INSTITUTE FOR ENERGY AND ENVIRONMENTAL RESEARCH HEIDELBERG

Smart Freight Centre

Fuel Emission Factors in ISO 14083

A brief description of the derivation of emission factors

July 2023

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This report was written by Kirsten Biemann of ifeu and Mehul Khandelwal of Smart Freight Centre.

About Smart Freight Centre

Smart Freight Centre is an international non-profit organization focused on reducing greenhouse gas emissions from freight transportation. Smart Freight Centre's vision is an efficient and zero emission global logistics sector. Smart Freight Centre's mission is to collaborate with the organization's global partners to quantify impacts, identify solutions, and propagate logistics decarbonization strategies. Smart Freight Centre's goal is to guide the global logistics industry in tracking and reducing the industry's greenhouse gas emissions by one billion tonnes by 2030 and to reach zero emissions by 2050 or earlier, consistent with a 1.5°C future.

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Executive Summary

Recently launched ISO 14083 is an internationally recognized standard that includes a harmonized approach for calculating GHG emission factors. The standard is designed to achieve fair comparability of emissions from different sources, by using well-established and peer-reviewed sources to determine the emission factors.

Where national legislation mandates the use of specific GHG emission factors, users should use the most current and updated official GHG emission factors available, wherever possible matching up to the expected approach for generating emission factors set out in ISO 14083. This allows for greater accuracy and reliability in emission calculations and permits a more accurate comparison of emissions from different sources. ISO 14083 also requires consideration and inclusion of relevant climatic factors and other influencing factors when determining emission factors, making the standard more comprehensive and reliable.

This report provides an in-depth overview of current emission factors in Europe and North America according to ISO 14083. It analyzes recent updates to ecoinvent 3.9.1 for WTW values of fossil fuels in Europe and similar changes in the WTW values of some fuels in North America resulting from the latest update of the GREET model in 2022. The report presents updated emission factor values for Europe and the USA compared with the old values. Reliable data and sources are used throughout the report to provide an accurate and comprehensive overview. The updated values will be included in the next version of the GLEC Framework i.e. version 3.0 in line with the approach for calculating GHG emission factors set out in the recently published ISO 14083.

1 Introduction

The normative annex of the ISO 14083[1] articulates the following statement " *Users of this standard shall use GHG emission factors for fuels which comply to the provisions in this document. The emission factors shall be listed and the following properties shall be given:*

- *Fuel type*
- *Lower heating value (MJ/kg)*
- *Density (kg/l)*
- *Operational GHG emissions (g CO_2e/MJ)*
- *Total GHG emissions (g CO_2e/MJ)*
- *Biofuel blend (in % energy content) (if applicable)*

Users shall clearly state the source of all GHG emission factors for fuels.

The potential for leakage of methane, itself a potent greenhouse gas, shall be taken into account when calculating the emissions resulting from provision and use of methane-containing fuels such as CNG, LNG, and their biogenic equivalents. Upstream venting of methane from the tank or at various points further up the supply chain shall be considered in the energy provision component of the overall emission factor.''

Furthermore, in an informative annex to ISO 14083[1], indicative emission factors for Europe and the US are provided. These cover a sample of values from well-established and peer-reviewed sources.

ISO 14083[1] ensures that the emission factor calculation is fair and leads to comparable results. Whenever national legislation mandates the use of specific GHG emission factors, users should use the most current updated official GHG emission factors and sources available.

1.1 Purpose of Document

One purpose of this report is to explain how the current emission factors for Europe and North America in ISO 14083 annex K [1] were derived. However, due to the latest update to Ecoinvent, which resulted in the release of version 3.9.1[2], released in October 2022, there has been a noticeable increase in the WTW values for some fossil fuels in Europe. Similar changes are also visible in the WTW values of some fuels in the North America based on the update of GREET model[3]. This document also provides a view into the updated fuel emission factor values for Europe and USA.

1.2 Methodology

1.2.1 General

The general idea for the emission factors in ISO 14083 [1] was to recommend well-established, peer-reviewed sources for GHG emission factors that follow the preferred methodology to be used in the GHG calculations within the scope of the standard - this includes the entire upstream process chain (including any emissions from energy production infrastructure). The preferred sources follow an attributional approach wherever possible since these factors will be used for emission accounting by the standard's users. The values have been supplemented in a limited number of instances with values from alternative sources that follow a consequential approach where that is the only viable option. The recommendation was for the emission factors to use the GWPs from the newest IPCC assessment report, 2021 (AR 6)[4]. In practice, many of the sources used were still based on AR5[5] at the time of compiling ISO 14083[1].

1.2.2 Europe

To provide the best possible set of emission factors in Europe, a combination of different sources was used, as no single source met all the requirements. In order to ensure that the calculations were accurate, all sources were thoroughly checked for validity and consistency and any discrepancies were properly accounted for, allowing for a reliable and robust set of emission factors to be produced. ecoinvent was used for the majority of fossil fuels, although additional information, such as missing density values, had to be added to the ecoinvent source material. The JEC WTW v5 study [6] was used to supplement ecoinvent; this had to be adjusted to conform with AR 5 GWPs as it still used AR 4. EcoTransIT World [7] was used for calculating the emission factors associated with bio-sourced based fuels, and Fuel EU maritime was used for the calculation of the operational emissions of gaseous marine-based fuels within ISO 14083[1].

