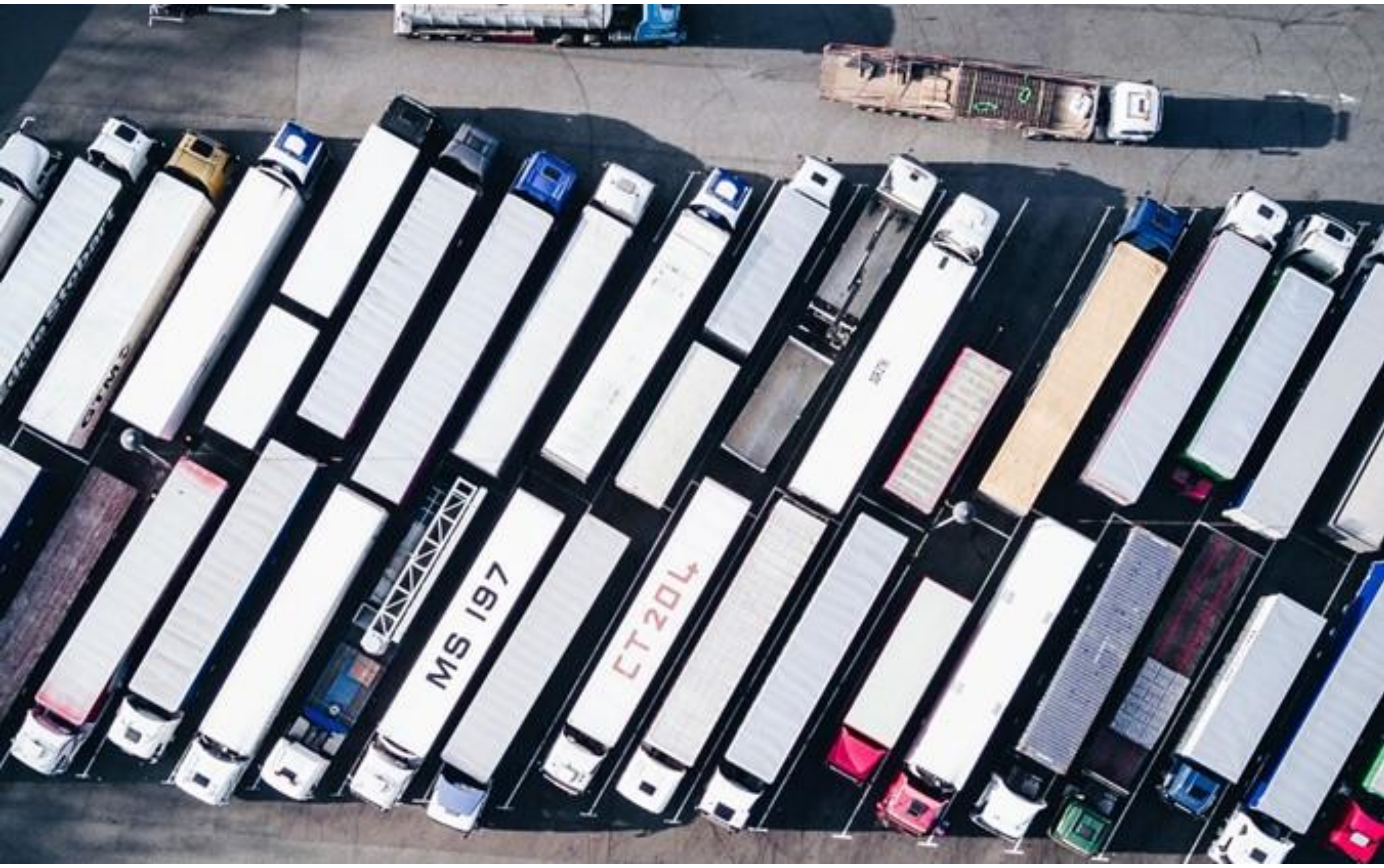
Smart Freight Centre

GHG emission factors for road freight vehicles

Desktop Review

September 2021



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Disclaimer

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This report was written by Rik Arends of Smart Freight Centre and Kirsten Biemann of ifeu and reviewed by Alan Lewis of Smart Freight Centre.

About Smart Freight Centre

Smart Freight Centre (SFC) is a global non-profit organization dedicated to an efficient and zero emission freight sector. We cover all freight and only freight. SFC works with the Global Logistics Emissions Council (GLEC) and other stakeholders to drive transparency and industry action – contributing to Paris Climate Agreement targets and Sustainable Development Goals.

Our role is to guide companies on their journey to zero emission logistics, advocate for supportive policy and programs, and raise awareness. Our goal is that 100+ multinationals reduce at least 30% of their logistics emissions by 2030 compared to 2015 and reach net-zero emissions by 2050.

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Executive Summary

More governments and companies are setting climate targets. The end goal is zero-emission transport for all road transport, and in this transition phase road freight transportation using low emission fuels is an important part of an effective strategy in the transition to net zero emissions. There exists a wide variety of potential transition fuels and there is a general consensus that there will not be a single low carbon fuel solution that fits all transport needs in the foreseeable future.

The aim of this report is to review, and contribute to the understanding of, the emission factors for various potential transition fuels. The report sets out a direction towards default values for emission calculation and reporting. It is a step in a wider, ongoing program to support the transition towards Low Emission Fuels and Vehicles for Road Freight, and builds upon SFC's 'Low Emission Fuels and Vehicles for Road Freight' introductory guide published in October 2020.

This report can act as a starting point to make emission calculations more consistent and reliable, and to inform better and aligned decision-making regarding uptake of low emission fuels (biofuels, synfuels and efuels) for the road freight sector. The intent is to use the authors' links to the relevant ISO working group in order to align the outputs of this report with emission factors proposed in ISO 14083.

The report reviews the methods of four different sources and compares the emission factors for fossil fuels, biofuels, synthetic fuels and efuels. The sources covered are: JEC WTW study v5, published October 2020, EU Renewable Energy Directive (RED II), UK BEIS (formerly Defra) 2020 data and the Dutch CO_2emissiefactoren

The analysis and review lead to the following conclusions:

- The emission factors are highly dependent on the feedstock or electricity used for the production of the fuel. In the case of biofuels the distinction can be made between crop-based feedstock and waste-based feedstock to produce the fuel. For synfuels and efuels the carbon content of the electricity used largely determines the actual emission factors.
- This report provides a first indication of potential representative and conservative emission factors. For calculating and reporting on the new fuels, it is important to understand and certify the source and the lifecycle GHG emissions of the fuels. It is proposed to use conservative values for calculating and reporting in the absence of a fuel certificate.
- For gaseous fuels, methane slip is not covered in the reviewed studies, even though it is a strong greenhouse gas and even a small slippage can have a significant effect on the GHG emissions.
- For biofuels, the direct and indirect contribution to land use change for crop-based fuels can be significant and should be considered when selecting the specific feedstock for the production of the biofuel. However, the methodology to calculate and attribute the effects of land use change to the emission factor is still under development.
- Once a fuel moves from a relatively small production volume to a substantial share of the market, an attributional approach to emission accounting should be applied. This to avoid 'negative GHG emission factors' that might result when a marginal approach is used.

The recommendations to move forward are as follows:

- Further review of the emission factors from additional sources to (i) address the data gaps for synfuels and efuels, (ii) review the market/technical readiness of several fuels, (iii) assess the impact of construction of additional infrastructure for efuels, (iv) review methodologies and options for incorporation of land use change in the emission factor, (v) identify and review other sustainability criteria.
- Carry out consultations with experts, end users, associations, Governments to (i) harmonize approach and coverage of calculating GHG emissions from transition fuels, (ii) identify end user challenges in procuring and reporting on transition fuels, (iii) discuss the concept and methodology for Total Emissions of Ownership
- Establish a default methodology and reporting guidance for the calculation of Total Emissions of Ownership including (i) establishing default emission factors, (ii) standardize questions and methodologies, (iii) link back to the development of wider industry guidelines (e.g. ISO 14083).

