practitioners include the emission credit to make the system comparable to a fossil natural gas system. A fundamental LCA principle is that the systems being compared provide the same services it is necessary to compare the emissions from a fossil natural gas system that supplies one MJ of methane and includes methane disposal (land application) with a system that provides both one MJ of methane and the disposal of manure. The equation form of this statement is shown below where the equals sign means comparable to.

One MJ of Fossil Methane + Manure disposal emissions = One MJ of Methane from Manure

Rearranging the equation becomes

One MJ of Fossil Methane = One MJ of Methane from Manure + Credit for Manure disposal emissions

So the credit for the avoided manure emissions becomes part of the attributional LCA where equivalent systems are compared. **The Study inappropriately account for these avoided emissions in their counterfactual scenario rather than in their attributional analysis.**

3.3.3 Emission Burden Free?

All of the secondary feedstocks are analyzed as being emission burden free at the point of production. This is a common treatment in LCA work for waste products. One issue that most

LCA practitioners and many regulators struggle with is the definition of wastes, residues and co-products. When do wastes become residues that have some economic value?

If the counterfactual assumptions are true; that all of the secondary feedstocks are used for energy production it becomes difficult to classify them as waste materials that are emission free. A much stronger argument can be made that they are co-products of the system that produced them and some of the emissions associated with production system should be allocated to the secondary feedstock. For example, Borrionet al (2012) applied mass allocation between wheat and wheat straw for a LCA of wheat straw ethanol. If that is the case then the emissions for the primary feedstocks would all be lower and there should be a counterfactual emission credit for all of the primary feedstocks to be consistent with the counterfactual assumptions.

So not only is counterfactual assumption that the secondary feedstocks are already fully utilized not supported by the data, but if they were fully utilized then they should have some of the emissions associated with the primary feedstocks allocated to them, which was not done.

3.4 CO-PRODUCT TREATMENT

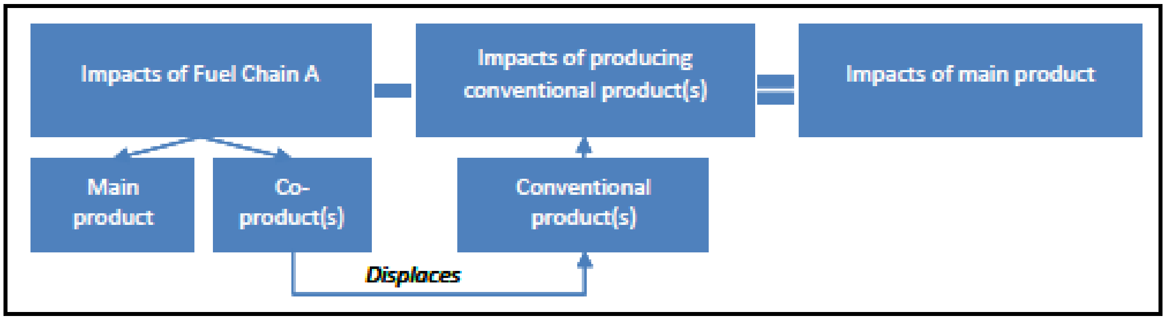
One of the novel aspects of the study was to investigate alternative approaches for dealing with emission attributions to co-products. While the general practice in European fuel regulations has been to use energy allocation to attribute some of the system emissions to the co-products and thus reduce the emissions attributed to the primary product, ISO LCA guidelines recommend that allocation be avoided by employing system expansion also known as the displacement or substitution approach to co-products. With the ISO preferred approach co-products receive a credit for the emissions that are avoided by not having to produce the products that the co-products displace in the marketplace. This is the alternative approach investigated in the Study.

An argument can be made that allocation by energy is not appropriate for co-products that are not used for energy production. Some systems may have co-products with no energy content and thus receive no share of the emissions associated with the production of the primary product.

The displacement approach is used for electricity as a co-product in some EU systems and is essentially what has been done for most of the counterfactual scenarios. The displacement approach is used for some fuel production pathways in the California LCFS program and some of the US RFS2 pathways employ the displacement approach for co-products.

Only the energy allocation approach for co-products was used for the results presented in the report. The substitution method is described in the Appendix A3.7 in the Study report and the substitution results are presented in the Results Viewer Excel file. The illustrative diagram is shown in Figure 3-5.

Figure 3-5 The Substitution Method



The Study based the impacts associated with producing conventional products on ecoinvent modelling for all co-products, except co-products which would displace conventional diesel, gasoline, natural gas or electricity. In the cases where the co-product can substitute for diesel, gasoline and natural gas, the displacement credit is equivalent to their impact (up to point of production) as already modelled in the fuels' module under their respective chains. Where electricity is produced as a co-product, the substitution credit is equivalent to electricity impact as modelled. Thus the displacement or substitution is already used for some fuel chains in the primary results.

Some examples are shown in Table 3-2. When energy allocation is employed the emissions for both the feedstock and the fuel processing stages are reduced. When the substitution method is used the co-product credit is applied just to the fuel processing stage. So the feedstock emissions are always higher and the fuel processing emissions are always lower for the substitution approach. These results are extracted from the Results Viewer.

The oilseed fuels have lower emissions with the substitution approach. Since the same effect is seen for FAME and HVO this must be related to the protein meal and not the co-products from the fuel production process. **The significantly different results should be highlighted to policy makers as the emission benefits currently attributed to these fuels might be significantly underestimated.**

There is little difference in the two co-product treatments in the primary ethanol fuels. This is surprising since this is not seen in other GHG models such as GREET or GHGenius where allocation by energy tends to provide lower overall emissions than the substitution approach. When the energy allocation approach for co-products was selected for the RED one of the arguments was that this would remove the incentive for plants to lower their GHG emissions by using the animal feed co-product for fuel. This would suggest that this isn't a concern.

The other caveat is that the substitution results are also dependent on the quality of the information from the modelling with the ecoinvent database for the substituted products. The following table compares the Study results for some of the fuel chains using the two different approaches to dealing with co-products. The table highlights how different approaches to dealing with co-products can lead to different conclusions with respect to the sustainability of the fuel chain.

Table 3-2 Energy Allocation vs Substitution

Fuel Chain	Approach	Feedstock	Processing	Transport	Counterfactual	Total WTT
		g CO_2eq/MJ				
F-Rapeseed	Energy	44.2	13.7	1.2	0.0	59.0
	Substitution	76.8	-31.3	1.2	0.0	46.7
F-Sunflower	Energy	30.5	13.4	1.2	0.0	45.1
	Substitution	51.2	-28.9	1.2	0.0	23.4
HVO-Rapeseed	Energy	47.2	12.5	1.2	0.0	60.8
	Substitution	78.6	-26.9	1.2	0.0	52.9
E-Wheat	Energy	42.2	29.5	1.5	0.0	73.2
	Substitution	73.2	-1.3	1.5	0.0	73.3
E-Corn	Energy	34.2	29.6	1.5	0.0	65.3
	Substitution	51.9	10.8	1.5	0.0	64.9
Syn Diesel-Forest Res	Energy	10.1	14.1	1.2	61.6	25.4
	Substitution	18.5	-25.6	1.2	112.4	-6.0
E-Straw	Energy	17.7	9.9	1.5	65.1	29.1
	Substitution	24.9	-35.3	1.5	91.3	-8.9

The higher counterfactual emissions in the substitution cases are a result of the displacement credit is only for the emissions displaced up to the point of production and exclude any emission benefits from the use of the product. **This choice is not justified in the Study report and this has not been properly stated in the Study report potentially giving the impression that the reported data reflects a unanimous view (which is clearly not the case).**

3.5 LAND-USE CHANGE

While the authors, in the Executive Summary, indicated that they were happy with the methods that were used for analyzing the fuel supply chains, the treatment of land use change is not an area where there is consensus on the scientific approach that can be used. Even in the Delphi surveys that were undertaken by the authors there was not a clear consensus on the issue of indirect land use change. In the first round of the Delphi surveys, only 22 of the 35 participants responded to the question on the inclusion of indirect land use change and of those only seven strongly agreed with the inclusion of indirect land use change. Of the 23 participants who answered to the question about how to characterise ILUC, only 3 supported Globiom, while the two most selected answered were I don't know or ILUC should not be included. In the second round of the Delphi survey just over half of the respondents supported the inclusion of ILUC. **Clearly there are still methodological as well as data issues to be resolved.**

In the Results Viewer, the Land Use Change emissions and the Counterfactual emissions are optional extras. So the results can be viewed with and without these emissions. There are two issues with the inclusion of indirect land use values. The first is the values themselves since the model results are almost impossible to audit or verify with real world data. The second is the general approach of adding values from an attributional and a consequential LCA together since they model very different scenarios.

3.5.1 Land Use Change Values

The Study acknowledged that there are a number of publications using the GLOBIOM and GTAP models which provide land use change emissions. These are economic equilibrium models that respond to a demand shock. The size of the demand shocks are not related to any fuel mix considered in this Study. For this Study the land use change values from the 2015 GLOBIOM study (Valin et al) without any discussion of why these were used rather than values from GTAP or from Annex VIII of the RED II.