Four main groups of fuels were identified for Europe which were represented in different ways in ISO 14083:

- Liquid fossil fuels (gasoline, diesel, liquified petroleum gas (LPG), kerosene, light fuel oil (LFO) and heavy fuel oil (HFO))
- Gaseous fossil fuels (compressed natural gas (CNG), liquified natural gas (LNG), and hydrogen from steam methane reforming (H_2 SMR))
- Biofuels (biodiesel (FAME), hydrotreated vegetable oil (HVO) / hydroprocessed esters and fatty acids (HEFA), ethanol, compressed biomethane, liquified biomethane)
- Electricity (value provided for EU 2019 electricity mix including average grid losses)

1.2.3 North America

For North America, we derived the emission factors primarily for the USA based on one particular source, namely GREET[8], [9] (Greenhouse gases, Regulated Emissions, and Energy use in Technologies), which is a full life-cycle model developed by Argonne National Laboratory, sponsored by U.S. Department of Energy. GREET evaluates the energy and emission impacts of advanced and new transportation fuels, the fuel cycle from well to wheel (WTW), and the vehicle cycle based on material recovery and vehicle disposal. GREET allows researchers and analysts to evaluate various vehicle and fuel combinations on a full fuel-cycle/vehicle-cycle basis.

For the USA, also four main groups of fuels were identified and no changes were made representing in ISO 14083:

- Liquid fossil fuels (gasoline, diesel, liquified petroleum gas (LPG), kerosene, marine diesel oil (MDO), marine gas oil (MGO), very low sulfur fuel oil (VLSFO), ultra-low sulfur fuel oil (ULSFO))
- Gaseous fuel oils, (compressed natural gas (CNG) and liquified natural gas (LNG))
- Biofuels (ethanol, biodiesel, hydrotreated vegetable oil (HVO))
- Electricity (value provided for US 2019 electricity mix including average grid losses)

1.3 GHG emission factors and sources

Emission factors are important for calculating transport emissions and carbon footprints. They provide a consistent way to convert fuel and energy used in freight transportation into greenhouse gas emission values. However, the emission factor can vary depending on factors such as the type of fuel, production and consumption locations, distribution methods, and production processes, etc.

Conventional fuels i.e. fossil fuels, come from various sources and go through established processes to meet local fuel quality standards. It's not common practice to determine the exact emission factor for each batch of fuel. Instead, representative values are used, assuming that emissions will average out over time to match the representative value. National emission factor databases may reflect variations in fuel standards and local industrial energy efficiency as well as variations in crude oil supply in different regions, there is for example a huge difference between tar sands and conventional crudes, but for conventional fuels with well-known feedstocks and production processes, the variation tends to be low. Methane emissions also vary widely between different regions.

New fuels, including some renewable fuels and low life-cycle GHG emissions, have less standardized production processes and can vary more throughout their life cycle. They can be made from a wider range of feedstocks, leading to greater variability.

Emission factors are subdivided into two categories:

- energy production emissions (upstream or WTT phase), and
- operational emissions (point of use or TTW phase)

The total GHG value is the addition of the above two phases into a WTW figure that represents the full energy life cycle.

In ISO 14083[1], GHG emission factors are derived primarily from sources developed in and designed for use in Europe and the US. For locations outside Europe and the US, where no nationally mandated values are applicable, users can use the provided values. Alternatively, they can identify an alternate source or use their own values if calculated in accordance with the ISO 14083 approach.

When calculating the well-to-wheel emissions of CNG and LNG fuels, it is crucial to consider the potential methane leakage at various stages, including upstream processes, refueling, and engine operations. Methane venting during refueling and in the supply chain is accounted for in the well-to-tank component. Additionally, the tank-to-wheel emissions require a more intricate approach due to "methane slip," which calculates the impact of unburned fuel released into the atmosphere alongside the emissions resulting from the majority of the fuel combustion. In ISO 14083, the operational GHG emissions from methane-based fuels are considered in a different way than for other fuels. The extent of the methane slip varies according to the engine technology, the way the engine is run, and any GHG emission abatement technology that is fitted. The legislation that applies to engines used in different situations also varies, with different limits on methane emissions applied by location and mode [1]. Consequently, determining definitive emissions values for LNG or CNG use can be challenging. We have provided an initial estimation of methane slip and its impact on TTW emissions, differentiating by engine technology when information is available.

Emission factors need to be reviewed on a regular basis:

- Keeping them up to date with the latest updates from the chosen sources.
- Incorporating new, improved information about low-carbon fuels alongside the information for conventional fuels as it becomes available.

1.3.1 Europe

The values for Europe in ISO 14083 include the use of three main sources for emission factor calculations:

- the ecoinvent database version 3.8 (cut-off system model) [10] for all liquid fossil fuels,
- the JEC well-to-wheel study v.5 [6] for all fossil gaseous fuels (amended to reflect AR5 instead of AR 4)
- and values prepared by ifeu Institute for the EcoTransIT methodology report 2022 [7] for biofuels and electricity.

Fuel densities were added for liquid fossil fuels, taken from JEC WTW study v.5 for gasoline/diesel, EN 16258 [11] for LPG, kerosene and HFO, and from fuel provider information for LFO [12]. In addition to this, operational GHG emissions values for kerosene were changed to 3.16 kg CO_2e/kg fuel, in line with IATA/ ICAO comment [13]. This led to an increase compared to the original ecoinvent data but aligned the EU operational GHG emission factors for kerosene with those in the US.