1 Introduction

1.1 Background

Increasing numbers of governments and companies are setting climate targets, including for freight and logistics, with the objective to reach zero emission transport by 2050[1]. As a result, transition plans are being formed at company, policy and legislative levels. The question of how to best capture the potentially substantial benefits of low emission fuels and vehicles in delivering this transition is a recurring hot topic, with many different options being considered. There is a general consensus that there will not be a single low carbon fuel solution that fits all transport needs in the foreseeable future. This has led to discussions about a wide range of transition fuels that have the potential to both deliver lower emissions in the short term and help contribute to the longer-term technology transition to zero emissions before 2050.

In a first report for RVO, published in October 2020, we set out the current landscape across all fuel types and technologies for road freight transport applications in the context of a full fuel cycle or "well to wheel" approach to Greenhouse Gas (GHG) emissions.

This report builds on that first step by taking a next step towards aligning the approach to a list of full fuel cycle GHG emission factors at global level, across all modes, and updating the content based on the best existing information. We do this by reviewing and comparing the latest available GHG emission factors from a selection of well-regarded emission factor sources, in this case focusing on road transport fuels and energy sources.

1.2 Objectives and scope

The ultimate goal is to provide support for more companies to reduce the GHG emissions that result from road freight transport.

Our intention is to provide, with this being the first of a series of project steps, practical recommendations that will clarify the values to be used when calculating the emissions of low-emission fuels and hence help companies and investors with their decision making and public authorities to set supportive policy.

Providing well-founded information about the life cycle GHG emissions of potential low emission transition fuels and vehicles to companies will support this directly by feeding into transparent and consistent calculation and reporting of their emissions and ultimately into well-founded investments in low / zero emission transition fuels and freight vehicles. Working on this in partnership with public authorities ensures a consistent approach that is aligned with a longer-term vision and strategy to bring about a zero emission freight transport sector.

The intent is to use the authors' links to the relevant ISO working group in order to align the outputs of this report with emission factors proposed in ISO 14083.

1.3 Report content and structure

We have started by taking a small number of well-respected European GHG emission factor sources that are widely used for road transport GHG emission calculations and have conducted a desktop review to understand the current state of the art in terms of coverage, GHG emission factor values and variability.

The output is an extended list of road transport transition fuels and energy sources with associated GHG emission factors, formulated in such a way that they provide practical input for implementation by companies.

As a result, we make observations and draw initial conclusions about:

- the general effectiveness of different types of transition fuel
- the different sources of emission factors used
- where further work on emission factors is needed as an enabler in order to provide both companies and policy makers with information that will help them take meaningful steps towards an effective strategy to reduce emissions from road freight transport

[1] This could include offsetting and other mechanisms to reach zero emissions.

The rest of the report is set out as follows:

- The analysis section presents:
  - a short review of the emission factors sources that have been reviewed
  - headline results about the GHG emission benefits of some of the transition fuels included in the review
  - variation in the emission factors for selected fuels from source to source
  - an overview of the impact that the feedstock and production process can have on the GHG emissions for a specific fuel type
- Conclusions, building on the information and analysis
- Recommendations on further improving the information available and filling gaps.

The appendices include more detailed information in support of the report findings. The report is accompanied by a detailed spreadsheet in which key data from the selected emission factor sources for the specified road transport fuels have been pulled together into a single location for use in developing the report's conclusions and recommendations.

2 Analysis

2.1 Overview of emission factor sources

The sources of emission factors chosen for this initial desktop review are:

- JEC WTW study v5, published October 2020 (JEC version 5 - 2020 | EU Science Hub (europa.eu))
- EU Renewable Energy Directive (RED II)
- UK BEIS (formerly Defra) 2020 data (https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2019)
- The Dutch CO_2emissiefactoren (https://www.co2emissiefactoren.nl)

These were chosen as the best starting point for the initial review because of their direct relevance to the European context, together with:

- For JEC v5 the fact that it was recently published after a long wait and that previous versions of this report (JEC V 3 and 4) had been used as a basis for many other key European standards, for instance the EN16258 standard on transport GHG calculation and reporting
- RED II: Defines a series of sustainability and GHG emission criteria that bioliquids used in transport must comply with in Europe
- UK BEIS: its widespread use by many companies at global level due to its long-established market presence and focus on comprehensive, user-friendly style
- CO_2emissiefactoren: Overview developed by a consortium to harmonize emission calculations, utilizing a wide range of pre-existing Netherlands-specific and international studies about greenhouse gas emissions; updated annually.

Initially a comparison of the methodological background of the different sources was carried out by looking at the scope, system boundaries and other methodological choices.

An overview of the main results is shown in Table 1.

		JEC WTW study v5	RED 2	CO_2 emissiefactoren	UK BEIS
Scope	Time period validity	2016 and 2025+	2018	2020	2019
	New energy infrastructure construction included	No	No	No	No
	Geographic boundary	Europe	Europe	NL	UK
Fuel Cycle	WTT	Yes	Yes	Yes	Yes
	Disaggregation of WTT elements	Yes	Yes, partially	No	No
	TTW	Yes	Yes, partially	Yes	Yes
Emissions	CO_2	Yes	No	No	Yes
	CO_2e	Yes	Yes	Yes	Yes
	CH_4 contribution separated	Yes	No	No	Yes
	N_2O contribution separated	Yes	No	No	Yes
Land use	Direct LUC	No	Yes, partially	No	No
	Indirect LUC	Yes, partially	Yes, partially	Yes, partially	No
Allocation approach	Attributional	No	Yes		
	Consequential	Yes	Yes, energy allocation		Implied
	Mixed	Yes			
	Approach to biogenic emissions	CO_2 balance	CO_2 balance	CO_2 balance	CO_2 balance
	Approach to waste feedstock	emission free	emission free		emission free
Fuel properties	Density and heating value provided?	Yes, lower heating value	Yes, lower heating value	No	Yes, lower heating value

Table 1: Overview of scope and methodological approach of in the 4 source reports included in this desk review

2.1.1 Attribution and methodology

One major difference between the sources is the handling of multi-functional processes, e.g. when a refinery supplies a wide range of products, or when certain biofuel pathways also produce energy or animal feed as by products. Oil refineries, especially, are highly complex and integrated systems supplying a large number of different products with different properties, and thus always need an approach on how to allocate emissions to the multiple products arising from the refining process(es).

The JEC WTW study v5 uses as marginal (consequential) approach. A linear programming model of an oil refinery was used to check what changes result from a marginal difference in a certain refinery output. Using these results, a division of the refinery emissions was applied between the products. This results in relatively high emissions for products that are in high demand like diesel or gasoline and lower (or even negative emissions) for by products like bitumen or heavy fuel oil.

This differs from the approach taken by LCA databases such as ecoinvent[2] or GaBi[3], which use a step by step attributional approach for the oil refinery. Each product accumulates its own share of the emissions as it passes through the refinery. The attributional approach leads to a different balance in emissions across the refinery outputs, with lower well-to-tank emissions for gasoline and diesel than the marginal approach taken in the JEC WTW v5 study.

In contrast, the RED 2 directive follows a mainly attributional approach by allocating the process emissions to products according to their share of the energy content. Only for wet manure which is used as a feedstock for biomethane production, is a credit for avoided direct methane emissions given to the output.

The UK BEIS and CO_2emissiefactoren website data are similar to each other in that their primary function is to provide information in a format that is more directly useable by practitioners, whether companies with a need to report emissions or those that support them to do so. The main difference between them is that UK BEIS provides much greater detail in the background to and the breakdown of the emission factors provided; it is also the output of a more comprehensive, self-contained analysis, whereas the CO_2emissiefactoren website generally refers to selected, well-regarded external sources. In both cases, much of the basis of the outputs can ultimately be traced back to the JEC WTW v4 study published in 2014.