An updated version of the GLOBIOM model has also been used to calculate the land use change impacts of sustainable aviation fuels. The aviation fuels were also analyzed with the GTAP model (used in California for ILUC values). The two model development teams also worked together to investigate differences in their results and to try and reconcile the differences. The comparison of the results from these efforts is shown in the following table. The aviation fuels used a 25 year amortization period rather than the 20 year period used in the 2015 GLOBIOM study.

Table 3-3 Land Use Change Values

	Transportation Fuels	Aviation Fuels	
	2015 GLOBIOM	GLOBIOM	GTAP
	g CO_2/MJ		
Corn	14	25.3	24.9
Sugarcane	17	8.3	9
Rapeseed	65	27.5	20.7
Soybean (US)	150	50.5	22.5
Soybean (Brazil)		117.9	95.4
Palm	231	60.2	34.6

There is a significant difference in the ethanol based fuels used for transportation and the fuels used for aviation and that may explain the difference in the corn results. The oilseed values from the latest GLOBIOM modelling are significantly lower than the 2015 values used in The Study. The GTAP values for corn and sugarcane are essentially the same as the latest Globiom results but GTAP delivers lower, and in some cases drastically lower results for oil seeds than GLOBIOM.

Tyner et al (2018) compared the results from GLOBIOM and GTAP for several biofuels and investigated the reasons for the differences. They found a number of reasons for the differences. There were three main factors.

> *The livestock rebound effect is very important in driving emissions in GLOBIOM. Essentially, the added supply of protein feedstuffs induces GLOBIOM to grow more grains to make use of the protein feeds in a larger livestock sector. Essentially, all the emission associated with the growth in the livestock sector gets charged to the biofuels.*
>
> *The palm oil yield and peat oxidation factor are also quite important. Since palm oil substitutes for other vegetable oils, what happens to palm and its emissions is important in all the pathways, but especially, of course, the oilseed pathways. In this analysis, we detail a number of reasons why we believe that the palm oil yield and peat oxidation factors in GLOBIOM do not provide an accurate representation of what seems to be actually happening in the region or in world markets.*

Finally, the abandoned land emission factors and use of abandoned land in some but not all pathways also are important. We provide data to support that the approach to handling abandoned land and the emission factors assigned to it may not be appropriate in GLOBIOM.

Some of the differences between GTAP and GLOBIOM have been addressed since the 2015 report since the aviation fuel results are much closer. A full description of the changes made to both models can be found in the ICAO document "CORSIA Eligible Fuels – Life Cycle Assessment Methodology." Since there are still difference in the oilseed sector, and especially for soybeans it is likely that the livestock rebound effect is not totally resolved.

The CORSIA report concluded that the estimation of ILUC emissions is subject to substantial uncertainties that need to be kept in mind to put results in perspective. In general, these uncertainties can be classified in four main categories: (1) methodology, (2) model design, (3) data, and (4) parameters.

To reconcile the different values from the two models, CORSIA took the following approach.

1. If the difference between the two model values for a particular region and pathway is 8.9 g CO_2e/MJ or less (10% of the fossil jet fuel value), then the proposed ILUC value is the average of the two model results.
2. Where the difference was greater than 8.9, the lower of the two model values plus an adjustment factor of 4.45 g CO_2e/MJ (half of 8.9).

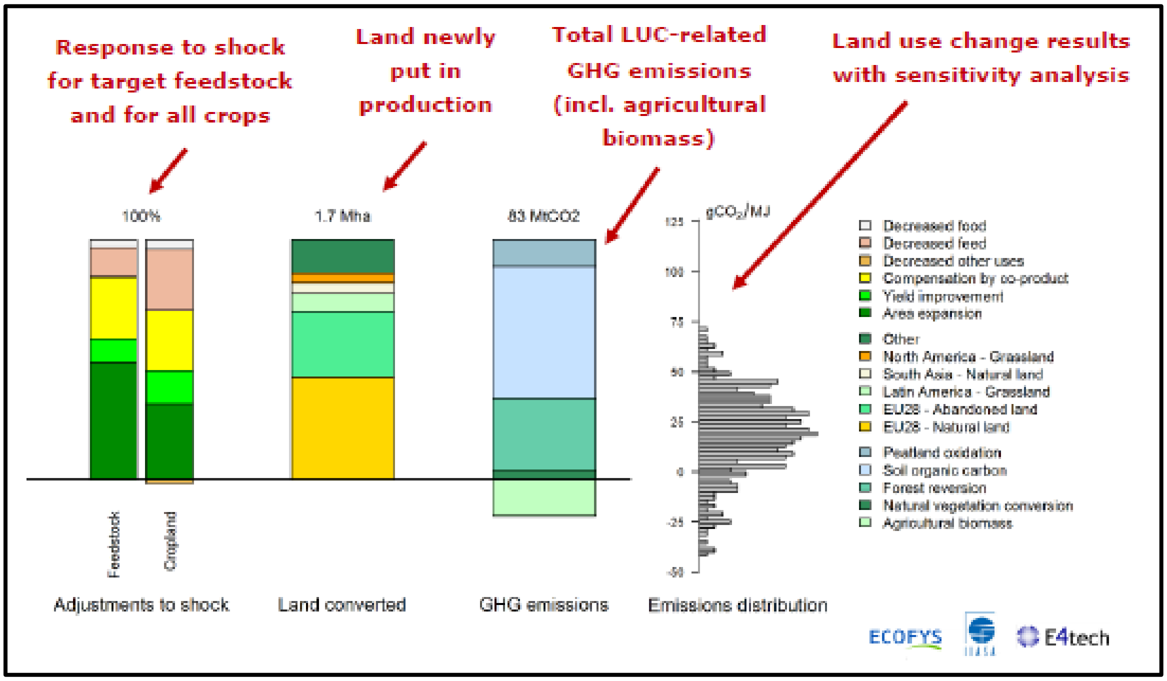
This approach essentially assigns more weight to the lower GTAP results than the GLOBIOM results. It is a practical way to deal with the fact that there remains a range of ILUC values and that there is still significant uncertainty surrounding this issue.

3.5.2 The Hybrid LCA

The land use change emissions are developed from applying a demand shock to an existing economic system which responds and returns a new equilibrium state and the difference in the existing and new state is used to calculate a change in emissions. **In the Study work, for both the counterfactual results and the land use change results the attributional results and the consequential values are simply added together. However simply adding consequential results to an attributional result is not the same as undertaking a proper consequential LCA.**

To arrive at the land use change emissions there is a base case determined which has the existing biofuel volume. To that base case additional biofuel demand is added, say a 20% increase in biofuel demand and the models work to find a new equilibrium where some of the increased demand is met through increased production and some is met through the re-allocation of feedstock from current demand to biofuel production. The emissions calculated are divided by the size of the increased biofuel demand to arrive at a g CO_2/MJ value. An example from the Globiom report is shown below.

Figure 3-6 ILUC Calculations



The approach used in California and in reports that have used the GLOBIOM results has been to simply add the attributional LCA value to the land use change value. This applies the land use change emissions to the production in the base case which in most cases has been achieved by bringing idle land back into production, by increasing crop yields, by changes in diets, by improved efficiencies or other means without impact the total quantity of idle land. An argument can be made that a more appropriate approach would be to divide the new land use emissions by the total biofuel production and not just the new production if the desired outcome is to understand the emissions of all of the biofuel that is being produced and used.

Another challenge of adding the attributional and consequential results is that the quantity of feedstock used to make the 1.2 times the current volume of biofuels is not 1.2 times the quantity of feedstock used to make the current volume. The models reach a new equilibrium when some of the new demand for feedstock is produced by reallocating feedstock from existing non fuel uses through what could be broadly called efficiency gains in the system. For example, people might eat less red meat and more poultry which has the impact of requiring less animal feed and the difference in feed can be used for biofuels. So by simply adding the two values together we are essentially counting the emissions from some of the feedstock production twice.

There is surprisingly little in the academic literature about this issue. However it should be clear that **adding an attributional LCA results to a partial consequential result is not the same as undertaking a full consequential analysis. Furthermore the sum of the two values almost certainly overstates what a full consequential analysis would show.**

3.6 Key Findings

The Study encompasses a number of what they called novel aspects. However there are issues with most of the novel aspects. These include.

1. The forecasts of future emissions would appear to only include changes in the emission intensity of electricity. There are no changes in agricultural production despite this being a major objective of a new CAP. There do not appear to be any changes in alternative fuel production technologies even though new technologies are being adopted and there are incentives for industry to reduce emissions, with emissions already being clearly lower currently than 5 to 10 years ago.
2. The counterfactual cases (one for each secondary feedstock) do not reflect the range of current use of these feedstocks in most cases and thus the counterfactual results have little validity.
3. Using the substitution method for dealing with co-products, which is the ISO preferred approach, produces lower emissions for oilseed based fuels and similar results for starch based fuels. The issue of the implications of one co-product allocation method compared to another is very poorly understood by most people other than LCA practitioners. It can have a significant impact on the results and the Study has not done anything to explain the reasons for the differences.
4. There have been changes to the GLOBIOM model since the 2015 work was done that has resulted in lower land use change values. The GTAP model also generally produces lower land use change values that GLOBIOM, particularly for oilseed based fuels. The availability of lower land use emissions from newer modelling frameworks is not acknowledged in the Study report.
5. The simple addition of values from an attributional analysis and a partial consequential analysis provides a distorted view of the emission profile. The resulting product almost certainly overstates the results from a proper consequential analysis.

