CLEVER

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LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND DEFINITIONS

ABBREVIATION	DEFINITION
BC	Black carbon
CCS	Carbon capture and storage
CCU	Carbon capture and utilisation
CO_2 e	Carbon dioxide equivalent
DAC	Direct air capture
DoA	Description of Action
dLUC	Direct land-use change
EC	European Commission
EF	Emission factor
ETS	Emissions Trading System
FAME	Fatty Acid Methyl Ester
FC	Fuel Cell
GA	Grant Agreement
GHG	Greenhouse gases
GWP	Global warming potential
HAE	High altitude emissions
HEU	Horizon Europe
HVO	Hydrotreated Vegetable Oil
ICE	Internal combustion engine
iLUC	Indirect land use change
kWh	Kilo watt hour
LHV	Lower heating value
MJ	Megajoule
MRV	Monitoring, Reporting and Verification
NEATS	Non-CO2 Aviation Effects Tracking System
PEF	Product Environmental Footprint
Pkm	Person kilometre
RCF	Recycled carbon fuel
RED	Renewable Energy Directive
RFNBO	Renewable fuel of non-biological origin
SCR	Selective Catalytic Reduction
SI engine	Spark-Ignition engine
tkm	Tonne kilometre

ABBREVIATION	DEFINITION
TtW	Tank-to-Wheel/wake
WtT	Well-to-Tank
WtW	Well-to-Wheel/wake

Short name and name of beneficiaries

SHORT NAME	NAME
3OC	Three O’Clock
ALICE	Alliance for Logistics Innovation through Collaboration in Europe
EMI	Emisia SA – Anonino Etairia Perivallontikon Kai Energiakon Meleton Kai Anaptixis Logismikou
GR	GreenRouter Srl
IFEU	Institut für Energie – und Umweltforschung Heidelberg gGmbH
MEO	Meo Carbon Solutions GmbH
PNO	PNO Innovation S.l.
RIC	RICARDO-AEA LTD
SFC	Smart Freight Centre
UITP	Union Internationale des Transports Publics
ZN	ZN

EXECUTIVE (PUBLISHABLE) SUMMARY

This section is not part of the draft and will be finalized in the finalised version only.

NORMATIVE REFERENCES

This section describes the normative references used in the CLEVER framework. It constitutes an unfinished section currently and will be finalized only for the final version of the CLEVER framework

ISO 14040:2996; Environmental management – Life cycle assessment – Principles and framework
Establishes the general principles, framework, and terminology for conducting life cycle assessments (LCA). It defines the concepts of goal and scope, functional unit, system boundaries, and environmental impact categories. This document provides the conceptual basis for any life cycle assessment methodology and is necessary for ensuring consistency and comparability across LCAs.

ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines
Specifies the requirements for conducting life cycle assessments, including life cycle inventory (LCI) analysis, life cycle impact assessment (LCIA), allocation rules, and interpretation of results. It provides guidance on reporting and transparency, ensuring that LCA results are methodologically robust and reproducible.

ISO 14067:2018: Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification
Specifies principles, requirements, and guidelines for the quantification and communication of the carbon footprint of products (CFP), based on life cycle assessment (LCA). It defines the concepts of product system, functional unit, system boundaries, and allocation, and provides guidance on data quality, reporting, and verification. This document ensures consistent calculation and reporting of product carbon footprints and complements ISO 14040/44 by focusing specifically on greenhouse gas emissions.

ISO 14060:2020; Environmental management – Carbon neutrality – Principles and guidance
Specifies principles and guidance for achieving carbon neutrality for organizations, products, and services. It provides a framework for measuring, reducing, and offsetting greenhouse gas (GHG) emissions, including defining organizational and product boundaries, selecting GHG sources, and reporting requirements. This document complements ISO 14040/44 and ISO 14067 by providing guidance for carbon neutrality claims and ensuring consistency, transparency, and credibility in carbon management practices.

ISO 14064-1:2019; Greenhouse gases – Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals
Provides requirements and guidance for designing, developing, managing, and reporting organization-level GHG inventories. It defines organizational boundaries, GHG sources and sinks, quantification methodologies, and reporting formats. This standard ensures consistency, transparency, and comparability of GHG accounting across organizations and supports verification and certification processes.

ISO 14071:2023; Greenhouse gases – Quantification and reporting of organizational-level greenhouse gas emissions – Guidance for applying ISO 14064-1
Provides guidance on implementing ISO 14064-1 for organization-level GHG inventories. It offers practical recommendations for identifying sources and sinks, quantifying emissions and removals, defining organizational and operational boundaries, and ensuring completeness, consistency, transparency, and accuracy in reporting. This standard supports reliable, comparable, and verifiable organizational GHG accounting.

ISO 14083:2023; Greenhouse gases – Quantification of greenhouse gas emissions and removal for transport services

Specifies principles, requirements, and guidelines for the quantification of GHG emissions and removals associated with transport services, including freight and passenger transport. It defines the functional unit, system boundaries, and methodological approaches to ensure consistency, transparency, and comparability in GHG assessments across different transport modes. This standard provides the foundation for calculating emission intensities per tonne-kilometre or per person-kilometre, supporting climate impact assessments and reporting for transport operations.

IPCC, 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Provides internationally accepted methodologies for estimating anthropogenic greenhouse gas emissions and removals for all sectors, including energy, industrial processes, agriculture, and land use. It defines emission factors, activity data requirements, and accounting principles for compiling national greenhouse gas inventories.

IPCC, 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Provides updates and methodological refinements to the IPCC 2006 Guidelines. It incorporates improved emission factors, additional methodological options, and guidance on uncertainty analysis and reporting. The refinement ensures that inventory estimates reflect the latest scientific knowledge and best practices.

European Commission, Renewable Energy Directive (RED II/III)

Key European regulation with respect to renewable energy governance within the European Union. Establishes sustainability criteria and greenhouse gas accounting methodologies for biofuels, bioliquids, and biomass fuels within the European Union. It provides regulatory requirements for emissions accounting, including methodological rules for land-use change, and sets minimum sustainability standards for renewable energy production.

TERMS AND DEFINITIONS

This section describes the terms and definitions used in the CLEVER framework. It constitutes an unfinished section currently and will be finalized only for the final version of the CLEVER framework

For the purposes of this document, the following terms and definitions apply:

Assessment period:

Timeframe or time period over which lifecycle inventory data and corresponding environmental impacts are analysed. Also referred to as *temporal boundary*.

Soil organic carbon (SOC):

The carbon component of organic compounds present in soil, including biomass residues, microbial biomass, and humified organic matter.

Enhanced soil carbon accumulation (ESCA):

An increase in SOC due to management practices that improve carbon input to the soil relative to a baseline management scenario.

Attributional LCA (aLCA):
Life cycle assessment that quantifies environmental impacts of a product system based on average conditions and existing supply chains.

Carbon storage permanence:
The long-term stability of stored carbon such that it is not subject to re-release under foreseeable management or environmental conditions.

Transport Service Provider (TSP):
An organization or entity that *carries out transport operations* within a transport chain for passengers or freight, including the movement of goods or people across one or more transport chain elements, and is responsible for operational data associated with those operations.

Primary data:
Defined in ISO 14083:2023 as "quantified value of a process or an activity obtained from a direct measurement or a calculation based on direct measurements"

Refers to data collected directly from specific processes or organisations for the purpose of the assessment, typically reflecting site-specific or supplier-specific conditions, either directly measured or calculated based on direct measurement

Secondary data:
Defined in ISO 14083:2023 as "data which do not fulfil the requirements for primary data", includes both "modelled data" and "default values".

Refers to data not directly collected for the specific system under study, including data from databases, literature, industry averages, or default emission factors. Secondary data may represent either specific or aggregated systems.

Energy carrier (from ISO 14083:2023)

Substance or phenomenon that can be used to produce mechanical work or heat or to operate chemical or physical processes (including electricity as well as liquid or gaseous fuels from different fuel pathways)

Energy provision GHG emissions (amended from ISO 14083:2023)

GHG emissions from production, storage, processing and distribution of an energy carrier used for vehicle operation

Operational GHG emissions (amended from ISO 14083:2023)

GHG emissions resulting from vehicle operation

Total GHG emissions (amended from ISO 14083)

Sum of all GHG emissions (from energy provision and operation)

GHG emission factor (amended from ISO 14083:2023)

Coefficient relating GHG activity data (quantitative measure of activities resulting in GHG emissions) with the GHG emission (usually depicted as g CO_2 e/ MJ of an energy carrier)

GHG emission intensity (from ISO 14083:2023)

coefficient relating specified GHG activity data with the GHG emission (usually depicted as g CO_2 e/ pkm or g CO_2 e/ tkm)

1 INTRODUCTION

1.1 GENERAL INTRODUCTION TO THE CLEVER PROJECT

The CLEVER project, funded by the European Union's Horizon Europe programme, aims to develop a standardized and future-proof emission factor methodology for the global transport and logistics sector, together with accurate and representative default emission factors calculated using the CLEVER methodology, for a selection of critical energy carriers for the European transport sector. By building a comprehensive, harmonized framework for emission accounting across all transport modes, CLEVER supports more consistent reporting, informed decision-making, and the adoption of sustainable practices in line with European and international climate goals.

The CLEVER project aims to achieve the following key objectives:

- Enable international collaboration by developing common tools and methods that support alignment across organizations involved in emission factor development and application throughout the energy lifecycle (Well-to-Wheel).
- Identify critical gaps in current emission factors and accounting methodologies, covering both conventional and alternative fuels across all modes in the transport and logistics sector.
- Develop a unified, transparent methodology with clear calculation rules and aligned fuel specifications that can be widely accepted and used across industries.
- Create a reliable and globally applicable framework with a validated set of default emission factors to ensure consistent and accurate emissions reporting.
- Support real-world implementation by increasing industry understanding of the methodology's benefits and practical use in operations.
- Drive long-term impact by promoting the adoption of CLEVER outputs through policy engagement, stakeholder collaboration, and alignment with international standards and regulations.

Within the first phase of the CLEVER project, in-depth work was conducted including compilation of the relevant initiatives, emission factor reference sources and regulatory frameworks which are collected in the CLEVER Repository, along with a further survey of value chain stakeholders, the extraction of conclusions from the Emission Factor Knowledge Database in the State-of-the-Art Review and an exhaustive gap analysis.

As part of its scientific State-of-the-Art analysis, CLEVER examined existing emission factor databases, tools, and scientific literature, uncovering significant gaps including inconsistent methodologies, limited information on emerging fuels, and insufficient tools for assessing emissions from fuel blends. A stakeholder survey with over 160 participants highlighted the critical need for standardized approaches, detailed fuel-specific data, regular updates and dedicated support for fuel blend calculations. Based on these findings, CLEVER is focused on developing rigorous methodologies, expanding its fuel data collection, designing specialized tools for blended fuels and maintaining continuous stakeholder engagement to ensure its outputs are relevant and actionable.

The Gap Analysis, informed by extensive input from CLEVER Expert Forum members and broader stakeholder consultation, identifies major challenges such as methodological inconsistencies, complex fuel classifications, structural misalignment across regulations both internal to and between different organizations and a lack of transparency that undermines confidence in emission data. It emphasizes the necessity of creating harmonized, clear, and adaptable methodologies that address a wide range of fuel types and lifecycle stages while ensuring alignment with regulatory frameworks. Drawing on these insights and ongoing collaboration with Expert Forum members, CLEVER aims to deliver a transparent and comprehensive methodology. To support widespread adoption, the project develops practical use cases, offers trainings and engages with regulators and certification bodies, recognizing that timely stakeholder buy-in is crucial for the global impact of the CLEVER project.

Last year, building on the insights from the scientific State-of-the-Art review and the Gap Analysis, the goal, scope and system boundary were defined in a report which underwent a public consultation. In this report, the complete CLEVER methodology is presented while integrating the final version of the goal and scope report. Based on this methodology, the CLEVER project team is currently developing a set of robust and harmonized emission factors.

1.2 INTRODUCTION TO THE CLEVER METHODOLOGY

This document introduces the CLEVER methodology, expanding upon the previously defined goal and scope of the CLEVER framework.

In accordance with ISO 14040/44:2006, both goal and scope are the key initial elements of any LCA. Together with inventory analysis, impact assessment, and finally the interpretation of results, they form the basic structure. The purpose of the goal in the sense of an LCA is to describe the overall purpose of the assessment at hand, from which all other major relevant elements, in particular the functionality/functional unit, are derived. The scope determines the framework for the assessment, both in conceptual as well as technical terms. A key element of the scope is the applied system boundary, which further specifies key criteria and methodological decisions.

The full CLEVER methodology provides more detailed guidance and rules for doing a CLEVER-compliant assessment of climate impacts from energy carriers used in transportation.

The CLEVER framework builds upon the ISO 14083:2023 standard, covering major parts of the overall transport sector value chain, with an emphasis on the upstream energy carrier provision and utilization within vehicles or vessels. CLEVER Emission Factors (EF) are generated by applying this CLEVER framework. It is used to develop the Default GHG emission factors for the European Commission's *CountEmissions EU* regulation.

This document specifies key methodological aspects of the CLEVER framework and refines more generalized LCA procedures and elements with the specific aim of fulfilling the requirements of ISO 14083:2023 and *CountEmissions EU*. Chapter 2 provides some background to the development of the CLEVER framework and defines the goal, while Chapter 3 introduces the scope. Detailed guidance on specific scope elements of the CLEVER methodology are set out in Chapter 3.17 and Chapter 5 specifies rules for conformity assessment.

2 BACKGROUND AND GOAL

2.1 REGULATORY BACKGROUND AND POLICY CONTEXT

While the CLEVER framework aims at universal / global applicability for the purpose of calculating energy- or fuel- related GHG emissions in line with ISO 14083:2023, the *CountEmissions EU* legislative initiative constitutes the regulatory background as an element of the broader EU climate change policy. In the following, this chapter briefly describes the regulatory background.

With the adoption of the European Green Deal (2021), the European Climate Law as well as further legislative steps outlined in the "Fit for 55" legislative package (as of Oct. 9th 2023), the European Union (EU) continues to move ahead in order to accelerate the transition toward achieving the goal of becoming the first climate-neutral continent (EU Climate Law, Green Deal). In combination with supplementary / complementary legislative tools and instruments, such as the revised Renewable Energy Directive (Directive (EU) 2023/2413) or the *ReFuelEU* initiative, all sectors of Europe's economies are covered, with sector-specific commitments (European Parliament, 2021) (European Commission, 2023).

Whereas some key sectors, such as power generation or heating, are on their way to meeting their respective sectoral goals, the transport sector still faces notable challenges in reducing emissions. In 2022, transport activities accounted for roughly 29 % of all GHG emissions in the EU and, as such, remains one of the largest contributing sectors, with GHG emissions in excess of the reference year 1990 (European Environmental Agency, 2024).

To meet the specific challenges of the transport sector, the EU adopted or proposed additional legislative instruments and strategies, such as the Commission's *Sustainable and Smart Mobility Strategy*[1] (SSMS, outlined within the Green Deal), to address specific freight and passenger transport issues. One key aim of the SSMS is to provide a *framework for the harmonized measurement of greenhouse gas emissions from transport and logistics*. This initiative is meant to ensure the use of a single calculation methodology based on the international standard on "Greenhouse gases — Quantification and reporting of greenhouse gas emissions arising from transport chain operations" (ISO 14083:2023), thus avoiding methodological dissonance within calculations (ISO, 2023). The initiative also provides databases containing emission factors and emission intensities, again based on a single, consistent methodology. This key part of the SSMS is currently in the process of implementation as the *CountEmissions EU* regulation (proposal for a regulation of the European Parliament and of the Council on the accounting of greenhouse gas emissions of transport services), introduced in July 2023. After adoption by both Council and European Parliament (2024), a final political agreement was reached in November 2025, with the Council formally adopting the regulation in early 2026. The regulation is expected to enter into force later in 2026, pending the (expected) confirmation of the European Parliament.

At its core, the *CountEmissions EU* initiative aims for a single universal methodology for the calculation and assessment of GHG emissions from transport services (Soone & Svahn, 2025). Both freight and passenger

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[1] Among other goals outlined in the SSMS, a key objective described is an emission reduction of the transport sector by 90 % in 2050. For reference, see: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020DC0789

transport are addressed, as are hub operations, allowing for a comprehensive calculation of emissions from logistics services. The goal of the methodology to be established is to allow for a comparison of the GHG emissions of different transport services, while ensuring that the underlying data is reliable, precise, and robust. The CLEVER framework, whose goal and scope are outlined within this document, is a key element of the overall *CountEmissions EU* methodology package, focusing primarily on energy provision and utilization by providing a methodology for the calculation of GHG emission factors for energy carriers used in transportation.

This document adds detail about the methodology to the goal and scope of the CLEVER framework described in Deliverable 3.1. One key aim of CLEVER is harmonization with existing best practice and guidelines, frameworks and standards in the context of transport sector and logistics emission accounting. As such, the reference methodology of *CountEmissions EU* and CLEVER is the ISO 14083:2023 standard on “Quantification and reporting of GHG emissions arising from transport chain operations”. In this ISO standard, key rules for the calculation of climate impacts from transport operations are outlined. However, while ISO 14083:2023 also covers GHG emission factors from different energy carriers through an outline guidance in Annex J, a further, more detailed, elaboration of rules on how to calculate these emission factors is lacking. Additionally, the CLEVER project aims at demonstrating and applying the CLEVER framework to provide a set of up-to-date, transparent, reliable and ready-to-use GHG emission factors of the most commonly used or emerging energy carriers in the transport sector.

2.2 GOAL OF CLEVER GHG EMISSION FACTORS

CLEVER aims at establishing a common methodology for the accurate quantification of GHG emission factors of current or emerging fuel- and energy-carrier pathways used in transport and logistics. The methodology is developed in alignment with the requirements set out in Article 3 (1) of the Delegated Regulation (EU) 2026 /xx (*CountEmissions EU*, *CEEU*). As specified in Article 3, the common methodology further builds upon the methodological principles of ISO 14083:2023. The Delegated Regulation (EU) 2026/xx and ISO 14083:2023 constitute the primary normative references for the CLEVER framework. However, the application of CLEVER is not limited to regulatory compliance under Delegated Regulation (EU) 2026/xx. Rather, it is designed as a stand-alone, universally applicable framework for GHG emission accounting in transport and logistics. Furthermore, the CLEVER framework aims at providing the underlying methodology used to calculate the *Default emission factors* for transport energy carriers typically used in the European Union, as specified in Article 7 (1) of DR (EU) 2026/xx. These Default GHG emission factors will be further integrated into a core *Central Union database*. Furthermore, it aims at providing the underlying methodology for any other external (third-party) compliance option, such as e.g. an external database (Article 6 CEEU). Additionally, it may be used for any other non-regulatory purposes (e.g. internal decision support) or as a general reference methodology for the assessment of energy-carriers in transport following ISO 14083:2023.

The CLEVER framework aims at covering energy carriers for all means of transport, including road, waterborne i.e. both marine and inland waterway, rail and aviation. These GHG emission factors are intended to be used in the subsequent calculation of the climate impacts from transport operations. Multiplying the energy demand per tonne-kilometre (tkm) or person-kilometre (pkm) with the applicable GHG emission factor(s) of the used energy carrier(s) from CLEVER, GHG emission intensities for different transport operations may be obtained, thus depicting the whole logistics value chain (including hub operations). By applying the full scope of ISO 14083:2018 as also mandated by Delegated Regulation (EU) 2026/xx *CountEmissions EU*, a fair comparison of the emission performance of different transport services per tonne-kilometre or person-kilometre is possible.

The CLEVER framework covers key elements of the overall scope of ISO 14083:2023 and CEEU, but does not aim at covering the whole scope, as it focuses on the provision of fuel- or energy-related GHG emission factors (emissions per unit of energy) and not GHG emission intensities. Hence, a direct comparison of CLEVER values for different energy carrier pathways does not lead to a fully meaningful assessment of the climate impacts of the overall transportation service on its own. Nonetheless, CLEVER provides an indispensable input to such an assessment, especially in the context of decarbonization options. CLEVER GHG emission factors cannot be used as a stand-alone metric to determine the GHG-intensity of transport services because several key elements (e.g. energy demand during vehicle/ vessel operation or vehicle load factors) must be combined with the CLEVER emission factors to determine the overall GHG-intensities. CLEVER values constitute an important input, in combination with further supplementing information and data covering complexities related to vehicle/ vessel usage and hub operations, to the holistic calculation of GHG-intensities per tonne-kilometre or passenger-kilometre, which depicts the overall ISO 14083:2023 and CountEmissions EU scope.

Only if the operational conditions of using different energy carriers are exactly the same (for example, if the energy demand of the vehicles/ vessels and exhaust gas treatment as well as the operating conditions such as load factor or maximum load are not impacted by the chosen energy carrier pathway), does a direct comparison of CLEVER values for different energy carrier pathways lead to a fully meaningful assessment of the climate impacts of the overall transportation service.

The goal of CLEVER is to quantify all relevant contributions to climate change for each energy carrier by using the global warming potential in the form of CO_2-equivalents (CO_2 e) (GWP_{100} with a 100-year time horizon). In accordance with the cut-off criteria (chapter 3.5), all relevant climate impacts from the production and use of energy carriers by vehicles /vessels for passenger and freight transport are assessed. This includes liquid and gaseous fuels of fossil, biogenic or other origins, as well as electricity used in transportation. To accurately assess these impacts, the whole energy carrier lifecycle must be considered and included in the GHG emission factor for all energy carrier pathways. On this basis, CLEVER GHG emission factors are limited to one singular environmental impact metric – climate change. No other conclusions with respect to environmental impacts beyond climate change may be drawn from CLEVER values, nor are general assessments of sustainability of specific pathways possible.

CLEVER can be used in the following ways: Firstly, the derived Default GHG emission factors for the different energy carriers may directly be utilized within any calculation and assessment of climate impacts from transport operations, especially in the context of ISO 14083:2023 or *CountEmissions EU*. Secondly, instead of using Default GHG emission factors, interested parties may calculate *External GHG emission factors* according to the CLEVER methodology for compliance purposes under CountEmissions EU. This pertains in particular to specific energy carrier pathways, or energy carrier pathways not yet covered by the Default GHG emission factors, or depicting a different situation. Whenever the second option is chosen, the specific energy carrier pathway must be defined unambiguously and the CLEVER framework/methodology as well as the provisions specified in CEEU must be followed. Thirdly, any other non-compliance purpose may either use Default GHG emission factors or external GHG emission factors

In addition, the aim of CLEVER is to foster understanding of the GHG emission factors for different energy carrier pathways and different uses, to ensure a level playing field for all energy carrier pathways. This will enable users to report on the climate impacts of their transport operations using consistent, reliable and transparent GHG emission factors. It also helps to understand the calculation of climate impacts from transport operations and the GHG emission factors behind them.

Thus, the intended audience of the CLEVER framework and CLEVER-based emission factors are primarily entities intending to calculate GHG-emission factors, in particular for the purpose of compliance under *CountEmissions EU* or entities addressed in *CountEmissions EU*, with the intent of disclosing data and information of GHG emission intensities and climate impact of transport services (i.e. in compliance with ISO 14083:2023 or *CountEmissions EU*). Moreover, the intended audience constitutes a range of interested parties, regulators, decision makers and both service providers and consumers in the field of transport and logistics, as well as suppliers of energy carriers used in transport.

CLEVER will focus on existing and emerging energy carrier pathways and is intended to be used only for accounting/ reporting or verification purposes. It will thus aim at and provide average GHG emission factors using an attributional approach and will not directly assess impacts from displacement effects or changes to the global energy system (e.g., emissions for marginal electricity). One exception, with respect to the consideration of consequential effects, exists with the inclusion of iLUC (indirect land-use change), in recognition of the potentially significant effects associated with iLUC[2]. A comparison between different energy carrier pathways (including their usage) can still be made and can be used to inform potential changes (e.g., switching from a crop-based biofuel to a waste-based biofuel) by comparing the factors produced through the attributional approach, provided the operational conditions for the vehicle(s) and vessels are the same.

Any CLEVER assessment and calculated CLEVER GHG emission factors are meant to describe the status quo and to yield robust, average values; therefore, the inclusion or consideration of impacts from any form of emission offsetting or compensation measures are not allowed[3], in line with ISO 14083:2023.

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[2] Moreover, even though this technically constitutes a methodological inconsistency, consideration for iLUC is common practice and currently the most widely agreed approach. For reference see for instance ICAO CORSIA or GREET. The RED also discloses values for iLUC, however, they are not part of the overall GHG-emission factors.

[3] However, in some cases, dual reporting or – accounting may be an option (chapter 4.5);

3 SCOPE OF CLEVER GHG EMISSION FACTORS

The objective of the CLEVER framework is to provide guidance on the calculation of CLEVER GHG emission factors (EF) for fuels and energy carriers used in transport and logistics. In accordance with ISO 14083:2023 and the principal LCA ISO norms ISO 14040/44:2006, the scope of any CLEVER assessment must be consistent with the defined goal. Its outline must accurately reflect all relevant aspects in accordance with the cut-off criteria (chapter 3.5) of the energy carrier's lifecycle.

To allow for flexible use of CLEVER values for multiple purposes, CLEVER emission factors are modularly structured. The concept of modularity aims, in principle, at partitioning the overall CLEVER scope into smaller, modular components to reflect the contributions of specific elements (such as e.g. impacts from iLUC). The individual components of the modular approach are introduced in the following chapters and further information on how CLEVER results must be reported and the requirements for the breakdown into different components can be found in chapter 3.15 and 4.1.

Generally, the CLEVER framework distinguishes between different types of requirements. 'Must' or 'shall' inclusions are mandatory requirements for the calculation of any emission factor under the CLEVER methodology. 'Should' inclusions refer to topics where their exclusion (or choosing an alternative approach) must be clearly mentioned and justified. Not all requirements are relevant for all energy carrier pathways, so CLEVER also distinguishes between 'universal' requirements (relating to all energy carrier pathways) and 'specific' requirements (only relating to the specifically mentioned energy carrier pathways).