The preferred approach for GHG accounting is usually an attributional approach since it is well suited to look at average emissions from the actual use of fuels. The consequential approach is more appropriate for use in assessing changes away from the current situation, and so is best suited to look at the effect of substituting current fuels or production processes with alternative (new) technologies and feedstocks.

2.1.2 Coverage of land use change emissions

Potentially the most significant difference is whether, and with what approach, land use effects linked to the production of biofuels from food crops are considered. Two types of land use changes can occur: Direct land use change (dLUC) takes places when a certain land is converted e.g. from forest to farmland to produce crops for biofuels. Most land currently being used for biofuel production has already been converted in the past (earlier than the 20-year perspective usually taken by LUC changes) and is thus no longer relevant for inclusion.

Indirect land use change (iLUC) occurs when an increase in crop production for use as a feedstock in biofuels production leads to a displacement of food crops to other regions. The methodology to estimate iLUC effects is still relatively new and more uncertain than other aspects of the emission factors.

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[2] The ecoinvent refinery model uses a four step approach to allocation. The combined allocation procedure is stated by the following sequence of four rules:

a. In general, allocation is weighted according to the products' energy content, i.e. their lower heating values.
b. The burdens for the first step of separation (atmospheric distillation) are allocated to all co-products, including the atmospheric residue (bottom product).
c. The burdens for any subsequent process step that is intended to reduce the quantity of non-intended products (i.e. vacuum distillation and cracking) are allocated to all co-products except for exactly the non-intended bottom products (e.g. vacuum residue, cracking residue).
d. Retention of feedstock: The input material (feedstock) into a refinery process step is always allocated according to the 1st rule: e.g. visbreaker residue takes 40 % of the totalized co-product output of a visbreaker cracker, thus 40 % of the visbreaker input (vacuum distillate) and its upstream burden is allocated to the visbreaker residue.

[3] In GaBi a process by process allocation is applied. The environmental burden of each unit process are allocated to its outputs based on physical quantities. While unit process energy expenditures are allocated by mass, the crude oil and subsequent hydrocarbon demand is allocated by energy content. Therefore, each finished product receives an individual emissions backpack accumulated on the way through the refinery.

Because of the uncertainty, none of the sources directly includes the impacts from land use change; however, RED2 and the JEC WTW study v5 do include an assessment of the possible range of iLUC impacts from certain crop-based biofuels (e.g. maize, wheat, palm oil, soy or sugar beet).[4]

Bearing the uncertainty in mind, the effect of this additional iLUC contribution to the lifecycle emissions has been shown to outweigh the benefits of using some potential biofuel feedstocks, especially soy and palm oil. As a result, the implementation of the RED 2 has limited the amount of biofuel production from traditional crop-based feedstock in order to limit the impact of indirect land use change emissions.

2.1.3 Coverage of fuels

As well as taking similar, but not fully aligned, approaches the four sources have differing coverage in terms of which road transport fuels are included, which reflects their primary purpose. Table 2 sets out a summary of their coverage. The coverage of CO_2emissiefactoren and UK BEIS reflects the needs of companies that report based on fuels that currently exist in the market, whereas RED II focuses on biofuels and the JEC WTW v5 aims to present as broad a set of current and potential future road transport fuels as possible.

		JEC v5	RED 2	CO_2emissiefactoren	UK BEIS
Fossil fuels	Diesel	yes	(yes)[5]	yes	yes
	LNG	yes	no	yes	yes
	CNG	yes	no	yes	yes
	Hydrogen (from methane)	yes	no	yes	no
Biofuels	Biodiesel	yes	yes	yes	yes
	HVO	yes	yes	yes	yes
	Liquified Biomethane (LBM)	yes	no	no	no
	Compressed Biomethane (CBM)	yes	yes	yes	no
	Biomethanol	yes	yes	no	yes
	Bioethanol	yes	yes	yes	yes
	Biohydrogen	yes	no	no	no
Synthetic and e-fuels	Synthetic diesel	yes	no	no	no
	Synthetic methanol	yes	no	no	no
	Synthetic LNG	yes	no	no	no
	Synthetic CNG	yes	no	no	no
	eDiesel	yes	no	no	no
	eMethanol	yes	no	no	no
	eLNG	yes	no	no	no
	eCNG	yes	no	no	no
	eHydrogen	yes	no	yes	no
Electricity	Renewable	yes	no	no	no
	NL grid mix 2020/2030	no	no	yes	no
	EU/UK grid mix	yes	no	no	yes

Table 2: Overview of coverage of fuel types in the 4 source reports included in this desk review

The only fuels covered in all four sources are conventional biofuels such as HVO, bioethanol and biodiesel that are well enough established to be considered within the resources designed to support mainstream emission reporting from the transport sector, namely CO_2emissiefactoren and UK BEIS.

For additional details about each source see the Appendix.

[4] There is an increasing awareness about indirect land use change emission impacts. This report focuses only on European values and the sources generally refer back to the RED2 directive as the primary (legislative) reference point. However, it is worth noting that as this is a developing area alternative methodologies and calculation tools for ILUC emissions do coexist, an example being the CORSIA emission reporting guidance recently published by ICAO.

[5] RED2 provides a fossil comparator at 94g CO2e/MJ (WTW), irrespective of the type of fossil fuel.

2.2 GHG emission benefits of transition fuels

It's no surprise that biofuels generally lead to lower lifecycle emissions than equivalent fossil fuels (subject to the GHG emission impact of land use change mentioned previously), because according to established accounting practice, as long as there is a short duration replacement cycle of the biogenic feedstock, the CO_2 emissions from combustion are considered as being equivalent to, and cancelling out, the sequestered CO_2 during the feedstock growth phase. This approach to biogenic emission sequestration appears consistent across the four reports, both with each other and with current internationally established practice.

Nor is it a surprise that fuels that use waste feedstocks have low lifecycle emissions, as the production emissions are, by convention, allocated to the prior, primary use rather than this secondary phase. Nonetheless, there are still emissions associated with the processing and distribution phases. However, market-readiness of some biofuels from waste feedstock is still an issue and the amount of usable feedstock is limited.

As the search for low emission fuels intensifies, it seems that the routes to produce the potential alternatives become potentially more complex and more dependent upon other activities in the low emission transition such as the production of low carbon electricity or carbon capture and storage.

Some of the most promising life-cycle emission values are linked to the use of electricity, either through direct use or as a source of energy to power the processes involved in the production of synthetic fuels. The significant potential pressure on future electricity systems to generate and distribute sufficient low carbon, renewable electricity has been well documented. The potential benefits from these fuels is appealing, although at this early stage of development the greater complexity of some of these process chains does potentially increase the uncertainty associated with the final emission factors, given the significant impact that the electricity emission factor can have on the final value.

2.3 Variability between emission factor sources

Figure 1 shows wide variability across the values for each fuel in the four sources when considering WTW GHG emissions per MJ of energy[6].