4. DATA QUALITY

Life cycle analysis has become one of the most actively considered techniques for the study and analysis of strategies to meet environmental challenges. Undertaking an LCA is a process which relies on identifying all of the inputs and outputs to a system and processing that data into environmental categories (midpoints) so that comparisons can be made between alternative systems.

Data collection is the most time consuming aspect of performing an LCA. Almost since the introduction of LCA models in the early 1990s there has been an effort to share data on the various processes that make up a production system. With this sharing of data between LCA practitioners there developed a need to characterize and assess the quality of the data sets used for an LCA.

The primary sources of data are the ecoinvent database, the JRC, the JRC RED II default values (which are identified as a different source than just the JRC), Globiom, the JRC GNOC model, the JEC (JRC-Eucar-Concawe), and some data from individual companies.

4.1 COMPARISON OF RESULTS

The authors of the Study warn against comparing the results of their work to the results from other models due to the methodological differences in the different models but it is also possible that the differences are caused by differences in data. The most likely comparisons that should be made are with the REDII default values and the JEC version 5 work (published in 2020). Some of these comparisons are made below for some of the fuels.

4.1.1 Feedstock Cultivation

The feedstock emissions in the Study are from a combination of the use of the ecoinvent database and N_2O emissions from the JRC GNOC model. The first table compares the the Study results using energy allocation to those in the REDII.

Table 4-1 Feedstock Comparison – Energy Allocation

Feedstock	The Study	REDII
		g CO_2eq/MJ
Corn	34.2	25.5
Wheat	42.2	26.7
Sugar beet	19.8	9.6
Sugarcane	33.9	17.1
Rapeseed	44.2	32.0
Sunflower	30.5	26.1
Palm Oil	35.7	26.2
Straw	17.7	1.8
Forest residue	12.9	3.1
SRC	21.9	7.6

The Study values are all significantly higher than the REDII values. The authors of the Study suggests that one reason could be that they include the emissions associated with the production of the farm equipment but that is not the only possible reason as will be discussed later.

The next table compares the Study values using substitution to those of the JEC V5, which used the same co-product approach. While the fossil fuel values are similar (albeit using a different methodology) the values for biomass feedstocks are significantly higher.

Table 4-2 Feedstock Comparison - Substitution

Feedstock	The Study	JEC
	g CO_2eq/MJ	
Corn	51.9	36.0
Wheat	73.2	45.6
Sugar beet	32.7	13.2
Sugarcane	36.1	16.8
Rapeseed	76.8	52.5
Sunflower	52.4	41.1
Palm Oil	46.7	28.8
Straw	24.9	14.1
Forest residue	14.2	4.4
SRC	24.1	11.0
Gasoline	9.3	9.8
Diesel	8.1	10.8
Natural Gas	11.4	11.4
LPG	8.1	7.8

In Appendix 3 a more detailed review of the data used to develop some of these values is presented for a few of the feedstocks that are commonly used in the EU. For the feedstocks reviewed the data used for yield, fertiliser requirements, and the emissions associated with fertiliser production were old and not representative of the current production practices.

4.1.2 Biomass Processing

Similar comparisons are made for the biomass processing (or fuel production) stage. Here the typical values (not the default values which are 40% higher than the typical values) from the REDII are compared to the Study values. The Study results are all higher, but generally by a lower percentage than the feedstock cultivation differences. This would be expected because the data came from the JEC WTT work.

Table 4-3 Fuel Production Comparison – Energy Allocation

Feedstock	The Study	REDII
		g CO_2eq/MJ
Corn Ethanol	29.6	20.8
Wheat Ethanol (other cereals in REDII)	29.5	21.3
Sugar beet Ethanol	22.3	18.8
Sugarcane Ethanol	1.4	1.3
Rapeseed FAME	13.7	11.7
Sunflower FAME	13.4	11.8
Palm Oil FAME	11.4	13.2
Straw Ethanol	9.9	4.8
Forest residue Synthetic Diesel	14.1	0.1
SRC Gasoline	14.1	0.1

The next table compares the Study values using substitution to those of the JEC V5, which used the same co-product substitution approach. The values are all very different and not consistent with the JEC values being lower in some cases and higher in other cases. The Study used ecoinvent information for the co-product values, which is likely the source of the very different results.

Table 4-4 Fuel Production Comparison - Substitution

Feedstock	The Study	JEC
	g CO_2eq/MJ	
Corn Ethanol	10.8	-22.8
Wheat Ethanol	-1.3	-55.1
Sugar beet Ethanol	-6.0	7.2
Sugarcane Ethanol	-6.7	-2.6
Rapeseed FAME	-31.3	-5.7
Sunflower FAME	-28.9	-3.2
Palm Oil FAME	-0.9	-3.5
Straw Ethanol	-35.3	-3.1
Forest residue Diesel	-25.6	0.1
Gasoline	9.3	5.5
Diesel	8.8	7.2

With the very large differences between the Study results and the REDII and JEC results one has to question the data sources. The JRC has worked for the past decade to update their default values. The latest values (version 1d) (Edwards et al, 2019) which were used to develop the REDII values were revised and published in 2019 and are quite transparent with respect to the sources of the data that were used to develop the values. The process involved input from a wide variety of stakeholders. The JEC work involved the JRC and so there is some alignment between the values used for the REDII values and the version 5 of the JEC WTW work.

In order to better understand how or why the input data may differ between different LCA modelling efforts the following information on data quality is presented.

4.2 INTRODUCTION TO DATA QUALITY

ISO 14044 defines the ten key categories for addressing data quality. ISO requires LCA practitioners to address the following data quality areas if the “study is intended to be used in comparative assertions that are intended to be released to the public” (ISO, 2006).

1) Time related coverage
2) Geographical coverage
3) Technology coverage
4) Precision
5) Completeness
6) Representativeness
7) Consistency
8) Reproducibility
9) Sources of the data
10) Uncertainty of the information

The ISO 14040 and 14044 documents do not further define how these areas are to be addressed, but rather leaves this task to the discretion of the individual. The lack of a single data quality system requirement from ISO has spawned a wide range of quantitative and/or qualitative approaches for capturing data quality.

Weidema and Wesnaes (1996) published one of the first papers outlining a formal process for data quality management in life cycle inventory development. This paper has been cited 836 times according to Google Scholar. This paper introduced a number of data quality indicators which are still used today. They reported that the following indicators are both necessary and sufficient to define the quality of the datasets.

Reliability - The ‘reliability indicator’ relates to the sources, acquisition methods and verification procedures used to obtain the data.

Completeness - The ‘completeness indicator’ relates to the statistical properties of the data: how representative is the sample, does the sample include a sufficient number of data and is the period adequate to even out normal fluctuations.

Temporal Correlation - The ‘temporal indicator’ represents the time correlation between the year of study (as stated in the data quality goals) and the year of the obtained data. As technology develops very quickly in certain industries, ten years difference between the year of study and the year of the data might cause the emissions and the production efficiency to be totally changed.

Geographic Correlation - The ‘geographical indicator’ illustrates the geographical correlation between the defined area (as stated in data quality goals) and the obtained data. The production methods and the production conditions can be very different in different parts of the world

Technology Correlation - The ‘technological indicator’ is concerned with all other aspects of correlation than the temporal and geographical considerations. Although data may be of the desired age and representative of the desired geographical area, it may not be representative of the specific enterprises, processes or materials under study.

Weidema et al proposed a ranking from 1 to 5 for each of the indicators as shown in the following table.

Table 4-5 Data Quality Matrix

Indicator Score	1	2	3	4	5
Reliability	Verified data based on measurement	Verified data partly based on assumptions or non-verified data based on measurements	Non-verified data partly based on assumptions	Qualified estimate (by an industry expert)	Non-qualified estimate
Completeness	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations	Representative data from a smaller number of sites but for adequate periods.	Representative data from an adequate number of sites but from shorter periods.	Representative data but from a smaller number of sites and shorter periods or incomplete data from an adequate number of sites and periods.	Representativeness unknown or incomplete data from a number of sites and/or from shorter periods.
Temporal	Less than three years of difference to year of study	Less than six years difference	Less than 10 years difference	Less than 15 years	Age of data unknown or more than 15 years of difference
Geographical	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown area or area with very different production conditions
Technology	Data from enterprises, processes and materials under study	Data from processes and materials under study but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials but same technology	Data on related processes or materials different but technology

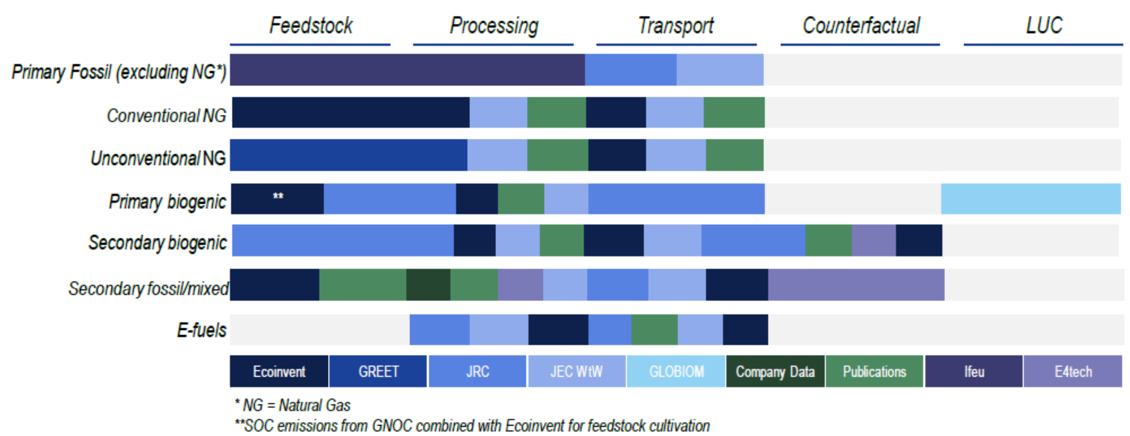
There have been other, similar quality matrices developed (Edelenand Ingwersen, 2016) that are very similar in concept but have different or expanded qualification in some of the boxes in the matrix.