The following aspects are elements of the overall scope and shall be considered:

a) A clear description of the product system under investigation (fuel pathway/energy carrier pathway utilized within a vehicle/vessel) shall be given (see also chapter 3.2). In particular, all relevant characteristics and technical aspects of the value chain shall be described.

b) Classification of fuel pathways (chapter 3.3). The CLEVER framework provides a classification metric to facilitate identification of energy carriers as well as some further methodological aspects that can be specific to a category but might not apply to another.

c) The functionality of ISO 14083:2023 and *CountEmissions EU* is GHG emission intensities, expressed as tonne-kilometre or person-kilometre as the basis for any assessment or comparison of GHG emissions from transport services. Due to the fact that the CLEVER framework only covers a part of the *full* scope, CLEVER specifies a functional unit of "Providing 1 MJ (LHV) of an energy carrier to a vehicle/vessel and use of that energy carrier up to the point just before its conversion into mechanical work" (see also chapter 3.4).

d) In particular, the applied system boundary (chapter 3.5) shall be described in detail. By default, any CLEVER assessment shall consider a WtW system boundary, covering both emissions and expenditures associated with energy carrier provision, including production, distribution and supply as well as operational emissions from fuel utilization and vehicle/ vessel operation. It also takes into account expenditures and emissions e.g., from fuel utilization ("tailpipe" emissions), emissions from exhaust gas treatment and additional climate impacts from vehicle/vessel operation that are ascribable to the fuel used. Assessed elements of the system boundary shall be described, disaggregated into specific WtT (focussing on fuel provision [production and delivery]) and TtW (focussing on fuel use and vehicle/vessel operation) parts. This further requires information on the geographical and temporal scope and the applied cut-offs. Infrastructure associated with the production and/or provision of energy (e.g. power plant infrastructure provision and construction) are generally part of the scope, whereas other infrastructure (e.g. roads, harbour facilities, etc.) are out of scope.

e) Life cycle inventory modelling (chapter 3.6) and multifunctionality (chapter 3.10): any assessment applying the CLEVER framework shall follow an attributional ('descriptive') approach to inventory modelling. With the exception of iLUC, no consequential elements, such as displacement effects shall be considered. Furthermore, multifunctionality shall be solved applying the hierarchy as defined in ISO 14044:2006 (Chapter 4.3.4.2), with allocation being the chosen approach, if no further subdivision is possible[4]. Further key methodological choices/settings to be described are (among others):

   a. Co-product allocation i.e., energy/exergy based (LHV) allocation as a default,
   b. Consideration of end-of-life modelling, and
   c. Definition of material flows, i.e., waste vs co-product classification and respective methodological handling.

f) To contextualize the applied data as the basis for the calculation of a CLEVER emission factor, their origin and quality shall be described (see also chapter 3.7). Furthermore, applied data shall be appropriate to the investigated product system and moreover consistent with the geographical and temporal scope. Any deviations shall be stated and justified, as well as any resulting limitations disclosed.

g) Sensitivity Analysis: Depending on the application case, sensitivity analysis may be required for key parameters (Chapter 3.8)

h) Assumptions and limitations (Chapter 0): when assumptions are made, especially ones with substantial influence or impact on results, they shall be mentioned, described and justified. Furthermore, the influence of assumptions and limitations shall be reflected when results are described and interpreted.

i) If carbon dioxide removals occur as part of the energy carrier lifecycle, they shall be reported separately and specific to the origin of the carbon (fossil, biogenic). Likewise, if carbon (dioxide) emissions from land-use change (LUC) occur, they shall be assessed and reported separately. Special attention shall be paid to avoid any double counting of removals and more generally in relation to consistency regarding the system boundary.

j) Attribution of biogenic carbon in multi-outputs (chapter 3.12): if feedstocks containing biogenic and fossil carbon are processed together (i.e., co-processing within a conversion unit of a conventional petrochemical refinery) and multiple outputs result from this process, the biogenic carbon shall be attributed to all outputs according to physical causalities, based on rules laid out in Delegated Regulation (EU) 2023/1640.

k) Emissions from land use/land use change (chapter 3.13). When land is required to produce fuels, e.g. to cultivate biomass, direct and/or indirect land use change and associated emissions can occur[5]. This pertains in particular to crop-based biofuels. Emissions from direct and/or indirect land use change shall be considered within the total CLEVER emission factors. Direct land use change shall

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[4] In principle, system expansion would be preferred to allocation, but given the context and goal of CLEVER, only allocation is a suitable approach. Chapter 3.10 provides the rationale and reasoning for this.

[5] These LUC related emissions can be substantial, depending on a range of factors, such as agricultural circumstances or the characteristics of local/regional (soil) conditions.

be based on current IPCC guidelines, more specifically Volume 4: Agriculture, Forestry and Other Land Use, 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, and reported as part of the core emission factor. Indirect land-use change shall be based on the ICAO CORSIA approach for aviation fuels, and SBTI Automotive Sector Net-Zero standard (Version 0.1, February 2026), for road- and marine fuels. The specific contribution of iLUC shall also be reported separately to the core emission factor. More information can be found in chapter 4.3.

l) Impact assessment methodology (chapter 3.14). The scope of ISO 14083:2023 and *CountEmissions EU*, and therefore also of the CLEVER framework, is limited to the climate impact of transport services, expressed via the impact category “Climate Change”. As default metric and indicator for the impact assessment in CLEVER, the latest characterization factors for GHG emissions from the IPCC Assessment Reports (currently, Assessment Report 6, IPCC 2023) using the GWP_{100} (global warming potential with a 100-year perspective without feedback) shall be utilized. The total climate change impacts are the sum of all GHG emissions multiplied by their respective GWP_{100y} factor. Biogenic carbon uptakes and emissions shall be included, using a characterization of -1 for biogenic carbon dioxide sequestration and +1 for biogenic carbon dioxide emissions.

m) Reporting requirements. Any calculation of CLEVER values shall be accompanied by a report describing all relevant aspects. Furthermore, when economic operators calculate and report *External GHG emission factors* applying the CLEVER framework instead of using CLEVER default values, additional requirements apply. Verification in the form of a Conformity Assessment ensures plausibility of calculated results and assesses compliance with the CLEVER framework.

3.1 APPLICATION OF THE FRAMEWORK

The CLEVER methodology / framework may be applied for different general purposes related to the quantification of GHG emission factors of fuels and energy carriers in transport.

In particular, the framework supports:

1. Calculation of (CLEVER) **Default emission factors (Central Union database of default greenhouse gas emission factors (Art. 7 CEEU), default values for greenhouse gas emission factors used within an EU calculation tool (Art. 8 CEEU))**; These shall be derived using consistent and robust assumptions and representative data. The selection of LCI / input data and methodological decisions /assumptions shall ensure that default emission factors do not underestimate GHG emissions associated with the assessed fuel / energy carrier under investigation while maintaining realism. Where uncertainty exists, conservative assumptions shall be applied. They are furthermore subject to *Conformity Assessment* (chapter 5).
2. Calculation of **External GHG emission factors for third-party calculation tools / datasets (Art. 11, CEEU)**, e.g., by data intermediaries or tool developers: Instead of using the *EU calculation tool* (outlined in Art. 8 CEEU), external calculation tools incl. GHG emission factors for fuels or energy carriers that might not be included within or differ from results in the *Central Union database* may constitute viable alternatives. Any external tool / dataset shall calculate GHG emission factors in accordance with the methodology defined in this framework. The calculation of emission factors beyond the *Central Union database* allows for the representation of different or specific processes, technologies, and operational conditions, provided that all methodological- and formal requirements (CEEU specifies the need for certification (Art. 11) of any external calculation tool by an accredited conformity assessment body (Art. 14)) are met.

3. Calculation of **GHG emission** factors for other applications (non-CEEU compliance), provided that other applications align with the methodological principles and system definitions specified in the CLEVER framework (e.g. ISO 14083:2023 compliant calculations). Other application cases may also include analytical or prospective assessments (e.g. of emerging fuel pathways). They may [6] furthermore be subject to *Conformity Assessment* (chapter 5).

The CLEVER methodology shall be applied consistently across all application types to ensure transparency, comparability, and robustness of results.

3.2 DESCRIPTION OF THE PRODUCT SYSTEM

A clear and comprehensive description of the product system (and its value-chain) that is the subject of a CLEVER assessment, including all relevant technical properties/characteristics (e.g. lower heating value, density or carbon content) and/or references to formal specifications (e.g. a fuel standard) of the fuel/energy carrier shall be provided. Moreover, the general technological, geographical and temporal context of the assessed energy carrier pathway shall be defined, with the goal of identification of the specific situation for which the derived results apply[7] and how they might compare to other values. If the emission factor to be calculated has a temporal limitation/time boundary, the period of time for which the emission factor is representative shall be specified. Other limitations shall also be clearly stated.

3.3 CLASSIFICATION OF ENERGY CARRIER PATHWAYS

It is recognised that certain scope requirements may not be relevant to all energy carriers, for example, land use change.

CLEVER uses a similar terminology as the Renewable Energy Directive (Directive (EU) 2018/2001, in short RED), to delineate different groupings (European Parliament and Council, 2018). In any CLEVER assessment, a classification of the fuel pathway under investigation shall be conducted to help identification and understanding. CLEVER groups all energy carriers under the categories of ‘fossil’, ‘renewable electricity’, ‘biogenic’, ‘e-fuel’ (incl. RFNBO, and RCF as specific sub-categories of e-fuels) and one additional group, ‘Other low-carbon fuels’, referring to possible fuel pathways that does not fit any of the above categories (e.g., a combination of different categories). Moreover, a combination of different categories is technically possible. Here, the respective rules apply for the different elements of the fuel according to their classification of their ‘parent’ categories (e.g. a fuel is part advanced biofuel and part e-fuel, then the respective rules apply).

Table 3-1: Energy carrier categories

Energy Carrier Category	Identification Code	Definition	Examples
Fossil	FOS	Liquid, gaseous or electrical non-renewable energies produced from fossil reserves such as natural gas, coal and oil.	• Fossil diesel, gasoline, kerosene or natural gas • Hydrogen via steam methane reforming or

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[6] Depending on the intent of disclosing output data to third-parties.

[7] This can be the specific real situation of an economic operator, but also an average (default) value.

Energy Carrier Category	Identification Code	Definition	Examples
			electrolysis powered by natural gas
Renewable Electricity (non-biogenic)	REE	Electrical power generation from primary renewable energy sources. This does not include nuclear energy (which is not renewable).	• Onshore and offshore wind electricity • Solar electricity • Water electricity • Geothermal electricity
Biogenic	BIO	Liquid and gaseous fuels produced from biomass such as food and feed crops, wastes, animal fats, and non-agricultural residues.	• Biomethane[8] • HVO[9] or FAME • Bioethanol
e-fuel		Liquid or gaseous fuels produced using electricity as the primary energy input, typically through the conversion of hydrogen and a carbon-containing feedstock into synthetic hydrocarbons. The hydrogen is commonly generated via SMR of natural gas or electrolysis, while the carbon source may originate from biogenic sources, industrial point sources, or direct air capture. Electricity used in production may be sourced from the grid or directly be supplied. Therefore, the overall greenhouse gas performance of e-fuels is highly dependent on the electricity mix.	• Hydrogen via SMR of natural gas • E-fuels, produced with grid electricity and a fossil point-source
RFNBO (Renewable Fuels from Non-Biological Origin)	RNB	Liquid or gaseous fuels that do not derive any of their energy content from biogenic or non-renewable sources. Hydrogen used in the production of RFNBOs must also be derived from renewable and non-biological sources. This will most commonly mean via electrolysis. Electricity supplied in the production of RFNBOs must also be considered fully renewable as defined by the delegated act on RFNBOs. The carbon source used in production also has specific rules defined in the	• Hydrogen via electrolysis powered by renewable energy • E-fuels such as e-gasoline or e-kerosene produced using non-biological energy sources

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[8] Biomethane is sometimes also called “renewable natural gas”

[9] HVO is sometimes also called “renewable diesel”, especially in the US. Either FAME or both HVO and FAME are sometimes called biodiesel.

Energy Carrier Category	Identification Code	Definition	Examples
		delegated act, which require it to not hold any energy content that feeds into the final fuel.	
RCF (Recycled Carbon Fuels)	RCF	Liquid or gaseous fuels produced from liquid or solid waste streams of non-renewable origin that are not suitable for material recovery, or from waste processing or exhaust gas of non-renewable origin which is an unavoidable and unintentional consequence of the production process in industrial installations.	• Synthetic gas produced from non-biological waste • Diesel, gasoline or SAF produced via Fischer Tropsch with a carbon source of non-recyclable and non-biological refuse
Other low-carbon fuels	OTH	Includes all other fuels which may not suit any of the categories above.	• Grid electricity • Other fringe cases

In addition to the above energy carrier categories, CLEVER recognises a need to further subdivide energy carriers according to their feedstock type to account for the associated, specific scope requirements. CLEVER does not give direction for the selection of certain feedstocks for use in energy production, though the user should note that restrictions exist under different regulations e.g., RED. For biofuels, a distinction between feedstocks is made using the categories of “food or feed crops”, “agricultural or forestry residues” and “waste”, as different methodology aspects can apply. Furthermore, the carbon source for e-fuels, RFNBOs, RCFs or other low-carbon fuels is distinguished between direct air capture (DAC) and carbon capture and utilisation (CCU) from a point source.

3.4 FUNCTION, FUNCTIONAL UNIT AND REFERENCE FLOW

The functionality of *CountEmissions EU* (as defined in the goal and scope section) is always the transportation of passengers or freight, and its functional unit thus is either person-kilometre or tonne-kilometre in line with any GHG assessment following ISO 14083:2023. CLEVER provides the needed energy provision and operational GHG emission factors to convert from an amount of energy carrier used per tkm or pkm to a GHG emission intensity per tkm or pkm.

Thus, the functionality of CLEVER is always the provision and use of an energy carrier coming from a specific energy carrier pathway for transportation purposes used in a certain vehicle/vessel under specified operating conditions. The functional unit of CLEVER is defined as “Providing 1 MJ (measured on the basis of LHV) of an energy carrier to a vehicle /vessel and usage of the energy carrier up to the point just before its conversion into mechanical energy”. To reflect this functional unit, CLEVER always operates using a reference flow[10] of 1 MJ of a certain energy carrier used in a specific vehicle/vessel (instead of the functional unit of pkm or tkm). The resulting emission factor of a fuel / energy carrier is thus the sum of all GHG emissions across all lifecycle stages, including use, divided by the delivered energy. As such, it is a sub-function of ISO 14083 that does not reflect the complete lifecycle of the transport or depict the full functionality of ISO 14083, and CLEVER

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[10] Also called “declared unit” in ISO 14067.

emission factors cannot be used directly to compare the climate impact of different transport chains on their own[11].

The reference flow of CLEVER encompasses information on the energy carrier type and its production pathway, as well as further information on the use as a transportation energy carrier (e.g. mode, vehicle / vessel and engine type). Information on the use is needed as the same fuel used under different operating conditions (e. g. in a different vehicle type or a different engine) may lead to different operational GHG emissions (e.g. due to varying levels of methane slip in different gas engine types). For some energy carrier pathways, a broad range of uses can be covered by the same factor (e. g. gasoline for road), while for others, a more granular approach is needed to correctly capture the impacts from the operational phase, for example. By adding information on the production pathway, a distinction between different ways of producing the same energy carrier can also be given.

Some (simplified) examples of reference flows are:

- 1 MJ of fossil compressed natural gas used in a truck with an SI engine
- 1 MJ of fossil kerosene used in an aircraft
- 1 MJ of fossil diesel used in a bus fitted with a selective catalytic reduction (SCR) system
- 1 MJ of biogenic liquefied natural gas produced from biowaste (using a closed digestate storage) used in an inland waterway ship with an Otto engine at medium speed
- 1 MJ of ultra-low sulphur heavy fuel oil used in a seagoing ship

Depending on the energy carrier pathway, the reference flow may also refer to a specific fuel volume (e.g. litre) or a specific fuel mass (e.g. kg) as well as to an amount of energy directly. At the end of the calculation, however, a conversion to 1 MJ is done using the density and / or the lower heating value.

3.5 SYSTEM BOUNDARY

The system boundary shall be cradle-to-grave[12] and shall include all significant contributions associated with the energy provision (well to tank or WtT) of the energy carrier as well as the operational (tank to wheel or TtW) processes specified in Figure 1.

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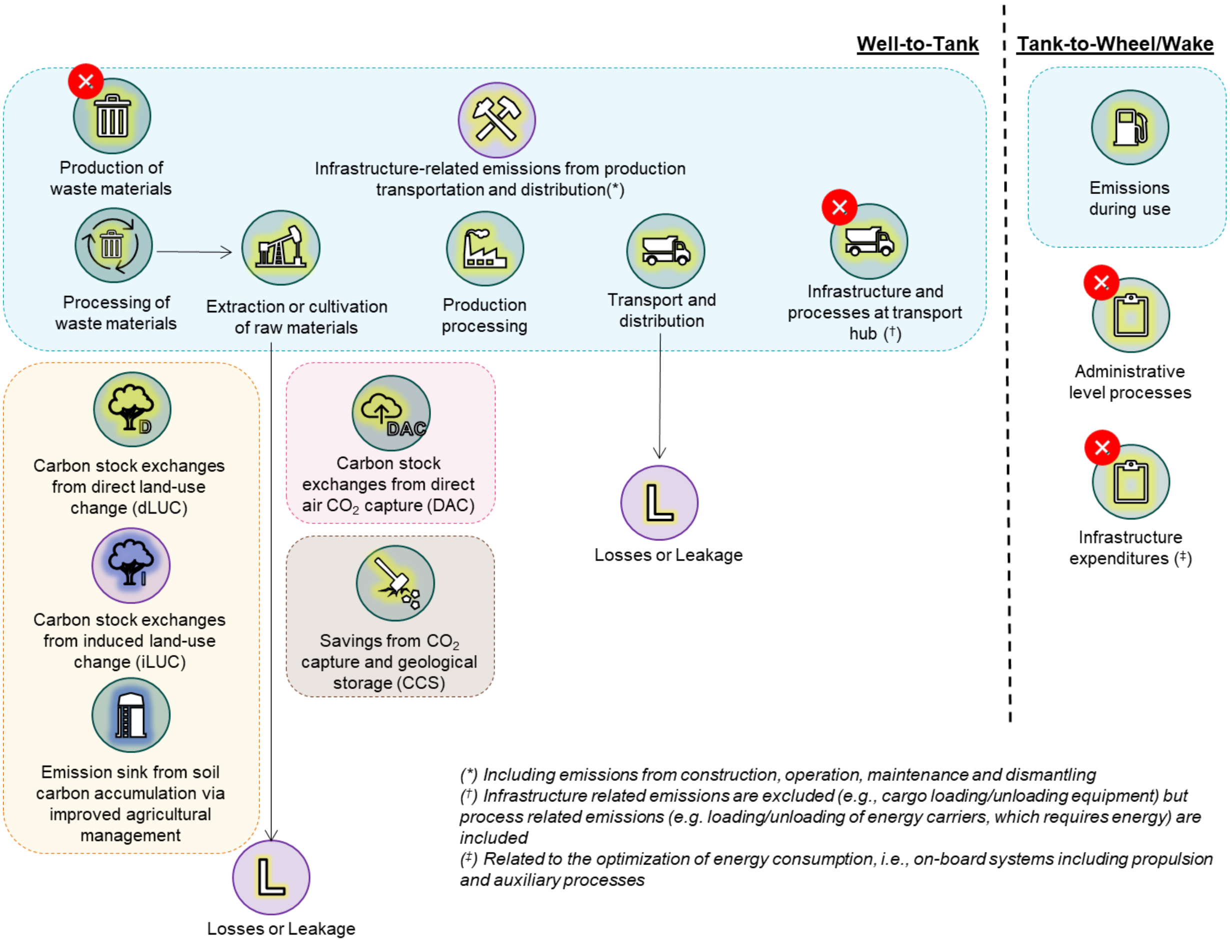
[11] However, by multiplying the amount of energy used per kilometre (as was obtained from the refuelling or charging station) (in MJ/km) with the GHG emission factor (in g/MJ), a GHG intensity (in g/km) can be obtained.

[12] Consistently with the CLEVER definition of Functional Unit (cf. chapter 3.4), the “grave” of an energy carrier is hereby intended to correspond to “the point just before its conversion into mechanical work”.



(*) Including emissions from construction, operation, maintenance and dismantling
(†) Infrastructure related emissions are excluded (e.g., cargo loading/unloading equipment) but process related emissions (e.g. loading/unloading of energy carriers, which requires energy) are included
(‡) Related to the optimization of energy consumption, i.e., on-board systems including propulsion and auxiliary processes

Figure 1 Simplified depiction of the CLEVER system boundary

Colour:	Key:
●	Baseline process. The process requirement is considered “baseline” and as such its inclusion is always required for compliance.
🟣	Advanced process. The process is required by CLEVER but is considered “advanced” as it is not included within RED methodology.
❌	The process is always excluded from the system boundary.
✕	Process is considered a “must”.
✕	Process is considered a “should”.
⬚	Process is considered “universal” and is thus applicable to all energy carriers.
⬚	Process is considered specific to bio-fuels, and to biomass used for electricity generation.
⬚	Process is considered specific to some RFNBO pathways.
⬚	Process is considered specific to some thermal electricity generation pathways (e.g. from coal, natural gas and biomass).

Figure 2 CLEVER system boundary explanation

Processes Included

The CLEVER system boundary for the life cycle of an energy carrier (split into energy provision or **WtT** and operational or **TtW** stages) should include all processes listed in Table 3-2. Two levels of process requirement are possible (respectively, “**must**”/“**shall**” and “**should**”, as previously defined in chapter 3). Additionally, for each process, indications are provided on:

- Whether the process requirement is to be considered “**baseline**” (its inclusion always required for compliance with RED) or “**advanced**” (required by CLEVER, but flagging divergence in other related methodologies, such as, e.g. RED).
- Whether the process requirement is “**universal**” (i.e., applicable to all energy carriers), or “**specific**” (only pertaining to some specific energy carrier types).

Table 3-2: CLEVER system boundary inclusions

WtT or TtW	Process	“must” or “should”	“Baseline” or “advanced” (with notes)	“universal” or “specific” (with notes)
WtT	Extraction or cultivation of raw materials (including processing of waste as an input)	Must	Baseline	Universal
WtT	Carbon stock exchanges caused by direct land-use change (dLUC)	Must	Baseline	Specific (only applies to bio-fuels, and to biomass used for electricity generation)

WtT or TtW	Process	"must" or "should"	"Baseline" or "advanced" (with notes)	"universal" or "specific" (with notes)
WtT	Carbon stock exchanges caused by indirect land-use change (iLUC)	Must	Advanced (not included in RED)	Specific (only applies to bio-fuels, and to biomass used for electricity generation)
WtT	Emission sink from soil carbon accumulation via improved agricultural management	Should	Baseline	Specific (only applies to bio-fuels, and to biomass used for electricity generation)
WtT	Carbon stock exchanges from direct air CO_2 capture (DAC)	Must	Baseline	Specific (only applies to some RFNBO pathways)
WtT	Emission sink from CO_2 capture and geological storage (CCS)	Must	Baseline	Specific (only applies to some thermal electricity generation pathways, e.g., from coal, natural gas, biomass or hydrogen production with CCS)
WtT	Production processing	Must	Baseline	Universal
WtT	Transport and distribution	Must	Baseline	Universal
WtT	Losses or leakage as a result of extraction, transport and distribution	Must	Advanced (not included in RED)	Specific (does not apply to electricity)
WtT	Infrastructure-related emissions from production, transportation and distribution (including construction, operation, maintenance and dismantling)	Must	Advanced (not included in RED)	Universal
TtW	Emissions from the fuel during use and other operational emissions	Must	Baseline / Advanced (in parts not included in RED)	Specific (does not apply to non-ICE drivetrains)
WtT (alternative: TtW)	Fossil operational CO_2 emissions from biofuels (covering fossil C in FAME and ethanol)	Must	Baseline	Specific (does not apply to non-ICE drivetrains)

Note: CLEVER users may decide to include fossil operational CO_2 emissions from biofuels into the TTW (operational) emissions instead, but it must be clearly stated which approach was taken.

It is to be noted that, while "losses or leakage" of GHG to the atmosphere during transport and distribution do not apply to electricity as an energy carrier, the latter is still in fact affected by energy losses (e.g., due to Joule effect), which must be factored in the assessment. In short, this principle applies to all energy carriers: for each MJ of fuel or electricity delivered to the vehicle or vessel, the assessment must scale up the demand to the upstream energy input required to produce transport and distribute that MJ, including all relevant energy losses along the chain. Additionally, energy losses occurring at the point of delivery (battery charging) shall be included within the CLEVER system boundary. This includes:

- **Off-board losses**: Energy dissipated by the charging station infrastructure.
- **On-board losses:** Energy dissipated by the vehicle/vessel internal systems during charging (contributing to the specific energy consumption per passenger-km or tonne-km).

It is acknowledged that carbon stock exchanges from indirect land-use change (iLUC) inevitably introduce consequential elements to the assessment, which, from a purely methodological perspective, conflict with CLEVER's overarching intent to remain strictly attributional. However, given the potentially very large relevance of these emissions for biofuel pathways, specifically where iLUC becomes the key determinant of whether the total GHG emission factor of the biofuel in question ends up being lower or higher than that of its fossil counterpart, the inclusion of this process is considered mandatory in CLEVER ("shall" designation). For further detail on the methodological approach and underlying general/partial equilibrium models to be used for the quantification of iLUC emissions, see chapter 3.13.

Processes Excluded

The CLEVER system boundary[13] shall always exclude the following processes:

- Production (as opposed to processing) of materials entering the system as a waste from a previous system (in alignment with the end-of-life approach in chapter 3.11);
- Infrastructure and processes at transport hubs unrelated or unspecific to the energy carrier under assessment (e.g., cargo loading/unloading equipment[14], or accommodations for passengers on the site of the transport hub);
- Processes at the administrative level of the organisations involved in any stage of the boundary;
- Infrastructure expenditures related to the optimization of energy consumption, i.e., on-board systems including propulsion and auxiliary processes.
- Vehicles, airframe, rolling stock or vessel manufacturing, maintenance and end-of-life (including also batteries for electric vehicles)
- Some operational processes with minor importance for overall GHG emissions not directly linked to use of the energy carrier in a vehicles or vessels (see sub-section on 'Handling of operational emissions with a minor relevance for the overall climate impacts' below)
- Any "avoided emissions" deriving from market-based emission credit adjustment mechanisms (in line with ISO 14083, GLEC Framework and *CountEmissions EU*).