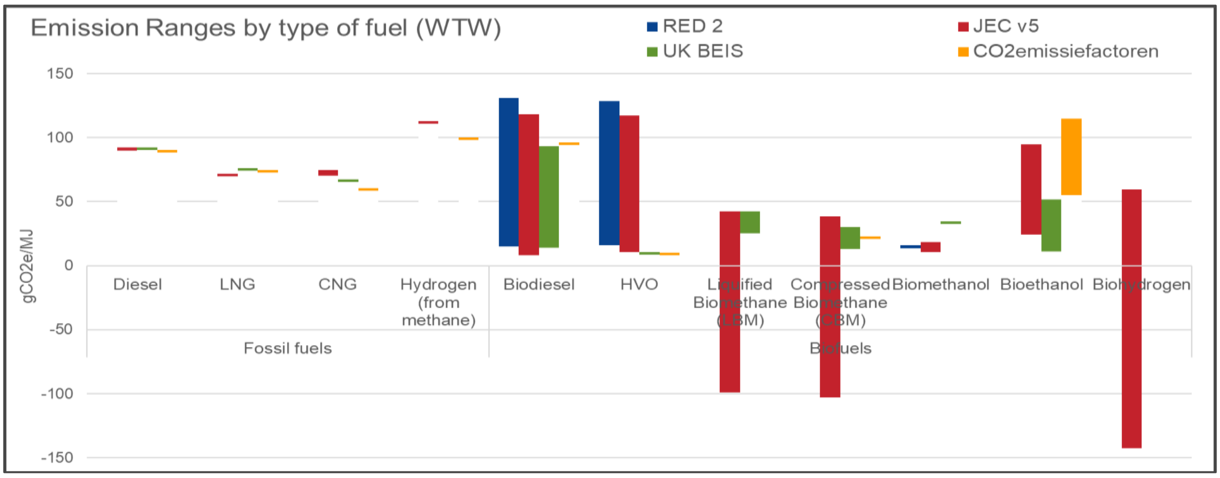

Figure 1: Variation in range of GHG emission factors by source report and fuel type (fossil fuels and biofuels)

The most striking feature is the wide range of values for individual fuels within the JEC WTW v5 study, although that is due to the nature of the study itself which includes as full a range of feedstocks and production pathways as possible.

Although technically feasible, many of the options included are unlikely to come to market soon due to lack of available feedstock, current immaturity of carbon capture and storage technologies, costs associated with the pathway, or lack of the necessary renewable electricity. This can, to a certain extent, obscure the variability that comes from like for like comparison.

[6] Note this tells only part of the story as regards final emissions per transport activity as other factors such as engine efficiency and vehicle utilization also have a significant part to play in the final emission intensity that is achieved. See Smart Freight Centre, Low Emission Fuels and Vehicles for Road Freight: introductory guide to support transition to zero emissions, 2020 for more information.

The coverage across the various sources decreases as novelty increases, and only JEC WTW v5 of the four chosen sources provides any insight for e-Fuels or a consideration of the impact of carbon capture and storage within the production process.

2.4 Variability within individual fuel types

There is significant variation in WTW GHG emissions within fuel types according to feedstock and production processes. Figure 2 collates the emission factors for each of the fuel type groups to show the variation in each one.

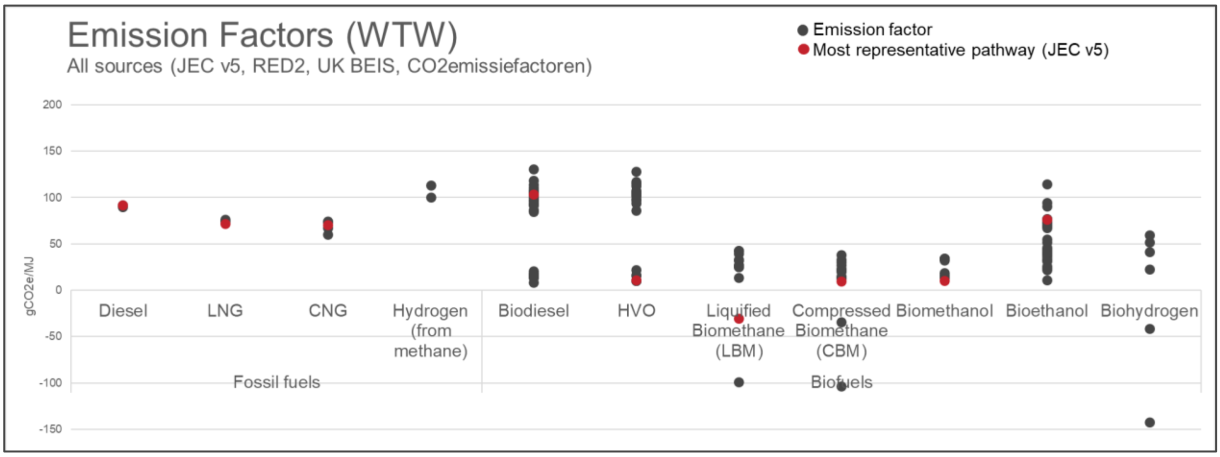

Figure 2: Variation in range of GHG emission factors by fuel type[7]

The emission factors for the fossil fuels (diesel, CNG & LNG) appear relatively close to each other across the sources as the viable production processes and associated values are well-established. As the novelty of the fuels and the variety of the feedstock and production pathways increases, so does the variability in the outputs.

The CO_2emissiefactoren emission factors for crop-based biofuels tended to be higher in the original reports because this source includes indirect land use GHG emissions in the core values, whereas the other sources state that indirect land use is an important factor that should be taken into account, but then do not include it in their headline values. As noted later in the report, we have added the iLUC values in the RED 2 to the WTT production and distribution values to provide a truer, full comparison.

The biodiesel values then split into two distinct groups, one for waste-based biofuels and the other (higher emission) group for crop-based biofuels.

We also found some difficulty in categorizing some of the fuels types as either biofuels, a categorization based on the feedstock, or synthetic or e-Fuels, which are categorizations based on the process, irrespective of feedstock.

The JEC WTW report identifies the most likely production pathway, combining feedstock and production process combination, and we have identified this in Figure 2. This assessment is based on establishing consensus among the JEC consortium partners, taking into account factors such as technological and commercial readiness and likely feedstock availability.

Figure 3 shows the contribution of the well-to-tank and tank-to-wheel phases as well as indirect land use, where applicable, to the overall WTW GHG emission factor. The high contribution of emissions from fossil fuels at point of use (tank-to-wheel) is clear and is in contrast to the relatively low contribution for biofuels because for biofuels the TTW emissions consist only of the CO_2 equivalent from non-CO_2 emissions such as CH_4 and N_2O.

The strong influence of the decision about whether to include indirect land use emissions on biodiesel emissions from crops such as soy, rapeseed and palm oil is evident, and shows why understanding and being able to track the origin of the fuels used is critical to achieving true emission reductions.

[7] The most representative pathway shown in the graph is based on the JEC v5 study. However, several pathways are still open to market and technical development. For instance, the most representative pathway for Liquified Biomethane (LBM) is from using the feedstock Open Manure, whereas the Compressed Biomethane most representative pathway is based on the Municipal waste. This explains some of the variation in the 'red' dot.