The Study considered 60 fuels in the study and for any given fuel there can be multiple data sets and multiple models that are used to determine the environmental attributes of the fuel system. There are too many fuels to do a detailed review of the quality of the data for each fuel chain. In Appendix 2 we present some comparison of the values in the data sets used by the Study for a fuel pathway and other results, including results in other datasets used by the Study in this work but not in the same fuel chain.

The reported data sources used for the different groups of fuel chains are shown in the following figure.

Figure 4-1 Data Sources Utilized

Figure 3.8: Summary chart of the different foreground data sources used in in the modelling of fuel chains



There can be three types of problems with the approach of using different data sources within the same analysis;

1. There can be an overlap between the system boundaries so that the same source of emissions (or sink) is counted twice.
2. There can be a gap between the models so that some emissions (or co-products) are missed.
3. There can be different approaches used in different parts of the supply chain.

4.2.1 Temporal Consistency

With so many data sources used there will be issues where the data is not always from the same period. Data that is 15 years old would be ranked a 4 and data over 20 years old would have the lowest possible ranking of a 5. The data for feedstock emissions came mostly from version 3.5 of ecoinvent database. While version 3.5 was released in 2018, the individual data sets are not updated every year. The ecoinvent data that would be used would be the fuel used per hectare (and therefore the crop yield), the fertiliser application rates, and the emission factors for fertiliser production.

In many cases ecoinvent has data for multiple regions and it is not possible to determine which dataset was used by the Study. The following table summarizes the original date for some of the feedstock data sets that would have been used for this work.

Table 4-6 ecoinvent Database

Input	Date and comments
Corn production	Global. This dataset has been copied from a US data set. There is no EU dataset. Data from 2004 to 2006 literature data sources.
Wheat production	Global. Averaged data from Germany, Spain, France and the US. 2001 to 2006.
Rapeseed production	Global. Averaged data from Germany, Spain, France and the US (the US is an insignificant producer of rapeseed). Data from 2000 to 2004.
UAN fertiliser	Originally published in 2000. European average is derived from mean values of several fertiliser plants within Europe.
Sugar beet	Global. 1996 to 2003. Refers to an average production in the Swiss lowlands. Yield data has been updated to avg of 2000, 2005, and 2008.

Clearly much of the data in the ecoinvent database used for this project would rate a 4 or 5 with respect to the data of the data.

More detailed information on the data is presented in Appendix 3.

4.2.2 Geographical Consistency

Biomass production parameters will vary significantly from region to region. Ideally the data would be representative of the entire EU. As shown in Table 4-6 the data can be collected from a relatively small region and represented as a global average. For the data sets that were used in The Study there don't appear to be any that are fully representative of the EU region.

4.2.3 Technology Coverage

The Study does not identify which specific technology has been used for each of the pathways. When one looks at the REDII default values it can be seen that for many of the pathways there are multiple types of plants with very large differences in emissions. The table below for corn ethanol demonstrates this.

Table 4-7 REDII Technologies

Process	Typical Processing Emissions, g CO_2/MJ
Ethanol from maize, NG boiler	20.8
Ethanol from maize, NG CHP	14.8
Ethanol from maize, lignite (and coal) CHP	28.6
Ethanol from maize, forest residues CHP	1.8

Reporting a single value when there is a wide range in the technologies employed as has been done in The Study is not very informative. Ideally a weighted average of all of the plants or the expectations of future plants would be incorporated.

Many EU ethanol plants capture the CO_2 from fermentation and this product is used for a variety of food and industrial applications. CO_2 has no energy and an allocation of emissions by energy content would not assign any credit to this product. This is not the practice in the RED where plants can get an emission credit for this material under certain circumstances.

ePURE have reported that their member companies had audited GHG emissions in 2019 of 23.1 g CO_2/MJ. **The Study reports an average value for wheat, corn, and sugar beet ethanol of 60.7 g CO_2/MJ, almost three times the industry reported value.** Part of the difference will be related to the technology coverage related to the use of bioenergy system to supply heat and power, and the types of technology used with respect to carbon capture and use.

4.2.4 Reliability and Consistency

Ideally the data that is used for modelling would be actual measurements that have been independently verified. That kind of data is rarely found in LCA models that are used for policy development for a variety of reasons including confidentiality.

4.3 KEY FINDINGS

We would suggest that improved data sets are required for almost all of the alternative fuel chains that were included in the report. The variance between the Study results and the REDII typical values, the JEC version 5 results, and in the case of ethanol, the audited industry performance is very troublesome. It is almost always possible to improve the quality of data used in models. As more attention is placed on climate change, more and higher quality data is being released. This new, high quality data needs to be incorporated into the LCA model. Modelling that relies on data that is 20 years old or older, as is the case with many of the fuel chains included in the Study, is just not acceptable in a modern LCA model.

The development of new datasets should be guided by the data quality matrix. The data should be updated at least every 6 years so that it ranks as a 1 or 2 in the quality matrix. Data that is not verified or based on estimates should not be acceptable. The data used for modelling should be taken from a representative sample of sites over a period long enough to remove seasonal variations. The data should be from a region with similar production practices as the study is investigating and finally the data should be representative of all of the technologies employed in the region to produce the product under study.

5. FINDINGS AND DISCUSSION

This work has reviewed the fuel chain results for the Study entitled “Determining the Environmental Impacts of Conventional and Alternatively Fuelled Vehicles through LCA”. We have not reviewed the vehicle aspects of the report, nor the electricity forecasts.

An objective of the Study was to combine past knowledge from the literature, as well as the knowledge and expertise from the project team and stakeholders to propose a comprehensive methodology filling past data and methodological gaps, as well as developing and applying more novel aspects to further enhance the analysis. The data and methodological gaps are not defined in the Study report so it isn’t possible to determine if that objective has been met.

Compared to the JEC wells to wheels study and the REDII default values there are more environmental mid points that are included in the results and an attempt has been made to include some potential counterfactual cases, land use change emissions for some pathways, and there are options to compare different approaches for dealing with co-products from the various systems. All of these could be considered methodological gaps that the Study attempted to fill. However the shortcomings of work including the use of poor quality data, inconsistent approaches to forecasting, inappropriate counterfactual cases, old land use change modelling results, and the questionable approach of simply adding attributional and consequential LCA results far outweigh the value of methodological gaps that might have been filled.

The Study includes a significant number of caveats with respect to how the results should be used. These include;

> *“However, it is not generally valid to compare the results from this study with those of other studies characterised by their own analytical boundaries, different data sources, and specific data processing choices. As a result, this study cannot be considered to provide definitive, absolute results on the environmental impacts of different vehicles.”*
>
> *“For fuels, different methodological approaches, assumptions and data sources are tested in this study, some of which were novel in nature or utilised data with significant underlying uncertainty. This means that the results should not be taken as an accurate, consistent representation of impacts across all of the fuel chains investigated.”*
>
> *“In addition, comparisons should not be made between fuel chains when these are evaluated via different methodological approaches or where data robustness is more limited.”*
>
> *“However, the breadth of the study did not allow for a consistent level of robustness and validation of all data, which, in several instances, were limited, especially for certain more novel energy and fuel chains.”*

Our review of the fuel chains would certainly support all of the caveats identified in the Study. However we would suggest that it is not just the novel fuel chains that lack robust data sets, but that concern would also apply to many of the well-established alternative fuel chains included in the model.

The novel methodologies employed In the Study have certainly been used in other models and studies before. Models that forecast future emissions for fuel chains are available, and this feature is included in both the GREET and GHGenius models. The forecasting that the Study has incorporated appears to be limited to the electricity production system, which is a worthwhile exercise but really needs to be extended to most of the other fuel chains before it can be used with confidence.