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[13] This excludes elements that are included in the broader *CountEmissions EU* scope but are not subject to CLEVER.

[14] Emissions due to cargo loading/unloading equipment/infrastructure are excluded; however, process-related emissions from loading/unloading of energy carriers are included.

- GHG emissions from refrigerant leakages during the operational phase of cooled transports (Note: these are required for a full assessment of the climate impacts from cooled transports under ISO 14083 and *CountEmissions EU* but cannot be included into the GHG emission factors of the energy carriers).

General Cut-offs

All processes, flows and activities attributable to the energy carrier system under assessment must be included in the system boundary and associated data collection must aim for completeness. Where quantitative data are available, these shall be included. In line with ISO 14044:2006, CLEVER permits the exclusion (or ‘cut-off’) of inputs or outputs, if necessary, but only if they contribute less than a specified proportion of the overall environmental significance. The use of any cut-off criterion must always be clearly stated and justified. To ensure consistency, CLEVER defines the cut-off rules as follows.

A CLEVER emission factor may only cut off flows from its calculation which cumulatively contribute to 3% or less of the total life-cycle impact of the energy carrier under assessment. In other words, cumulatively, all excluded flows must remain below this threshold, thereby ensuring at least 97% coverage of total GWP. This 3% cut-off threshold is chosen in alignment with the similar quantitative cut-off threshold for “environmental significance” set by the Product Environmental Footprint (PEF) guidelines (Annex I, Section 4.6.4); a screening study is recommended for the identification of the processes that may be cut off under this threshold.

This cut-off criterion, therefore, implicitly permits differences in system boundary across different energy carrier categories, i.e., where a process or a certain group of processes cumulatively contributes less than 3% of the total impact, then such process(es) may be excluded from the system boundary. It is common that certain upstream infrastructures get cut-off from the boundary on this basis (e.g., the infrastructure of a thermal fossil powerplant).

Most Important Processes

A screening study is used to identify flows suitable for ‘cut-off’ when setting the system boundary. This is also used for the early identification of the key hotspots across the fuel supply chain (in the case of fuel producers) or across the transport services (provided by the transport service providers). Aligned with the ISO 14067:2018, these hotspots across specific processes are captured as the “most important processes” which are *those that together contribute at least 80% to the total product life cycle GHG emissions, starting from the largest to the smallest contributions after cut-off*. Identification of the “most important processes” vary with the vehicle -powertrain technologies in questions, mode of transportation, distance travelled and mode combinations employed, energy carrier used to deliver ‘transport as a service’, load factor and duty cycle and other parameters, in the case of transport service providers. As for fuel producers, hotspots tend to vary with production route, region of production and relevant supply chain characteristics, among other contributing parameters.

Handling of operational emissions with a major relevance for the overall climate impacts

The scope of ISO 14083 and *CountEmissions EU*, and therefore the CLEVER framework, covers the whole value chain needed to depict the impacts of different transport services, including emissions from vehicle/vessel operation. Some elements of the operational phase are included within the ‘core’ emission factor of CLEVER, in particular those related to fuel combustion, nitrous oxide and methane emissions (including slip). Other, less uniformly considered elements, such as consideration of hydrogen losses or climate impacts from high altitude emissions of airplanes, or black carbon emissions from e.g. sea ships, are reported separately to the 'core' value, given their novelty. A core principle of the CLEVER project is its modular approach to emission factor development.

Crucially, this modularity strongly encourages and facilitates the use of specific, primary data by users. For example, where operators have access to reliable data on methane slip for their specific gas engine fleet, or measured N_2O emissions from their particular ammonia-fuelled engines or SCR systems, the CLEVER framework is designed to allow these primary values to seamlessly replace the default factors provided. The reliability of such primary values, when used to substitute defaults, must be assured through appropriate certification or third-party verification processes. This prioritizes accuracy and reflects the actual performance of the technology in use, supporting more robust GHG accounting and targeted emission reduction efforts.

CLEVER GHG emission factors always differentiate not only the energy carrier pathway, but also the use of this energy carrier. However, to make things easier, for some energy carrier types, a range of different engine/vehicle/vessel types and operating conditions can be captured using the same factor by using an average over a range of different applications. This might lead to a possible over- or underestimation of certain impacts; whenever an underestimation occurs this must always stay below the overall cut-off criteria specified.

For instance, the nitrous oxide emission factors of a typical medium-sized heavy-duty truck (weighing between 14 to 20 tonnes) vary depending on the Euro vehicle standard, reflecting the developments in regulatory measures and technology. Specifically, the emission factors, as calculated with COPERT (Calculations of Emissions from Road Transports – tool, (E:MISIA, 2025)), are as follows: 0.0015 g/MJ for Euro I and II, 0.0007 g/MJ for Euro III, 0.0016 g/MJ for Euro IV, 0.0044 g/MJ for Euro V, 0.0054 g/MJ for Euro VI, and 0.0025 g/MJ for Euro VII. The increase at Euro IV and Euro V is largely due to the use of SCR to comply with the strict NO_X emissions standards. This example illustrates the importance of tailoring emission factors to capture the differentiation between energy carrier pathways and vehicle/vessel use within the CLEVER framework.

Emissions from Methane slip and exhaust gas treatment

Accurately quantifying the full climate impact of transport operations requires looking beyond the CO_2 emissions resulting from complete fuel combustion. The generation of non-CO_2 GHGs, notably methane (CH_4) and nitrous oxide (N_2O), during vehicle/vessel operation is often highly dependent on the specific energy carrier and, crucially, the engine type, combustion conditions and any aftertreatment technology employed. Furthermore, exhaust gas treatment systems themselves can be a source of GHG emissions. The CLEVER methodology will address these complexities by developing technology-specific emission factors for CH_4, N_2O and auxiliary inputs within its modular framework.

Methane emissions during the operational phase primarily arise from 'methane slip' in engines running on gaseous fuels like natural gas (CNG/LNG) or biomethane. Methane slip refers to the release of uncombusted methane fuel through the exhaust. Given methane's high GWP (both, fossil and biogenic), even small amounts of slip can significantly increase the overall TTW GHG emissions, potentially offsetting the CO_2 benefits compared to liquid fuels. The extent of methane slip varies considerably depending on the engine technology (e.g., spark-ignition vs. high-pressure direct injection, lean-burn vs. stoichiometric, specific dual-fuel engine designs) and potentially its age and maintenance condition. Recognizing this variability, the CLEVER methodology will provide default methane slip factors differentiated by major engine technology categories relevant to road, maritime, inland waterway and other transport applications.

N_2O is generally formed during high-temperature combustion processes due to partial oxidation of atmospheric nitrogen. While present (in comparatively small quantities) in the exhaust of conventional fuel engines, its emission levels can be particularly significant and variable when using alternative fuels like ammonia (NH_3). The combustion chemistry of ammonia is complex, and under certain conditions (influenced by temperature, pressure, fuel/air mix, catalysts), significant amounts of N_2O can be produced, alongside desired N_2 and water. Following the principles outlined for Mobile Combustion in the 2006 IPCC Guidelines for National GHG Inventories (Volume 2, Chapter 3), which emphasises that N_2O emissions are highly dependent on technology and emission control systems rather than just fuel carbon content, the CLEVER methodology recognises the critical need to account for these technology-specific N_2O emissions, particularly acknowledging their potential severity when originating from the fuel's own nitrogen content in ammonia combustion. Furthermore, Selective Catalytic Reduction (SCR) systems, commonly used to reduce NO_X emissions (especially in modern diesel engines and potentially future ammonia engines), can also inadvertently generate N_2O as a by-product. In addition to N2O, the operation of SCR systems requires the consumption of urea (e.g. AdBlue). The hydrolysis of this urea within the exhaust stream generates fossil CO2 emissions that must be accounted for. The CLEVER methodology will therefore account for operational N_2O emissions and CO_2 from urea consumption, aiming to provide differentiated factors based on fuel type, primary engine technology and the presence/type of relevant aftertreatment systems (like SCR), while acknowledging the higher uncertainty and data scarcity, especially for emerging pathways like ammonia combustion.

Within a CLEVER assessment, values for methane (incl. slip) are represented by EF_{CH4} , while N_2O emissions are covered under EF_{N2O}, and CO_2 emissions are covered under EF_{CO2}. Both shall be included into the 'core' emission factor.

Global warming potential of Hydrogen

The use of hydrogen as a transport fuel, either in Internal Combustion Engines (ICEs) or Fuel Cells (FCs), introduces operational emission considerations beyond the primary water vapor output. Specifically, "hydrogen slip" – the release of uncombusted or unreacted hydrogen from the energy converter (engine or fuel cell stack) during operation – needs to be accounted for. While distinct from fugitive hydrogen losses from storage tanks or distribution infrastructure (which are considered in the energy provision phase or as separate operational fugitive emissions), hydrogen slip contributes directly to the operational emissions profile.

Hydrogen itself is not a direct GHG, but it acts as an indirect one, influencing the atmospheric concentrations of methane, ozone and stratospheric water vapor, ultimately contributing to warming. Based on recent scientific assessments, although not yet formally adopted in IPCC GWP tables, hydrogen exhibits a significant climate impact. For the purposes of the CLEVER methodology, a GWP100 of 11.6 kg CO_2 e per kg H_2 will be utilized, reflecting current scientific understanding[15]. Recognizing that official GWP values for hydrogen will

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[15] For reference, see Sand, M., Skeie, R.B., Sandstad, M. *et al.* A multi-model assessment of the Global Warming Potential of hydrogen. *Commun Earth Environ* **4**, 203 (2023). https://doi.org/10.1038/s43247-023-00857-8

further evolve, the climate impact associated with hydrogen emissions (both slip and any upstream fugitive losses allocated to the operational phase) will be reported as a separate H_2-specific CO_2 e value within the CLEVER framework, as part of the additional climate impacts covered in CLEVER. This approach ensures transparency and allows users to easily adjust the total GHG impact in the future if an official GWP100 for hydrogen is updated by bodies like the IPCC.

Consistent with its overall approach, the CLEVER methodology will adopt a modular structure for hydrogen emission factors. This will involve providing default operational emission factors that account for hydrogen slip, differentiated where possible based on the energy conversion technology (ICE vs. FC) and potentially sub-categories, if data allows.

This modularity enables and encourages the integration of primary data. Operators who have access to specific, measured data regarding hydrogen slip or total operational hydrogen losses for their fleet or equipment are strongly encouraged to use these primary values within the CLEVER framework. Substituting default values with verified, specific data will significantly enhance the accuracy and relevance of the resulting GHG emission calculations, providing a more precise reflection of operational performance.

Within a CLEVER assessment, values for the GWP of hydrogen emissions are represented by $EF_{Hydrogen}$ and will be grouped under the emission factor for additional climate impacts.

Climate Impacts from high altitude emissions

Aircraft operating at high altitudes generate climate impacts beyond their direct CO_2 emissions. These "non-CO_2 aviation effects" include the formation of persistent condensation trails (contrails) and contrail-cirrus clouds and the impact of nitrogen oxides on atmospheric ozone and methane concentrations, as well as direct emissions of water vapor, black carbon and sulphate aerosols. Collectively, these effects contribute significantly to aviation's overall climate forcing, particularly on shorter time scales. Additional climate impacts from non-CO_2 effects contribute 66% of the total global warming potential of aviation today according to (Lee et al. 2023). Their quantification is associated with considerable variations in the values due to complex dependencies on altitude, geographical location, atmospheric conditions, time of day and aircraft/engine technology. Thus, any generalised factor is associated with a certain uncertainty.

Despite the uncertainties, the magnitude of these effects necessitates their consideration in a comprehensive assessment of aviation's climate impact. With the increasing use of sustainable aviation fuels, the GHG emissions from flights will decrease, leading to an even higher relative importance of the non-CO_2 climate effects. Many current emission factor systems either omit these effects or use highly simplified approaches. The CLEVER methodology provides a transparent way to acknowledge these effects within its emission factor framework, balancing the need for inclusion with the current scientific complexities and uncertainties.

For users needing detailed analysis of non-CO_2 aviation effects, especially for specific flights, CLEVER refers to the EU MRV system (Monitoring, Reporting and Verification of CO_2 emissions) under the ETS II (European

Union Emissions Trading System) and the NEATS (Non-CO_2 Aviation Effects Tracking System) IT tool for quantification[16].

The CO_2-equivalent impact derived should be reported as a separate, distinct component alongside the other factors depicting parts of the value chain, such as the 'core' value. This will allow users to:

- Clearly identify the contribution of non-CO_2 aviation effects.
- Adapt their reporting, if operators want to utilize a CLEVER value for other specific frameworks (e.g., a corporate reporting scheme) that can have different scopes or requirements for non-CO_2 effects.
- Facilitate future updates. As scientific understanding improves and authoritative bodies establish refined GWP-like metrics or consensus approaches for non-CO_2 aviation effects, this separate component can be readily adjusted without altering the other modular emission factors and may become mandatory in the future.

Within a CLEVER assessment, values for the non-CO_2 climate impacts from high altitude emissions are represented by EF_{HAE} and are grouped under the emission factor for additional climate impacts. Even though inclusion of climate impacts of airplanes at high-altitude is strongly encouraged, their inclusion is currently not mandatory.

Climate impacts of black Carbon emissions

Black Carbon (BC), a component of particulate matter also known as soot, is a potent short-lived climate pollutant with significant atmospheric warming effects. It impacts climate through various mechanisms, including the absorption of sunlight in the atmosphere and the reduction of reflectivity when deposited on snow and ice, accelerating melting.

Despite its recognized climate impact, BC is not currently assigned a Global Warming Potential by the IPCC, and its comprehensive integration into standardized GHG emission factor methodologies remains a challenge. Most existing emission factor databases do not systematically include BC's climate effects in CO_2-equivalent terms, often due to the complexities in quantifying its diverse impacts and the lack of a universally agreed metric. However, recent scientific assessments, including those by Bond et al. (2013), and subsequent analysis (e.g., ICCT, 2024), highlight an effective GWP100 for BC (e.g. 900) and underscore the importance of its consideration.

The CLEVER project acknowledges the importance of addressing the climate impact of BC emissions from transport operations. However, definition of a specific methodological approach to quantifying and incorporating the climate effects of BC within the CLEVER emission factors is beyond the scope of the current project. Instead users wishing to include BC in their overall emission factor are referred to the practical guidelines developed by the Stockholm Environment Institute (SEI) and Climate and Clean Air Coalition (CCAC) (Stockholm Environment Institute and Climate and Clean Air Coalition, 2022) and the Air Pollutant Emission Methodology for the Logistics Sector (Smart Freight Centre and Stockholm Environment Institute, 2025) and annex to the GLEC Framework represented as Module 6.

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[16] https://climate.ec.europa.eu/document/download/2efafc7e-8b25-4763-906f-a7ba23b466d2_en?filename=policy_ets_avaiation_explainer_non-co2_mrv_tasks_for_ao_en.pdf

Consistent with the approach for other climate forcers with evolving metrics or significant uncertainties, it is envisaged that any climate impact attributed to BC emissions, based on the GLEC guidance or other emerging scientific consensus, will be reported as a separate component within the CLEVER emission factor. This will ensure transparency and allow for straightforward adjustments in the future as scientific understanding and standardized metrics for BC's climate impact mature and become more widely adopted.

Within a CLEVER assessment, values for the climate impacts of black carbon emissions are represented by EF_{BC} and will be grouped under the emission factor for additional climate impacts.

Handling of operational emissions with a minor relevance for the overall climate impacts

Not included in the system boundary (due to their minor relevance) are:

- *Changes in GHG emissions due to fuel evaporation for gasoline engines*:
  Fuel evaporation losses typically account for about 1% to 2% of total annual fuel consumption of gasoline vehicles. Evaporated fuel is released directly into the atmosphere as Volatile Organic Compounds (VOCs), which contribute to air pollution, and it might seem that CO_2 emissions are therefore 'reduced' because the fuel is not combusted; however, that is not the case, since the evaporated fuel is eventually oxidized to CO_2 in the atmosphere anyway. Hence, fuel evaporation does not result in a net change to climate impact. The extra fuel demand due to evaporative losses is instead to be later explicitly included in the vehicle's total energy demand, reflecting the amount of fuel that must be purchased (supplied) to the vehicle (increased MJ/tonne-km or MJ/passenger-km). Methodologies for estimating evaporative emissions are complex, incorporating factors such as emission control technology, fuel specifications, driving dynamics, and even ambient conditions like temperature, and are subject to inherent uncertainties. It is important to note that these specific evaporative emissions typically concern volatile liquid fuels like gasoline and should not be confused with 'methane slip' from gaseous fuels (e.g. LNG, CNG) which represents a distinct fugitive emission pathway for methane.[17]

3.6 LIFE CYCLE INVENTORY (LCI) MODELLING

As the approach to life cycle inventory modelling, an attributional approach shall always be utilized (as described in the goal section). This extends to all data sets and processes utilized within the inventory modelling, and with the exemption of the iLUC-value, which is in its nature consequential, all other elements shall strictly follow attributional modelling principles. This includes specifically the addressing of multifunctionality (see chapter 3.10). Another key influencing factor for the appropriate modelling of the LCI, data appropriateness and quality are described in the following chapter.

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[17] While early assessments often excluded unintentional lubricant oil combustion due to its minimal contribution to total CO_2 emissions (<1%), the CLEVER framework recognizes its highly significant contribution to non-CO_2 climate forcers, specifically Black Carbon. Because this impact can be substantial, particularly in large 2-stroke marine engines and older vehicle fleets, exclusion is not permitted. Lubricant oil emissions fall within the system boundary. They may only be excluded from a specific pathway calculation if a screening study demonstrates that their climate impact (including BC) (combined with all other climate impacts subject to a cut.-off) falls below the general 3% cut-off threshold defined for the CLEVER framework.

3.7 DATA AND DATA QUALITY

Data choice and -quality are of key importance when conducting a CLEVER assessment. Data must be collected for all unit processes within the system boundary and the sources and quality of data used in the generation of emission factors must be documented and assessed. A CLEVER assessment shall utilize the best data available and prioritize the most representative data with respect to the goal of the assessment. Where a specific situation or installation is investigated, primary data shall be prioritized over secondary data, where such data are available and applicable. Commonly, data used in the assessment of fuels or energy carriers may stem from a combination of sources, requiring a clear and unambiguous documentation of (different) applied data, including qualitatively and quantitatively characterization.

Data selection shall be based on fitness for purpose in relation to the defined goal and scope of the CLEVER assessment, in accordance with ISO 14040/44:2006. In particular, the level of representativeness of the emission factor under scope (e.g., representation of an average fuel pathway vs. assessment of a specific situation) shall determine the appropriate level of data aggregation and the choice of primary or secondary data.

For each energy carrier assessed, all unit processes within the defined system boundary must be supported by explicit and traceable data collection, proportional to the significance of involved processes and entities (i.e., transport service providers, fuel producers, other entities along the value chain of fuels). In general, collected data shall be complete, robust, consistent, plausible and representative of the subject of the investigation. The origin and quality of all data must be documented with sufficient transparency to allow independent review, third-party assurance, and external verification.

The CLEVER framework distinguishes two principal data types: Primary data and secondary data.

1. **Primary data** – foreground activity data collected by a specific organisation for the manufacture of a product under its own operation for which the immediate assessment is being undertaken. For example, the quantity of electricity required to manufacture the assessed product.
2. **Secondary data** – either foreground or background data, which has been derived from an existing database, literature source or supplier. For example, emission factor profile for producing 1 kg of low-alloyed steel.

Where the use of secondary data is required, CLEVER defines the following hierarchy as the order of preference for secondary data sources:

a. Verified foreground or background data from *statistically representative* organisations in the direct value chain of the specific fuel/energy carrier being assessed (it is important to avoid using data from relatively minor producers which may not be representative for the fuel/energy carrier on the broader national/international scale).
b. Reputable industry-average life-cycle data from LCI databases, industry association reports, government statistics, etc.
c. Foreground or background data from literature or scientific papers, including proxies.
d. Foreground or background data based on assumptions, that is conservative, transparent, subject to sensitivity analysis.

The choice between primary and secondary data shall follow the intended level of specificity of the assessment. For studies aiming to represent average conditions, secondary data such as default or aggregated emission factors may be appropriate. For studies aiming to represent specific technologies or installations, priority shall be given to primary or otherwise technology-specific data. The representativeness of the selected data shall be demonstrated.

The selection of data shall follow the intended level of representativeness defined in the goal and scope:

- For assessments of specific processes, technologies, or installations, priority shall be given to primary data. Where such data is not available, technology specific data shall be chosen.
- For assessments aiming at representing average or generic systems (such as e.g. Default values), secondary data such as aggregated or average data may be appropriate, provided that their representativeness is demonstrated.

In all cases, the appropriateness of the selected data shall be assessed. Where data are not fully representative, limitations shall be documented and their influence on results evaluated, where relevant, through sensitivity analysis.

For both, foreground- (processes specific to the product system under investigation and direct control or strong influence of the entity conducting the assessment) and background (processes that are not under the direct control or strong influence of the entity conducting the assessment) processes, primary data or secondary data may be used, depending on the appropriateness and provided that data quality requirements are met. Commonly, data used in the assessment of fuels or energy carriers may stem from a combination of sources. In such cases, clear and unambiguous documentation of all applied data shall be ensured, including qualitative and quantitative characterisation of data sources, assumptions, and limitations.

Further details on how minimum data requirements evolve with regard to the reporting entity is presented in the section below.

Examples of typical foreground processes for transport service providers or energy carrier providers

For Transport Service Providers (TSPs):
Foreground processes typically include transport, handling and storage operations directly managed by the TSP. As such, foreground processes of TSPs by definition are outside of the general CLEVER scope. The following section thus constitutes a recommendation and is included to provide context.

Primary data must reflect the actual operational condition of the vehicle, vessel, aircraft or equipment. Primary data requirements for TSPs could include:

a. **Activity and energy use data**
   - Direct vehicle-, vessel-, aircraft- or equipment-level fuel consumption (litres, kg, kWh, MJ).
   - Electricity consumption for EVs, hybrid systems, shore power or battery-swap systems.
   - Auxiliary energy use (e.g., reefer units, onboard electricity generation).
   - Fuel dispensing/bunkering records, supplier invoices, or smart-meter measurements.

b. **Operational parameters**
   - Trip logs, routing data, load factors and GPS/telematics outputs, if available.
   - Engine type and combustion technology including emissions standard (Euro class, IMO tier).

c. **Contextual parameters**
   - Geographic scope (city, regional, international).
   - Modal specifics (road/rail/inland waterway/maritime/aviation).
   - Logistics handling steps directly controlled by the operator (e.g., consolidation, warehousing).

NOTE: Where Transport Service Providers (TSPs) use a specific dedicated renewable fuel, they may opt to account for this following the provisions set out in chapters 4.5 and 5 instead of using the location-based energy mix.

Energy carrier provision:
Given the focus of the CLEVER framework on fuel and energy provision, the provision and – in particular – the production of used energy carriers constitute the main foreground product systems. Foreground processes cover all steps within the fuel production facility and associated operations, including feedstock preparation, conversion, upgrading, and facility-controlled distribution steps. Fuel producers must strive to prioritise primary data, for the following parameters

a. **Process inputs and outputs**
   - Energy- and mass-balances for processes (e.g., in the form of a material bill)
   - Feedstock quantities, types and characteristics (e.g., moisture, oil content, composition).
   - On-site energy consumption by source (e.g., electricity, steam, natural gas, hydrogen, biomass, etc.).
   - Process yields, co-product outputs, and material balances.

b. **Direct emissions and environmental exchanges**
   - Combustion emissions, process emissions (CO_2, CH_4, N_2O), flaring, and venting.
   - Fugitive emissions, e.g. methane slip in biomethane or LNG plants, hydrogen evaporation losses.

c. **Facility-specific operational data**

General Data Quality Requirements

This chapter specifies the minimum data requirements and data quality standards for compliance with the CLEVER assessment framework, in accordance with ISO 14040/44:2006 and reflecting the recommendations of the *European Commission Environmental Footprint (PEF)* methodology. Generally, data quality criteria apply to both primary- and secondary data sources. However, requirements differ with respect to assessing uncertainty (primary data) and sensitivity (secondary data) of results and the *Data Quality Rating* (only applies to secondary data, see further below).

For primary data, uncertainty shall be assessed for key parameters that are directly measured or monitored (e.g., energy consumption, emissions from fuel use, material consumption rates), where variability of parameters can be quantified, based on measurements or operational records.

For secondary data, where uncertainty cannot be comprehensively quantified, e.g. due to lack of access to underlying datasets or other limitations, key parameters shall be assessed by sensitivity analysis. Chapter 3.8 provides additional guidance on both, uncertainty- and sensitivity analysis.

For each energy carrier assessed, all unit processes within the defined system boundary shall be supported by explicit and traceable data collection, proportional to the significance of the processes. In general, collected data shall be complete, consistent, plausible, robust, traceable and representative of the subject of the assessment. The origin, quality, and treatment of all data shall be documented with sufficient transparency to allow independent review, third-party assurance, and external verification.

For both, primary and secondary data sources, the same following quality criteria shall apply uniformly, in line with ISO 14040/44:2006:

- Representativeness: Data shall be representative of the process, technology, and conditions defined in the goal and scope of the assessment. In particular for secondary data, technological, geographical, and temporal representative-ness shall be ensured or, where not fully achievable, justified and documented. Note: These three aspects are also covered by a data quality rating (see next subchapter for more details).
- Relevance of identified hotspots: For processes identified as significant contributors to total lifecycle impacts (hotspots), data of the highest achievable representativeness shall be used. Depending on the application case and in particular the intent to disclose results to third parties, identified hotspots are key parameters subject to either uncertainty analysis (primary data) or sensitivity analysis (secondary data, see chapter 3.8). Where such data are not available, the use of less representative data shall be justified with documented evidence, including the influence of the choice of this data on overall results, as an additional item of the sensitivity analysis.
- Data source transparency: The origin of all data shall be clearly documented, including data sources (depending on data type e.g., measurements, supplier information, databases, literature), underlying assumptions, and any applied conversions or calculations.
- Data collection methodology: The method of data collection shall be described, including measurement approaches, calculation procedures, and data processing steps. For measured primary data, the period of data collection shall be specified and shall, where applicable, cover at least one representative year of operation, unless otherwise justified.