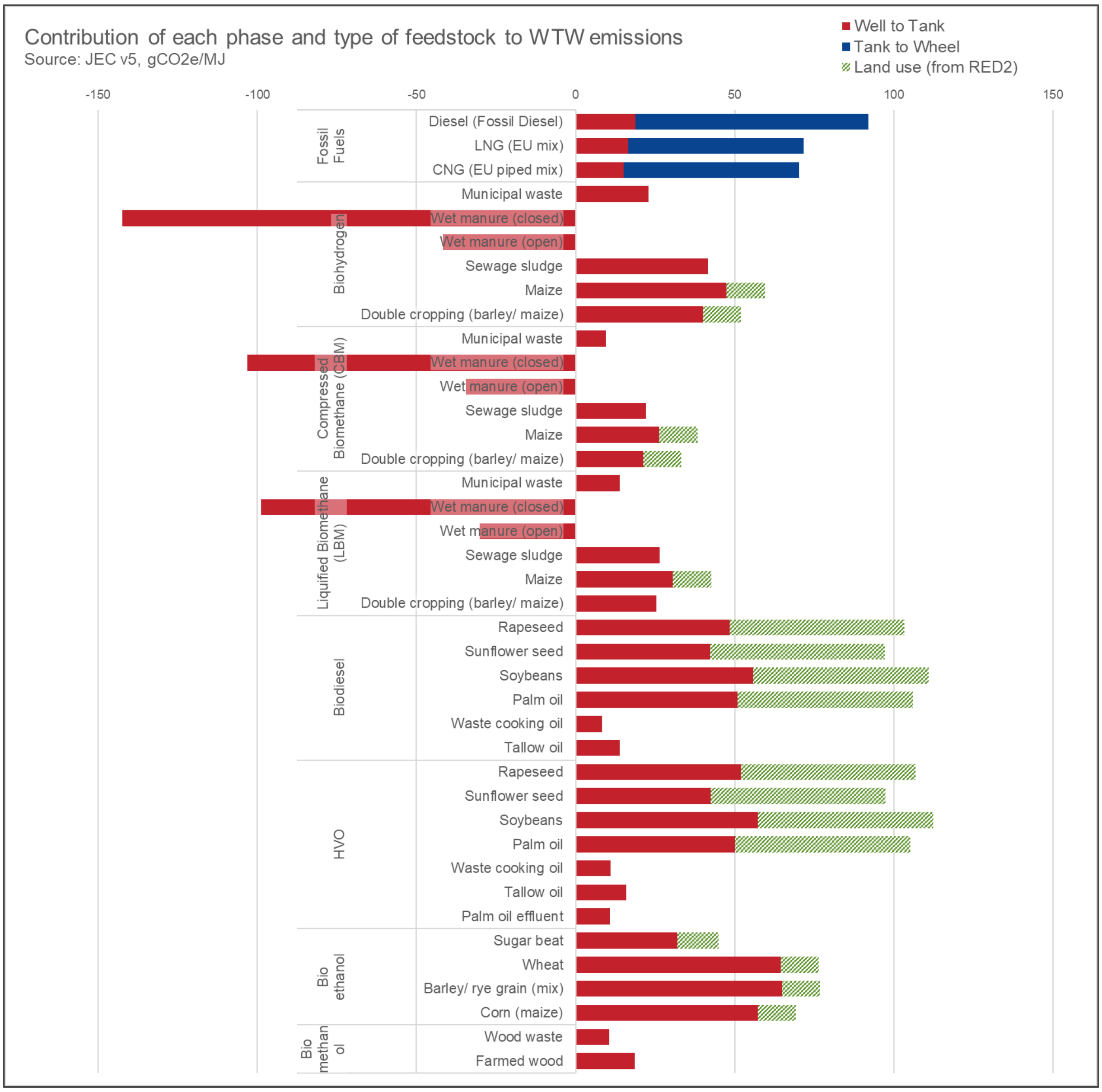

Figure 3: Contribution of different phases to the WTW GHG emission factor (fossil and biofuels).

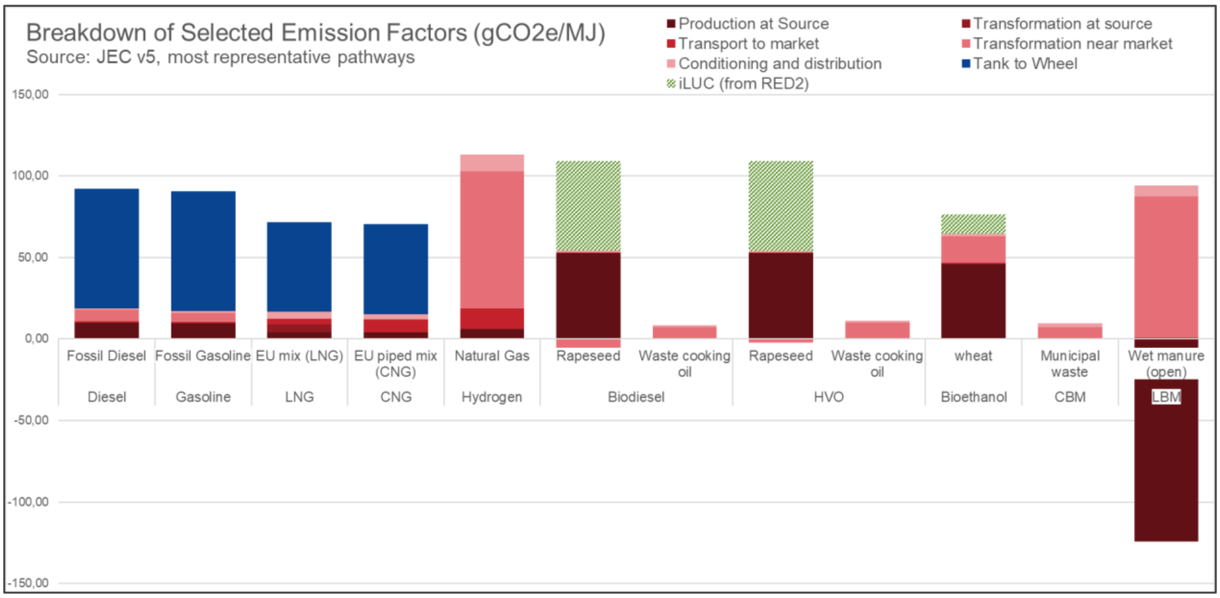

Figure 4: Breakdown of life-cycle emissions to include visibility of the well-to-tank phases of selected fuels.

The pathways presented in Figure 4 were selected due to their high relevance for the fuel market today. Various other pathways exist. Rapeseed is currently the most used feedstock for biodiesel production. Hydrotreated vegetable oil (HVO) is often produced from waste cooking oil due its good environmental performance. For CBM (compressed biomethane) and LBM (liquefied biomethane) two pathways using the feedstock with the highest availability, organic waste and wet manure, were chosen. Negative emissions from wet manure are due to a credit given for avoided direct methane emissions.

The relative efficiency of well-established industrial processes associated with processing of conventional fossil fuels is evident within their well-to-tank emission breakdown, and part of what makes them difficult to replace.

The strong contribution from agricultural inputs is clear for the rapeseed biodiesel, reducing its potential benefit, especially when the contribution of iLUC emissions is included.

In contrast, the relative simplicity of the emission cycle of HVO and biodiesel from waste cooking oil, with low emission values, shows why there has been so much recent focus on this as a ‘low hanging fruit’. For this reason, the amount of biofuel from waste cooking oil in Europe is growing. However, more than half of the feedstock is already imported from countries outside of the European Union (main exporters are China, Malaysia and Indonesia) and concerns have been raised about whether this really helps contribute to overall sustainability in the sector.

2.5 Synthetic and eFuels

Only one of the sources, the JEC WTW study v5, also includes possible future fuel pathways and gives values for synthetic fuels either from biomass-based feedstock or from directly using (renewable) electricity. For synthetic biofuels from biomass the most common route is a Fischer-Tropsch-Synthesis. However, other production routes are possible: a HTL (hydrothermal liquefaction and upgrading) or a black liquor gasification.

Here the biggest contributions come from the transformation of the electricity to the fuel (for eFuels) or from biomass production and transformation. By using carbon capture in storage (CCS) lower emissions can be achieved in the future.

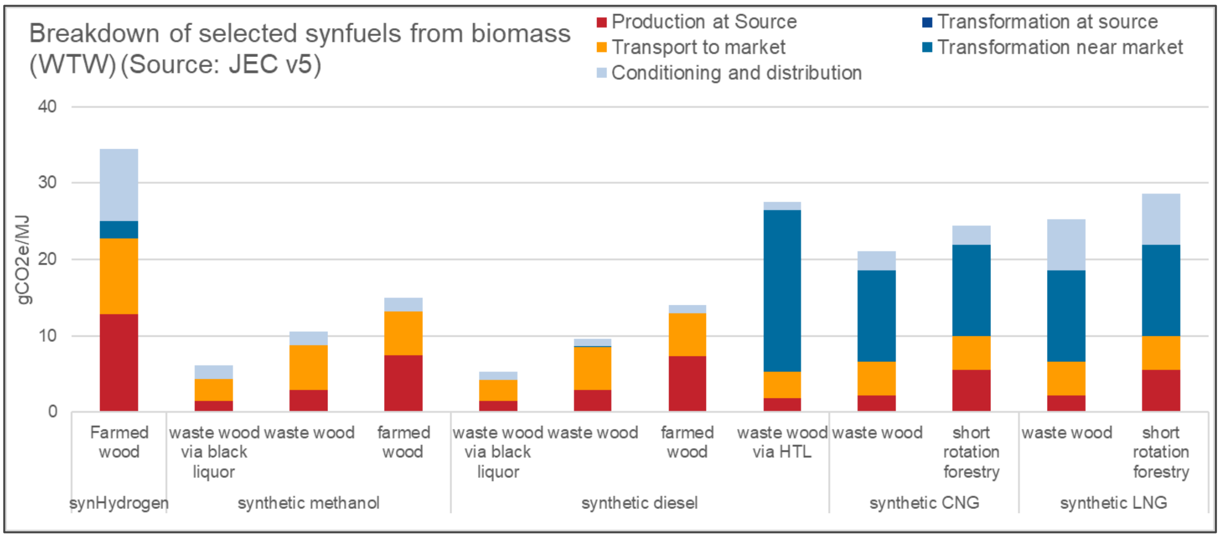

Figure 5: Breakdown of life-cycle emissions for synthetic fuels from JEC WTW study v5.