The forecasts of future emissions in the Study would appear to only include changes in the emission intensity of electricity. There are no changes in agricultural production despite this being a major objective of a new CAP. There do not appear to be any changes in alternative fuel production technologies even though new technologies are being adopted and there are incentives for industry to reduce emissions, with emissions already being clearly lower currently than 5 to 10 years ago. In section 3 of this report and in Appendix 1, there are a number of datasets presented that challenge the assumptions made in the Study that no changes in emission intensity would occur over the next 30 years.

The author of the Study acknowledges and recommends that other counterfactual cases should be run. The cases that were run do not reflect the current use of the secondary feedstocks that were studied. Assuming that all of these feedstocks are currently used for electricity production and assigning an emission penalty for diverting them to produce alternative transportation fuels runs the risk of ignoring a substantial resource that can be utilized to reduce the greenhouse gas emissions in Europe today.

ISO LCA guidelines recommend using substitution for dealing with co-products so the ability of this model to easily switch between energy allocation and substitution is a worthwhile tool for policy makers. Many of the fuel pathways, particularly the oilseed pathways have significantly lower emissions when substitution is used. However, the very small difference in results for the starch pathways is surprising and not consistent with other models. The value of the co-products was established using the ecoinvent database and there are certainly issues with that database with respect to the emissions for the primary biomass feedstocks. This may also impact the substitution results for some or all of the pathways.

There is also a lack of understanding of the implications of the different approaches for dealing with co-products amongst many policy makers. The Study unfortunately provided no discussion of the implications of their findings with the two approaches that they employed. It is only through the analysis of the Results Viewers that one sees the impact of the different approaches.

The inclusion of the GLOBIOM 2015 land use change values in the Study model presents challenges. The results of that study diverged significantly from the results that other models showed for the same feedstocks. The developers of the GLOBIOM model and the developers of the GTAP model worked together in the development of land use change factors for sustainable aviation fuels. There were a large number of changes that were made to the GLOBIOM model as a result of that efforts and their land use change values are now significantly lower for oilseeds than they were in the 2015 report. It is also interesting that there were still large differences between GTAP and GLOBIOM, ICAO employed a screening tool that resulted in a final value much closer to the GTAP values than the GLOBIOM values.

There are significant issues with the simple addition of the results from an attributional LCA (the direct emissions) and a partial consequential LCA (the ILUC results). The resulting value is not representative of either a comprehensive attributional LCA or a full consequential LCA. The value is almost certainly higher than one would find from a full consequential LCA analysis. More work needs to be done on this issue by the LCA community.

Finally, we have very strong reservations about the quality of some of the data that have been used in The Study. The model output is only as strong as the quality of the data that goes into the model. Every year new and better quality data sources become available for LCA practitioners. Some of this is because of stronger reporting requirements that governments have placed on companies and other actors in society. Some of it is because some companies are becoming more transparent with respect to their performance to maintain their social licenses to operate. The academic community is developing better tools to help understanding some of the process that generate emissions so that more accurate reporting can happen. The use of data that was developed twenty years ago is unacceptable in a modern LCA tool.

Appendix 3 in this report compares some of the data used in the Study with other data sources. In almost all cases the Study used input values that are significantly higher than current practices. These high values almost certainly account for the higher values for many fuel chains that the Study reported and not, as the authors claimed, because the Study used broader system boundaries.

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7. APPENDIX 1 - FORECASTING

The Study developed a forecast for the carbon emissions of electricity and that impacted all of the fuel chains. For other aspects of the fuel chains there are no changes over time, which is a highly unlikely scenario.

7.1 EXAMPLES OF PAST TRENDS

High quality data for LCA work is not always available with the precision that one would prefer but there are a number of data sets available from the FAO and some member states that do show trends in key parameters from 1961 to the present time. The data is aggregated in many cases but there are a few datasets that are interesting.

7.1.1 GHG Emission Intensity for Cereals

The FAO reports calculated GHG emissions for cereals. This data domain was created in 2016 but uses the data from 1961 to the present. The general equation

$$EI_{C,\,A,\,Y} = \Sigma\, GHG_{C,\,A,\,Y} / PC,_{\,A,\,Y}$$

Where, for each country A and year Y:

$EI_{C,\,A,\,Y}$ = Emission intensities, in kg of CO_2eq per kg of commodity C;

$\Sigma\ GHG_{C,A,Y}$ = Total greenhouse gas emissions associated to the production of commodity C, generated within the farm gate.

$P_{C,A,Y}$ = Quantity of Production (in kg) of commodity C.

For cereals the analysis includes Barley, Maize, Millet, Oats, Rice, Rye, Sorghum and Wheat. Emissions intensities are computed and disseminated for Rice and for the aggregate “Cereals excluding rice”.

The emissions associated to crop cultivation considered herein for each one of these cereals are those of nitrous oxide gas (N_2O) from: Crop Residues; Burning of Crop Residues; Synthetic Fertilizers; and for rice only, of methane gas (CH4) from paddy rice fields. Specifically for cereals excluding rice:

$$\Sigma GHG_{C,A,Y} = GHG_{Crop\ Residues\ C,A,Y} + GHG_{Burning\ C,A,Y} + GHG_{Fert\ C,A,Y}$$

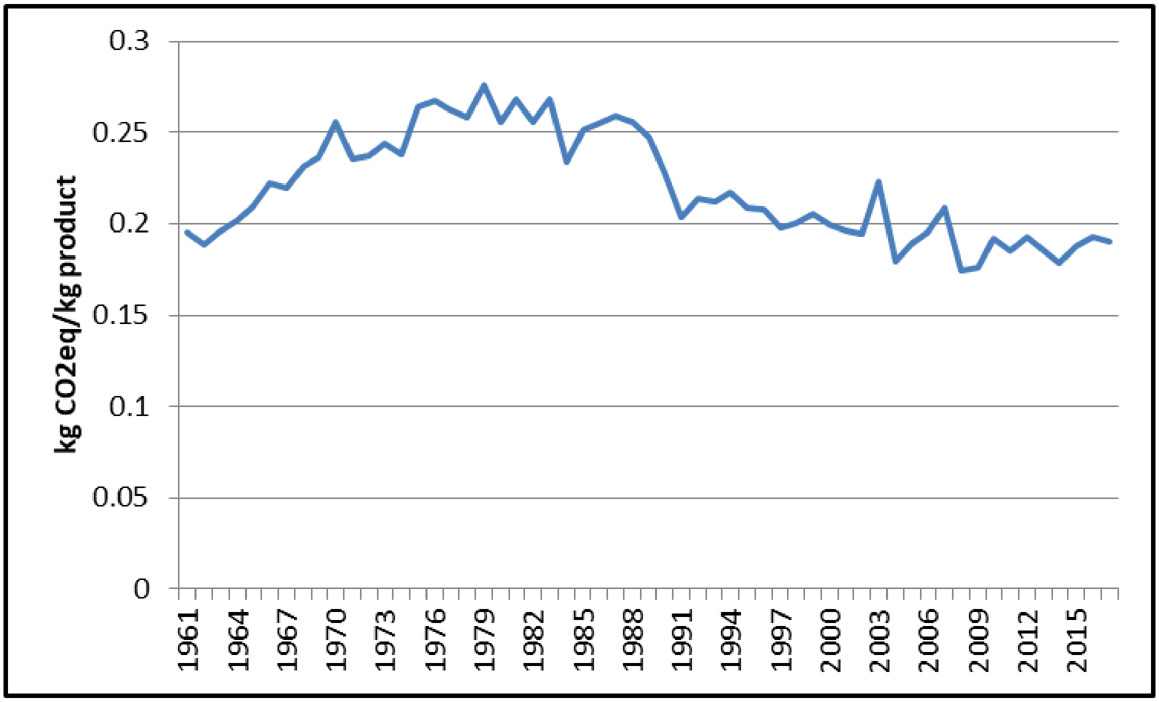
$GHG\ Fert_{C,A,Y}$ represents the emissions from fertilizers applied to commodity crop C in country area A and year Y, expressed as a share, $\alpha_{C,A,}$ of the GHG emissions from total fertilizers applied to all crops:

$$GHG_{Fert\ C,A,Y} = \alpha_{C,A} * GHG_{Fertilizer,\ A,\ Y}$$

The coefficient $\alpha_{C,\,A}$ was obtained from existing FAO information (2002) on N fertilizers use by crop, relative to a 1995–2000 average.

The results for the EU 28 are shown in the following figure.

Figure 7-1 GHG Emission Intensity for Cereals excluding Rice



Since the early 1990s the GHG emission intensity for cereal production in the EU has been declining. These emissions do not include the direct field energy use, these emissions are generally related to area and as crop yield increase, the per unit of production emissions would be expected to decrease.