- Completeness: Data shall cover all relevant input and output flows of the processes within the defined system boundary, consistent with the applied cut-off rules and system definition (see chapter 3.5)
- Consistency: Data shall be applied consistently across the assessment with respect to system boundaries, allocation approaches, functional unit, and methodological assumptions.
- Plausibility and internal validation: All data shall be subject to plausibility checks, including identification of potential outliers or inconsistencies. Where applicable, internal consistency shall be verified (e.g., as regards mass- and energy balances).
- Data gaps and Limitations: Data gaps and limitations shall be explicitly reported. Where these may influence the results, their impact shall be evaluated through sensitivity analysis (or other appropriate methods, see chapter 3.8).

While the criteria above apply to all data, the means of verification for compliance with the requirements differs. For primary data, this entails measurements, operational data and records, e.g., meter readings, fuel purchase records, or supplier disclosures, while for secondary data, literature sources, LCI(A) models, representative averages and other aggregated data are evaluated / assessed.

Guidance for novel / emerging fuels

For emerging fuels/pathways (e.g., e-fuels, advanced SAF, novel H_2 carriers) with scarce primary/ or representative secondary data, compliance prioritises conservatism and transparency shall be prioritized over completeness. Prospective assessments (e.g., pilot plants, lab-scale) are informational only, and must flag reduced inherent data quality (expect DQR scores ≥2 across criteria due to low tech/time representativeness).
For emerging fuels or pathways (e.g., e-fuels, advanced SAF) where representative secondary data is scarce:

- Secondary data shall follow this hierarchy of preference: verified pilot-scale data; laboratory or proxy data; analogous established pathways (supported by sensitivity analysis on key parameters such as yields and energy requirements).
- Conservative parameter values shall be applied (e.g., upper-bound electricity grid emission factors, lower-bound process yields), accompanied by comprehensive uncertainty and sensitivity analyses focused on “most important processes”.
- Data gaps shall be explicitly documented, with secondary/proxies used to achieve at least 80 % coverage of hotspot GHG contributions, subject to independent third-party review.

Reports shall clearly flag such pathways as "Prospective assessment for informational purposes only".

Data Quality Rating

When conducting a CLEVER assessment, data quality shall be assessed quantitatively for all secondary data used (both for foreground and background). CLEVER requires that the three data quality aspects be considered for all studies, regardless of specific aim of the assessment. These include *Time-related coverage, Geographical coverage* and *Technology coverage* which are required to be assessed **quantitatively**, by means of the **Data Quality Rating (DQR)** procedure. Table 3-4Table 3-3: Data quality aspects and definitions to be considered for a CLEVER study. specifies the definition of each of these criteria in scope of the data quality rating procedure. Data Quality rating procedure for this guidance draws upon the guidelines presented in the

EU PEF guidelines, with some minor adaptations for an optimal balance between ensuring sufficient data quality and minimise unnecessary burdens for practitioners.

Data Quality Rating is applied separately for:

- Well-to-Tank processes, pertaining the provision of fuels and energy carriers, and
- Tank-to-Wheel/Wake processes, covering the fuel use onboard;

Within each stage, data quality assessment focuses only on processes identified as “most important”, meaning those processes that collectively account for at least 80 % of total GHG emissions for that stage. Any process, irrespective of fore- or background that falls within this category must always be supported by appropriately robust representative data. For the Tank-to-Wheel/Wake part, commonly default values (Tier 1 – fuel specific – and Tier 2 – technology specific, for reference, see chapter 4.6) are used. Data quality assessment thus is of particular importance, where modelled data (Tier 3 approach) are chosen. Where default values (Tier 1, Tier 2) are used, no further data quality assessment is required from the user as data quality assessment was already done for the initial value generation.

For each of the identified relevant processes, data quality is evaluated using the three mandatory criteria

Table 3-3: Data quality aspects and definitions to be considered for a CLEVER study.

Data Quality Aspect	Description
Time-related coverage	Desired age of data and the minimum length of time over which data should be collected.
Geographical coverage	Area from which data for unit processes should be collected to satisfy the goal of the study.
Technology coverage	Type of technology (specific or average mix).

Data used for each of these identified significant processes receives a score (1= best; 3 = worst) for each criterion. Data characteristics that a practitioner must determine before scoring the data quality is tabulated below

Table 3-4: Data Quality Representativeness Scoring Criteria for Time-related, Geographical, and Technological Dimensions

Criterion	Score	Description
Time-related representativeness	**High (1)**	Data is sourced from the same year as the assessed process (e.g., 2026).
	Medium (2)	Data is from within ±5 years of the assessment year (e.g., 2022 data for a 2026 process).
	Low (3)	Data differs by more than 5 years from the assessment year (e.g., 2015 data for a 2026 process).
Geographical representativeness	**High (1)**	Data is sourced from the same country as the assessed process (e.g., Germany).
	Medium (2)	Data comes from the same broader region (e.g., Europe, for a process located in Germany).

	Low (3)	Data comes from a different world region (e.g., Asia, for a process located in Germany).
Technological representativeness	**High (1)**	Data reflects the assessed technology or a closely related technology family with consistent inputs/outputs.
	Medium (2)	Data reflects the assessed or a related technology family but presents minor inconsistencies across sources.
	Low (3)	Data is generic or from different technologies, with significant input/output.

For each life-cycle stage (WtT and TtW separately), overall data quality is assessed across the three DQ criteria using a weighted average of scores from the "most important processes". Weights reflect each process's relative GHG contribution (%) to that stage's total, normalised by the sum of hotspot contributions.

Equation 1 Formula for the calculation of Data Quality Rating

$$DQR_c = \frac{\sum DQ_{i,c} \times w_i}{\sum w_i}$$

The criterion-specific DQR (DQR_c) aggregates individual DQ scores ($DQ_{i,c}$) from most important processes (*i*) within a life-cycle stage (WTT or TTW). Weights (w_i) are proportional to each process's GHG emissions (GHG_i) relative to total hotspot emissions ($\sum GHG_{hotspots}$), ensuring emissions-dominant processes drive the overall rating. Finally, the overall DQR for respective entire lifecycle stage (respectively WtT or TtW) is calculated as the straight average of the three criterion-specific DQR. An empirical expression of this approach has been presented separately for WTT and TTW DQR reporting.

Equation 2 Formula for the calculation of WtT Data Quality Rating

$$DQR_{WTT} = \frac{DQR_{time,WTT} + DQR_{tech,WTT} + DQR_{geo,WTT}}{3}$$

Equation 3 Formula for the calculation of TtW Data Quality Rating

$$DQR_{TTW} = \frac{DQR_{time,TTW} + DQR_{tech,TTW} + DQR_{geo,TTW}}{3}$$

Data Quality ratings evaluates the data reliability via the following quality thresholds. Lower DQR values indicate higher data quality, reflecting data that is recent, geographically and technologically representative, while a high DQR signals poorer data quality:

- DQR ≤ 1.5: Good quality
- 1.5 < DQR < 2.5: Average quality
- DQR ≥ 2.5: Poor quality

Comparisons of CLEVER outputs

Under circumstances where two or more energy carrier emission factors are compared, the equivalence of the systems and associated data quality must be evaluated before interpreting the results. This must be enacted for all application options listed in chapter 3.1. Whilst CLEVER default factors are developed with consideration of likely comparison by users, it cannot be guaranteed that the system boundary and data quality associated with each factor are exactly aligned to make them comparable. Therefore, consideration of system boundary and data quality should be taken prior to consideration of results. CLEVER recommends that a critical review should be performed if comparative assertions are intended to be disclosed to the public (see also chapter 5.1).

3.8 UNCERTAINTY AND SENSITIVITY ANALYSIS

The robustness of results in a CLEVER assessment shall be evaluated through the application of uncertainty analysis and sensitivity analysis. These approaches address different sources of variability and shall be applied in accordance with the nature of the underlying data and methodological choices. In general, they apply to a selection of identified parameters and methodological assumptions / choices that significantly contribute to or influence overall results.

Uncertainty analysis refers to the quantitative characterization of variability in parameters / data, primarily associated with data and parameters based on measurements or operational records. It is applicable where sufficient information exists to describe the statistical distribution or variability of data. Sensitivity analysis refers to the systematic variation of parameters and data, as well as methodological choices or decisions, in order to assess their influence on results. It is applicable where uncertainty cannot be adequately quantified, or where choices in modelling, assumptions, or data selection may significantly affect outcomes.

Within the CLEVER framework, the origin of the data determines the choice of either uncertainty analysis (primary data) or sensitivity analysis (secondary data). For primary data, uncertainty analysis shall be applied where parameters are measurable and variability can be quantified. For secondary data, sensitivity analysis shall be applied to reflect the influence of data selection, aggregation, or potential representativeness limitations. Methodological assumptions and choices shall always be assessed by means of sensitivity analysis, as these cannot be meaningfully represented through statistical uncertainty. Where both, uncertainty and sensitivity analysis are conducted, a combination of both may apply.

Default emission factors

When new default values are developed and incorporated into the Central Union Database, a uncertainty analysis or sensitivity analysis shall be conducted during the assessment to assess the influence of key parameters and methodological choices on the resulting emission factors. The analysis shall demonstrate that the selected default value represents a conservative estimate of emissions within plausible parameter ranges and that the result remains robust under reasonable variations of the most influential parameters.

Where default values provided by the Central Union Database are applied without modification by economic operators or third parties, an additional sensitivity analysis is not required, as the underlying uncertainty and parameter variability have already been addressed during the development of the default values.

Other applications (e.g. external calculation tools)

Where economic operators or third parties apply the CLEVER framework using operator-specific data, calculated values, or assumptions that deviate from CLEVER default values, an uncertainty analysis or sensitivity analysis shall be performed. In such cases, the analysis shall evaluate the impact of variations in the most relevant input parameters - such as energy demand, process efficiency, feedstock transport distance, or other parameters with a potentially significant influence on lifecycle GHG emissions - in order to demonstrate the robustness and transparency of the calculated results.

If the CLEVER framework is applied without the intent to disclose results to third parties (e.g., for internal decision support), sensitivity analysis is not required.

3.9 ASSUMPTIONS AND LIMITATIONS

Any key assumption that was made must be clearly stated and described. Moreover, if an assumption influences overall results, for instance by more than 10 percentage points, a sensitivity analysis shall be performed to assess the significance of the assumption.[18] Key assumptions pertain to methodical choices as well as both fore- and background data.

If limitations to the investigated fuel pathway exist, they must be stated and described clearly to allow for the reader to draw correct conclusions. Limitations might pertain:

- General methodological limitations (e.g. which key methodical choices or assumptions were taken and how they might limit the interpretation of results)
- General context (e.g. with respect to the utilized technology and / or specifics of the fuel production and utilization)
- Geographical coverage
- Temporal (or time-related) coverage
- Limitations to the utilized data: Inconsistencies of applied data, e.g. as regards their temporal coverage, or their general appropriateness for the investigated product system shall be stated.

The consequences of the limitations, especially regarding the interpretation of results and their comparability with other values, shall be stated within the report/documentation.

3.10 HANDLING OF MULTIFUNCTIONALITY

Some processes are multifunctional. These multiple functions are represented in LCI models by desired (or “functional”) output or, in the case of waste treatment, input flows. Common examples of multifunctional processes are heat and power cogeneration as well as recycling. These functional flows are from here on referred to as (co-) products[19].

Among the co-products, one is usually referred to as the main (intended) product, whereas products with smaller revenues (whether intended or incidental to the production of the main product) are defined as by-products. Waste flows are not products.

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[18] For example, the choice of electricity mix can have significant influence on results. If the electricity mix is not based on official data or calculations based on official data, but rather assumed (e.g. to depict changes over time), and choice of carbon intensity of the consumed electricity shows significant impact on overall results, a sensitivity analysis with a different assumed electricity mix helps contextualize results and put them into perspective.

[19] ISO 14040 uses a broad definition of products, which includes services. Under this definition, waste treatment, a service, can be considered a product which is represented in LCI modelling by an input flow.

To address multifunctionality in line with CLEVER, the following decision hierarchy shall be applied:

1. Avoid allocation by subdivision or system expansion (*without* substitution)
2. If this is not feasible, use the following allocation approaches:
    a. Allocation based on exergy for combined heat and power (CHP) generation
    b. Allocation based on energy for all other processes directly responsible for the (co)-production of energy carriers
    c. Economic allocation for processes not directly responsible for the co-production of energy carriers

The choices for this decision hierarchy are explained and justified as follows.

Multifunctional processes must be modelled in line with the decision hierarchy defined by ISO 14044:2006 and adopted within the EF method (Recommendations 2279/2021 - Annex I – section 4.5). This hierarchy lists the following options:(1) Subdivision or system expansion, (2) Allocation based on a relevant underlying physical relationship (mass or energy/exergy), (3) Economic allocation. According to this hierarchy, wherever possible, **subdivision or system expansion** shall be used to avoid allocation (ISO, 2006).

Subdivision works by breaking down a single multifunctional process into smaller, monofunctional sub-processes, each responsible for a distinct product. Where subdivision is possible, inventory data is collected only for those inputs and outputs directly attributable to the product under investigation. Emissions and burdens can thus be attributed to the distinct product directly and no other metric of allocating burdens is needed. Subdivision is only possible if the system to be divided comprises of two or more distinct systems, where each of the non-functional flows (e.g. energy/material demand, resulting emissions or wastes) can be unequivocally attributed to a single product[20].

There are two types of **System expansion.** The first refers to expanding the system boundary by including additional products in the functional unit (e.g., the production of 1 kWh of electricity and 2 kWh of heat). In this case, the cumulative life-cycle impacts are communicated for the expanded system as a whole rather than for one individual co-product only. However, if the aim of the study is to focus on one single product (e.g., one specific energy carrier or fuel, as is the case in CLEVER), then system expansion is not a suitable approach as no conclusions on the impact of each individual product can be drawn.

The second type of system expansion, i.e., **System expansion by substitution**, is a way of expanding the system without adding functions to the functional unit. This approach can be used when the additional supply of co-product(s) of a multifunctional process results in a reduced need for the production of one or more alternative product(s) which are substituted by the co-product(s). This approach describes a change and is therefore inherently consequential. As CLEVER is using an attributional approach (i.e. mathematically describing a stationary system), substitution is not in line with the goal and scope of the CLEVER framework and must not be applied.

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[20] Subdivision into “virtual” sub-processes by attributing a certain fraction of the non-functional flow to each of the functional flows is synonymous with allocation and does not fall under the definition of subdivision.

In many cases, avoiding allocation by subdivision or system expansion is not feasible or not compatible with an attributional assessment of a given product. Thus, allocation is the most relevant approach to address multifunctionality in CLEVER assessments[21].

The preferred option for allocation in CLEVER, consistently with the ISO hierarchy, is **physical allocation**, whereby all the non-functional inputs and outputs to/from the multifunctional process are partitioned (allocated) between the various co-products. Generally, the physical relationship may be established using metrics such as:

- Mass or volume;
- Number of units;
- Energy or exergy content (e.g. MJ of fuels produced).

The latter option (**physical allocation based on energy or exergy content**) is used as the default in CLEVER for all multifunctional processes directly responsible for the (co)-production of energy carriers.

Exergy is the theoretically maximum amount of energy that can be converted into work as a system is brought into equilibrium with its environment. As such, the exergy of an energy carrier is always lower than its energy, and more significantly so when dealing with thermal fuels. Exergy-based allocation shall be used for combined heat and power generation (CHP), where electricity has a considerably higher exergy (comparable to its energy), compared to heat (for which exergy is a lot smaller than energy).

For all other multifunctional processes directly responsible for the (co)-production of energy carriers, such as multiple solid/liquid/gaseous thermal fuels, energy-based allocation on the basis of the fuels' respective lower heating values (LHV) shall be the preferred allocation metric. This is to limit unnecessary complexity where minimal differences in exergy/energy among co-products apply.

For multifunctional processes not directly responsible for the co-production of energy carriers, energy and exergy are not usable metrics. In this case **economic allocation** is recommended instead, even though economic allocation is the least preferred option in the allocation hierarchy of ISO 14044. Economic allocation opens the door to potential inconsistencies if/when the economic values of co-products change over time relative to one another, which may lead to market-induced distortions, i.e.: different shares of total emissions being assigned to each co-product, even if the actual physical process itself has not undergone any modifications. It is, however, almost universally adopted by most widely-used LCI databases (e.g. ecoinvent) when modelling non-energy co-products, and thus allows for consistent allocation between foreground and background models.

The full CLEVER methodology will include further information on handling of multifunctionalities for the different energy carrier pathways, as e. g. fossil fuel refineries are highly complex systems which might need a step-by-step allocation approach.

Finally, two specific cases of multifunctionality need to be mentioned and addressed:

1) Allocation of captured fossil carbon as a co-product of systems equipped with Carbon Capture and Utilization (CCU) equipment.

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[21] The renewable energy directive follows an attributional logic, apart from the credits given for avoided methane emissions from manure.

2) Allocation of biogenic carbon in multi-outputs (i.e. co-processing), covered in chapter 3.12.and 4.2.

If CO_2 from fossil fuel combustion is captured (e.g., at a power plant stack) and later "utilized" to produce a synthetic fuel, the captured CO_2 can only be accounted for as either (i) reducing the CO_2 emission intensity of the CCU-equipped emitter (e.g., as reduced GHG emissions assigned to the electricity generated by the power plant), or (ii) as a negative contribution to the GHG emission accounting along the (WtT) supply chain of the synthetic fuel, but not both. As a default assumption and in order to align with contemporary European legislation (specifically Delegated Regulation (EU) 2023/1185), it is assumed that the CO_2 producing process accounts for the EOL CO_2 emission (option II). For synthetic fuels the CO_2 emissions from fuel combustion can be considered carbon neutral (equivalent to a 100:0 system allocation between CO_2 producing – and CO_2 using product systems). After 2035 (in case of CO_2 from fossil fuel combustion in electricity generation), and 2040 (in case of CO_2 from other industrial processes listed / covered under the EU ETS[22]), respectively, the assumed carbon neutrality no longer applies, and EOL CO_2 emissions from fuel combustion are considered fossil and fully part of the fuels' lifecycle.

Special attention warrants the consideration of biogenic CO_2 removals, if/when they arise from CCU implemented at e.g. bio-ethanol production, where biogenic CO_2 is separated. If the bio-ethanol already claims the captured biogenic CO_2 emissions as a negative emission, then the subsequent CO_2 using process has to account for this biogenic CO_2 emission at EoL.

Since attributing the used CO_2 emissions to both product systems would constitute double counting, this is not allowed in CLEVER.

3.11 END-OF-LIFE

Most processes along the energy provision supply chain of an energy carrier produce waste. Waste outputs are not products. The waste flows themselves are therefore not assigned any emissions/impacts and are available for subsequent product systems burden free. Regarding allocation, waste flows shall be treated like other non-functional flows such as emissions. They shall therefore be partitioned between all co-products using the allocation rules set by CLEVER framework.

The partitioning of burdens and credits between a product system producing waste and the one using the waste needs to be addressed. While in theory, the end-of-life treatment such as recycling or waste disposal can be addressed like any multifunctional process, this is usually not practical. CLEVER therefore follows the methodological principles as defined in RED II (Directive (EU) 2018/2001) and RED III (Directive (EU) 2023/2413), according to which all waste flows shall be cut-off at the point of collection. This pertains also to the treatment of wastes, e.g. within waste incineration (European Commission, 2023).

While CLEVER follows the cut-off at the point of collection approach, there are other options as regards the handling of wastes. For example, the ecoinvent database uses the cut-off approach, as applied e.g. in the system model "allocation, cut-off by classification", where the primary production of a material is always allocated to the primary user. Here, it is distinguished between recyclable materials, for which an interest in

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[22] Directive 2003/87/EC

their collection exists, and waste products, for which there is no interest in their collection. These material types are treated differently regarding their allocation[23]:

- Recyclable materials leave the system boundaries at the point of their collection. The product system providing these recyclable materials shall not receive any credits or burdens from their recycling or further use. The product using recyclable materials shall only carry the burdens from their recycling (from collection onward, comparable to the RED approach described above).
- The treatment of waste products is included in the system boundaries of the waste-producing product system, which shall carry all the burdens. Co-products from waste treatment (e.g. heat or power from waste incineration) are available burden-free for subsequent product systems.

This difference for certain waste streams must be considered, when utilizing datasets from sources that consider a differentiation of waste streams (e.g. ecoinvent)[24].

CLEVER considers both waste products and recyclable materials to fall under the waste definition of the EU's Waste Framework Directive (Directive 2008/98/EC), where waste is defined as 'any substance or object which the holder discards or intends or is required to discard' (Art. 3 (1)) (European Parliament and Council, Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives, 2008). Key for classification of a material as waste is therefore primarily the intent to discard, or the act of (or requirement to) discarding said material, irrespective of the fate of the material or the subsequent treatment / handling. Waste can still have a positive market value (e.g. UCO) which can be closely linked to waste characteristics[25].

In many cases, the impact of End-of-Life modeling choices is relatively small. Whenever the input of secondary material and the output of recyclable material are similar to each other, the results resemble a closed-loop recycling approach.

Challenges of fraudulent practices in the European biofuels market with waste-based feedstocks

Waste-based biofuels, defined and mandated by the RED (more specifically within Annex IX, part a and part b) saw substantial growth within the European biofuels market, primarily due to their high emission saving potential. However, especially UCO (used cooking oil) and increasingly POME (palm oil mill effluent) as well as other waste-based feedstocks, mainly biogenic oils from industrial waste, sometimes also referred to as 'brown grease', are suspect to fraudulent practices, such as re-declaring virgin vegetable oil, such as palm oil, as waste. These challenges are especially pronounced when these feedstocks are imported from developing countries with limited market access for auditors. This has led to these feedstocks being heavily scrutinized in Europe in the last years, with some certification schemes assessing them as high risk. However, so far, no credible mitigation strategy to avoid criminal activities was

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[23] This distinction contrasts with Directive (EU) 2018/2001 and Directive (EU) 2023/2413, according to which all waste flows shall be cut off at the point of collection.

[24] However, this difference in EoL approach can be considered negligible for most datasets, with the exception of cases where secondary products from waste treatment play a substantial role.

[25] The positive market value is caused primarily by UCO's waste characteristics, making it applicable for different purposes.

successful. Special attention shall thus be paid regarding the credibility of waste-based feedstocks when they are subject of a CLEVER assessment.

3.12 ATTRIBUTION OF BIOGENIC CARBON IN MULTI-OUTPUTS

The attribution of biogenic carbon in multi-output systems shall be in line with the principles of Delegated Regulation (EU) 2023/1640 (European Comission, 2023).

If, within a process or process stage, both a fossil and a biogenic carbon source are used (e.g. during co-processing of fossil and biogenic intermediates/feedstocks within a shared process) and the product or products from this process contain carbon, the biogenic carbon shall be attributed to all resulting products in accordance with physical reality. To this end, the carbon content and origin of carbon shall be determined by measurement for all products from the process, while the total biogenic carbon amount in the products together with potential process losses (e.g. in the form of biogenic CO_2 emissions, solid wastes, wastewater etc.) shall equal the biogenic carbon fed to the process.

As a method of choice, the radiocarbon method (^{14}C) as outlined in **Delegated Regulation (EU) 2023/1640** shall be chosen as the main method[26]. Moreover, the exemptions regarding the choice of main testing method for the attribution of carbon laid out in Article 1 et seq. apply (European Comission, 2023).

3.13 HANDLING OF LAND USE AND LAND USE CHANGE

Both land use and land-use change can result in emissions. Land use describes the use of land to cultivate biomass (e.g. for the production of biofuels) and typical emission sources are NO_2 emissions from the use of fertilizers or emissions from organic soils, e.g. from the drainage of moors. Within CLEVER, emissions from LUC are thus part of general fuel production / feedstock provision.

The assessment of land-use change requires additional information on the nature of current and previous land utilization. When land is converted from one use form, defined and classified in land-use categories (for reference, see IPCC Good Practice Guidance for LULUCF, Chapter 2.2) to arable land/“cropland” for the purpose of producing biomass as feedstock for the production of biofuels, associated land-use change emissions shall be calculated and accounted for (IPCC, 2003).

In principle, two forms of land-use change are distinguished: direct land-use change (dLUC) and/or indirect land-use change (iLUC). Direct land-use change occurs if the change in use of land from one category to arable land/“cropland” occurs directly with the purpose of producing biofuels[27]. Indirect land-use change occurs, if the change in use of land from one category to arable land/[“cropland”] occurs as an indirect result, following an introduction/uptake or expansion of biomass cultivation for the purpose of biofuel production on already established arable land with the result that previous agricultural activities (e.g. for the production of food or feed crops) are displaced, leading to land-use change. For both, dLUC and/or iLUC, emissions

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[26] Article 6 of Delegated Regulation (EU) 2023/1640 specifies AMS – Accelerator Mass Spectrometry or LSC – Liquid Scintillation Counting as reference methods.

[27] In other words: the land where cultivation of biomass takes place is part of the system or within the system boundary.

occurring due to LUC are commonly annualized over a 20-year (dLUC) and 25-year (iLUC, following the CORSIA approach) time horizon[28].

Within the CLEVER framework, both dLUC and/or iLUC are assessed using a quantified approach[29], leading to specific emission factors that are part of the total CLEVER emission factor. If dLUC occurs, the respective emission factor EF_{dLUC} shall be grouped under the 'core' emission factor. If iLUC occurs, the respective emission factor EF_{iLUC} shall be reported separately, following the modularity concept.

If dLUC occurs, emissions shall be calculated based on current IPCC guidelines, more specifically Volume 4: Agriculture, Forestry and Other Land Use, 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019).