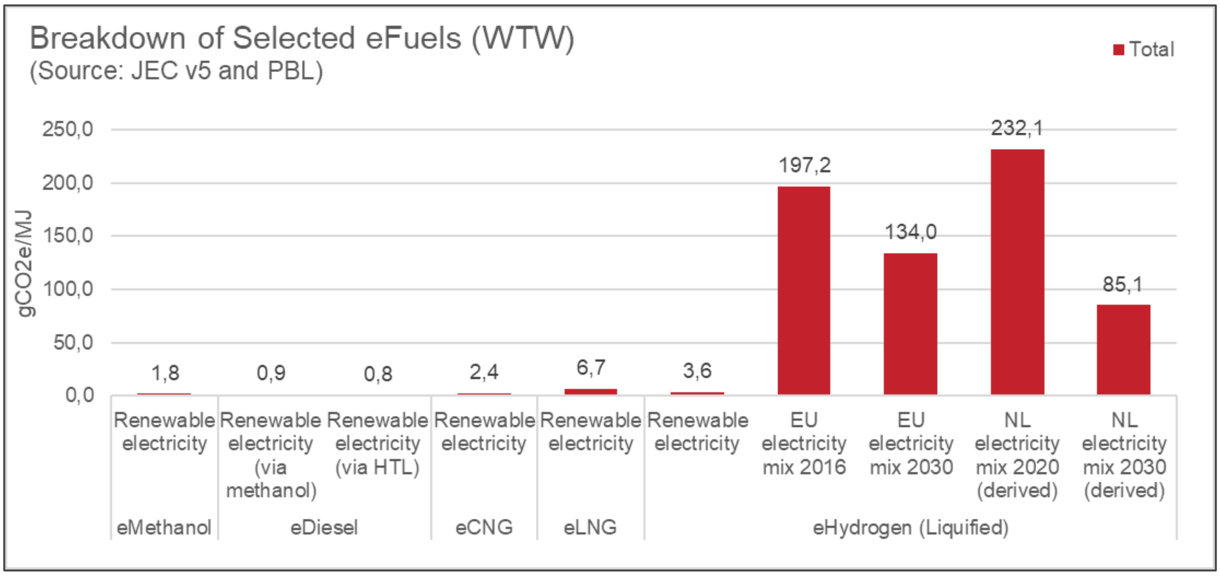

Figure 6: Breakdown of life-cycle emissions for eFuels from JEC WTW study v5 and PBL[8]

While the GHG benefits from eFuels using (additional) renewable electricity can be quite high, the amount of energy needed for the production of eDiesel is more than 5 times higher than for conventional diesel, when comparing the WTW energy demand for heavy duty vehicles according to JEC WTW study v5.

The manufacturing and construction of (additional) energy plants producing green electricity, such as windmill and solar parks, carries a risk of higher environmental impacts, unless the materials needed (e.g. cement) are also produced in a sustainable fashion. According to the UBA study SYSEET, the lowest achievable GHG emissions for eDiesel are around 5,5 gCO_2e/MJ under optimal conditions when the PtX plants and the offshore wind park construction is included. Furthermore, an increase in the impact from the energy generation infrastructure is observed in all other impact categories especially for land use change or in the water footprint[9]. These effects are not covered in the JEC WTW study v5, since impacts from the construction and manufacturing of (additional) infrastructure are explicitly excluded.

The central requirement for achieving GHG savings from eFuels is therefore the use of *additional* renewable electricity. This is also acknowledged in the RED 2 directive, where it is stated that a temporal and geographical correlation between the extra electricity production and the eFuel production should be

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[8] The production of eHydrogen from the NL electricity mix is derived from the EU values, utilizing the PBL Klimaat- en Energieverkenning (2020)

[9] UBA Syseet, https://www.umweltbundesamt.de/publikationen/systemvergleich-speicherbarer-energietraeger-aus

present. Figure 6 provides an indication of the significant variation for example in the production of hydrogen from electricity, as well as for other eFuels.

According to the RED 2 the average share of renewable electricity in the country of production should be used to account for the production of eFuels. Minimum greenhouse gas savings should be 70%. Electricity for eFuel production can only be counted as fully renewable if the installation producing the renewable electricity comes into operation at the same time or after the eFuel production facility and is either not connected to the grid or it can be ensured that grid electricity is not used.

The development of a delegated act to supplement the RED 2 directive with further criteria is, however, still outstanding.

We have included the 2019 and 2030 electricity generation factor from the PBL Klimaat- en Energieverkenning (2020) to aid comparison[10]. It is worth noting that the Dutch electricity emission factor is currently higher than the EU average and slightly higher than the value suggested by SFC's internal analyses as being the breakeven point in GHG emission terms for conversion from diesel to battery power. This emphasizes the significant work that still needs to be done to support an electricity-led decarbonization of the road transport sector.

[10] There exists a linear correlation between the emission factor for the production of eHydrogen and the carbon content of the electricity used. To estimate the emission factor for eHydrogen, based on the Dutch electricity network in 2019 and 2030, the carbon content of the Netherlands electricity mix is used and correlated to the eHydrogen values produced by the JEC v5 study utilizing the EU electricity mix of 2016 and 2030.

3 Conclusions

3.1 Representative and default emission factors

Based on the previous analysis, it can be concluded that a large variation exists in the GHG emissions from the new transition fuels. A representative value or conservative default value are therefore, by definition, not necessarily representative of the fuel being used, and highly dependent on the assumptions made about the feedstock, production and transformation process and transport of the fuel.

However, to facilitate an initial discussion and support GHG calculations for new transition fuels, the following factors are proposed as preliminary representative and default values, taking into account the following:

- The representative values are in general based on the JEC v5 most representative pathway.
- The default values are based on the maximum value across all sources, unless stated otherwise. The default value is explicitly considered a conservative value to stimulate the suppliers of the particular fuel to review the lifecycle GHG emissions and sustainability credentials of the fuel supplied (see also conclusion 3.4 Accounting and traceability)
- The value of HVO is separated into two factors, to distinguish the significant difference in emission factors depending on whether the fuel is produced from waste cooking oil or from a food crop, such as palm oil or soy bean.

As a next step, the following tables will need to be extensively reviewed and discussed with several stakeholders to confirm the emission factor values.