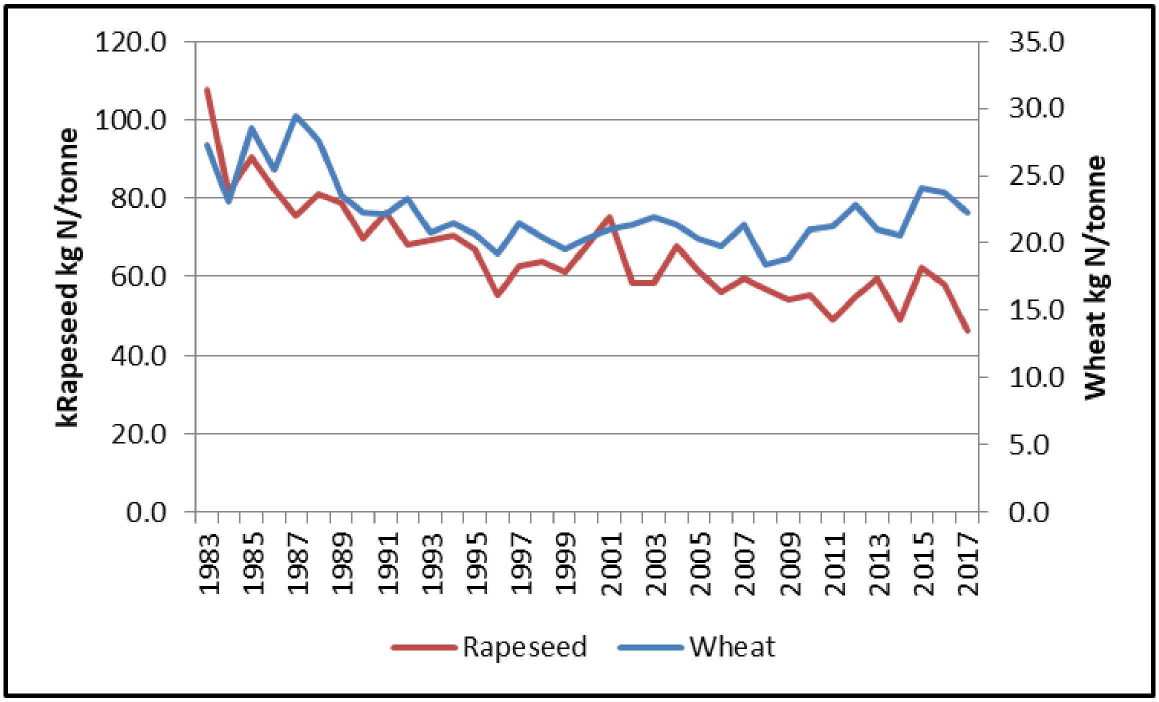
These emission calculations would also not take into account any reduction in the emission intensity of fertiliser production. Fertilizer Europe (2020) claims;

> *The European Fertilizer industry has heavily invested in its production processes and has achieved GHG emission reduction of more than 40% since 2005. Continued industry investment means that European mineral fertilizer producers have the lowest carbon footprint of the worldwide industry. Their ammonia plants are the most-energy efficient and the most of their nitric acid facilities are fitted with modern emissions abatement technologies to limit their nitrous oxide (N_2O) emissions.*

7.1.2 UK Fertiliser Intensity Wheat and Rapeseed

The Department for Environment Food and Rural Affairs in the UK maintains long term fertiliser application rate data for the major crops in the UK. Data is available for biofuel feedstocks such as wheat and rapeseed. The long-term nitrogen fertilizer application rates are shown in the following figure.

Figure 7-2 N Fertiliser Application Rates



The UK nitrogen fertiliser application rates also show downward trends in application rates.

7.2 SUMMARY

The examples of long-term trends in GHG emissions and fertiliser application rates do not support the assumption that there will be no changes in the GHG emissions of primary biomass feedstocks between 2020 and 2050 as has been assumed in The Study.

8. APPENDIX 2 – EXISTING USES OF SECONDARY FEEDSTOCKS

A critical component of developing realistic counterfactual cases is understanding the current utilization of the feedstocks in question. There are three primary secondary feedstocks that have been assumed to be burned for electricity as the counterfactual case in The Study.

The Study uses a single value for the carbon intensity of electricity for each period for all of Europe. This approach is only valid if all of Europe has a single interconnected grid and the resource is completely utilized. If the resource is not currently fully utilized then it is difficult to justify the counterfactual case that there is a diversion from electricity production and the electricity would have to be replaced from other sources. In regions where there may be resource limitations the impact could be larger or smaller than calculated depending on the carbon intensity of the local grid.

8.1 MSW

Municipal solid waste MSW) statistics are kept by Eurostat (2020). The statistics are shown for the past several years in the following table.

Table 8-1 MSW Statistics

	2017	2018	2018 %
	1,000 Tonnes		
Waste generated	218,684	219,856	
Disposal - landfill and other	**52,620**	**52,131**	**24%**
Disposal - incineration	1,393	1,174	1%
Recovery - energy recovery	57,586	57,555	26%
Recycling - material	65,654	67,053	30%
Recycling - composting and digestion	36,892	37,215	17%

One quarter of MSW is currently either landfilled or incinerated without any energy recovery. This is about equal to the quantity that is combusted for energy recovery.

The material that is currently landfilled or incinerated without energy recovery would be available for use for fuel production without any counterfactual emissions. In fact there may be a reduction in methane emissions from landfilling as most landfill gas capture systems are not 100% effective.

Composting oxidizes part of the organic carbon to CO_2 without providing any energy recovery. While composting is an acceptable component of the three Rs (reduce, reuse, recycle) from a GHG perspective it is an inefficient use of resources. From a GHG emission perspective some of this material might also be available for fuel use without any counterfactual emissions.

While landfilling is being discouraged in Europe and there is a preference for incineration with energy recovery that does not mean that there will be power production from this material and that this is the counterfactual case.

The available data does not support a counterfactual case where electricity from the combustion of MSW would have to be replaced by other sources of electricity as there is surplus MSW available for utilization.

8.2 STRAW

Detailed information on the quantity of straw currently used for power production in the EU is difficult to find. Eurostat does report the quantity of power production produced by primary biofuels used. Primary biofuels include solid wood, black liquor, animal waste, bagasse, renewable fraction of industrial waste, and other vegetal material and residues. About 3% of EU power is produced from these materials but no further breakdown by the contribution from each source if provided. The quantity was 360 PJ in 2018.

The European Commission has published studies on the availability of crop residues for energy utilization. Scarlat investigated the potential and limitations of crop residues for bioenergy use. Monforti et al (2015) updated the earlier work and added the need to preserve soil carbon. Scarlat et al (2010) reported that;

> *Denmark is a pioneer in the use of straw for energy production with about 11 combined heat and power (CHP) plants, using 17.9 PJ of straw from the 44 PJ residues available on average in Denmark. One straw plant in UK (Ely) uses 2.9 PJ of straw every year, compared with 88 PJ residues found available on average in this study in the UK. Another large power plant in Spain, Sanguesa, currently uses 2.3 PJ of straw, while the available residue amount is 124 PJ on average. This shows that, even in the most advanced countries in EU from the point of view of bioenergy production, crop residues are used only to a very small extent compared to their potential.*

The current utilization quoted above is 23 PJ of straw. This would produce less than 10 PJ of electricity or less than 3% of the biomass power produced in the EU. This 23 PJ of straw used for power production can be compared to the 1090 to 1900 PJ of available residue found in the Scarlat study.

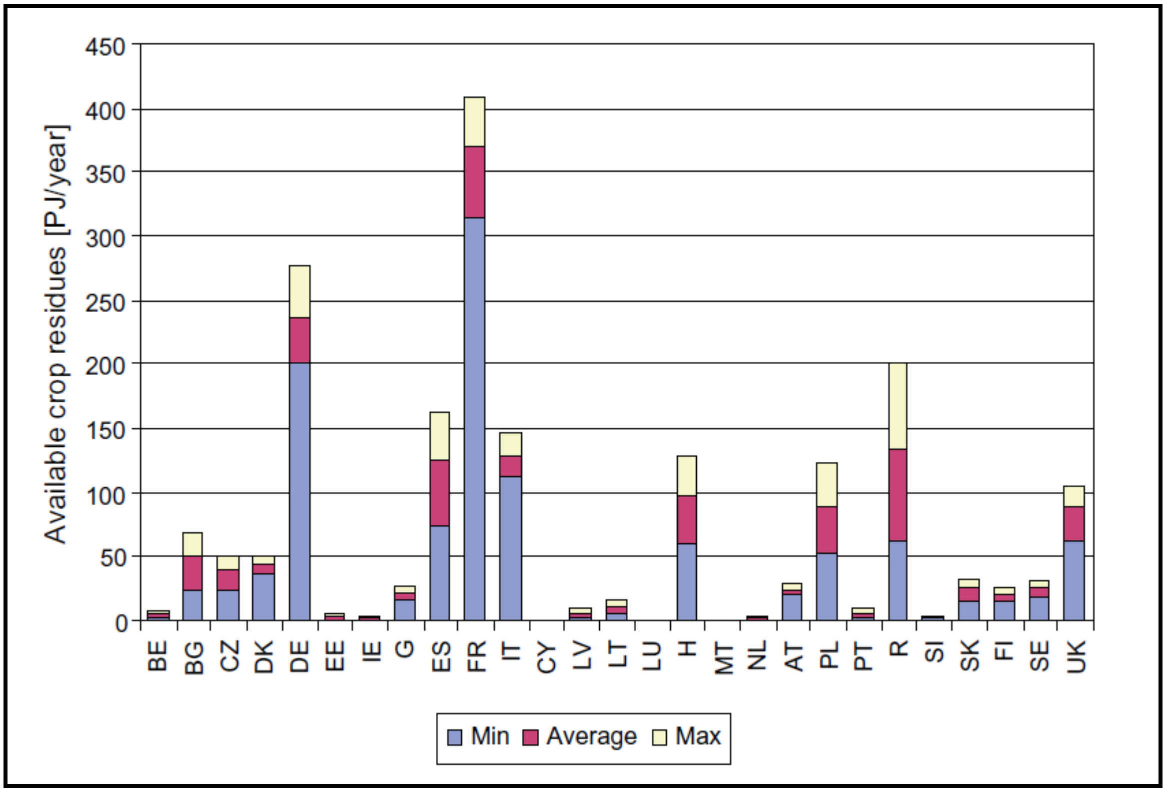
Ecofys report on “Low ILUC potential of wastes and residues for biofuels” by Spöttle et al (2013) also looked at and estimated the current use of straw. The reports states that;