If fuel production leads to iLUC, geographic- and fuel-specific iLUC, should be applied, based on ICAO's CORSIA framework for aviation fuels, and SBTI Automotive Sector Net-Zero standard (Version 0.1, February 2026), for road- and marine fuels. Further guidance on the consideration of dLUC and iLUC are provided in chapter 4.3. If in the future, a different approach to the assessment of emissions/removals from iLUC will be the scientific and political consensus, the CLEVER framework will consider the consensus approach and adopt it if considered suitable for the context of CLEVER/*CountEmissions EU*.

3.14 LIFE CYCLE IMPACT ASSESSMENT (LCIA) METHODOLOGY

CLEVER GHG emission factors must include all relevant climate impacts from the provision and the use of the energy carriers in transportation. The scope is limited to the impact category of "Climate Change" (at midpoint level). At its core, any CLEVER assessment must include all climate impacts given in the latest IPCC guidelines[30] using the GWP_{100} (global warming potential with a 100-year perspective without feedback) since it is the most widely used and accepted metric. In addition, a GWP_{100} factor for hydrogen of 11.6 kg CO_2 e/kg (Warwick, et al., 2022; Ocko & Hamburg, 2022; European Commission, et al., 2022) should be used, as this GHG will probably be added in the next IPCC assessment report. Other metrics may also be used in addition (e. g. the GWP_{20} with a 20-year timeframe or the GTP_{100}).

Any CLEVER assessment must not only assess the GWP_{100} but also list the main greenhouse gas components individually, which covers carbon dioxide (fossil and biogenic), methane (biogenic and fossil) and nitrous oxide (biogenic and fossil) as well as hydrogen. As CLEVER always accounts for the full oxidation of all carbon in the fuel, operational methane emissions from fossil fuel pathways may be characterised using the factor for biogenic methane.

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[28] Corresponding to utilizing IPCC's Tier 1 approach, in other words: total LUC related emissions are spread over a 20y period, with each year being attributed 1/20 of total emissions. For example, if LUC occurred in 2010, all sourced biomass from this land will be attributed respective emissions / removals until 2030.

[29] As alternative to quantifying LUC contributions, a risk-based assessment of feedstocks and subsequent exclusion of specific feedstocks assessed as high-LUC risk exists and is utilized e.g. within the EC's Renewable Energy Directive (Directive (EC) 2001/2018)

[30] IPCC, 2023: *Climate Change 2023: Synthesis Report.* Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115, doi: 10.59327/IPCC/AR6-9789291691647.

In addition to the core GHG emission factors, a CLEVER assessment should also include climate impacts not directly linked to the classical greenhouse gases, including those from high altitude emissions of airplanes as well as black carbon emissions.

Handling of biogenic carbon

For biogenic carbon dioxide a -1/+1 accounting method is chosen. Thus, carbon uptake must be recorded as a negative CO_2 emission, whereas the carbon release during the fuel combustion must be recorded as a positive CO_2 emission. Any CLEVER assessment thus shall characterize the removal of CO_2 and uptake within biomass as -1 kg $CO2_2$-eq./ 1 kg $CO_{2,\ biogenic}$. When biogenic carbon is released, emissions of biogenic CO_2 shall be characterized as +1 kg CO_2 / 1 kg $CO_{2,\ biogenic}$.

However, for biofuels, as well as e-fuels using carbon dioxide from direct air capture, the uptake and the subsequent release of the carbon dioxide cancel each other out when looking at the full energy carrier lifecycle. Uptake and emissions of biogenic carbon dioxide should also be reported separately from the other greenhouse gases, to ensure that the factors can be used for reporting according to the Corporate Sustainability Reporting Directive (CSRD), which mandates to report biogenic carbon dioxide separately while otherwise following the carbon neutral approach, as well as other reporting programs that require this information. Biogenic methane (CH_4) and biogenic nitrous oxides (N_2O) have a GWP and thus have to be considered as part of the overall emission factor[31]. Consideration of permanent biogenic carbon dioxide removals is outlined in the following chapter.

Generally, this approach assumes that any carbon dioxide emitted is balanced out by an uptake of carbon dioxide from the atmosphere in a timely fashion. While this is true for short-lived biomass (e.g., from crops), this might not be true for wood or other perennial biomass sources, as it takes considerable time for a tree to grow and to store the carbon dioxide. In the future, the general assumption of biogenic carbon neutrality may be adjusted and other characterization approaches from a dynamic LCA may be used to account for the possible temporal imbalances between biomass growth (and carbon uptake) to harvesting and use (and corresponding carbon dioxide emissions).

Handling of carbon dioxide removals

Carbon dioxide removals may only be considered if they are directly and physically linked to the fuel production process. This can entail carbon dioxide uptake by plant growth via synthesis or direct air capture (DAC) of CO_2. Here, the fuel itself acts as a (short-term)[32] carbon sink, with corresponding carbon dioxide release when the fuel is converted/used/utilized. Overall, both these options do not result in a net carbon removal with respect to the carbon within the fuel, but a neutral carbon balance. A second option for carbon dioxide removals to be applicable within the CLEVER framework pertains to permanent carbon dioxide removed and stored via CCS (carbon capture and storage) that would otherwise have been emitted (e.g. as

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[31] As the full oxidation of the carbon in the fuel is included in the operational CO_2 emissions, the characterisation factor for biogenic CH_4 may be used for combustion emissions of fossil fuels.

[32] Since the carbon is sequestered within a fuel, no intermediate nor long-term storage are commonly assumed and thus, no storage effects of this sink may be considered within the GHG emission calculation, irrespective of the origin of the carbon. For reference, see chapter 4.4.

part of the production process). If this carbon is stored in a permanent technical sink (for 100 years or more, with any losses accounted for), and it is biogenic in its origin, it may be counted as a negative emission (-1 kg C / kg $C_{biogenic}$ removed). Besides real carbon dioxide removals described above, no carbon offsetting/ compensation shall be considered when calculating CLEVER GHG emission factors. Chapter 4.4 provides additional information on provisions and handling of permanent carbon removals and delayed emissions.

Example: Bio-methane

To illustrate the handling of biogenic carbon dioxide emissions or removals, consider bio-methane. Firstly, during the plant's growth, carbon dioxide is removed from the atmosphere, resulting in – 3.67 kg CO_2/ kg C sequestered. Secondly, during combustion, the biogenic carbon within the bio-methane is oxidized to CO_2, resulting in + 3.67 kg CO_2/ $C_{in\ bio\text{-}methane}$. If there are no direct fugitive methane emissions from slippage or leakage, the resulting carbon dioxide emissions would thus be zero. If methane leakage or slippage occurs, this results in an operational CH_4 emission with a respective GWP, resulting in a net-positive emission even if the carbon dioxide removal is included. If, during production of bio-methane from biogas, the separated biogenic carbon dioxide[33] is stored permanently (over at least 100 years) via carbon capture and storage (CCS), the amount of separated and sequestered biogenic carbon dioxide leads to a net-negative emission, lowering the emission factor of the bio-methane.

In general, double counting of potential carbon dioxide removals must be avoided and special attention should be paid for the calculation of CLEVER compliant values. This pertains, in particular, to carbon dioxide removals that are claimed by any third-party involved within the carbon dioxide removing process for regulatory compliance. These removals shall either be attributed to the CO_2 producing process or to the fuel producing process, but cannot be counted twice (for reference, see chapter 3.14).

3.15 RESULT PRESENTATION

Results (and their interpretation) shall be reflective of the goal and scope of the assessment and the specific pathway under investigation. Moreover, they shall consider any limitations and assumptions made and cannot make any generalized claim regarding the environmental impact beyond the impact on climate change. Furthermore, the interpretation of results shall also reflect on the data quality, appropriateness and completeness as well as the influence of potential cut-offs.

Whenever a result of a CLEVER assessment is communicated, it must include all information on the chosen energy carrier pathway as well as the usage (vehicle/vessel type and engine/aftertreatment, if relevant) and shall be given per MJ of fuel consumed. In addition, results for alternative units such as kg, m^3 or L of fuel may also be given.

Results shall always be given in the following format:

$$EF_{Total} = EF_{Core} + EF_{iLUC} + EF_{ACI}$$

with EF_{Total} constituting the total CLEVER GHG emission factor

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[33] Biogas consists of both methane and carbon dioxide, whereas vehicles and vessels usually need "pure" bio-methane.

with EF_{Core} including all GHG emissions and processes inside of the system boundary (apart from iLUC and additional climate impacts)

with EF_{iLUC} representing contributions from iLUC (indirect land use change)

with EF_{ACI} representing additional climate impacts (divided into impacts of hydrogen $EF_{Hydrogen}$, impacts from high altitude emissions of airplanes EF_{HAE}, and black carbon EF_{BC})

The core GHG emission factor can also be broken down further, to enable impacts from energy provision infrastructure or direct land use change to be given separately, as this enhances the transparency and may facilitate comparisons with other methodologies (e.g., energy infrastructure emissions are part of the "core" in CLEVER, but they are excluded in RED).

Both the total GHG emissions (formerly also called Well-to-Wheel, $EF_{Total\ WTW}$) and the energy provision GHG emissions (formerly called well-to-tank, $EF_{Total,WtT}$) as well as the operational GHG emissions (formerly called Tank-to-Wheel, $EF_{Total,TtW}$) shall be reported.

In addition to the GWP100 following the latest IPCC guideline, the operational GHG emissions of the main greenhouse gases (carbon dioxide, methane and nitrous oxide) shall also be reported separately and the used characterisation factors (or their source) shall be clearly stated.

Any result presentation thus includes values for the following:

- Information on energy carrier pathway and usage[34]
- Information on data quality
- Lower heating value (MJ/kg)
- Density (kg/L), for liquid fuels only
- Overall data quality rating (see chapter 3.7)
- GHG emissions total ($EF_{total,\ WTW}$) (g CO_2 e/MJ)
- GHG emissions energy provision ($EF_{total,\ WTT}$) (g CO_2 e/MJ)
- GHG emissions operational ($EF_{total,\ TTW}$) (g CO_2 e/MJ)
- GHG emissions operational from CO_2 (g CO_2 e/MJ)
- GHG emissions operational from CH_4 (g CO_2 e/MJ)
- GHG emissions operational from N_2O (g CO_2 e/MJ)
- GHG emissions operational from H_2 (g CO_2 e/MJ)
- CO_2 emissions operational from biogenic CO_2 (g CO_2/MJ)
- GHG emissions total from H_2 (EF_{H2}) (g CO_2 e/MJ)
- Climate impacts total from iLUC (EF_{iLUC}) (g CO_2 e/MJ), from energy provision only
- Climate impacts total from black carbon (EF_{BC}) (g CO_2 e/MJ), from operation only (optional)
- Climate impacts total from high altitude emissions (EF_{HAE}) (g CO_2 e/MJ), from operation only (optional)

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[34] More detailed requirements for the presentation of the information on energy carrier pathway and usage will be included into the full CLEVER framework.

This leads to the following complete formula:

$$EF_{total,WTW} = EF_{energy\ provision\ core} + EF_{iLUC} + EF_{TTW.CO2} + EF_{TTW,CH4} + EF_{TTW,N2O} + EF_{TTW.H2} + EF_{TTW,HAE} + EF_{TTW.BC}$$

Following ISO 14083:2023, any GHG emission factor shall be complemented by further information on the density (for liquid fuels) as well as the lower heating value (for gaseous and liquid) fuels as well as the information given in the reporting (ISO, 2023). Chapter 4.1 provides further detail.

3.16 INTERPRETATION OF RESULTS

Interpretation of LCIA results constitutes the synthesis of inventory analysis and impact assessment and findings/results are translated into conclusions. In accordance with ISO 14040/44:2006, any CLEVER assessment shall interpret resulting emission factors systematically, transparently and consistently against the background of the defined goal, scope and functionality of the assessment. No conclusions may be drawn as regards pathways not subject of /under investigation.

The interpretation of results serves the purpose of identifying significant / substantial contributions ("hotspots, e.g. operational emissions for conventionally fuelled ICE drivetrains, fuel provision in case of renewable alternatives). Moreover, the interpretation shall serve as evaluation of robustness, completeness and methodological consistency as regards goal and applied methods. Furthermore, the interpretation must clearly state limitations, such as data gaps (e.g., limited primary data for subcontracted carriers), methodological constraints (e.g., choice of impact assessment method), temporal or geographical representativeness, or exclusion of certain life cycle stages. In addition, uncertainties shall be assessed. Conclusions drawn and recommendations shall consider the above and moreover be in line with the stated goal and shall be supported by the findings of the CLEVER assessment.

It is important to note that GHG emission factors calculated according to the CLEVER methodology cannot be used as a stand-alone metric to compare the climate impacts of transportation.

3.17 REPORTING REQUIREMENTS

When calculating a CLEVER GHG emission factor, a comprehensive and transparent report shall be produced to provide additional information on how the factors were derived. The aim of the report shall be, firstly, to demonstrate compliance with the applied CLEVER framework and, secondly, to describe the pathway under study and additionally document and inform about all relevant aspects pertaining – in particular – to the applied methodological approach and methodological decisions taken as well as disclose and provide information on utilized data and its data quality.

As a basis, the items listed above from chapter 3.1 to 3.15 shall be addressed within any reporting that follows the CLEVER framework. Furthermore, if compliance is sought also with ISO 14067:2018, cross-reference with Chapter 7 (in particular section 7.3) of ISO 14067:2018, regarding reporting requirements is advised (ISO, 2018).

Further reporting requirements are given in the chapter 4.7.

4 GENERAL METHODOLOGICAL CONSIDERATIONS

Building on the previous chapters on goal and scope, this chapter provides additional methodological considerations. It includes:

- An overview and a guidance of the different life cycle stages (including the full CLEVER formula)
- Pathway-specific system boundaries
- Further guidance on handling of land-use change
- Guidance on handling of temporal storages or delayed emissions
- Provisions for calculation of fuel and electricity mixes
- Guidance on operational emissions
- Detailed reporting requirements

4.1 OVERVIEW AND GUIDANCE ON DIFFERENT LIFE CYCLE STAGES

The CLEVER framework focuses on fuels and transport sector energy carriers, considering all lifecycle stages from well to wheel/wake (thus covering the total GHG emissions). The overall scope of CLEVER can be subdivided into further components, *upstream or energy provision (well to tank),* where fuel / energy provision is covered, and *downstream or operational emissions (tank to wheel/wake),* where the operational emissions from use of the energy carriers (or sometimes auxiliaries) in a vehicle are covered. Core elements of both upstream and downstream life cycle steps are described in the following:

Upstream Emissions (WtT)

- Feedstock provision (Resource extraction and feedstock cultivation): This stage comprises all upstream processes associated with resource extraction as well as biomass feedstock production, including seed and planting material supply, land occupation and land-use change (direct and indirect, where applicable), and the production and application of fertilizers and other agricultural inputs. It also further includes feedstock transformation (e.g. rapeseed → oil mill → rapeseed oil)
- Transport (to market): This stage covers the transport of feedstock or intermediates from the point of extraction / production to the conversion facility in the target market. It includes fuel combustion and upstream fuel supply emissions for all the relevant transport modes. Emissions from these activities are included within the well-to-tank emission factors.
- Fuel production (fuel processing / conversion): This step convers emissions arising from the conversion of feedstock into fuel or energy carrier (e.g. from rapeseed oil to FAME). It includes emissions associated with process energy consumption (electricity, heat, auxiliary fuels), material inputs, and direct process emissions such as methane leakage or N_2O.
- Fuel storage, transport, and distribution: This stage covers emissions associated with the storage, transport and distribution of the final fuel to the point of use. It includes energy consumption and losses occurring within the distribution system.

Downstream Emissions (TtW)

- Operational emissions: The emissions occurring during the final use of the fuel, e.g. from combustion or conversion to mechanical energy. Further guidance on operational emissions can be found in chapter 4.6.

Annotated formula

In general, any emission factor calculated following the CLEVER framework consists of a core emission factor and additional components. While the inclusion of an iLUC emission factor is mandatory (unless iLUC did not take place), black carbon and high-altitude emissions are optional (but strongly encouraged due to their high relevance) (see also chapter 3.15).

The total emission factor entails all relevant life cycle emissions and removals associated with the investigated pathway beyond iLUC, and shall be further subdivided into *operational emissions* $EF_{operational}$ (including biogenic CO₂ emissions, see chapter 3.14) and emissions from *energy provision* $EF_{energy\ provision}$ (Equation 4).

Equation 4 Subdivision of total emission factor (mandatory)

$$EF_{total} = EF_{energy\ provision\ core} + EF_{iLUC} + EF_{operational} + EF_{ACI\ (optional)}$$

A mandatory break-down of the operational emissions into the different GHG components is shown in Equation 5.

Equation 5 Subdivision of core emission factor (operational) (mandatory)

$$EF_{operational} = EF_{TTW.CO2} + EF_{TTW,CH4} + EF_{TTW,N2O} + EF_{TTW,H2}$$

The emission factor $EF_{energy\ provision}$. comprises all life cycle emissions and removals associated with the supply of the used fuel / energy carrier to the point of utilization within a vehicle/vessel, including emissions from resource extraction or cultivation (including dLUC, see chapter 4.3), including pre-treatment steps (EF_{Re}), transport emissions to the market (EF_{TR}), emissions from processing/conversion (EF_{Con}), emission from fuel storage, transport and distribution (EF_{Dis}). Emissions from energy provision infrastructure (EF_{Infr}) or direct land use change (EF_{dLUC}) may also be given as separate terms. Thus, the energy provision emissions may be broken down as shown in Equation 6.

Equation 6 Subdivision of core emission factor for energy provision (optional)

$$EF_{energy\ provision\ core} = EF_{Re} + EF_{Tr} + EF_{Con} + EF_{Dis} + EF_{Infr} + EF_{dLUC}$$

4.2 SPECIAL CONSIDERATIONS FOR SYSTEM BOUNDARIES FOR DIFFERENT ENERGY CARRIER PATHWAYS

The CLEVER methodology adopts a "Well-to-Wheel/Wake" approach, encompassing all processes from the extraction of raw materials to the final use of the fuel in the vehicle or vessel. The system boundary is divided into two main stages: the Well-to-Tank (WtT) phase, which covers fuel production and distribution, and the Tank-to-Wheel/Wake (TtW) phase, which accounts for the combustion or usage of the fuel on board. The focus is primarily on the WtT phase due to the need to determine the emission factors of the energy carriers via this methodology, while TtW emissions are handled separately based on the fuel's carbon content and engine performance.

The system boundary strictly follows an attributional approach, accounting for physically connected flows of energy and materials. This methodology excludes indirect effects such as infrastructure construction (e.g. for roads or railway tracks), capital goods (e.g. vehicle manufacturing), and employee commuting, consistent with the system boundary of ISO 14083:2023. A list of key inclusions and exclusions can be found in chapter 3.5.

The following section presents a detailed overview of the system boundary considerations for each key energy carrier / fuel category used in transport. While the general WtT principles apply universally, certain pathways necessitate specific boundary definitions to account for unique feedstock characteristics, process complexities or co-product management. These distinctions are critical for ensuring accurate attributional accounting and comparability across diverse fuel types.

Fossil fuel pathways (i.e. Diesel, Gasoline, Kerosene, LNG, Hydrogen)

For fossil-based pathways, the system boundary begins at the point of raw material extraction (e.g. crude oil wellhead, natural gas well) and ends at fuel use within a vehicle. It includes all venting, flaring and fugitive emissions associated with extraction, processing and (pipeline) transport.

More specifically,

a) **Feedstock provision:** This stage encompasses all activities associated with the discovery and recovery of raw hydrocarbons. While emissions from capital good production (e.g. wells, rigs, pipelines) may be excluded due to their minor contribution to overall emissions (using a cut-off), in particular methane emissions from venting and flaring, or leakages can have substantial influence on overall emissions from fossil fuels, thus warranting special attention / consideration when assessing fossil fuels. Moreover, key emission sources during the acquisition of fossil fuels may arise from energy consumption during feedstock production. This includes fuel consumed during exploration and drilling operations, as well as the energy required for extraction (lifting via pumps) and initial separation of oil, gas, and water at the wellhead as well as efforts associated with Enhanced Oil Recovery (EOR) processes, such as steam or CO_2 injection.

b) **Fuel production**: The boundary encompasses the entire refinery or processing plant operation, including, in particular, energy consumption for different refinery processes and provision of process materials. The specific conversion route for each refinery product is specific to each product, the technical / chemical propositions and characteristics as well as market demand. Key energy demanding processes are distillation steps (both atmospheric and vacuum distillation), cracking and reforming processes of fossil intermediates and upgrading processes, in particular desulfurisation (hydrotreatment), as well as auxiliary processes, such as e.g. cooling and pumping. Hydrogen inputs for desulfurisation are included within the refinery boundary, e.g. as a by-product of the reforming process to produce gasoline or other refinery-internal sources. In case internal sources do not meet consumption, hydrogen is commonly produced via SMR of methane and thus added as an additional upstream burden. Emissions attributable to the conventional and alternative sources of hydrogen utilised in refining and upgrading the distillation cuts also need to be accounted for when considering emissions from refining processes. In addition to hydrogen supply, process energy in form of electricity, heat and steam are required – dependent on the fossil product at hand. Considering the fact that the integrated energy provision systems commonly associated with petrochemical refineries are based on the thermal recovery of fossil co-products or wastes, emissions from the refinery energy supply substantially influence / determine refining emissions. Refinery complexity (and market demand) usually determines specific consumption rates, but crude oil qualities[35] also play a significant role. All auxiliary utilities, including onsite or imported electricity, steam generation, cooling water systems, and wastewater treatment, shall be accounted for, as are emissions from refinery flaring and venting.

Methodological attention shall be paid as regards the multifunctionality of refineries. For multi-product systems like refineries that consist of a series of multifunctional individual processes, emission accounting requires a suitable allocation method that allows for a stringent attribution of emissions to all refinery products in line with overall allocation principles of CLEVER. Emissions shall be allocated to energy-dense co-products (gasoline, diesel, jet fuel, LPG, petrochemical feedstocks) using energy allocation based on lower heating value (LHV) on a process step by process step basis, with clear justification per ISO 14044:2006 hierarchy. Special consideration shall be paid to the allocation of upstream burdens associated with refinery internal intermediates (e.g. vacuum gas oil) to all resulting products, including both, co-products and bottoms, while process step emissions should be allocated to intended co-products only, in line with overall CLEVER provisions. Catalyst production and use (e.g. zeolites for cracking, nickel-molybdenum for hydrotreating) are included if contributing >1% of total WtT emissions, as per the cut-off criteria set in chapter 3.5.

c) **Transport & Distribution:** All emissions from the transport of crude oil or natural gas to the refinery (via tanker, pipeline, rail) and the subsequent transport to fuel depots and final distribution of finished fuels to the refuelling station or bunkering facility are part of the CLEVER system boundary. This encompasses fuel consumption by a flexible combination of ocean-going tankers, pipeline compressors, rail locomotives, barges and road tankers, as well as fugitive emissions from product loading/unloading operations (volatile organic compounds) and methane slip and storage losses / emissions. For marine fuels, the boundary includes fuel conditioning and heating losses at bunkering terminals, particularly for high-viscosity fuels such as heavy fuel oil (HFO). Storage losses from evaporative emissions at distribution terminals are included, where significant.

d) **Fuel use and emissions from fuel combustion**

All direct emissions from the combustion of refined fossil fuels (e.g. gasoline, diesel, jet fuel, bunker fuels, natural gas, liquefied petroleum gas) in end-use applications are included. This covers, (among others) combustion-related CO_2, CH_4 and N_2O generated in engines, turbines, boilers, heaters and other energy-conversion equipment, as defined in chapter 4.6. The boundary includes losses or leakages while stored in the vehicle tank / storage systems, but excludes upstream emissions already accounted for in the fuel production and transport stages. For further information, see chapter 4.6.

Key considerations:

- **Energy provision**: Where energy (electricity, steam, heat) is consumed in upstream extraction, refining or transport / pipeline operations, fossil fuel production commonly utilizes a proportion of the respective fuel for the provision of energy, e.g. natural gas is used to provide the pressure in pipelines, or fossil co-products / residues (off-gases, petroleum coke) are utilized to produce electricity, heat

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[35] Commonly assessed using the parameters API density and sulphur content.

and steam in refineries. For refineries with combined heat and power (CHP) generation, allocation between electricity and steam follows energy allocation principles presented in chapter 3.10.

- **Fugitive emissions, emissions from venting and flaring:** Current scientific analysis show that emissions consisting of methane losses (e.g. from venting, fugitive losses from leakages) as well as emissions from flaring both contribute substantially to upstream fossil fuel emissions. These effects are technology and country-specific, owing to the differences in extraction methods used, infrastructure conditions and maintenance and other factors. Following this, special consideration shall be paid as regards the contribution of this emission source in general, as well as the use of technology/region-specific data. Where available, regional-, technology- or actual values measured by the economic operators within the value chain shall be used. In the absence of specific data, conservative assumptions shall be taken.
- **Carbon Capture and Storage (CCS) & Carbon Recycling:** For pathways involving CCS (Blue H_2) or CCU (e-Fuels), the system boundary is defined by the permanence of storage (see chapter 4.4). The boundary ends at the point of injection into the geological formation. Monitoring energy is excluded unless significant.

Biogenic pathways (i.e., Liquid and gaseous biofuels incl. co-processing in refineries)

The system boundary for biogenic pathways starts at the cultivation of biomass or the collection of waste/residues, encompassing all upstream agricultural/collection activities and possible pre-treatment steps, transports, biomass conversion / processing, and fuel transport, storage and distribution. Final utilisation of the fuel within a vehicle constitutes the end of the system boundary. The following describes the most important aspects for bio-based pathways.

a) **Feedstock provision:**

- **Cultivation (Crops):** For crop-based fuels (e.g. corn ethanol, rapeseed biodiesel), the boundary includes emissions from fertiliser and pesticide production and use, machinery use on the farm, irrigation energy and direct soil emissions (N_2O) from fertilizer application. As N_2O is a potent GHG, crop cultivation with high demand in N-fertilizer are particular sensitive to agroeconomic conditions. In addition, emissions from land use-change shall be considered in accordance with the provisions in chapter 3.13 and chapter 4.3

- **Collection (Residues/Waste):** For residues (e.g. straw, used cooking oil (UCO), manure), the boundary begins at the point of collection. The upstream burden of producing the residue (e.g. growing the wheat for straw, cooking the food for UCO) is excluded ("zero burden" at the farm gate/source), as specified in chapter 3.11. Collection energy (gathering from dispersed sources, transport to aggregation points) and any pre-processing (baling, chipping, cleaning) are fully included.