		Indicative most representative value		Indicative default value (conservative)	
Fossil fuels	Diesel	92.1	*JEC most representative path*	92.1	*JEC value*
	LNG	71.7	*JEC most representative path*	76.4	*UK BEIS Value*
	CNG	70.3	*JEC most representative path*	74.7	*JEC value*
	Hydrogen (from methane)	113.0	*JEC most representative path*	113.0	*JEC value*
Biofuels[11]	Biodiesel (crop-based)	103.4	*JEC most representative path (rapeseed)*	130.7	*RED2 value from palm oil*
	Biodiesel (waste-based)	10,1	*NL emissiefactoren*	17,51	*UK BEIS value (from brown grease)*
	HVO (crop-based)	106,9	*JEC (rapeseed)*	128.3	*Maximum value from palm oil*
	HVO (waste-based)	11.1	*JEC most representative path (waste cooking oil)*	16.0	*RED2 value*
	Liquified Biomethane (LBM)	28.1	*UK BEIS average value*	42.6	*JEC maximum value from maize*
	Compressed Biomethane (CBM)	9.5	*JEC most representative path; UK BEIS is 15.8 and NL CO_2emissiefactoren is 23*	38.3	*JEC maximum value from maize*
	Biomethanol	10.5	*JEC most representative path (waste wood)*	34.4	*UK BEIS Value (several sources)*
	Bioethanol	76.5	*JEC most representative path (wheat)*	94.7	*JEC maximum value from wheat; CO_2emissiefactoren value is higher (114,6) but dates from 2011*
	Biohydrogen		*No value; highly dependent on feedstock*	59.5	*JEC maximum value from maize*
Electric	Renewable	0.0	*100% renewable energy*	132.3	*NL grid mix (2020)*

Table 3. Draft and preliminary list of representative and default values of Well-to-Wheel emissions, inclusive of indirect Land Use Change (gCO_2e/MJ)

[11] The presented biofuels values include (i) the impact of iLUC and (ii) a specific feedstock as mentioned. Both aspects significantly impact the actual the emission factors. Alternative representative values could consider the specific market average (e.g. European or Dutch biofuel).

		Indicative most representative value		Indicative default value (conservative)
Synthetic fuels[12]	Synthetic diesel	5.3	*JEC value (waste wood via black liquor)*	*No commercially and technology ready product yet. Therefore no value*
	Synthetic methanol	6.2	*JEC value (waste wood via black liquor)*	
	Synthetic LNG	25.3	*JEC most representative path (waste wood)*	
	Synthetic CNG	21.0	*JEC most representative path (waste wood)*	
eFuels[13]	eDiesel	0.9	*JEC from additional renewable energy; excluding infrastructure construction emissions*	*Further review is required to consider the emissions of construction of the additional renewable energy to develop a default value.*
	eMethanol	0.0	*JEC from additional renewable energy*	
	eLNG	6.7	*JEC from additional renewable energy*	
	eCNG	2.4	*JEC from additional renewable energy*	
	eHydrogen	9.5	*JEC from additional renewable energy; compressed hydrogen; alternative most likely from Natural Gas: 113.0*	

Table 4. Draft and preliminary list of representative values for Synthetic and eFuels for Well-to-Wheel emissions (gCO_2e/MJ)

3.2 Methane slip

In recent years there has been much debate about the potential benefits of gaseous fuels, particularly natural gas, as part of the energy transition to a low carbon transport sector. One of the points of controversy is that the fuel itself, methane, is both volatile and a strong greenhouse gas, meaning that it does not take much leakage to negate any benefit from the theoretical benefits that might result from full combustion of what is potentially a more energy efficient fuel.

An in-depth discussion of this issue is not part of the scope of this study. However, given the importance of the issue, we have checked and neither the UK BEIS nor the JEC v5 take methane slip at the point of use into account. This means that the GHG emission factors for gas vehicles would be a lower bound estimate of the overall GHG impact. The approach of how to address this will need to be considered elsewhere, and is complicated because:

- the evidence on this issue is steadily evolving,
- different gas engine technologies appear to have different rates of methane slip, depending on their combustion technology and operating pressure, and
- that engine manufacturers are investing in efforts to rectify the problem.

A study by TNO[14] shows that the impact from methane slip for two new LNG trucks is about 2 g CO_2e/ km, which leads to the conclusion that impacts from methane slip can be managed and are, ideally, pretty low.

3.3 Land use change

The contribution of land use change, both direct and indirect, to the GHG impacts of biofuels has been identified as a significant contributor to WTT emissions. However, the majority of the sources reviewed in this study do not include land use change emission values as part of their inventory. For example, the UK BEIS emission factors list, merely refers users to the standard land use values in the RED2 in a way that could easily be overlooked, and although JEC WTW v5 contains an annex that explains the importance of taking direct and indirect land use effects into account, and provides a table that shows the wide variability

[12] No direct comparison of RED2 Synthetic biodiesel and JEC synfuels was possible, although in future research this can be explored further.

[13] Given the very low emission factor values, there is some concern about the relative variation of the emission factors for eFuels, in particular the relative higher value of eHydrogen in comparison to eDiesel and eMethanol.

[14] TNO 2017 R11336 Emissions testing of two Euro VI LNG heavy-duty vehicles in the Netherlands: tank-to-wheel emissions - see page 27, venting and other losses are also discussed.

in the direct land use impact of growing biofuel crops (depending on the nature of the prior vegetation and the crop grown), it does not provide a clear guidance on how to do so. This is said to be because of the uncertainty in the values that result from what is a relatively new study area. Nonetheless it would be wise to try to include a best estimate of land use impacts in the WTT phase, even if they need to be subsequently changed as the science behind the values develops, and we have tried to do this where relevant by following their recommendations and adding the values in the RED 2 to the WTT production and distribution values.

On this topic, the producers of CO_2emissiefactoren should be congratulated for making the effort to include an indirect land use contribution to their emission factor values, even though the basis of the values included could be more transparent.

3.4 Accounting and traceability

The greater variability in emission factors observed among the new fuels will have consequences on how their GHG impacts can be accounted:

- In order to capture a credible value for the deployment of new fuels the suppliers of these fuels will need to provide certificates from reputable issuers that show both the lifecycle GHG emissions and the sustainability credentials of the fuel supplied;
  - This type of approach is already being pursued through schemes such as RED 2 for biofuels, California's LCSF scheme for road transport, CORSIA for sustainable aviation fuel, ISCC and others, but would benefit from cross sector coordination
  - To help verification of the actual fuel being used some form of trace marking of fuels could be beneficial, as developed by Bunkertrace (https://bunkertrace.co/solutions/products), for example
- In the absence of robust fuel certification, default values will be made available for each fuel type, based on the worst case scenario to avoid claims being made that do not match the true feedstock and process path.
- This will have knock-on impact on the approach to transport emission accounting. The end user is less likely to know the exact credentials of the fuel used for their contracted transportation, except in circumstances where they take responsibility for sourcing the fuel for their transport suppliers through a collaborative approach to decarbonization.

As a result, there will need to be less reliance on standard GHG emission factors and much greater use of certified values that specifically relate to each batch or at minimum each specific supplier / fuel combination.

3.5 Negative GHG emissions

Both the marginal approach to emission accounting presented in JEC v5 and the developing indirect land use change methodology can result in negative GHG emission factors in a relatively small number of cases. This results from the approach taken and could lead to perverse or unintended consequences, where increased use of certain fuels could be perceived as being beneficial for the environment.

This emphasizes that once a fuel moves from a relatively small production volume to a substantial share of the market, an attributional approach to emission accounting should be applied.

3.6 Carbon capture and storage / use of flue gases

Several of the JEC pathways offer options with and without carbon capture and storage during the processing phase, to show the impact of this technology on the overall pathway. We have not been able to investigate these effects in great detail at this stage, other than to acknowledge the impact is generally significant.

Some of the pathways are based on CO_2-rich flue gases being used as a feedstock to the subsequent fuel production pathway. This is perhaps the ultimate transition fuel, as it is only likely to be viable as a production pathway in a fossil-based industrial society prior to a low-carbon transition. In some economic scenarios, shifting to such feedstocks might run the risk of tying in 'production' of CO_2 flue gases leading to lock-in effects of old (coal) power plants. This would need to be further investigated by sector economic experts.

3.7 Wider Sustainability

As well as the primary focus of this report, namely fuel cycle GHG emissions values, it is important to consider other sustainability factors to ensure there are no unintended environmental consequences. The RED 2 addresses this through criteria that are focused on the prior status of the land used for production of biogenic feedstocks. Other initiatives, for example the Sustainable Shipping Initiative, are proposing broader lists of criteria linked to the UN Sustainable Development Goals to include issues such as labor conditions and human rights considerations, safety standards, air quality impacts, water use, food security and support for socio-economic development.