> *Incorporation of straw is currently the most common use following harvest, although the degree to which straw is incorporated varies in different parts of the EU, between farm type and size.”*
>
> *Denmark is the market leader in using straw for energy generation in both Europe and globally, with a history dating back to the early 1990s. Around 1.8 million tonnes per year are currently burned, of which around 57% is wheat straw and 30% barley straw with the remainder made up of rape, rye, triticale and oat straw.*

1.8 million tonnes of straw is about 32 PJ of energy, slightly higher than the Scarlat estimate but far below the quantity that is available.

Scarlat considered crop residue production, the sustainable removal rates, the use for mushroom production and animal bedding. The following figure shows their estimate of the availability of crop residues for bioenergy production in different countries.

Figure 8-1 Crop Residue Availability



The Monforti work in 2015 provided a more detailed geographic picture of where the residues where available but the findings are similar to the earlier work.

If the crop residues are not used for energy, livestock bedding, or other applications such as mushroom production that leaves burning in the field or incorporation into the soil as the current use. Legislation within the EU has largely outlawed the practice of field burning agricultural wastes, leaving incorporation into the soil as the dominant use of straw across Europe.

Once again the available data does not support a counterfactual case where electricity from the combustion of straw would have to be replaced by other sources of electricity as there is surplus crop residue available for utilization.

8.3 Forest Residue

Spöttle et al (2013) also looked at the forest residue availability and current uses. The availability is shown in the following table.

Table 8-2 Woody Residues

Category	Annual potential (1,000 m^3)
Bark	62,005
Branches & tops from managed forests (average scenario)	28,699
Woody farm residues	15,982
Sawdust (from sawmills)	27,461
Cutter shavings (from sawmills)	20,219
Total	154,366

There is some existing energy use of this material: bark, sawdust, and cutter shavings are reported to be fully utilized. Forest residue and woody farm residues are reported to be available.

As with the other secondary biomass feedstock there is considerable volume that is currently not utilized and could be used for biofuel production without having any impact on power production. The counterfactual case is therefore unrealistic.

9. APPENDIX 3 – DATA QUALITY

Comparison of the data used for primary biomass feedstocks compared to other data sources are presented in this section. The data used for The Study pathways is the data from the ecoinvent database. This data is would generally be classified as a 4 or a 5 for each category shown in the data quality matrix. In many cases The Study values are not even close to more recent values from other sources. Three feedstocks and the fertiliser production emissions are discussed below.

9.1 PRIMARY BIOGENIC FEEDSTOCKS

Three important biofuel feedstocks in the EU are wheat, corn, and rapeseed (Mellios et al, 2020). The data used for the modelling is compared to other data sources below. Factors that will impact the GHG emissions are the fertiliser application rates, the energy use, and the yield (since energy use is related to the area more than the production), higher yields will result in lower energy use per tonne of crop.

The information is meant to be illustrative of the quality of data used by the Study. Investigating every single feedstock in the Study is beyond the scope of this work, so other feedstocks may or may not have the same issues as identified below.

9.1.1 Wheat

The modelling assumptions are for wheat production (global) in ecoinvent. The locations of considered datasets in the averaging procedure for this global dataset are Germany, Spain, France and USA. This activity starts after the harvest of the previous crop. The inputs of seeds, mineral fertilisers, pesticides and irrigation water are considered. It is assumed that no organic fertilisers are applied.

The dataset includes all machine operations and corresponding machine infrastructure and sheds. Machine operations are: soil cultivation, sowing, fertilisation, irrigation, weed control, pest and pathogen control, combine-harvest and transport from field to farm. Further, direct field emissions are included. This activity ends after harvest and drying of grains at the farm gate. The data represents the period 2001 to 2006.

Table 9-1 Wheat Modelling Parameters

Parameters	Value
Yield	3.45 tonnes/ha
Nitrogen fertiliser, as N	7.87 kg/tonne
Urea, as N	3.30 kg/tonne
Ammonia, liquid	7.60 kg/tonne
Ammonium nitrate, as N	9.04 kg/tonne
Ammonium sulfate, as N	0.68 kg/tonne
Total N	28.49 kg/tonne
Potassium chloride, as K_2O	19.71 kg/tonne
Phosphate fertiliser, as P_2O_5	14.24 kg/tonne
Lime	0.57 kg/tonne
Fuel use	89.8 litres/ha
Fuel use	26.1 litres/tonne

The UK data shown earlier reported an average yield for the last 5 years of 8.4 tonnes/ha, a N fertiliser rate of 22.4 kg/tonne, a P rate of 3.3 kg/tonne, and a K rate of 4.0 kg/tonne. All of these values would result in far lower GHG emissions for wheat production that calculated in The Study.

The Study values are compared to the JRC default values used for REDII in the following table. These values were entered into Biograce and the GHG emission contribution for the inputs and for N2O, which were scaled from the Biograce default value, were calculated. These are also shown in the table.

Table 9-2 JRC Defaults vs The Study Wheat Production Parameters

	UK Data	The Study	JRC	% Difference between JRC and The Study
Yield, tonnes/ha	8.4	3.45	5.67	+64
N kg/tonne	22.4	28.49	19.69	-31
P kg/tonne	3.3	14.24	4.05	-72
K kg/tonne	4.0	19.71	3.18	-84
Fuel litres/tonne	n.r.	26.1	20.3	-23
GHG, kg/tonne	239	296	223	-25

The JRC values are fairly well aligned with the UK fertiliser data. For each of these important input parameters the ecoinvent values produce significantly higher GHG emissions than the JRC default values. The difference in fertiliser inputs alone accounts for a difference of 5.6 g CO_2/MJ after allocation.

9.1.2 Rapeseed

Rapeseed is a major source of feedstock for biodiesel in Europe. The Study looked at rapeseed, sunflower seed, and palm oil as feedstocks for biodiesel and HVO production. The modelling assumptions are for rapeseed production (global) in ecoinvent. The locations of considered datasets in the averaging procedure for this global dataset are Germany, France and USA. This activity starts after the harvest of the previous crop. The inputs of seeds, mineral fertilisers, pesticides and irrigation water are considered. It is assumed that no organic fertilisers are applied. It is not clear why the US is included as they are a minor producer.

The time period that was used for data collection is 2000 to 2004. The original source for the data is not reported.

Table 9-3 Rapeseed Modelling Parameters

Parameters	Value
Yield	2.93 tonnes/ha
Nitrogen fertiliser, as N	8.1 kg/tonne
Urea, as N	10.0 kg/tonne
Ammonia, liquid	3.5 kg/tonne
Ammonium nitrate, as N	25.9 kg/tonne
Ammonium sulfate, as N	1.6 kg/tonne
Total N	49.1 kg/tonne
Potassium chloride, as K_2O	16.1 kg/tonne
Phosphate fertiliser, as P_2O_5	20.2 kg/tonne
Lime	3.8 kg/tonne
Fuel use	135 litres/ha
Fuel use	46.1 litres/tonne

Table 9-4 JRC Defaults vs The Study Rapeseed Production Parameters

	The Study	JRC	% Difference
Yield, tonnes/ha	2.93	3.15	8%
N kg/tonne	49.1	45.1	-8%
P kg/tonne	16.1	10.2	-37%
K kg/tonne	20.2	13.7	-32%
Fuel litres/tonne	46.1	34.1	-26%

The deviation between the ecoinvent data and the JRC default values is not as great for rapeseed as it is for wheat but for every parameter the JRC values will provide lower GHG emissions. Rapeseed also has a high fertiliser demand so it will be more sensitive to the fertiliser emission factors than wheat is.

9.1.3 Corn

Corn has become the major crop for ethanol production in Europe. The data in ecoinvent is for US corn production. This activity starts after the harvest of the previous crop. The inputs of seeds, mineral fertilisers, pesticides and irrigation water are considered. It is assumed that no organic fertilisers are applied.

The dataset includes all machine operations and corresponding machine infrastructure and sheds. Machine operations are: soil cultivation, transport of seeds, fertilisers and pesticides to the field sowing, fertilisation, irrigation, weed control, pest and pathogen control, combine-harvest, transport from field to farm (15 km) and drying of grains. The data is for the period 2004 to 2006. It is reported to be literature data.