- **Pre-treatment:** Some biogenic pathways require pre-treatment steps, such as e.g. drying or milling. Energy and process expenditures shall be accounted for, as shall be their respective upstream burdens for their provision. Pre-treatment steps can result in multiple co-products: In the rapeseed oil production pathway, co-products such as rapeseed meal used as animal feed are generated during oil extraction. Consequently, the environmental burdens of the process must be allocated between rapeseed oil and the co-product.

b) **Fuel production:** This stage covers the conversion of biogenic intermediates to biofuels, e.g. in biorefinery processes, including fermentation (ethanol), transesterification (FAME/biodiesel), anaerobic digestion (biomethane), hydrotreating (HVO) and biogas upgrading. Some more novel biofuel pathways, in particular utilizing advanced feedstocks also include gasification (e.g. to produce pyrolysis oils) or co-processing in petrochemical refineries. All process energy (heat, steam, electricity, chemicals) is included, with special attention as regards the energy provision, since many biogenic conversion pathways utilize a proportion of the biomass to generate the required process energy (e.g. during biogas / biomethane production, or in the case of bioethanol from sugarcane / bagasse). Auxiliary inputs, including enzyme production (for cellulosic ethanol), methanol and catalyst (transesterification) and hydrogen (HVO processing), are accounted for as upstream burdens. Emissions from methane slip (particularly from biogas upgrading membranes or pressure swing adsorption units), wastewater treatment and refinery flaring/venting shall be included. During fuel production / conversion, multiple co-products may be generated. These are subject to allocation in accordance with chapter 3.10. Special consideration shall be paid regarding the attribution of biogenic carbon in all output fractions from co-processing (see chapter 3.12).

c) **Transportation & Distribution:** Includes transport of biomass or other feedstocks from collection points (e.g., farms, forests, waste facilities) to the feedstock-conversion or biorefinery site via truck, rail, barge or pipeline. This covers fuel consumption and associated GHG emissions from all transport modes, as well as any pre-treatment or conditioning steps required prior to conversion into fuel. For gaseous or volatile feedstocks, fugitive emissions occurring during loading, unloading, temporary storage and compression at collection or transfer points are included using appropriate emission factors, where significant. This also includes transport of final fuel from the production plant to the refuelling/bunkering facility via truck, rail, barge or pipeline. For biomethane distributed via natural gas grids, fugitive methane emissions from compression stations, distribution pipelines and vehicle refuelling infrastructure shall be considered using region-specific leakage factors, where available. Storage losses from evaporative emissions at distribution terminals are to be included, where significant.

d) **Fuel use and emissions from fuel combustion:** For biogenic fuels, the fuel use and combustion stage covers all direct emissions released when the fuel is combusted in end-use applications (e.g. road, rail, aviation, shipping or power generation). The boundary includes operational combustion emissions at the point of use, typically expressed per unit of energy delivered (e.g. per MJ or per km/ton-km). CO_2 released from the oxidation of the carbon content of the fuel, split into:

   - Biogenic CO_2 (from carbon originally captured during biomass growth), which shall be considered to offset carbon dioxide uptake during plant growth (for reference, see chapter 3.14);
   - Fossil-derived CO_2 (e.g. from fossil-based additives, fossil-CO_2 feedstocks or upstream process emissions), which is fully included in the fuel-pathway GHG balance.

Key Considerations:

– **Biogenic CO_2 uptake** during biomass growth and subsequent **release** during fuel combustion are counted as zero net emissions, following a ±1 accounting approach (see chapter 3.14). However, all non-CO_2 greenhouse gases (biogenic CH_4 from anaerobic decomposition, N_2O from fertilizer/digestate application) are fully accounted for using 100-year global warming potentials (GWP_{100}) from the latest IPCC assessment report (AR6 at time of publication).

- **Land-use change** is treated as a decisive factor for crop-based biofuels, with direct and indirect impacts either explicitly modelled or represented via default factors. No credits are granted for avoided emissions or system-expansion effects; only the incremental burdens on the biofuel pathway are accounted for**.**
- **Burden allocation** across co-products and excess energy (e.g. glycerol, lignin, heat or power) follows a consistent, transparent criterion (e.g. energy content or economic value). For fossil-based methanol in FAME production, the system boundary requires either counting the upstream fossil-carbon as fossil-derived CO_2 within the fuel pathway or recognising that part of the fuel has a fossil origin, in line with RED-type practice and with internal consistency across the deliverable.

Handling of co-processing of biofuels in refineries

When assessing biofuels from co-processing of biogenic feedstocks / intermediates in petrochemical refineries the following aspects warrant special consideration:

- **Biogenic feedstock / intermediate:** These need to be considered in terms of their specific provision, with different biomass sources resulting in different GHG intensities, e.g. depending on the biomass origin (i.e. crop based vs. waste based) or need for pre-treatment (e.g. stabilized pyrolysis oils that are mildly hydrotreated before entering the refinery) or transport distances. Moreover, biogenic intermediates / feedstocks differ in terms of their chemical properties and characteristics, compared to fossil crude oil, influencing both refinery integration at large and specific gate-to-gate processing emissions.
- **Robust / realistic assumptions as regards the potential of biomass integration within a refinery:** Petrochemical refineries are specialized to process crude oil, and considering the differences in chemical properties between fossil and biogenic intermediates, co-processing commonly is limited or requires modification to the refinery infrastructure / process operations.
- **Biogenic intermediates** may differ from fossil ones in terms of the specific mass- and energy-balances, even when sharing a conversion unit. The differences of chemical properties can result in additional energy or hydrogen demand or reduced conversion efficiency / yields, resulting in the need of separate mass- and energy- balances to allow for the specific attribution to bio-products from co-processing. If co-processing leads to an increased hydrogen demand, this might result in an additional external hydrogen production that needs to be considered.
- **Biogenic carbon** follows general carbon streams within a petrochemical refinery, resulting in biogenic fractions in all output-streams, both intended (e.g. fuels) and non-intended (e.g. off-gases, bottoms). Where biogenic carbon enters the refinery internal energy provision, following the combustion of bottom products or off-gases, resulting emissions are biogenic CO_2.
- **Tracking of biogenic carbon:** CLEVER, in line with Delegated Regulation (EU) 2023/1640, mandates ^{14}C or a comparable method to track the fate of biogenic carbon among refinery / process outputs. No other allocation metric or mass-balancing apply.

E-Fuels (incl. RFNBOs)

For synthetic fuels (e-Hydrogen, e-Methanol, e-Kerosene), the system boundary starts with the **provision of (renewable) electricity** . Final use of fuel onboard a vehicle constitutes the end of the system boundary.

While general provisions regarding electricity production are included further below, this section considers electricity only as one aspect.

a) **Feedstock provision**

- **Renewable Electricity**: This stage, for renewable electricity generation, includes activities covering the manufacturing, installation, operation, maintenance and decommissioning of dedicated renewable assets (wind turbines, solar PV, hydroelectric facilities). Since commonly, renewable electricity generation does not result in direct fossil emissions, infrastructure provision constitutes a key aspect. If a direct connection to a dedicated renewable asset is claimed, the boundary is limited to that specific asset, provided temporal correlation (hourly or monthly matching between generation and electrolyser operation), geographic correlation, and additionality (new capacity commissioned within 36 months of electrolyzer operation) criteria per RFNBO Delegated Regulation (EU 2023/1185) are met. Consistent with CLEVER's broader scope beyond RED II/RED III regulatory categories, e-fuel pathways must be modelled using actual or representative electricity-supply mixes, including non-renewable components where applicable, rather than assuming exclusive RE-electricity by default. For transparency, dual reporting (dual accounting) is recommended:
    - A primary result based on grid-or-mix-electricity intensities;
    - An alternative value reflecting a lower-carbon electricity-supply scenario (e.g. PPA-linked or RE-only, where corresponding certificates were acquired) that can be reported alongside the first, but without displacing it as the default.
- **Grid Electricity**: If grid electricity is drawn, e.g., when dedicated renewables are unavailable, or if e-fuels are produced using non-renewable electricity (e.g. fossil-based or low-renewable grid mix), the average grid carbon intensity for the specific region and time period applies, depending on the chosen methodological assumptions. This includes emissions from all grid-mix generation technologies, transmission and distribution losses.

RFNBO-specific electricity conditions in EU legislation:

Under the EU Renewable Energy Directive (RED II/RED III), renewable liquid and gaseous fuels of non-biological origin (RFNBOs) – including many e-fuels – can only count as renewable if their electricity input meets strict criteria. Key conditions include: Renewable origin, temporal correlation, geographical correlation, additionality and GHG-saving threshold. These criteria will be specified in the ANNEX (final version). These conditions narrowly define "RFNBOs" as a category. Is it crucial to note that CLEVER convers all e-fuel pathways, including those that do not meet the Regulation EU 2023/1185 definition for RFNBO (i.e., those using non-renewable or mixed sources of electricity) by applying consistent GHG accounting rules across the entire supply chain

- **Hydrogen:** Hydrogen for e-fuel production may be sourced through water electrolysis using renewable electricity or through fossil-based routes such as steam methane reforming[36] of natural gas or biomass gasification. CLEVER methodology accounts for all possible sources of hydrogen production, appending the upstream production emissions to the fuel's GHG calculation, irrespective of regional production or imports from outside the EU. While the CLEVER default parameters assume EU-based production of e-fuels, the actual GHG intensity of pathways involving externally sourced hydrogen can differ significantly due to upstream conditions and long-distance transport. Therefore, where e-fuels are sourced globally, the fuels' GHG calculations shall also consider non-EU supply chains accounting for representative transport stages and local conditions (i.e., electricity mix modelling, energy intensity of H2 production processes etc) to reflect real-world variability in emissions.

- **Carbon (CO_2):** While not all e-fuels / RFNBOs require carbon, for pathways where carbon is required, the provision can substantially influence results. In particular, energy for capturing, compressing and transporting CO_2 shall be considered. If the CO_2 is from Direct Air Capture (DAC), it enters the boundary as a feedstock with no upstream carbon burden. If fossil or biogenic CO_2 is used, the burdens of final emission of CO_2 shall be allocated to product system that is responsible for its' existence in the first place ("polluter pays" principle), but the impacts associated with capture/transport of the feedstock are allocated to the fuel. In line with provisions of RED II / RED III and the RFNBO Delegated Regulation (EU 2023/1185), fossil CO_2 is treated as 'carbon-neutral' feedstock only up to 2036 (i.e., from fossil-electricity sources) and 2041 (i.e., from other industrial sources). After these dates, fossil CO_2 must be fully included in the fuel's GHG emission calculation. For a pathway to qualify as an RFNBO, the fossil CO_2 must not have had a prior use; otherwise, it is classified as a "recycled carbon fuels" (RCF, see further below).

- **Nitrogen (for green ammonia):** For e-ammonia synthesis via the Haber-Bosch process, the system boundary includes in particular the air separation unit (ASU), and energy for nitrogen extraction via cryogenic separation or pressure swing adsorption (PSA).

b) **Fuel Production:** The boundary settings for each of the relevant e-fuel pathways are listed below.

- **Electrolysis**: (H_2 production): The main processes in water electrolysis are: Supplying water and renewable- or grid- electricity to an electrolyser, splitting water into hydrogen and oxygen via electrode reactions, transporting ions through the electrolyte/ membrane and collecting the product gases. Depending on the specific situation and methodical assumptions, oxygen could have co-product character, thus making need for allocation of impacts from electrolysis.

- **Synthesis loops**: The most commonly utilized processes include the Haber-Bosch process for ammonia, and Fischer-Tropsch for synthetic hydrocarbons (i.e., synthetic paraffinic kerosene and production of other FT-based cuts from the same process), while methanol is produced from H_2 + CO_2. Single-pass conversion efficiency, recycling loops and unreacted

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[36] Currently by far the most relevant process to provide for hydrogen globally.

gas purge losses shall be considered as well as energy provision and process material consumption.

- **Compression and liquefaction**: Energy for hydrogen compression (commonly ranging from 350-700 bar for transport, 1 bar for ammonia synthesis), ammonia refrigeration (-33°C) or cryogenic hydrogen liquefaction (-253°C) are common processes in e-fuels production. Amount and source of required energy shall be accounted for, where applicable.
- **Waste heat integration**: If high-temperature electrolysis (SOEC) or Fischer-Tropsch synthesis produce waste heat, and this heat can be utilized, it is subject to allocation, in line with chapter 3.10.

Key considerations: Fugitive emissions from electrolyser hydrogen crossover, ammonia slip and methanol evaporative losses are included using technology-specific factors.

c) **Transport and Distribution (T&D):** T&D encompasses the logistics required to move intermediate feedstocks and final fuels. This includes the transport of CO_2 from the capture site to the synthesis plant, and the distribution of the final synthetic fuel (e.g., e-Methanol, e-Kerosene) to the end-user. Crucially, the boundary accounts for the energy consumed in compression and liquefaction (particularly for Hydrogen and LNG-like carriers) at various stages of the supply chain, as well as any fugitive emissions or boil-off losses during storage and handling. Energy for compression/liquefaction at distribution nodes, fugitive emissions and boil-off losses during storage and handling (particularly for cryogenic hydrogen, LNG-like carriers) and bunkering energy (pumps, heating for viscous fuels) are commonly included.

d) **Fuel use and emissions from fuel combustion:** This includes covers all direct emissions released when the e-fuel is combusted in end-use applications (e.g. road vehicles, ships, aircraft or power generation). The boundary includes operational combustion emissions at the point of use, typically expressed per unit of energy delivered (e.g. per MJ or per ton km).

Electricity

The system boundary for electricity as an energy carrier and fuel begins at the point of **primary energy extraction** or **resource production**. It ends with the use of electricity within a vehicle or where electricity is used to produce e-fuels. The following describes the most relevant aspects as regards the system boundary of electricity provision.

a) **Fuel preparation**: Where fuels are required, e.g. in thermal power plants, the system boundary includes the provision of the fuels. Fuel provision and preparation shall thus consider exploration/ prospecting of fuel resources, fuel resource extraction and pre-treatment processes (e.g. drying, milling) including transport to the EU market, where fuels are sourced globally (e.g. hard coal). For bio-based electricity, fuel provision shall cover the provision of the biomass or biogenic intermediates / energy carriers (e.g. maize cultivation or manure collection in the case of biogas).

b) **Generation Infrastructure:** Provision of the power plant infrastructure can have substantial impacts on the electricity's GHG intensity. In particular for renewable electricity sources without direct emissions (PV, wind power, geothermal power, hydro). Commonly, for thermal power plants, emissions from infrastructure contribute comparatively little to overall emissions and may be subject to cut-off. Infrastructure provision includes resource extraction, material manufacture and transports, production of components, construction efforts as well as decommissioning at EoL. Energy provision along the value chain of infrastructure provision (i.e., the energy consumed during PV cell manufacturing) can thus substantially influence overall impacts.

c) **Operation and Maintenance:** Power plant operation include in particular direct emissions from fuel combustion, and thus is of key importance for thermal power plants, while operational emissions from RES can be zero or close to zero. For thermal power plants, the conversion efficiency can differ drastically depending on the technology and fuel37 and warrants specific consideration. Additionally, internal energy demand as well as auxiliaries may influence overall plant efficiencies. Maintenance can contribute significantly to overall impacts, where power plant operation is decentralized and situated in challenging or hard to reach locations (e.g., off-shore wind power generation). Generally, it can be stated that maintenance commonly has a bigger impact for electricity generation technologies without direct emissions.

d) **End of Life processes**: EOL in electricity generation is associated with the corresponding generation / plant infrastructure or process wastes, such as ashes or other residues. Disposal of wastes and other End-of-life processes shall be considered, but may be subject to cut-off, owning to their low impacts on overall results.

e) **Transmission & Distribution (T&D):** The boundary includes all grid losses i.e., technical losses in transmission lines and transformers, incurred between the point of electricity generation and the point of consumption (e.g., EV charger, electrolyser or other end-use facility) as well as the transmission infrastructure itself. Losses are accounted for by scaling up the generated electricity demand to reflect the higher amount of generation required to deliver a given quantity of electricity to the end user.

Grid-loss levels and electricity-mix composition vary significantly between regions and Member States, leading to large differences in the effective GHG intensity of both upstream electricity and direct electricity use (e.g., for EVs or electro-fuels). The methodology therefore mandates using region-specific transmission and distribution loss factors and representative grid- mix data for each country or market, leading to the calculation of the relevant GHG emissions pertaining to that electricity mix, rather than applying generic EU-wide defaults. It is also important to include direct GHG emissions due to SF6 from electricity transformation.

Furthermore, electricity production can generally be distinguished by their grid connection. In particular in the case of e-fuels (RFNBOs), dedicated (renewable) power generation not connected to the grid may take place, resulting in potential additional impacts from storage, internal cabling and conversion equipment.

Note: For handling of electricity mixes see also chapter 4.5.

4.3 GUIDANCE FOR CALCULATION OF LUC

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[37] For example, natural gas power plants can achieve comparatively high efficiencies, while lignite power plants commonly have low efficiencies, owning to both, technological differences and fuel characteristics

This chapter supplements chapter 3.13 and provides technical guidance on how to calculate land use-change related emissions. The following chapters shall be updated if there is a new and scientifically commonly agreed consensus on approaches to consider land use-change.

Direct Land use-change

Direct land use change (dLUC) refers to greenhouse gas emissions arising from the direct conversion of land from one use category to another (e.g., forest to cropland) as a consequence of biomass (feedstock for e.g. biofuels) production. Emissions arise from the change in carbon stocks[38] (biomass and soil carbon stocks) as a result of land conversion, attributed to all products[39].

When conducting a CLEVER assessment, emissions from dLUC shall be quantified where agricultural biomass production results in the direct conversion of land from one IPCC land-use category to another within the defined product system boundary. Emissions from LUC shall be calculated in accordance with the calculation rules set out in the IPCC 2006 Guidelines[40], taking into account the clarifications and updated parameters of the 2019 Refinement[41], and consistent with the life cycle inventory requirements of ISO 14044:2006 and greenhouse gas quantification principles of ISO 14067:2018.

Direct land-use change (dLUC) is inherently site-specific, because it reflects the actual carbon stock change resulting from a defined land conversion at a specific location and time. Therefore, unlike iLUC (see below), there are no global default dLUC emission factors that can be universally applied per feedstock. The emissions from dLUC can vary and depend, in particular, on (changing) carbon stocks and crop productivity (yield), and are annualized over a time frame of 20 years. They are site-specific and have thus to be calculated, utilizing further information on carbon stocks (Chapters 4 - 9, IPCC 2019 refinements, Volume 4 – AFOLU). In general, all IPCC Tiers 1-3 (see Info-Box below) may be utilized to calculate dLUC emissions, in accordance with the rules specified in (IPCC, 2006) (IPCC, 2019). Choice of approach (applied Tier), description of land conversion (incl. carbon pools), assumptions and utilized data shall be documented as part of the overall CLEVER report, if applicable.

If a Tier 1 approach is chosen, default carbon stock values shall be derived from the respective IPCC tables and selected according to corresponding climate zone, ecological region and land-use category.

The following Equation 7 corresponding to an IPCC Tier 1 calculation approach (see info-box below) describes the calculation of emissions from DLUC per MJ of fuel. The factor C describes the specific amount of biomass required per (final) MJ_{fuel}:

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[38] These losses or releases of carbon stocks can result from changes in above- and below-ground biomass, soil organic carbon or loss in carbon sequestration.

[39] Functionalities can vary, e.g. per ha*a or per $MJ_{Biofuel}$

[40] IPCC (2006): 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme. Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T. and Tanabe, K. (eds.). IGES, Japan.

[41] IPCC (2019): 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Calvo Buendia, E., Tanabe, K., Kranjc, A., et al. (eds.). IPCC, Switzerland.

Equation 7: Calculation of e_{DLUC} based on IPCC 2006

$$e_{DLUC} = (CS_R - CS_A) * \frac{44}{12} * \frac{1}{20} * \frac{1}{P} * C$$

e_{DLUC}: emission factor for direct land use-change [g CO_2 e/MJ_{fuel}]
CS_R: Carbon stock of reference land-use
CS_A: Carbon stock of actual land-use
P: Crop productivity [kg/ha*a]
$\frac{44}{12}$: The term refers to the oxidation of the carbon (stock) to carbon dioxide (44.01 g/mol and 12.01 g/mol refer to the molecular weight of CO_2 and C, respectively)
$\frac{1}{20}$: This term refers to the annualization period of 20 years;
C: Specific consumption rate[42] of crop per MJ of fuel [kg/MJ_{fuel}]

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[42] This term describes the overall process efficiency / conversion of biogenic feedstock to fuel.

Info-Box: Additional info on dLUC calculations according to IPCC 2006/2019; Simplified example of DLUC calculation (IPCC Tier 1)

Generally, IPCC distinguishes three different tiers of calculation that follows a simple hierarchical structure. As tiers increase from Tier 1 to Tier 3, uncertainty decreases and methodological precision improves, but data and resource requirements and methodological complexity also increase.

IPCC Tier 1:

Uses globally applicable default emission factors and carbon stock values provided by the IPCC, combined with basic land-use activity data, to estimate dLUC emissions with limited country specificity.

IPCC Tier 2:

Applies country- or region-specific carbon stock data and emission factors, improving accuracy by reflecting national ecological conditions while retaining the same basic methodological structure as Tier 1.

IPCC Tier 3:

Employs detailed, higher-resolution methods such as spatially explicit models, repeated field measurements, or dynamic carbon stock modelling, using comprehensive national datasets to achieve the highest level of accuracy and specificity.

Simplified example of dLUC calculation, according to IPCC Tier 1:

In short, dLUC according to Tier 1 methodology compares the carbon stocks (both within the soil, where the majority of carbon is stored, and within the growing biomass) of each land use form (category), adjusted for regional characteristics.

For the production of maize in central Europe, an area (1 ha) classified as *grassland* is transformed to *cropland*.

- As climate zone, a temperate and moist situation is assumed, and a mineral soil type.
- The reference land use case, grassland is assumed to amount to roughly 100 t C/ha, with 95 t C/ha from soil organic carbon (SOC) and 5 t C/ha from carbon within the biomass.
- As regards the SOC of the new cropland, a FLU (land-use factor) of 0.8 is assumed, meaning that 80 % of SOC is retained. The SOC of cropland thus is 0.8 * 95 = 76 t C/ha.
- For the growing biomass, only marginal changes are assumed, thus remaining at 5 t C/ha. The new land use form, cropland now amounts to 81 t C/ha.

The delta of initial reference carbon stock / ha and the new land use form is thus 100 – 81 = 19 t C/ha. Full oxidation of this released carbon is assumed stoichiometrically:

$$19 * \frac{44\frac{g}{mol}}{12\frac{g}{mol}} = 19 * 3.67 = 69.7\ [\frac{t\ CO2}{ha}]$$

This amount of CO_2 is amortized over the course of 20 years, the per year fraction thus is:

$$\frac{69.7}{20} = 3.5\ [\frac{\mathrm{t\ CO2}}{\mathrm{ha}} * \mathrm{a}\ ]$$

Finally, this value must be expressed per unit product, e.g. per kg maize or per MJ_{Maize}. Under assumption of a representative yield of 10 t $maize_{dry}$ / ha*a (expressed as P, plant productivity in Equation 3 above) and

Indirect Land use change

Indirect land use change (iLUC) refers to greenhouse gas emissions resulting from (market-mediated) land conversion that occurs outside the physical boundary of an agricultural product system under investigation, when increased demand[43] for the produced (assessed) biomass displaces existing agricultural production and induces expansion into previously unmanaged [44] land. Unlike direct land use change, iLUC cannot be directly observed within the product system under investigation and is typically estimated using economic equilibrium models consistent with land carbon stock accounting principles, following the Intergovernmental Panel on Climate Change guidelines (IPCC, 2019).

Indirect land use change (iLUC) emissions shall be quantified in a CLEVER assessment, where increased demand for agricultural biomass within the defined product system boundary induces market-mediated land conversion outside that system boundary, resulting in the expansion of agricultural production into other land-use categories. iLUC emissions shall be attributed to the functional unit of the assessed product system (e.g. biomass or biofuel production) in accordance with sector-specific (aviation, road and marine) default values. Where land-use change occurs, either dLUC or iLUC shall be assessed. Where direct land conversion is demonstrably excluded, only the applicable iLUC factor shall be applied.

For the quantification of iLUC emissions for fuels, CLEVER distinguishes the following sources: For aviation fuels, default iLUC values shall follow the methodology and values adopted under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) established by the International Civil Aviation Organization (ICAO). For road and marine fuels, iLUC treatment shall be consistent with guidance provided under the Science Based Targets initiative (SBTi) Automotive sector framework. Given the SBTi approach is based on CORSIA, the approach to iLUC, and resulting values, can be aligned across modes and sectors creating a consistent approach in a complex and evolving field. iLUC emissions are specific to different biogenic feedstocks.

Waste- or residue-based feedstocks do not get assigned any iLUC burden by definition (see chapter 3.10).

Aviation Fuels

For aviation fuels, iLUC values shall be taken from ICAO CORSIA (CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels, Chapter 5, tables 7 – 12). For pathways, where different crop production regions are distinguished, the matching region shall be selected. If the feedstock region is not listed in the CORSIA table, the "Global" value shall be selected as a default. Only in cases, where a different listed region more adequately approximates the actual region, the respective different region may be selected as a proxy instead of the "Global" value. Justification has to be provided for any selection as to why selecting a different region is more adequate. The selected value (g CO_2e/MJ_{fuel}) and version of the CORSIA reference source shall be documented.

Under ICAO's CORSIA framework, iLUC emissions are estimated using two different (economic) equilibrium models, GLOBIOM (Global Biosphere Management Model, IIASA, Austria) and GTAP (Global Trade Analysis Project, Center for Global Trade Analysis, Perdue University, USA). GLOBIOM represents a partial-equilibrium

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[43] For example, as a reaction to a policy change or other macro-economic decisions.