At this point we are only able to acknowledge this as an important issue for further consideration.

4 Recommendations & Next Steps

This report outlined an overview of the GHG emission factors, sources that contribute to these and the variation that exists. This is a subject that remains under significant development, in particular the understanding of indirect land use change, as well as the full impact of production of synthetic and eFuels. Therefore, the following recommendations and next steps are considered:

1. Identify additional sources for fuel groups that lack data in this initial review; this covers primarily synthetic fuels and unblended eFuels. This will fill data gaps for these fuels, by identifying other sources and bringing in the extra information to check for consistency / completeness as well as allowing consideration of other factors such as the impact of infrastructure developments required for some of the new fuels.
2. Further in-depth assessment of the impact of each element within the process chain of biofuels, synthetic fuels and e-Fuels, where the sources allow. The presentation in this report is primarily from the new JEC WTW v5 report. Further investigation will enable clarification of any remaining uncertainties as regards individual emission values and open questions within the decisions made by JEC when they prioritize certain feedstocks in terms of market readiness based on the technical process / feedstock availability / cost.
3. In-depth consideration of broader sustainability issues. This could start with additional scrutiny of iLUC emission calculation approaches being taken in other sectors (e.g., aviation by ICAO/CORSIA) or global regions, but also be broadened to review the full list of issues identified in RED 2 and broader sustainability criteria that are being in other sectors such as the Sustainable Shipping Initiative.
4. Carry out one-to-one followed by round table consultations with experts, end users (shippers, logistic service providers and carriers), fuel certifiers, government associations and associated organizations to discuss:
   a. The approach and coverage of calculating and reporting GHG emissions from transition fuels.
   b. Efforts from end users in procuring transition fuels and reporting the associated GHG emissions, including the information required, format and reporting from business to business (B2B).
   c. The methodology and concept to apply the Total Emissions of Ownership in addition to the Total Cost of Ownership
5. Establish a default methodology and supporting tool to apply the concept of Total Emissions of Ownership through standard questions and default values. This could facilitate and support in the justification of providing financial incentives to accelerate the uptake of specific transition fuels and would link back to the development of wider industry guidelines (GLEC Framework and ISO 14083)
6. Establish case studies from end users in the calculation and reporting of greenhouse gas emissions from transition fuels.

Appendices

A.1. Individual Emission Factor Source Description Templates

		Source: RED 2	
Publisher		European Commission	
Developer		European Commission/ JEC	
Scope	time period validity	2018	
	System boundary / cut-off criteria		
	e.g. infrastructure (power plant construction) included	No	
	Geographic boundary?	Europe	with imports
	Energy carriers & feedstocks / processes covered		Focus on bio-energy
Fuel Cycle basis	WTT	Yes	WTT emissions in separate excel sheet
	Disaggregation of WTT elements	Yes, partially	cultivation, processing, transport/ distribution
	TTW	Yes, partially	GHG impact from direct emissions of CH4 and N2O given
Emissions included	CO_2	No	
	CO_2e	Yes	according to GWP 100a IPCC 2007
	CH_4 contribution separated	No	
	N_2O contribution separated	No	
Land use	Direct LUC	Yes	methodology in annex V part C section 7, but default/ typical values are given without LUC since only LUC after 2008 is considered relevant
	Indirect LUC	No	not included in default factors but given in separate annex VIII
Allocation approach	Attributional	Yes	energy allocation for all by-products
	Consequential		
	Mixed		credit for avioded CH4 emissions given when wet manure is used
	Approach to biogenic emissions		CO_2 balance
	Approach to waste feedstock		waste feedstocks without emissions
Presentation fuel properties	Density and heating value provided?	Yes	LHV (MJ/kg and MJ/l) in annex III
Comment(s) on data source(s)			background for calculations given in excel, data is in part based on different (very) old datasources
Additional Sustainability Criteria Included		Yes	avoidance of iLUC by limiting the amount of biofuels from food and feed crops as well as not
Electricity mix used	consumption or production mix?	N/A	not relevant
	losses included?		
	Year	2018	
	region/ country		
3rd party certification/ review		No	not stated

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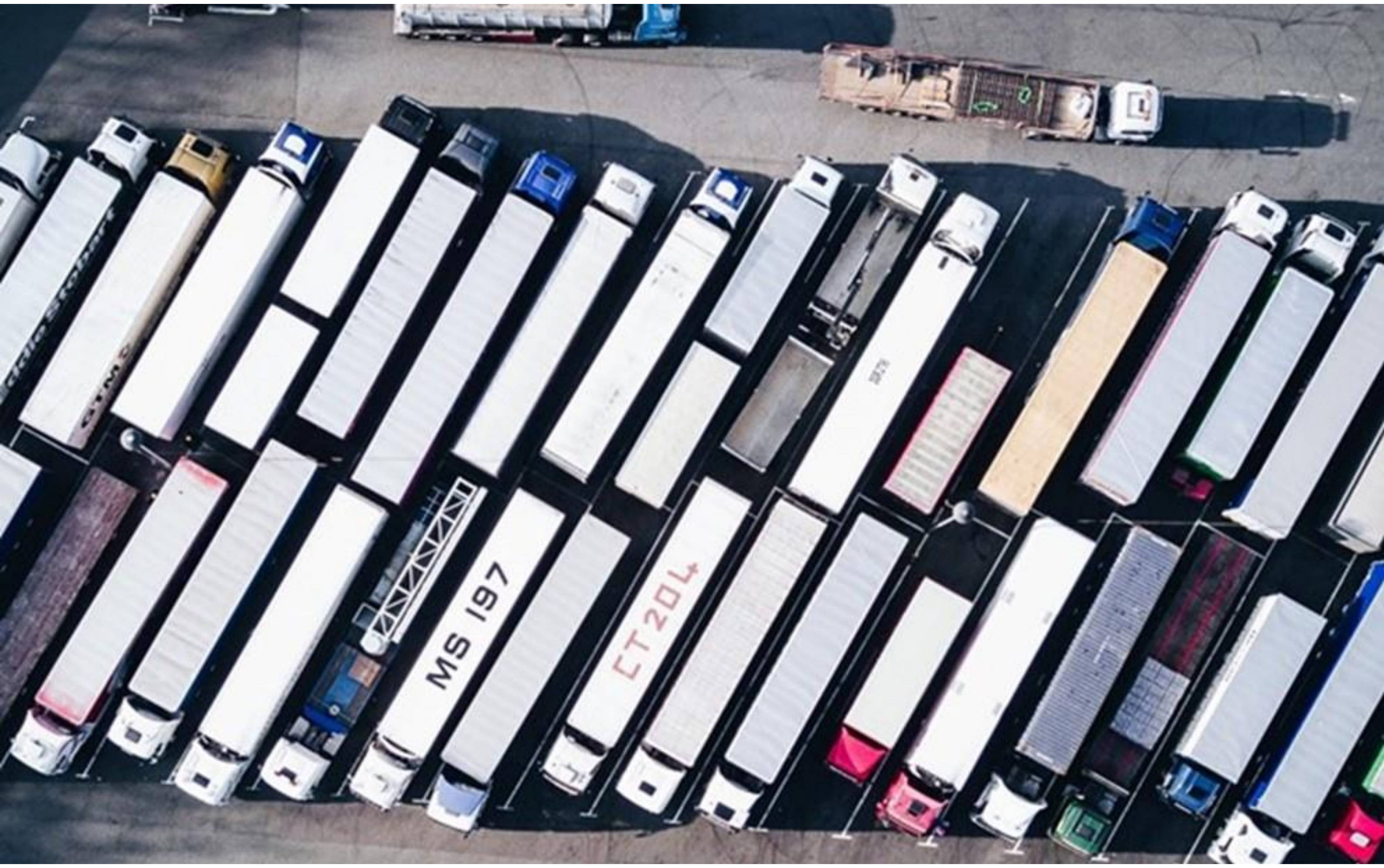

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