Operational emissions (tank-to-wheel) were split into fossil CO_2 emissions, which correspond to the amount of fuel burned, and non-CO_2 GHG emissions (CH_4 and N_2O), which depend on the application (e.g. truck or ship) and engine type. The non-CO_2 GHG TTW emissions do not include any short-lived climate forcers (e.g. black carbon or nitrogen oxides), but do include methane slip. The operational factor for biodiesel (FAME) also includes some fossil CO_2 emissions due to the presence of fossil methanol in the end product.

In Europe, the biofuel pre-chains came from the ifeu Institute, produced for EcoTransIT, and followed the RED II methodology. A typical European biofuel blend is composed of different feedstocks:

- biodiesel (FAME): 50% rapeseed, 40% used cooking oil, and 10% soybean
- ethanol: 40% maize, 35% sugar beet, and 25% wheat
- HVO/ HEFA: 50% rapeseed and 50% used cooking oil
- biomethane: 40% maize, 40% manure, and 20% biowaste

The EcoTransIT World methodology report is also set to publish electricity emission factors for different countries following the ISO 14083 methodology.

In spite of our best efforts the current ISO 14083 factors do have some drawbacks. Primarily, the ecoinvent database lacked reliable data on hydrogen from SMR as well as liquified natural gas. As a result, LNG and CNG values from the JEC WTW study v.5 [6]were used. Because the JEC WTW study v.5 used a consequential modeling approach the values are not directly comparable to the other factors and ideally would not be used for emission accounting.

The GHG emissions given in the JEC WTW study v.5 [6]do not explicitly consider emissions from infrastructure/ capital goods, however, as these are less than 1% of the total GHG emissions of conventional fossil oil and gas[14] this is not an issue.

Emission Factors in ISO 14083 annex K

Table 1 European GHG emission factors for Liquid fuels and electricity[1]

Energy Carrier	Lower heating value in MJ/ kg	Density in kg/l	GHG emission in g CO_{2e}/MJ (operational)	GHG emission (total) in g CO_2e/MJ (total)	GHG emission (operational) in kg CO_2e/kg (operational)	GHG emission (total) in kg CO_2e/kg (total)
Gasoline	42.5	0.743	75.1	90.1	3.19	3.83
Ethanol (40% maize, 35% sugar beet, 25% wheat)	27	0.78	0.3	48.2	0.01	1.30
Diesel	42.8	0.832	74.1	87.3	3.17	3.74
Biodiesel (50% rapeseed, 40% used cooking oil, 10% soybean)	37	0.892	4.1	38.3	0.15	1.42
Liquefied Petroleum Gas (LPG)	45.5	0.55	67.1	81.6	3.05	3.71
Jet Kerosene (Jet A1 and Jet A)	43	0.8	73.5	84.7	3.16	3.64
Heavy Fuel Oil (HFO) (2.5% sulfur)	41.2	0.97	76.8	85.4	3.17	3.52
Light Fuel Oil (LFO) (0.1% sulfur)	42.6	0.86	75.3	86.5	3.21	3.69
Hydrogen from steam reforming of natural gas	120	n.a.	0	114.4	0	13.73
HVO*/HEFA (SAF) (50% rapeseed, 50% used cooking oil)	44	0.77	0.1	28.6	0	1.26
Electricity European average (EU 28, 2019, including average losses)	n.a.	n.a.	0	97	n.a.	n.a.

Table 2 European GHG emission factors for gaseous fuels including methane slip[1]

Energy Carrier	Example applications	Lower heating value in MJ/ kg	Density in kg/l	GHG emission in g CO_{2e}/MJ (operational)	GHG emission (total) in g CO_{2e}/MJ (total)	GHG emission (operational) in kg CO_2e/kg (operational)	GHG emission (total) in kg CO_2e/kg (total)
CNG	Europe spark ignition truck	49.2	n.a.	56.6	72.7	2.79	3.58
LNG	Europe spark ignition truck	49.1	n.a.	57.9	75.5	2.84	3.71
Bio-CNG (40% maize, 40% manure, 20% biowaste)		50	n.a.	1.5	26.2	0.08	1.31
Bio-LNG (40% maize, 40% manure, 20% biowaste)		50	n.a.	1.5	30.4	0.08	1.52
LNG	Otto dual fuel ship (medium speed)	49.1	n.a.	73.6	91.2	3.61	4.48
LNG	Otto dual fuel ship (slow speed)	49.1	n.a.	66.0	83.6	3.24	4.10

1.3.2 North America

The emission factors for fuels from the GREET® database[9] are recognized as an official source by the US government published by Argonne National Laboratory,

GREET is a comprehensive model developed by the U.S. Department of Energy's Argonne National Laboratory to estimate life-cycle emissions of greenhouse gases, air pollutants, and other short-lived climate forcers from the operational (tank-to-wheel) of transportation subsectors and the building sectors. This model considers:

- Total energy consumption (non-renewable and renewable)
- Fossil fuel energy use (petroleum, natural gas, coal)
- Greenhouse gas emissions (CO_2, CH_4, N_2O)
- Air pollutant emissions (VOCs, CO, NO_x, SO_x, PM10, PM2.5)
- Water consumption

The values in the GREET include various phases of fuel production and use a wide range of vehicle types. Additionally, the model accounts for an extra emission of 4.02 gCO_2e/MJ for Biodiesel (BD) as the carbon intensity of Biodiesel is impacted by the fact that it contains fossil carbon originating from the conventional methanol used in the production. As Biodiesel includes fossil carbon from methanol, it has higher combustion emissions than Renewable Diesel, which reduces net differences between Biodiesel and Renewable Diesel routes. Combustion emissions are not zero due to non-CO_2 emissions (e.g., methane, nitrous oxide) from fuel combustion and C embedded in fossil methanol inputs.[15]

GREET also accounts for methane slip, which is commonly referred to as the unintended release of methane due to leakage from the production, storage, and transportation of fuel.