[44] Non-agricultural land (e.g. forest land, grassland..)

model[45] with in-detail consideration of land use and biophysical constraints, while GTAP constitutes a general-equilibrium model that is not limited to one market or sector, but considers all sectors. Both models simulate how increased biofuel demand affects agricultural production and commodity prices, as well as land expansion across different regions, translating these dynamics into land-use change with corresponding carbon stock changes / emissions. Both models provide complementary perspectives[46] while limiting the potential for structural (model) bias. For the purpose of deriving iLUC values for CORSIA, assumptions in both models were harmonized (where possible), and results for individual feedstocks / fuels constitute the average of both models[47].

Road and Marine Fuels

For road and marine fuels, iLUC values shall be taken from Table D2, Annex D, of the SBTi Automotive Sector Net-Zero standard (Version 0.1, February 2026).

The SBTi approach to iLUC can be understood as a hybrid, science-based methodology drawing explicitly on (i) the precautionary and risk-screening principles embedded in ICAO CORSIA sustainability criteria for biomass [link], and (ii) model-based land-use change assessments developed by the European Commission JRC (Joint Research Centre) (e.g. GLOBIOM- and MIRAGE-based analyses). These different sources are operationalized by combining feedstock-based iLUC risk screening, conservative use of peer-reviewed indicative (modelled) iLUC estimates, and the consideration of attribution of zero iLUC only for specific / individual cases, where additionality and non-displacement are robustly demonstrated, consistent with both CORSIA and JRC methodological assumptions.

As a basis for the SBTi iLUC factors, ICAO CORSIA values (ICAO, 2025) are adapted. ICAO CORSIA specifically addresses and assesses aviation fuels, while SBTi's approach focusses road fuels. This adaptation of values is critical and reflects differences in SAF / aviation fuels and their respective production pathways on the one hand, and corresponding equivalent road fuels (biodiesel, HVO, bioethanol) on the other. Key differences can occur as regards conversion rates, process yields and overall process efficiencies[48]. The selected value (g CO_2e/MJ_{fuel}), justification for the choice and source document (version) shall be documented.

CLEVER default values must always consider LUC. When actual CLEVER emission factors are calculated, a specific situation may exclude LUC emissions, if it can be demonstrated and independently verified that the used feedstock does not cause dLUC or iLUC.

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[45] Focusing on a specific sector or markets

[46] GLOBIOM focuses land-use dynamics more and offers a higher resolution, in particular beyond the North American market, while GTAP represents the North American market while offering a broader (macro)economic perspective.

[47] An adjusted average is used, if both models differ to a substantial degree.

[48] Given that iLUC values are reported on the basis of the energy content of the finished fuel, but caused by consumed biogenic feedstocks, conversion rate / process efficiencies directly determine the required supply of a given iLUC relevant feedstock.

Info-Box: Why a consequential element is necessary

Although the applied concept of iLUC and iLUC emissions are consequential by nature, their inclusion in an attributional GHG-accounting framework like CLEVER is justified because, without accounting for market-mediated land conversion, the reported GHG performance of biofuels would be systematically overstated, in particular as regards a like for like comparison with other fuels. Inclusion allows quantification of emissions that would not otherwise be captured, reflecting the broader sustainability impact of biofuel production compared to unregulated agricultural commodities, such as e.g. feed or food crops. It is now widely accepted in the scientific- and policy community that iLUC can contribute materially to the greenhouse gas intensity of certain crop-based biofuels. Consequently, several key frameworks – including ICAO CORSIA for aviation and the SBTi Automotive guidance – incorporate quantified iLUC emission factors.

Enhanced Soil Carbon Accumulation

Enhanced soil carbon accumulation (ESCA) describes potential [increases / changes] in soil organic carbon stocks, resulting from (changes to) land management – or other practices – within the [biofuel] product system over a given timeframe. Related regulations (e.g. RED) or frameworks (..) may include a (permanent) emission credit associated with ESCA. As a default, no ESCA and associated effects shall be set assumed in any CLEVER assessment. Only for non-Default values, an ESCA value may be assessed.

For the calculation of actual emission factors according to the CLEVER framework, Economic Operators may account for ESCA, provided the specific requirements laid out below are met and sufficiently documented / reported / verified. In such cases, a CLEVER assessment shall consider Soil Organic carbon (SOC) changes caused by ESCA as temporal modifications of soil carbon stocks within the defined biofuel system boundary and assessment period. They shall not be equated with permanent atmospheric carbon dioxide removal (e.g. CCS) unless durability is demonstrated in accordance with defined permanence criteria (see Chapter 4.6).

Further requirements for the consideration of ESCA:

- **System boundary & attribution of ESCA:** ESCA shall only be included if both an increase in soil organic carbon[49] is directly attributable to (land) management practices / activities within the defined biofuel product system *and* causally linked to the production of the (assessed) biofuel. Furthermore, it must be ensured that only carbon fluxes physically and functionally associated with the biofuel production are considered. If the biofuel product system is multifunctional, ESCA shall be subject to allocation.
- **Definition of a baseline SOC stock:** A baseline scenario representing the SOC stock in the absence of the defined biofuel product system shall be established and documented. SOC changes shall be quantified relative to this baseline, ensuring that only net changes attributed to the biofuel product system are included.

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[49] A gross change of overall carbon is not equitable per se with ESCA. For example, if a change in management practices with the purpose increase yields takes place, gross carbon increases, but not in the form of enhanced soil carbon accumulation.

- **Definition of an assessment period:** An explicit assessment period shall be defined for [SOC changes /ESCA]. If amortization or averaging is applied (e.g., over 20 years, consistent with IPCC guidelines), the time horizon shall be documented, justified and consistently applied. Temporary carbon storage shall not be treated as a permanent negative emission unless permanence criteria are demonstrated (see Chapter 4.4).
- **Further conditionalities:** SOC accumulation shall be conditional upon the continuation of the activities included in the product system. The potential reversibility of carbon storage shall be acknowledged. Where contractual or monitoring mechanisms guarantee permanence, these shall be documented and may be considered in the assessment (in accordance with general handling of temporal / permanent storage).
- **Prohibition of misleading claims:** Negative emission claims equivalent to permanent carbon dioxide removal (e.g. CCS) shall not be made solely on the basis of temporary or management-dependent SOC increases.
- **Transparent documentation:** All assumptions, data sources and methodological choices regarding SOC changes shall be transparently documented. This includes:
    a. Definition of the bioenergy product system and system boundary
    b. Activities causing intended SOC changes
    c. Baseline scenario
    d. Assessment period and time horizon
    e. Treatment of potential reversibility and saturation[50] effects
    f. Any permanence guarantees or mitigation measures

Only if all of the requirements are met, can an ESCA value be considered. The calculation shall be in line with handling of temporal carbon storage, defined in chapter 4.4. Should in the future a scientifically recognized and agreed approach to ESCA emerge that is consistent with the general methodological provisions of the CLEVER framework, it shall be assessed, if this new approach is adopted accordingly to reflect the best available science.

4.4 TEMPORAL STORAGE / DELAYED EMISSIONS

The assessment of the temporal aspects of greenhouse gas emissions shall be conducted in accordance with ISO 14067:2018, chapter 6.4.8, taking into account the timing of emissions and removals, as well as their permanence.

In general, all GHG emissions and removals shall be considered with a *static approach* and hence calculated as if released or removed at the beginning of the assessment period without considering an effect of delayed GHG emissions[51] and removals (for reference, see Chapter 6.4.8, ISO 14067:2018). The effects of delayed emissions may only be considered, if delayed emissions (of product use or end of life) take place at least *ten years after* the product has been brought into use and, furthermore, if the timing of the emissions can be both

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[50] Saturation effects refer to the biogeochemical limitation whereby soil organic carbon stocks increase only up to a finite limit (equilibrium level), after which additional carbon inputs no longer result in sustained net accumulation.

[51] Delayed emissions are defined as emissions that occur at a specific point in time in the future after the initial carbon uptake or fuel production.

quantified and documented. If these conditions are met, then the effect of this delay in emissions may be assessed.

To this end, the reference year of product use has to be specified. A suitable methodology has to be selected to assess the effects of a delayed emission, expressed in CO_2 e. In any other case, emissions shall be treated as occurring instantaneously.

Emissions that may be subject to delay or permanent removal via storage are limited to those emissions from fuel / energy use and EoL, only. Upstream emissions associated with fuel / energy provision always need to be fully considered as released at the start of the assessment period.

Additionally, delayed emissions resulting from temporary carbon storage (e.g., in products, materials, or ecosystems) shall only be considered permanent, if the minimum retention period of the storage is 100 years. After this period, stored emissions shall be deemed permanently avoided, provided no release occurs. Retention periods of less than 100 years shall not be recognized as permanent storage and must be accounted for as delayed emissions within the accounting period. Furthermore, storage must be measurable, verifiable and durable.

If delayed emissions or permanent removals are considered within a CLEVER assessment, the following aspects shall be transparently reported:

- Timing of emissions
- Classification of storage (permanent, temporal)
- Duration of carbon retention
- Assumptions regarding storage, permanence and risk of release

4.5 CALCULATION OF FUEL AND ENERGY MIXES

As a framework, CLEVER is designed to be used for accounting purposes (see goal section) and thus follows an attributional approach suited to closely follow the physical reality.

This approach is closely linked to handling of fuel and energy mixes in CLEVER, which is why CLEVER accounts for physical fuel mixes and does not include any market-based measures (including mass balancing, book and claim or green electricity certificates/ power purchase agreements).

Info-Box: Explanation of general terms and concepts behind “location-based” vs “market-based” approaches

Location-Based Method

The location-based method provides emissions based on the average carbon intensity of the respective electricity grid for a geographic location. It reflects the regional or national electricity mix, including the proportion of electricity generated from fossil fuels, renewables and other sources as well as electricity losses. All electricity users are supplied from the same regional or national electricity grid and thus must use the same electricity emission factors.

In CLEVER, a similar concept is applied to other energy carriers apart from electricity (further explanations are given in the following subchapters) following the physical link between supply and demand.

Market-Based Methods

Market-based methods account for emissions based on the specific electricity a company buys. This specific electricity may not be supplied via a dedicated transmission line or local electricity grid. Instead, in this approach contractual instruments such as Renewable Energy Certificates (RECs), Guarantees of Origin (GOs), Power Purchase Agreements (PPAs) or supplier-specific emissions are used which can separate the physical supply from the purchaser. By using such market-based mechanisms, a company may claim emission reductions through energy procurement, even though the electricity they use still comes from the local electricity grid. In ISO 14083, market-based electricity may only be used for dual-reporting / dual-accounting (more explanations can be found in the subchapter on electricity mixes).

Apart from electricity, other energy carriers may also be linked to market-based methods through the application of a chain of custody system.

Chain of custody systems (based on ISO 22095)

A chain of custody system is a "*process by which inputs and outputs and associated information are transferred, monitored and controlled as they move through each step in the relevant supply chain*" (ISO 22095). It is linked to both the monitoring of physical properties and flows throughout a supply chain ("identity preserved" or "segregation"), as well as to market-based methods ("mass balancing" or "book and claim") where there is not necessarily a physical link between the final product and the claim/ documentation.

Note: The CLEVER framework is intended to facilitate the calculation of climate impacts from transport and logistics activities by providing a calculation framework and a selection of average GHG emission factors for different energy carriers following an attributional approach. It is closely linked to *CountEmissions EU* as well as ISO 14083. Here, the actual GHG emissions from transportation are calculated and disclosed. Neither of these accounting frameworks include carbon offsetting or any market-based values (such as values derived from a book and claim approach, with the exception of the possibility for dual accounting of renewable electricity in ISO 14083). However, the methodology (as well as the factors) from CLEVER can be used in calculations used to assess the possible impacts for the implementation of chain of custody systems such as "book and claim". This is done through the calculation of emissions from two actual transport services using attributional methods, followed by the substitution of the emissions associated with the use of a certain amount of lower emission fuel from its actual point of use to the other service with a corresponding transfer of emissions from the same amount of a higher emission fuel in the opposite direction. The net effect is zero as the substitution of emissions occurs in a closed system.

However, average values are not always suitable to assess the impacts from large scale changes, meaning care needs to be taken when it is proposed that average values are used in the impact assessment of large-scale decisions or changes.

Following ISO 14083, for cross-border transport services, users should use the fuel mix of the exact location(s) where they refueled. This also applies to battery-electric vehicles, where the charging location(s) determine which electricity mix is used. For directly grid-connected transport (e.g. electric trains) the electricity mix automatically changes at the country border.

All CLEVER fuel mixes must be calculated based on the energy content (energy-% based on LHV) of the different fuel pathways. Conversion to other units (volume-% or mass-%) is possible using densities and lower heating values.

The resulting formula is:

$$Biofuel\ share\ (\%) = amount\ of\ biofuel\ [MJ]\ /\ (amount\ of\ fossil\ fuel + amount\ of\ biofuel)\ [MJ]$$

Note: Biofuel shares may vary by country, fuel type and mode.

Generally, CLEVER distinguishes between grid-based energy carriers (electricity as well as gaseous fuels such as compressed natural gas) and non-grid-based fuels (liquid fuels such as diesel).

Electricity mixes

For any grid-based fuels, it is usually not possible to choose which exact fuel pathway to refuel with, as these energy carriers come from a grid that different producers feed into. Here, a pure location-based approach is required.

Therefore, CLEVER closely follows the methodology laid out in annex J of ISO 14083 and a location-based approach for electricity GHG emissions factors is compulsory. The GHG emission factors for electricity should refer to location-based consumption/ supply mixes which, unlike production mixes, also include net electricity imports from neighbouring countries. For regions or countries with low net electricity imports, the generation mix and consumption mix are very similar; in the case of high electricity imports, the GHG emission factors of the consumption mix may be either lower (if electricity is imported from countries with lower GHG emissions) or higher (if electricity is imported from countries with high GHG emissions) than the generation mix.

In addition (not as an alternative), GHG emissions calculated using a market-based approach may also be reported. In this case, additional prerequisites need to be fulfilled (see ISO 14083), and any electricity NOT covered by a guarantee of origin or certificate must use values for the residual electricity mix (see also ISO 14067). The only exception where green electricity may be used in a location- based approach without market-based measures is the so-called “behind-the-meter” electricity. This refers to the direct usage of electricity from a renewable source from a dedicated transmission line which is neither fed into the grid, nor sold to a third party (either physically or by certificate). In this case, robust proof must be provided and additional rules apply (see also info box).

Info-Box: Additional rules for "behind- the- meter" electricity

To be able to account for behind-the-meter renewable electricity, all of the following conditions must be met and proven:

- Direct (physical) link between producer and user ("dedicated transmission line")
- Renewable electricity is neither fed into the grid nor sold to a third party in any other way (physically or by any contractual mechanism or certificate)
- Charging during times when not enough renewable electricity is available is covered with the grid mix

Note: The GHG emission factors for renewable electricity must follow the same rules as the grid mixes and must include impacts from energy provision infrastructure as well as all losses.

Grid-based fuel mixes

Other grid-based fuels such as natural gas are handled like electricity and a location-based fuel mix is derived from statistical data.

In the case of biomethane, the amount of biomethane in the national natural gas grid is the relevant metric. Similar to electricity, biomethane is (mostly) fed into the grid and used by everyone taking natural gas from the grid. Hence it is not just used in the transport sector, but also by households (e. g. for heating purposes) or in the industry. While use of natural gas for heating or energy purposes is widespread in the EU, use in transport is still very limited.

Generally, many European countries have very small or even negligible amounts of biomethane available. Only a limited number of European countries (Denmark, France, Germany, Italy, Estonia, Finland, Netherlands and Sweden) are reported to produce relevant amounts of biomethane. Some of them inject almost all biomethane into the gas grid, whereas others have mostly decentralised (off-grid) solutions. For the entire EU27 the average share of biomethane in the natural gas grid in 2023 was around 2%.

For the biomethane share the following formula applies:

$$biomethane\ share = \frac{biomethane\ used\ in\ country\ (total, in\ MJ)}{biomethane\ used\ in\ country\ (total, in\ MJ) +\ natural\ gas\ used\ in\ country (total, in\ MJ)}$$

The biomethane share thus depends only on the country and not on the use, as the same biomethane share applies to the entire gas grid and the share is the same for all transport modes as well as any other uses (e.g. in households or industry).

It is possible to calculate with dedicated (off-grid) biomethane, as long as direct usage of this biomethane can be proven (by use of primary data on the amount of fuel and providing proof of its characteristics, for more information see also chapter 5) and it is neither fed into the grid nor sold to a third party (either physically or using a market-based mechanism) (see also chapter 5). However, it must be assured that the amount of biomethane not injected into the gas grid is not included into the location-based biomethane share already. If statistical data does not allow to differentiate, the usage of dedicated (off-grid) biomethane is not allowed to avoid double-counting.

Table shows an overview of the resulting grid-based energy carrier mixes relevant for the different modes.

Table 4-1: Grid-based energy carrier mixes for different modes

	Road	Rail	IWT	Air	Sea
CNG mix	X				
LNG mix	X		X		X
Electricity mix	X	X			
Renewable electricity (only behind-the-meter)	X	X			

Non-grid-based fuel mixes

Generally, it is easier for fuels to follow their characteristics throughout the supply chain than for electricity, as an electron cannot be traced, whereas for fuel mixes/ blends e.g. the exact amount of biogenic carbon in the fuel can be analysed (using the C14 method) and fuel batches can be kept separate from each other (at least for non-grid-based fuels). Still, most fuels today are supplied as already blended, average fuel mixes (with varying characteristics e.g. summer or winter grade or slightly different bio-content using a mixture of feedstocks for biofuel production).

A key element of the CLEVER methodology is to ensure that double-counting of renewable or other low emission fuels is avoided (which can easily happen when someone uses a location-based fuel mix and someone else uses a specific fuel type), while balancing ease of use/ feasibility and fairness ("level playing field") with the possibility to track improvements in the GHG emission factors of fuels (e. g. due to use of different fuel carrier pathways).

Generally, all fuel mixes in CLEVER are location-based fuel mixes with average biofuel shares; these are defined as follows:

- The location-based fuel mixes are not linked to exact fuel blends but reflect the average amount of renewable fuel in the mix in the different EU countries in a certain year derived from statistical data. Here fuel users do not need to know their exact fuel type/ blend or provide proof. Instead, everyone must use an emission factor associated with the same location-based fuel mix (regardless of whether they have used a specific fuel type or not). This approach leads to a level-playing field for everyone but does not encourage use of specific fuel types/ blends. It is aligned with the approach taken for grid-based fuels. However, in specific cases the statistical data allows differentiation between blended biofuels and pure biofuels (this is currently the case for biogasoline and biodiesel used in the EU). By using **location-based fuel mixes which do not include pure biofuels,** use of a dedicated, pure biofuel (not yet included in the mix) is possible without double-counting. However, users must use the emission factor for the location-based mix unless they can provide proof of directly having used a dedicated renewable or other low CI fuel (without taking mass-balancing into account).

CLEVER always mandates to use location-based fuel mixes (not including dedicated, pure renewable fuels). Instances where accounting for a non-grid-based dedicated renewable fuel is possible and the rules which apply are listed below. However, similar to green electricity, dual reporting (dual accounting) of an additional calculation taking into account market-based measures such as mass balancing may be done.

The average location-based biofuel share does not only vary by country and fuel type, but also by mode, as there are, for example, incentives to use biofuels in road transport, but not in IWT.

Generally, the granularity of the data on biofuel use in different statistics may vary for different regions and impacts the possibility to account for dedicated renewable fuels. Thus, if statistical data does not allow differentiation between blended and pure biofuels, accounting for dedicated biofuels is not allowed.

In Europe, Eurostat distinguishes between “blended biodiesel/ biogasoline” and “pure biodiesel/ biogasoline” as well as between different modes (road, rail, domestic navigation as well as aviation). This enables calculation of mode and fuel type specific location-based fuel mixes based on “blended biodiesel/ biogasoline” only and thus enables accounting for pure biodiesel/ biogasoline. Generally, biofuel usage varies greatly between the different EU countries. In 2023 the average amount of biodiesel in road transport in the EU27 was at 7.3%, with values for individual EU countries varying from 0% to 29%.

Table shows the relevant energy mixes for non-grid-based energy carriers for different transport modes.

Table 4-2: Relevant non-grid-based energy carrier mixes for different modes

	Road	Rail	IWT	Air	Sea
Diesel mix	X	X	X		X
Gasoline mix	X				
H2 mix* (non-grid-based)	X				
HFO					X
VLSFO					X
ULSFO mix*			X		X
Methanol mix*			X		X
Ammonia mix*			X		X
Kerosene mix				X (nat./ int.)	

* Currently purely fossil fuel as proxy. Future updates when data sources for international transports (e.g. sea or air) as well as for emerging fuel types (e.g. H2) are available should be done .

The diesel/ gasoline mixes include a blend of both fossil diesel/ gasoline with biodiesel (usually a mix of FAME and HVO from different feedstocks) and ethanol (also as a mix from different feedstocks).

Note: As there is not yet a hydrogen grid infrastructure in place, hydrogen today is a non-grid-based fuel. In future, this might change when hydrogen transport shifts from truck transport to a pipeline infrastructure (or the existing natural gas grid is repurposed) and hydrogen is used in other sectors, too.

Statistical data on RFNBOs is still emerging, but it is assumed that RFNBOs will be included in the fuel mixes in the future, when they become more widely available. As for dedicated biofuels, they can be accounted for as dedicated renewable fuels as long as they are not included in the location-based mix already.

Special considerations for renewable fuels

Generally, accounting for a dedicated renewable fuel may only be done in CLEVER when primary data on the amount of fuel, the exact fuel type and proof of its origin is available (without taking into account mass-balancing or any other market-based mechanism). This fuel must be a pure renewable fuel (e. g. an RFNBO or a pure biofuel) and is only allowed in cases where the location-based country- and mode-specific mix does not already include these dedicated renewable fuels. Dedicated renewable fuel can refer both to a (bio)fuel mix (made from different feedstocks) or a specific fuel pathway.

Table 4-3: Selected dedicated renewable fuels for different modes

	Road	Rail	IWT	Air	Sea
HVO100	X	X	X		
Biogasoline	X				
HEFA				X	
RFNBO	X	X	X	X	X
CBM	x				
LBM	x		x		X

Note: For biomethane is must be ensured that the biomethane is neither included in the location-based grid-mix already, nor fed physically into the gas grid (see subchapter on grid-based fuels for more details).

These rules serve to ensure that the renewable fuel is directly used and no double-counting occurs. Further rules on how proof must look like are given in chapter 5.

4.6 CALCULATION OF OPERATIONAL EMISSIONS

General approach to operational (TtW) emissions

The calculation of Tank-to-Wheel/Wake (TtW) emissions within the CLEVER framework follows the principle that while energy content is the driver for activity, the resulting emissions are a function of both fuel chemistry and conversion technology. To address the varying levels of data availability among users, ranging from simple fuel receipts to detailed telematics, CLEVER adopts a tiered methodological approach broadly aligned with international standards such as the IPCC Guidelines and the EMEP/EEA Guidebook.

The tiered methodology

To ensure wide applicability while incentivizing high accuracy, the calculation of TtW emissions is structured around three tiers of data granularity. The CLEVER framework provides default emission factors (primarily at Tier 1 and Tier 2 levels) and outlines the requirements for users to calculate and apply actual emission factors (typically requiring Tier 2 or Tier 3 data). To provide clear guidance for third parties applying this methodology, the following rules apply:

- Hierarchy of Data: Users shall utilize the highest tier for which reliable, verifiable data is available. The use of primary, specific data (actual values, measured by the EO) is always preferred over the use of generic averages (default values).
- Tier 1 (fuel-dependent): This method calculates emissions based solely on the quantity of fuel consumed. It shall be the standard approach for CO_2 emissions, where the carbon content of the fuel is the primary driver and is fundamentally linked to the fuel type.
- Tier 2 (technology-specific): This method differentiates emission factors based on the specific fuel and the energy converter technology (e.g. engine type, Euro standard, vessel class, installed abatement technology). This is the minimum mandatory tier for the accurate assessment of non-CO_2 GHGs (N_2O, CH_4) and Black Carbon (BC), as these emissions vary significantly based on engine design and exhaust aftertreatment.
- Tier 3 (operational / modelled): This method utilizes detailed activity data (e.g. vehicle speed, engine load profiles, cold-start patterns, specific routing) to model emissions dynamically for a specific operation.

Guidance on default vs. actual values

- Use of CLEVER default values: When a user has no access to the primary data required to calculate an actual emission factor, they must apply the relevant CLEVER default value. To ensure environmental integrity, CLEVER default values are established conservatively. This means they generally represent an upper-bound or worse-than-average estimate within a given technology class (e.g. assuming a high level of methane slip for a generic LNG engine category if the specific engine type is unknown).
- Use of actual values: Operators are strongly encouraged to collect primary data to calculate and report their actual emission factors (moving from Tier 2 defaults toward specific Tier 2 or Tier 3 calculations). If an operator can demonstrate, e.g. through appropriate monitoring, reporting and verification (see chapter 5), that their specific equipment or operational profile results in lower emissions than the conservative default, they are permitted to use this non-conservative, specific actual value.

Calculation logic by GHG and emission source

The methodological approach for deriving emission factors must reflect the physical formation mechanisms of each specific gas:

- **CO_2 (Ultimate CO_2):** The calculation of CO_2 emissions will follow the carbon balance method. This method assumes the complete oxidation of the fuel's carbon content during combustion. Default CO_2 emission factors are derived directly from the fuel's chemical composition (Carbon-to-Hydrogen ratio) and its Lower Heating Value (LHV). This represents a Tier 1 approach.
- **Non-CO_2 combustion by-products (N_2O, CH_4 from incomplete combustion):** These emissions cannot be derived solely from fuel composition. They are highly sensitive to the specific energy converter and operational conditions. Therefore, the calculation of N_2O and combustion-derived CH_4 must utilize a technology-specific approach (minimum Tier 2). Users applying actual values must

base them on primary data relevant to their specific engine type and aftertreatment systems (e.g. SCR efficiency impact on N_2O).

- **Fugitive emissions and slip (methane slip, H_2 leakage):** For gaseous fuels, the release of unburnt fuel into the atmosphere constitutes a significant GHG source that must be accounted for in the TtW phase. These emissions (e.g. methane slip from marine LNG engines, hydrogen leakage from FCEV storage/systems) shall be quantified as a specific percentage of the total fuel energy or mass throughput and added to any direct combustion emissions.