Machine usage is modelled with US diesel consumptions, German field works and Swiss machines.

Table 9-5 Corn Modelling Parameters

Parameters	Value
Yield	9.31 tonnes/ha
Urea, as N	3.5 kg/tonne
Ammonia, liquid	8.4 kg/tonne
Ammonium nitrate, as N	4.9 kg/tonne
Total N	16.9 kg/tonne
Potassium chloride, as K_2O	7.2 kg/tonne
Phosphate fertiliser, as P_2O_5	5.8 kg/tonne
Lime	30.4 kg/tonne
Fuel use	70.7 litres/ha
Fuel use	7.59 litres/tonne

The corn data set is compared to the latest JRC default values in the following table. In this case there are two different geographies that are compared. The latest data for US corn production is also presented. In this case there is a mix of higher and lower values for the Study values compared to the JRC values.

Table 9-6 JRC Defaults vs The Study Corn Production Parameters

	The Study	JRC	% Difference	USDA (2019)
Yield, tonnes/ha	9.31	7.13	-23%	10.91
N kg/tonne	16.9	16.7	-1%	15.1
P kg/tonne	7.2	4.1	-43%	6.7
K kg/tonne	5.8	3.8	-34%	8.6
Fuel litres/tonne	7.59	16.6	119%	10 (2010)

9.2 FERTILISER PRODUCTION

The emissions for fertiliser production times the quantity of fertiliser applied will result in the fertiliser emissions per tonne of crop. The public data in the ecoinvent database does not generally provide the actual GHG emissions per unit of fertiliser. There is one exception and that is UAN fertiliser where the GHG emissions are provided using ecoinvent 3.3, however that nitrogen product is not an input the three feedstocks that were documented above. There were no changes to the fertiliser datasets between version 3.3 and 3.5. There were also no changes between version 2.2 and 3.3 for these datasets.

The fertiliser data in ecoinvent is from 1999 or earlier. It was not based on manufacturing data. The datasets state;

> *Production inventory was derived from detailed literature studies and specifications from the manufacturer, relevant for the European production. Transport specifications of the fertiliser product to the regional department store, which were not included in the reference used for this inventory, were complemented by data given in Patyk &Reinhardt (1997).*

In order to compare the fertilizer production emissions used in The Study with other values, alternative sources of ecoinvent information was required. Dr. Joost Vogtlander of Delft University of Technology has published the GHG emissions all of the materials in the ecoinvent database, these GHG emission values are now only available for students but earlier versions were accessible to non-students. The GHG emissions for UAN fertiliser are identical in his dataset to the value in the ecoinvent UAN version 3.3 and it is assumed that the Vogtlander values for other fertiliser products are the same as those used in The Study. The Vogtlander results from the earlier versions are presented below and compared to other values in the literature.

9.2.1 Nitrogen Fertiliser

The nitrogen fertiliser GHG emissions from ecoinvent (Vogtlander) are shown in the following table.

Table 9-7 ecoinvent Nitrogen Fertiliser

Product	GHG Emissions, kg CO_2eq/kg N
Ammonium Nitrate	8.551
Ammonium Sulphate	2.691
Calcium Ammonia Nitrate	8.654
Urea	3.304
UAN	5.838

There are other sources of emission data on fertilisers that are more current (Hoaxa et al, 2018, Brentrup et al, 2016). Both publications are related to Fertilizer Europe. The Hoaxa report describes an online calculator that is available to fertilizer manufacturers. The tool has been developed to calculate and provide reference values for carbon emissions for selected fertilisers based on EU average (ammonia and nitric acid), EU BAT (ammonia and nitric acid) as well as other defined references. It also calculates emission factors required in the LCA calculators for agriculture, such as the CoolFarmTool or other similar tools for calculating the LCA for food products and from agriculture.

Those emissions are summarized in the following table.

Table 9-8 Other Nitrogen Fertiliser GHG Emissions

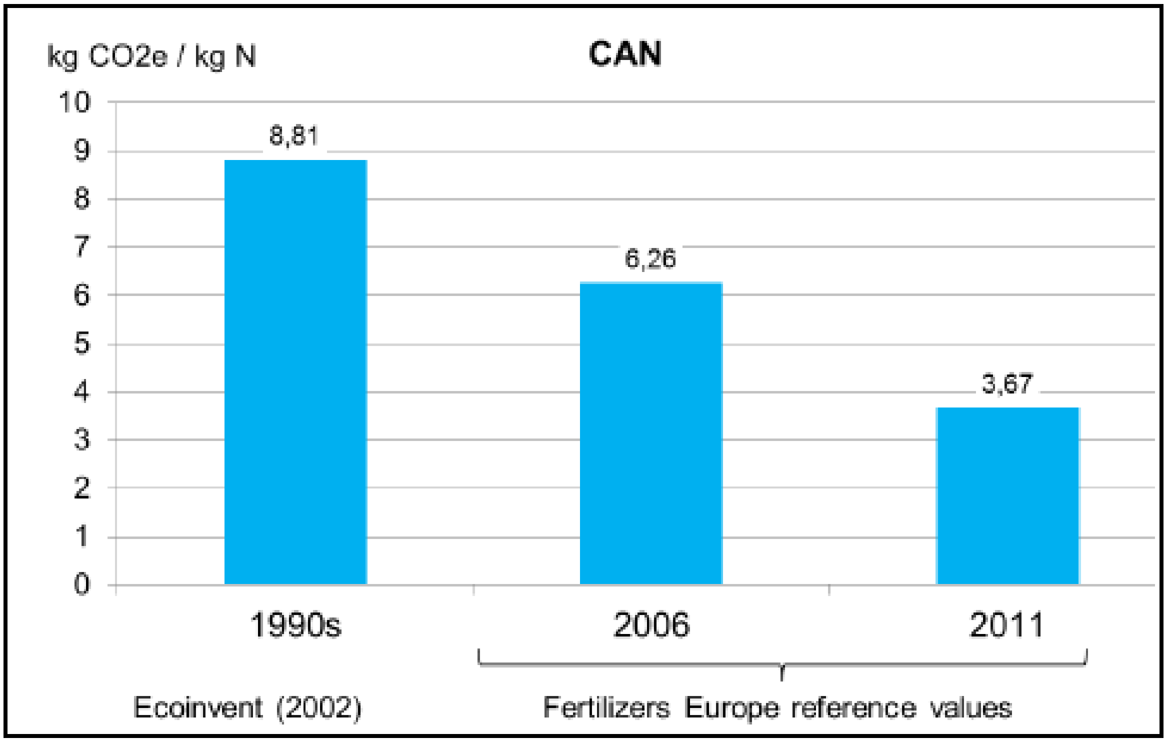
Product	Brentrup	Hoaxa
Baseline Year	Europe 2011	Europe 2014
	GHG Emissions, kg CO_2eq/kg N	
Ammonium Nitrate	3.52	3.32
Ammonium Sulphate	2.71	n.r.
Calcium Ammonia Nitrate	3.70	3.52
Urea	3.52	3.50
UAN	3.53	3.40

Individual fertiliser producers can use the tool to determine the GHG emissions of their actual production and to have their results verified by an external auditor. CF Fertilisers UK Ltd. has done that for their ammonium nitrate production and reported results for 2010 (5.4 kg CO_2eq/kg N) and 2016 (3.4 kg CO_2eq/kg N).

The nitrogen fertiliser emission factors in ecoinvent are very old and don't represent the technology in use in Europe today. The ammonium nitrate emissions could be as much as 2.5 times the current industry average.

In the Brentrup publication the progression of the emissions for calcium ammonium nitrate are shown over time, including the ecoinvent value. This is shown in the following figure.

Figure 9-1 CAN Emissions over Time



It is clear that there have been significant reductions (more than 50%) in the GHG emissions for nitrogen fertilizers in the past twenty years. The use of fertiliser production emissions from ecoinvent version 3.5 grossly overstates these emissions and there can be no justification for using them or keeping them constant through to 2050.

9.2.2 Phosphorus Fertiliser

Phosphorus fertiliser has the second highest contribution to fertilizer manufacturing GHG emissions from crop production. It is usually supplied as ammonium phosphate or diammonium phosphate. The ecoinvent emissions are 1.60 kg CO_2eq/kg P_2O_5.

Kool et al (2012) reported the emissions for phosphorus fertilizer as 0.97 kg CO_2eq/kg P_2O_5 in Western Europe.

9.2.3 Potassium Fertiliser

Potassium fertilizer usually has the lowest GHG emission impact of the fertilizers. The value from ecoinvent is 0.497 kg CO_2eq/kg K_2O. Kool et al reported emissions of 0.56 kg CO_2eq/kg K_2O in Western Europe.

DISCLAIMER - The above position paper/recommendation/statement has been drafted by the assigned working group of the Alternative & Renewable Transport Fuels Forum (ART Fuels Forum) after exchange of opinions and internal consultation among the Forum members. The content of the report does not necessarily reflect the views of all members of the ART Fuels Forum, but is a synthesis of the main positions. The positions, recommendations and statements listed above are those of the members of the ART Fuels Forum and do not necessarily reflect either the official position of the Commission or the complete position of the members of the ART Fuels Forum.

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