In the US, the biofuel pre-chains come from the GREET model only and are considered 100% blends. The emission factors in ISO 14083 for North America were based on the 2021 GREET model [8]. All greenhouse gas emission factors were calculated using the GWP 100a (without climate-carbon feedback) in accordance with IPCC AR 5[5].

Emission Factors in ISO 14083 annex K

Table 3 US GHG emission factors for liquid fuels and electricity[1]

Energy Carrier	Lower heating value in MJ/ kg	Density in kg/l	GHG emission in g CO_{2e}/MJ (operational)	GHG emission (total) in g CO_2e/MJ (total)	GHG emission (operational) in kg CO_2e/kg (operational)	GHG emission (total) in kg CO_2e/kg (total)
Gasoline	41.7	0.749	73.0	90.2	3.04	3.76
Ethanol (corn)	27.0	0.789	0.3	55.6	0.01	1.49
Diesel	42.6	0.847	75.0	90.5	3.20	3.86
Biodiesel (soybean)	37.7	0.881	4.1	20.6	0.15	0.78
HVO (tallow)	44.0	0.779	0.1	17.7	0.002	0.78
Liquefied Petroleum Gas (LPG)	46.6	0.508	64.8	78.7	3.02	3.66
Jet Kerosene (Jet A1 and Jet A)	43.2	0.802	73.2	84.8	3.16	3.66
Heavy Fuel Oil (HFO) (2.7% sulfur)	39.5	0.991	81.7	94.3	3.23	3.72
Very low sulfur fuel oil (VLSFO) (0.5% sulfur)	39.5	0.991	81.7	95.6	3.23	3.78
Ultra low sulfur fuel oil (ULSFO) (0.1 % sulfur)	39.5	0.991	81.7	95.9	3.23	3.79

Energy Carrier	Lower heating value in MJ/ kg	Density in kg/l	GHG emission in g CO_{2e}/MJ (operational)	GHG emission (total) in g CO_2e/MJ (total)	GHG emission (operational) in kg CO_2e/kg (operational)	GHG emission (total) in kg CO_2e/kg (total)
Marine Diesel Oil (MDO) (0.5 % sulfur)	41.0	0.914	78.6	92.1	3.22	3.76
Marine gas oil (MGO) (1.0 % sulfur)	42.8	0.837	75.2	87.8	3.22	3.76
Electricity US (2019) (including average losses)	n.a.	n.a.	0	118.0	n.a.	n.a.

Note: The last column was not included in the ISO 14083 annex K directly

Table 4 US GHG emission factors for gaseous fuels[1]

Energy Carrier	Application	Lower heating value in MJ/ kg	Density in kg/l	GHG emission in g CO_{2e}/MJ (operational)	GHG emission (total) in g CO_2e/MJ (total)	GHG emission (operational) in kg CO_2e/kg (operational)	GHG emission (total) in kg CO_2e/kg (total)
Compressed Natural Gas (CNG)	North America spark ignition truck	47.1	n.a.	56.8	73.7	2.67	3.47
Liquified Natural Gas (LNG)	North America spark ignition truck	48.6	n.a.	57.0	76.7	2.77	3.72

1.4 Emission Factors update

It is crucial that emission factors are based on the most credible sources and are developed by specialists. The full development of emission factors used in the GLEC Framework is outside the technical scope, however, we have updated the original values from ISO 14083 using the same sources and are thus in line with the approach described in Annex J of ISO 14083[1]. The ISO 14083 incorporates emissions associated with fuel and energy production infrastructure, which is not yet common in all emission factor sources.

The emission factors are presented in the same format as ISO 14083, providing CO_2e emissions for different phases of the fuel cycle. They are shown in terms of mass and energy content, and density is included when relevant for calculating emissions per volume. Non-CO_2 operational [1]GHG emissions are also accounted for, considering variations between different vehicles/engine types and after-treatment systems, where applicable for corporate reporting purposes based on CDP and SBTi.

To ensure consistency, the latest Global Warming Potential (GWP) values from IPCC AR6[4] have been used to convert all fuel emission factors to current CO_2e based on new values of GHGs, unlike the values in Annex K of ISO 14083, which were based on IPCC AR5 [5].

Due to much wider variability among emission factors of renewable fuels, the values that are described here are conservative i.e. at the higher end of the possible range. If an organization can determine the energy carrier it has utilized and has access to a certified emission factor for that specific product, which is provided by a reputable organization (such as RSB, ISCC, etc.) following the emission factor guidelines outlined in Annex J of ISO 14083, we strongly recommend employing this value, supported by the accompanying documentation.

The selection of emission factors in the GLEC Framework aims to align with nationally published values, existing transportation standards, and those used by representative UN bodies. However, several countries have independently published their own national emission factors, leading to potential confusion and uncertainty. Furthermore, CORSIA provides guidance for air transport emissions, and the International Maritime Organization (IMO) is anticipated to release its own well-to-wheel (WTW) emission factors in the near future. This current lack of coordination highlights the need for a coherent and comprehensive set of GHG emission factors in the global logistics sector.

While efforts are underway to develop such a comprehensive set, companies are advised to adhere to specific emission factors mandated by national or international legislation, ensuring clear documentation of the values used. In cases where no explicitly stated emission factors are available, it is recommended to utilize the higher values quoted in the North American and European tables to prevent inadvertent underestimation of emissions. As knowledge in this field advances, regular updates to the emission factors within the GLEC Framework are expected to reflect the evolving understanding of GHG emissions.

The input data used in the framework are the latest updates from reliable sources. We have taken all possible steps to provide a detailed starting point for companies wishing to calculate emissions in a harmonized and representative way. However, the higher energy provision (WTT) values that result from the ecoinvent update do highlight how easy it is for emission factors from different sources to become significantly misaligned with each other until consensus is re-established.

1.4.1 Europe

Notably, there have been significant revisions in ecoinvent version 3.9.1 and the GREET 2022 annual update between the drafting of ISO 14083 and the production of GLEC Framework V3 to be launched later this year.

The use of ecoinvent 3.9.1 [2] is particularly important as it addresses previously unidentified high levels of methane venting in the fossil fuel extraction phase, resulting in significantly higher energy

[1] Non-CO2 operational greenhouse gases include methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF6), and other fluorinated gases.

production (WTT phase) emissions, in some cases up to 50%, for fossil and fossil-derived fuels from previous estimates.

In the latest update of the ecoinvent 3.9.1 WTT factors[2], different regions and countries producing crude oil have been added, as have updated consumption mixes of refineries in Europe. Additionally, updated data on the flaring of natural gas from the Global Gas Flaring Reduction Partnership (GGFR) of the World Bank, as well as methane emissions from gas venting and fugitive emission sources from the International Energy Agency Methane Tracker 2022 have been considered.

The GHG emission factors for fossil fuels have been recalculated using the GWP 100a (without climate-carbon feedback) taken from the IPCC AR 6[4], i.e. updated from AR 5. Taken together these factors led to an overall increase of the overall (WTW) GHG emission factors for fossil fuels of around 10% due to an increase in well-to-tank emission elements as shown in [2] This update is set to offer significant improvements in the accuracy and reliability of the ISO 14083 emission factors.

Table 5 European GHG emission factors for Liquid fuels and electricity [2], [6], [7], [16]

Energy Carrier	Lower heating value (MJ/kg)	Density (kg/l)	GHG emission (operational / TTW) (g CO_{2e}/MJ)	GHG emission (total / WTW) (g CO_2e/MJ)	GHG emission (operational / TTW) (kg CO_2e/kg)	GHG emission (total / WTW) (kg CO_2e/kg)	Non-CO_2 GHG emissions (operational / TTW) (g CO_2e/MJ)	Source
Gasoline	42.5	0.74	75.1	99.1	3.19	4.21	0.61	ecoinvent v3.9.1
Ethanol (40 % maize, 35 % sugar beet, 25 % wheat)	27.0	0.78	0.02	47.9	0.0005	1.29	0.02	ifeu, infras & Fraunhofer IML, 2022
Diesel	42.8	0.83	74.1	96.6	3.17	4.13	0.05	ecoinvent v3.9.1
Biodiesel (50 % rapeseed, 40 % used cooking oil, 10 % soybean)	37.0	0.89	0.05	34.3	0.0019	1.27	0.05	ifeu, infras & Fraunhofer IML, 2022
Liquefied Petroleu	45.5	0.55	67.1	90.3	3.05	4.11	0.33	ecoinvent v3.9.1

Energy Carrier	Lower heating value (MJ/kg)	Density (kg/l)	GHG emission (operational / TTW) (g CO_{2e}/MJ)	GHG emission (total / WTW) (g CO_2e/MJ)	GHG emission (operational / TTW) (kg CO_2e/kg)	GHG emission (total / WTW) (kg CO_2e/kg)	Non-CO_2 GHG emissions (operational / TTW) (g CO_2e/MJ)	Source
m Gas (LPG)								
Jet Kerosene (Jet A1 and Jet A)	43.0	0.80	73.5	93.5	3.16	4.02	0.17	ecoinvent v3.9.1 and CORSIA, 2019
Heavy Fuel Oil (HFO) (2.5 % sulfur)	41.2	0.97	76.8	93.7	3.16	3.86	1.33	ecoinvent v3.9.1
Light Fuel Oil (LFO) (0.1 % sulfur)	42.6	0.86	75.3	95.4	3.21	4.06	1.33	ecoinvent v3.9.1
Hydrogen from steam reforming of natural gas	120.0	n.a.	0	160.7	0	19.29	0.00	JEC 2020, modified
HVO/HEFA (SAF) (50 % rapeseed, 50 % used cooking oil)	44.0	0.77	0.05	28.6	0.0022	1.26	0.05	ifeu, infras & Fraunhofer IML, 2022
Electricity European average (EU 27, 2019, including average losses)	n.a.	n.a.	0	97.0	n.a.	n.a.	n.a.	ifeu, infras & Fraunhofer IML, 2022

Table 6 European GHG emission factors for gaseous fuels including methane slip[6], [7], [16]

Energy Carrier	Example Application	Lower heating value (MJ/kg)	Density (kg/l)	GHG emission (operational / TTW) (g CO_{2e}/MJ)	GHG emission (total / WTW) (g CO_2e/MJ)	GHG emission (operational / TTW) (kg CO_2e/kg)	GHG emission (total / WTW) (kg CO_2e/kg)	Non-CO_2 GHG emissions (operational / TTW) (g CO_2e/MJ)	Source
Compressed Natural Gas (CNG)	Europe spark ignition truck	49.2	n.a.	55.2	77.8	2.79	3.83	1.50[2]	JEC 2020, modified
Liquefied Natural Gas (LNG)	Europe spark ignition truck	49.1	n.a.	56.5	81.1	2.77	3.98	1.50	JEC 2020, modified
Bio-CNG (40 % maize, 40 % manure, 20 % biowaste)	Europe spark ignition truck	50.0	n.a.	0.05	24.8	0.0025	1.24	1.50	JEC 2020 and ifeu, infras & Fraunhofer IML, 2022
Bio-LNG (40 % maize, 40 % manure, 20 % biowaste)[3]	Europe spark ignition truck	50.0	n.a.	0.05	28.9	0.0025	1.44	1.50	JEC 2020 and ifeu, infras & Fraunhofer IML, 2022
Liquefied Natural Gas (LNG)	Otto dual fuel ship (medium speed)	49.1	n.a.	73.6	98.3	3.61	4.82	17.20	JEC 2020 and European Commission, Fuel.EU Maritime

[2] The non-GHG values for the gaseous fuels are inconsistent in the new update of GREET, therefore, they were sourced from previous values as mentioned in ISO 14083.

[3] Factors based on long distance / heavy duty road transport only, as LNG is not recommended for light duty / urban distribution.

Energy Carrier	Example Application	Lower heating value (MJ/kg)	Density (kg/l)	GHG emission (operational / TTW) (g CO_{2e}/MJ)	GHG emission (total / WTW) (g $CO_{2}e$/MJ)	GHG emission (operational / TTW) (kg $CO_{2}e$/kg)	GHG emission (total / WTW) (kg $CO_{2}e$/kg)	Non-CO_2 GHG emissions (operational / TTW) (g $CO_{2}e$/MJ)	Source
									Annex 2021
Liquefied Natural Gas (LNG)	Otto dual fuel ship (slow speed)	49.1	n.a.	66.0	90.7	3.24	4.45	9.60	JEC 2020 and European Commission, Fuel.EU Maritime Annex 2021

Comments:

- GHG emission factors for biofuels can vary significantly based on the mix of feedstocks and the production process. When certified waste stream feedstocks are used, there is a possibility of achieving low or even negative emission factors under specific conditions. It is crucial to carefully verify the emission factors in such cases to prevent unintended consequences and the exaggeration of emission reduction benefits.

- Bio-LNG and bio-CNG must meet GHG reduction thresholds to qualify under RED2.

- Additionally, Fuel EU Maritime mentions an LNG application with lower methane slip emissions, but its technology definition remains unclear, and therefore it has not been included in this context.

- The emission factors used in this framework are sourced from ecoinvent v3.9.1[2]. The ecoinvent factors as well as the European electricity emission factor are the only ones that are confirmed to include fuel and energy production infrastructure in the well-to-tank (WTT) element. This inclusion is a new requirement in ISO 14083 that enhances the accuracy of emissions calculations.

- It is important to note that the electricity emission factor mentioned above is obtained from a different source than the one used for calculating the default emission intensities for EU rail. Unfortunately, we are unable to provide the specific IEA values in this context.

- In addition, all operational non-CO_2 GHG emissions for European fuels were updated using the latest GREET values similar to the previous year. However, due to inconsistency in the gaseous fuels in the new update, the previous year's conservative values were used for all the gaseous fuels.

1.4.2 North America

In the latest update to GREET model in 2022, the values have been updated to IPCC AR 6[3], [4] to produce the latest values that will be included in the GLEC Framework update.

Table 7 US GHG emission factors for liquid fuels and electricity [3], [9], [17]

Energy Carrier	Lower heating value (MJ/kg)	Density (kg/l)	GHG emission (operational / TTW) (g CO_{2e}/MJ)	GHG emission (total / WTW) (g CO_2e/MJ)	GHG emission (operational / TTW) (kg CO_2e/kg)	GHG emission (total / WTW) (kg CO_2e/kg)	Non-CO_2 GHG emissions (operational / TTW) (g CO_2e/MJ)	Source
Gasoline	41.7	0.749	73.0	90.5	3.04	3.78	0.61	GREET 2022
Ethanol (corn)	27.0	0.789	0.3	51.5	0.01	1.39	0.02	GREET 2022
Diesel	42.6	0.847	75.7	91.4	3.22	3.89	0.05	GREET 2022
Biodiesel (soybean)	37.7	0.881	0.8	22.0	0.03	0.83	0.05	GREET 2022
HVO (tallow)	44.0	0.779	0.8	18.6	0.04	0.82	0.05	GREET 2022
Liquefied Petroleum Gas (LPG)	46.6	0.508	64.8	78.7	3.02	3.66	0.33	GREET 2022
Jet Kerosene (Jet A1 and Jet A)	43.2	0.802	73.2	84.8	3.16	3.66	0.17	GREET 2022
Heavy Fuel Oil (HFO) (2.7 % sulfur)	39.5	0.991	81.8	94.6	3.23	3.74	1.33	GREET 2022
Very Low Sulfur Fuel Oil	39.5	0.991	81.8	95.9	3.23	3.79	1.33	GREET 2022

Energy Carrier	Lower heating value (MJ/kg)	Density (kg/l)	GHG emission (operational / TTW) (g CO_{2e}/MJ)	GHG emission (total / WTW) (g CO_2e/MJ)	GHG emission (operational / TTW) (kg CO_2e/kg)	GHG emission (total / WTW) (kg CO_2e/kg)	Non-CO_2 GHG emissions (operational / TTW) (g CO_2e/MJ)	Source
(VLSFO) (0.5 % sulfur)								
Ultra Low Sulfur Fuel Oil (ULSFO) (0.1% sulfur)	39.5	0.991	81.8	96.2	3.23	3.80	1.33	GREET 2022
Marine Diesel Oil (MDO) (0.5 % sulfur)	41.0	0.914	78.7	92.3	3.22	3.78	1.26	GREET 2022
Marine Gas Oil (MGO) (1.0 % sulfur)	42.8	0.837	75.2	88.1	3.22	3.77	1.20	GREET 2022
Electricity US (2019) (incl. average losses)	n.a.	n.a.	0	118	n.a.	n.a.	n.a.	USEPA eGRID Summary Tables. 2021

Table 8 US GHG emission factors for gaseous fuels[3], [9]

Energy Carrier	Example Application	Lower heating value (MJ/kg)	Density (kg/l)	GHG emission (operational / TTW) (g CO_{2e}/MJ)	GHG emission (total / WTW) (g CO_2e/MJ)	GHG emission (operational / TTW) (kg CO_2e/kg)	GHG emission (total / WTW) (kg CO_2e/kg)	Non-CO_2 GHG emissions (operational / TTW) (g CO_2e/MJ)	Source
Compressed Natural Gas (CNG)	North America spark ignition truck	47.1	n.a.	57.4	74.6	2.70	3.51	1.50[4]	GREET 2022
Liquefied Natural Gas (LNG)	North America spark ignition truck	48.6	n.a.	57.6	76.9	2.80	3.74	1.50	GREET 2022

Updates:

- In previous GREET model, an extra emission of 4.02 gCO_2e/MJ for Biodiesel (BD) was accounted for as the carbon intensity of Biodiesel contained fossil carbon originating from the conventional methanol used in the production[8]. As Biodiesel includes fossil carbon from methanol, it had higher combustion emissions, however, in current GREET 2022, this value is not accounted separately as it is already included in the pre-chain calculations[9].
- Non-CO_2 GHG emissions (operational) values have been updated.

1.5 Scaling Emission Factors: ISO 14083 to GLEC Version 3

1.5.1 Europe

Considering the potential challenges faced by companies that have already committed to specific emission reduction trajectories, the significant increase in European emission factors resulting from the energy provision emission values for fossil fuels due to higher methane emissions for crude sourced from ecoinvent 3.9.1 [2] may pose a considerable problem. Adjusting to these new values requires revising the emission baseline and readjusting future targets and trajectories, which is a complex undertaking.

[4] The non-GHG values for the gaseous fuels are inconsistent in the new update of GREET, therefore, they were sourced from previous values as mentioned in ISO 14083.

To assist companies in contextualizing the new European values within the framework of their previous baseline, the following approximate scaling factors are provided. These scaling factors aim to facilitate the calculation of emissions using the latest European values while considering the existing baseline and commitments made by the companies.

Table 9 Scaling of emission factor for Europe

Fuel	WTT % increase	TTW % increase	WTW % increase
Diesel	39%	-1%	6%
Gasoline	67%	-2%	9%
LPG	194%	-2%	19%
Jet A	23%	-1%	4%
HFO	169%	0%	13%
LNG	49%	-2%	9%
CNG	39%	-2%	7%

Based on the information provided, companies in different sectors can anticipate the following approximate changes in well-to-wheel (WTW) emissions across all fuels, considering the revised European emission factors:

- For companies with aviation emissions as the dominant contributor, a rough estimate suggests a 5% increase in WTW emissions.
- Companies heavily reliant on road transport emissions can expect a slightly higher range of 6 to 7% increase in WTW emissions across all fuels.
- In the case of companies where maritime emissions play a significant role, a larger increase of around 10% in WTW emissions across all fuels can be anticipated.

It is important to note that these figures serve as approximate scaling factors and should be used as a guide to assess the impact of the updated European emission factors on previous baseline calculations.

1.5.2 North America

Emission factors vary from the previous GREET 2021 model[8], [18]. Considering the potential challenges faced by companies that have already committed to specific emission reduction trajectories for US, the variation in US emission factors resulting from the update of the production processes of the GREET model may provide an issue. Adjusting to these new values requires revising the emission baseline and readjusting future targets and trajectories, which is a complex undertaking.

To support companies in contextualizing the new US values within the framework similar to European values of their previous baseline, the following approximate scaling factors are provided. These scaling factors aim to facilitate the calculation of emissions using the latest GREET values while considering the existing baseline and commitments made by the companies.

Table 10 Scaling of emission factors for US

Fuel	WTT % increase	TTW % increase	WTW % increase
Diesel	-1%	-1%	-1%
Gasoline	-2%	0%	-0.3%
Ethanol	7%	0%	7%
Biodiesel	-28%	80%	-7%
HVO	-1%	-1500%	-5%
LPG	0%	0%	0%
Jet A	0%	0%	0%
HFO	-2%	-0.1%	-0.3%
VLSFO	-1%	-0.1%	-0.3%
ULSFO	-1%	-0.1%	-0.3%
MDO	-1%	-0.1%	-0.2%
MGO	-2%	0%	-0.3%
LNG	2%	-1%	-0.3%
CNG	-2%	-1%	-1%

Based on the information provided, companies in different sectors can anticipate the following approximate changes in well-to-wheel (WTW) emissions across all fuels, considering the revised US emission factors.

Future improvements

As explained earlier in this report, the emission factor values included in ISO 14083 are not without their shortcomings. Two of the most pressing issues that have already been identified include:

1. The reliance on older data sets to calculate emission factors, which will be out of date by the time ISO 14083 is published.
2. The lack of emission factors for countries other than Europe or North America has raised questions in some countries. The purpose of the ISO 14083 standard is not to be a repository of emission factors, but rather to set out the methodology for transport sector GHG emission calculations. It was for this reason that the emission factors themselves are not compulsory and that national values that follow the methodology set out in ISO 14083 may be used.

These two issues are particularly pressing in locations, such as Europe, where energy policies and regulations are constantly evolving in response to economic, environmental, and political pressures. Unfortunately, due to ISO's lengthy timeline for publishing its standards, it was not possible to address these issues in the final version of ISO 14083. However, it has been possible update the values as explained for inclusion in the latest GLEC Framework and further updates will be incorporated as they occur. By using the latest version of the GLEC Framework, companies will be able to ensure that their emissions are properly accounted for and that their reports are more reliable. These values will be put forward when the time does come for the next periodic update of ISO 14083.

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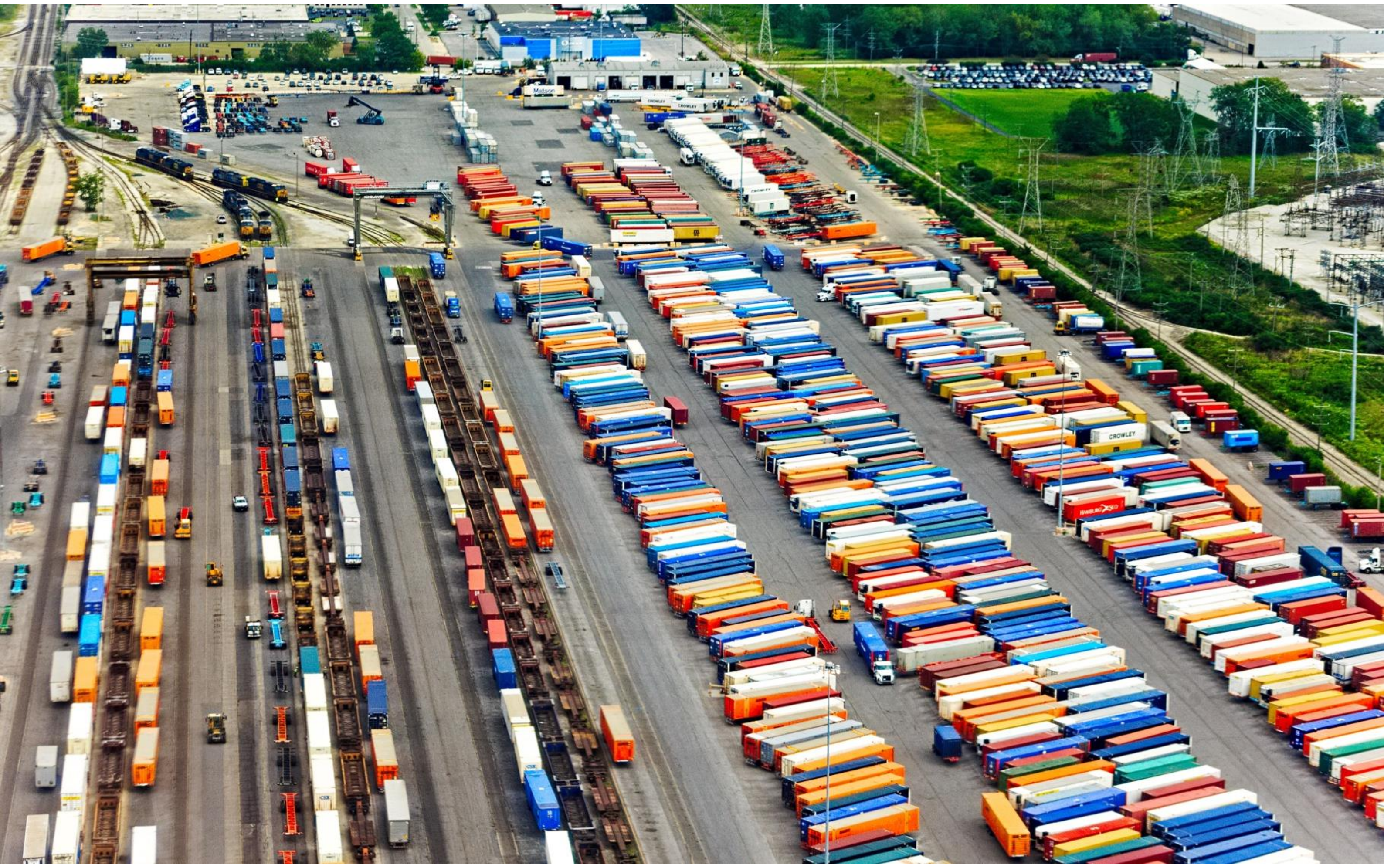

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