Accounting for auxiliary inputs

To ensure a complete system boundary, the TtW calculation must include emissions from consumable fluids that are essential for the vehicle's operation but are not the primary fuel (unless they are subject to a cut-off):

- Urea (AdBlue) consumption: For vehicles and vessels utilizing Selective Catalytic Reduction (SCR) systems, the hydrolysis of the urea solution generates fossil CO_2. These emissions shall be included in the TtW assessment. The calculation must be based on actual or conservative default urea consumption rates relative to fuel use (applying a standard conversion, e.g. 0.26 kg CO_2 per litre of standard urea solution).
- Lubricant oil combustion: Unintentional combustion of lubricant oil contributes to CO_2, CH_4, N_2O, and also BC emissions. While the direct CO_2 contribution relative to the main fuel is often small, the contribution to BC can be substantial. Therefore, lubricant oil emissions are included within the CLEVER system boundary. They must be quantified for modes where this consumption substantially impacts the total climate footprint (e.g. large marine engines, 2-stroke L-category vehicles). For specific pathways where the overall climate impact of lubricant combustion is proven to be negligible, it may be excluded, but this is subject strictly to demonstrating it falls below the general 3% cut-off criteria defined in chapter 3.5.

Mode-specific considerations:

Road

Road transport requires a highly granular approach compared to other modes due to the distinct impact of driving cycles (urban vs. highway) and the rapid evolution of engine technologies (Euro standards).

For petrol passenger cars, emissions are highly dependent on catalyst efficiency and operating temperature. Older technologies (e.g. Euro 1-4) exhibit significantly higher N_2O and CH_4 emissions, particularly in urban, cold-start conditions. In contrast, modern vehicles (Euro 5-6) demonstrate substantially lower factors across all conditions.

For diesel vehicles, methane emissions are generally negligible compared to petrol. However, N_2O emissions are significant and heavily influenced by NOx abatement technologies. Diesel vehicles without SCR exhibit higher N_2O in urban conditions due to cold starts. Modern vehicles equipped with SCR (e.g. Euro 6/VI) show distinct N_2O profiles, as N_2O can be formed as a by-product of the catalytic reduction process itself.

For Natural Gas (CNG/LNG) vehicles, methane slip is the primary concern. Spark-ignition (SI) engines, particularly in light-duty stop-and-go traffic, exhibit the highest CH_4 emissions. Heavy-duty SI engines typically show lower, but still significant, slip values.

For Hydrogen powertrains, while tailpipe CO_2 is zero, H_2 leakage from the fuel system must be accounted for in Fuel Cell Electric Vehicles (FCEV). For Hydrogen Internal Combustion Engines (H_2 ICEV), this factor must also account for engine slip (unburnt hydrogen escaping the exhaust), alongside potential N_2O formation from high-temperature combustion.

Sea

Maritime transport is characterized by large slow-speed and medium-speed engines. While currently dominated by liquid fossil fuels, the transition to gaseous and alternative fuels dictates specific methodological needs.

For conventional liquid fuels (such as HFO, LFO etc), methane emissions are relatively low. Nitrous oxide emissions, however, are a notable contributor to the overall GHG profile and are dependent on the specific engine cycle and loading.

For Liquefied Natural Gas (LNG), N_2O emissions are generally lower than diesel. However, methane slip is the primary GHG concern and varies significantly according to engine technology. For example, low-pressure dual-fuel (LPDF) engines typically exhibit significantly higher slip rates compared to high-pressure direct injection (HPDI) engines.

For emerging methanol engines, operational N_2O and CH_4 emissions are generally considered comparable to or lower than conventional diesel, though technology-specific data for dual-fuel engines must be applied as it becomes available.

For ammonia-fuelled vessels, N_2O emissions are a critical area of potential high impact. Due to the nitrogen content in the fuel, N_2O formation during combustion can be significant and highly variable, heavily dependent on engine technology and the efficiency of SCR systems.

Inland waterway

Currently, inland waterway transport uses almost exclusively fossil diesel (sometimes including a specific amount of biodiesel or very occasionally pure HVO100). For diesel (or HVO) inland ships, the operational N_2O emissions are considered relatively stable across engine types, while CH_4 emissions are generally low, typically scaling as a small percentage of overall hydrocarbon (HC) emissions (which decrease in newer engines).

In addition, some inland ships using LNG are operated in Europe. They face the exact same methodological challenges concerning methane slip as sea-going ships; therefore, the handling of operational methane emissions for LNG IWT is aligned with the marine sector. Similarly, considerations for emerging fuels like methanol, ammonia, or hydrogen in IWT follow the same technological principles outlined in the paragraph on sea ships.

Rail

The majority of train transport in mainland Europe is electrified. However, for shunting operations or for tracks that are not electrified, a situation that is common in many places around the world, diesel (sometimes including a specific amount of biodiesel or pure HVO100) is used.

Emerging concepts include battery-electric and hydrogen fuel cell trains. For diesel trains, the impact of operational N_2O and CH_4 on total GHG emissions is very small. Methane is typically a minor fraction of overall hydrocarbon emissions, and N_2O remains relatively constant across train types. For hydrogen fuel cell trains, the methodology must account for hydrogen losses (leakage) during operation and refuelling, consistent with the approach used for heavy-duty road transport.

Air

Current aircraft are almost exclusively fuelled by (fossil) kerosene and in very small amounts by sustainable aviation fuels (SAFs) such as bio-kerosene. It is assumed that the operational CH_4 and N_2O emissions for SAFs will be very similar to those of fossil kerosene.

The impact from operational N_2O and CH_4 emissions of aircraft is typically a very minor fraction of the overall operational GHG emissions. Generally, exhaust gas emissions vary by flight phase, being higher during the Landing and Take-Off (LTO) cycle. Consequently, non-CO_2 impacts from exhaust gases result in slightly higher overall emission factors for short-haul flights compared to long-haul flights.

Aircraft emissions at high altitudes are very important for the climate impact of air transports and are covered in CLEVER by a separate emission factor (EF_{HAE}). However, they are not dependent on the fuel being used, but rather on altitude, latitude, time of the day, environmental conditions and aircraft model. It is highly recommended to include them into any GHG calculation of air transports and a short description of them can be found in annex 7.1.

4.7 DETAILED REPORTING REQUIREMENTS

General provisions

Any CLEVER calculation shall be accompanied by a “CLEVER report” that documents the calculation and the underlying assumptions and limitations. The CLEVER report serves to document the calculated results as well as all elements necessary for understanding and interpreting the calculated results/emission factors. The CLEVER report shall be transparent and written in a neutral manner and without bias. This entails all relevant definitions, system descriptions, calculation steps, assumptions and utilized data as well as limitations. Additionally, the CLEVER report shall act as reference document for the purpose of verification / certification procedures, including any review statement.

If the CLEVER assessment is carried out with the goal of generating a Default emission factor, the accompanying CLEVER report shall always be made publicly available. If the CLEVER assessment is carried out with the goal of generating External GHG emission factors, the accompanying CLEVER report shall be made available on demand.

Required information/Elements for the CLEVER Report

Any CLEVER report shall include a comprehensive / technical description of the investigated fuel pathway, specifying all relevant elements of the fuels’ life cycle. In accordance with ISO 14067:2018, the CLEVER report shall include the following elements:

a) Functional unit and reference flow (see chapter 3.4);
b) Applied system boundary (incl. geographical and temporal scopes) (see chapter 3.5);
c) List of life cycle stages / important unit processes (see chapter 4.2);

d) Applied data, data collection and data quality assessment (see chapter 4.4);
e) Impact assessment methodology and applied characterization factors for assessed GHG (se chapter 3.14)
f) Applied Cut-Offs (see chapter 3.5);
g) Applied allocation approach and -factors (see chapter 3.10);
h) Assumptions and decisions taken (see chapter 0)
i) Effects of temporal or permanent storage or effects of delayed emissions, incl. accompanying specifications (see chapter 4.4);
j) Interpretation of results (see chapter 3.16)
k) Limitations (see chapter 0)

Furthermore, the reporting requirements of aspects specific to certain pathways (e.g., origin of carbon source for e-fuels, specifications for dLUC or iLUC calculations (see chapter 4.3)) apply.

If a comparative study for multiple fuel pathways is carried out, the provisions of Annex B of ISO 14067:2018 apply.

Review of datasets for the CLEVER database

Whenever the intention of calculating values according to the CLEVER methodology is to add to or to update the existing default GHG emission factors in the database, a critical external review according to ISO 14067 should be conducted and quality checks as well as verification is a must (see also chapter 5).

5 CONFORMITY ASSESSMENT

This section addresses Conformity Assessment in the context of CLEVER and *CountEmissions EU* and pertains in particular the provision of GHG emission factors for different applications. As outlined in chapter 3.1 above, CEEU specifies two distinct sources for compliance purposes – the *Central Union database* and a corresponding EU calculation tool (using *Default GHG emission factors*) and external (third-party) tools and data sets (using *External GHG emission factors,* calculated with the CLEVER framework). Following their applicability for compliance purposes, the same general requirements as regards verification and certification apply. For any other purposes with the intend to disclose results to third parties, the same requirements are mandated. For any other purpose, the same requirements are recommended, but not mandated. If the CLEVER framework or GHG emission factors based on the CLEVER framework are used within other frameworks, then the corresponding requirements of the framework in question apply.

The emission factors developed under the CLEVER framework cover a broad spectrum of fuel pathways, ranging from fossil-based to renewable- and low carbon intensity energy carriers. *CountEmissions EU* places particular emphasis on the application of ISO 14083:2023, an international standard that provides a harmonized methodology for logistics emissions accounting. Accordingly, the CLEVER framework has been designed to be fully aligned with ISO 14083:2023. Within this context, *conformity assessment* plays a critical role for several reasons:

- The Transport Service Providers (TSPs) may choose to apply the default emission factors from the CECD directly or obtain a GHG emission factor from an accredited external calculation tool[52], depending on their operational needs.
- TSPs typically use multiple energy carriers across their fleets on an annual basis. In some cases, there will be varying pathways associated with a single energy carrier according to the chosen supplier. Applying conformity assessment to the methodologies and data sources used for fuel-pathway emission calculations helps promote consistency, transparency, and comparability.
- The potential use of a large number of novel fuel batches increases the risk of misreporting, whether intentional or unintentional, thereby reinforcing the need for independent conformity assessment.

In order to safeguard the integrity of sustainability claims and prevent emissions reductions from being overestimated, conformity assessment must be carried out with a high level of rigour and methodological consistency. Conformity assessment covers two distinct aspects: Firstly, verification (incl. Critical Review) of compliance with the CLEVER framework, in particular with respect to the methodological aspects and the calculation of emission factors. Secondly, certification of claimed renewable- and low carbon intensity fuels / feedstocks to guarantee that the provisions as regards physical supply and use are met. The following chapters provide guidance on each aspect.

5.1 VERIFICATION AND CRITICAL REVIEW

For any CLEVER assessment with the purpose of calculating Default GHG emission factors (for the purpose of inclusion within the Central Union database, specified in Art. 7 CEEU), or calculation and provision of

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[52] As specified in Art. 11 of CountEmissions EU.

External GHG emission factors[53] (for reference, see Art. 6 CEEU), or any other non-compliance purposes with the intention to disclose calculated values to third parties, external verification is required. This verification process must ensure accuracy, transparency and adherence to the principles and rules defined in the CLEVER framework. This also applies in particular to cases, where an assessment is carried out with the purpose of adding to the *Central Union database* or other compliance options.

If the CLEVER assessment or a CLEVER emission factor are used only for internal purposes (e.g., for internal decision support) without the intend to disclose results to third parties, an external verification is not required.

Where verification is mandated, in particular for compliance under the *CountEmissions EU* framework, an accredited conformity assessment body (CAB) shall verify the reliability, credibility, accuracy and methodological adherence of the calculated emission factors and accompanying supporting material[54]. This verification shall include an assessment of the calculation methodology applied, the sources and quality of the input data used (i.e., primary or secondary data), the correctness of the calculations performed and the consistent application of common metrics. In general, verification procedures are recommended to follow the provisions defined in the ISO 14060 family, in particular ISO 14064-3:2019.

If a CLEVER assessment is carried out with the purpose of comparing two or more fuel pathways / energy vectors (e.g., comparative assertions between different fuels which do not change the operational conditions of the transport are intended), a critical review in accordance with ISO 14071:2024 should be carried out.

Where the CLEVER methodology is applied to generate values intended for use within other regulatory or non-regulatory frameworks (e.g., CORSIA, LCFS, GHGP), the verification procedures specified by the respective framework shall apply. This ensures that the resulting values conform to the methodological and conformity-assessment requirements established by the framework in which they are ultimately deployed.

5.2 CERTIFICATION AND CONSIDERATIONS FOR USAGE OF FOSSIL AND DEDICATED RENEWABLE FUEL MIXES

While the above covers the verification of methodological rigor, certification addresses the origin and characteristics of specific renewable- or low carbon intensity fuels or feedstocks. As a core principle, physical supply and use of feedstocks, intermediates or fuels must be demonstrated, and market-based measures (e.g., “book & claim”) are not allowed under CLEVER[55], while separate and additional dual reporting (dual accounting) may be an option. At this stage, the fuel consumer may demonstrate the physical use of certified renewable fuels by means of a Proof of Compliance (PoC) or Proof of Sustainability (PoS) document issued for both grid- and non-grid-based renewable- or low carbon intensity- fuels under an approved certification scheme. The PoC or PoS shall constitute evidence of the origin, eligibility, and sustainability certification status of the feedstock, intermediate or fuel concerned. However, the GHG emission factor or default values

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[53] E.g. for use within an external calculation tool. For such cases, CEEU specifies further requirements, incl. a technical quality check (for reference, see (among others) Art. 6, Art. 9 and Art. 11 of CEEU).

[54] In alignment with the provisions specified for overall output data disclosure (for reference, see Art. 12 and Art. 13, Chapter IV, Delegated Regulation (EU) 2026/xxx).

[55] Physical- and activity based emission accounting is a core principle in ISO 14083:2023;

included in the PoC or PoS shall not be used to substitute for a CLEVER GHG emission factor[56] in general, nor for regulatory reporting or compliance demonstration by the fuel consumer, for example under *CountEmissions EU* (in the European context), in particular.

Instead, the fuel consumer shall use and report a GHG emission factor of the fuel used that is calculated in accordance with the CLEVER methodology, thus ensuring consistency with lifecycle-based transport emissions accounting principles and ISO 14083:2023. By design, this approach excludes the application of certified GHG values from other regulations[57] at the consumption stage, while maintaining the PoC or PoS as a necessary and verifiable instrument to substantiate that renewable or low carbon intensity feedstocks, intermediates or fuels have been used in the transport fleet.

In practice, TSPs would use different fuel types and fuel shares from different fuel mixes. Some of these fuels might be of fossil origin or renewable fuels of lower carbon intensity. For different fuel pathways, the TSP could directly use the CLEVER default emission factors where available or calculate using the CLEVER methodology. As noted previously, when the CLEVER methodology is applied to determine actual emission values, mandatory verification is required.

When renewable fuels with low associated emissions are used, additional traceability requirements must be met to demonstrate compliance under specific frameworks. These traceability requirements apply to both grid-based and non-grid-based fuels, including electricity supplied behind the meter and off-grid biomethane (for reference, see chapter 4.5). The following sections provide guidance on how renewable fuels can be appropriately handled within CLEVER and other international frameworks.

Special guidance for grid based renewable fuels

As outlined in chapter 4.5, for grid-based fuels, the CLEVER methodology consistently mandates to follow a location-based approach for calculating emission factors. This approach is aligned with handling of electricity mixes in ISO 14083:2023 and ensures a level playing field for all energy carriers. Fuels such as biomethane may also be supplied on an off-grid basis. In such cases, additional compliance requirements apply. Specifically, these fuels must be accompanied by a valid guarantee of origin (GoO) and an associated certificate or proof of delivery (such as a Proof of Sustainability (PoS)) and these instruments must be withdrawn from any other registry to prevent double counting.

Figure 3 illustrates how grid-based fuels supplied on an off-grid basis may demonstrate compliance under CLEVER. Consider a scenario in which a processing unit (the obligated entity) procures biomethane that is certified under an approved sustainability certification framework. The entity consumes a portion of this fuel itself and feeds the remaining portion into the gas grid. For the share of fuel sold onward, the entity submits the corresponding PoS to the national authority to comply with a specific scheme (e.g. RED).

In this case, the upstream PoS serves as a potential documentation source to demonstrate that the biomethane qualifies as an off- grid renewable fuel. Provided that the traceability is maintained and double

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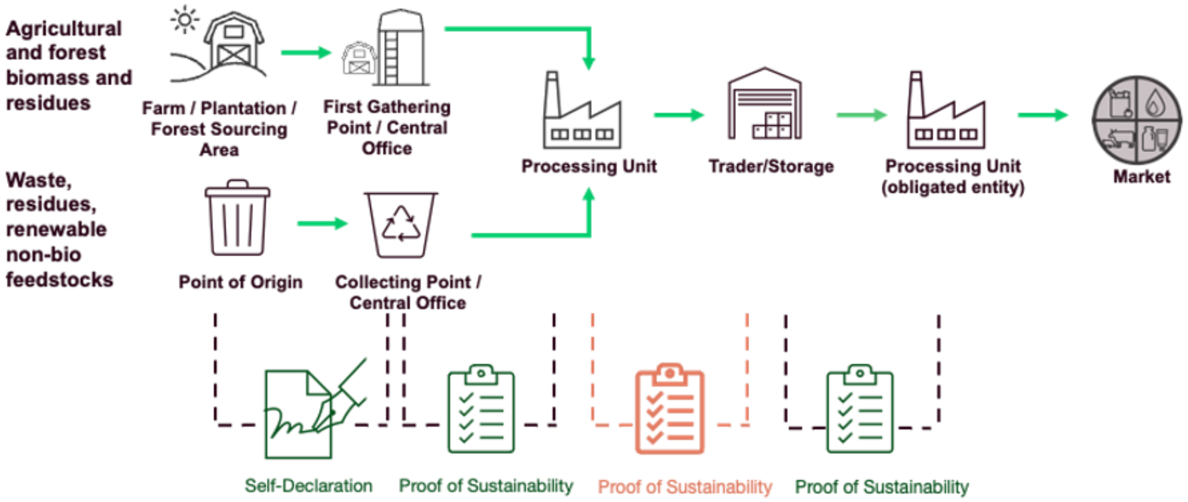
[56] Unless it can be demonstrated that the GHG emission factor given on the PoC or PoS document is obtained following the CLEVER framework.

[57] Unless it follows an identical methodology to CLEVER or is based on the CLEVER framework.

counting is avoided, the PoS (with physical segregation) may be used as evidence of compliance for the portion of renewable fuel consumed. Specific guidance on the chain-of-custody options applicable under a PoS, and their implications for the selection of emission factors within the CLEVER methodology, are provided in the accompanying information box.

Figure 3: Illustration showing the use of POS for compliance for the use of renewable fuels



Info-Box: Use of Proof of Sustainability as compliance for use of renewable fuels

A PoS may be used when the renewable fuel is not yet counted toward any national quota or when its sustainability criteria are not yet accounted for under any national or international sustainability frameworks

Case 1: PoS with Physical Segregation as Chain of Custody

A TSP using biomethane or biodiesel to fuel its trucks may calculate emissions using the CLEVER methodology for the specific fuel pathways, provided the renewable fuel use is demonstrated through a PoS supported by physical segregation as the CoC system.

Under this case, it is essential that the sustainable material specially for gaseous fuels, both upstream and downstream, is not injected into any interconnected gas grid, as full physical traceability must be maintained. It should be noted that such renewable fuels are not accounted for within national location-based mixes. If it is included, the TSP shall ensure that calculations are conducted in accordance with the location-based reporting approach.

Case 2: PoS with Mass-Balance as Chain of Custody

If the TSP can only demonstrate fuel use via a PoS supported by a mass balance CoC system, the TSP must apply the location based approach used in the CLEVER default emission factors. In this scenario, emissions must reflect the national natural gas grid mix, including the average country specific biomethane share.

The above two cases are for guidance for compliance under CLEVER and *CountEmissions EU*, which recommends location- based reporting. Market based reporting may also be reported along with location-based reporting, but the respective international framework shall explicitly support such reporting.

Special guidance for non - grid based renewable fuels

For non-grid based renewable fuels such as dedicated biofuels or very high biofuel blends like E85, a different approach is required. This is mainly because many renewable fuels are blended to meet technical specifications, (e.g., ASTM requirements) or due to complex operational conditions that require the use of chain of custody systems such as mass balancing. As a result, many non-grid-based fuels are either mass balanced or blended with fossil fuels. However, there are exceptions, certain synthetic fuels produced within e-fuel/ RFNBO supply chains can be supplied as one hundred percent renewable fuels, and fuels such as HVO 100 may also be supplied as dedicated biofuels without blending and dedicated supply chain.

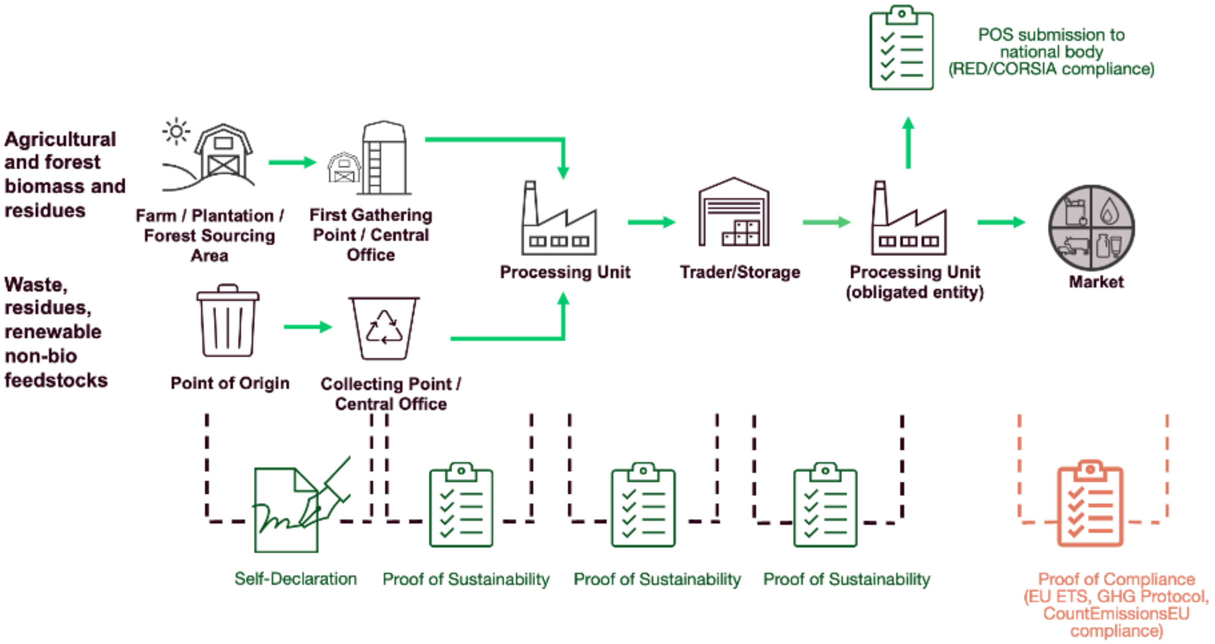
For non-grid renewable or low carbon intensity fuels, it is important to determine both the quantity of fuel physically delivered, and the origin of the fuel in order to apply the appropriate emission factor from the CLEVER database or to calculate the emission factor using the CLEVER methodology. Only for the fuel volumes that are physically supplied to the TSP, a respective corresponding CLEVER default or own actual calculated value corresponding to the fuel applies. A document like the Proof of Compliance (PoC) (used by voluntary schemes like the International Sustainability and Carbon Certification, ISCC) can be used as evidence of biofuel purchase and as confirmation of the feedstock or raw material used.. Specific guidance on the chain-of-custody options applicable under a PoC, and their implications for the selection of emission factors within the CLEVER methodology, are provided in the accompanying information box.

As noted earlier, CLEVER allows dual reporting (dual accounting) of emission factors. However, *CountEmissions EU* requires the exclusive use of the location-based approach. For non-grid fuels, a location-based approach is in practice the only feasible approach, because market-based accounting is not possible for these fuels, unless specifically allowed under / within specific regulations (e.g, zero rating of RED compliant fuels under EU ETS). Therefore, for compliance with other frameworks and regulations, a location-based approach is also recommended, unless stated in the respective framework.

Fuel suppliers typically provide sustainability evidence through a PoS issued under an approved certification scheme, confirming that a fuel batch meets defined regulatory criteria. Once used for compliance under a specific framework (e.g., RED, CORSIA), a PoS cannot be re-issued or reused. In cases where PoS documents are non-transferable, complementary mechanisms such as PoC documentation (under schemes like International Sustainability and Carbon Certification (ISCC) enable the forwarding of sustainability claims for use in other regulatory (e.g., EU ETS) or voluntary frameworks.

Figure 4 depicts how the PoS and PoC documents help Economic Operators (EOs) to comply with different regulatory requirements for both non-grid-based fuels and grid-based fuels.

Figure 4: Illustration showing the use of POC for compliance for the use of renewable fuels



Info-Box: Use of Proof of Compliance as compliance for use of renewable and low carbon intensity fuels

A PoC is required when a grid-based or non-grid-based renewable fuel batch is counted toward a national RED quota or toward any other national or international regulatory framework.

Case 1: PoC with Physical Segregation as Chain of Custody

A TSP using biomethane or biodiesel to fuel its trucks may calculate emissions using the dedicated fuel pathway default CLEVER emission factor, provided that the use of the renewable/low carbon intensity fuel is demonstrated through a PoC supported by physical segregation as the chain-of-custody (CoC) system.

In this scenario, it is essential that biomethane is not injected into any interconnected gas grid, as physical traceability of the specific fuel batch must be maintained. It should be noted that such renewable fuels are not accounted for within national location-based mixes. If it is included, the TSP shall ensure that calculations are conducted in accordance with the location-based reporting approach.

Case 2: PoC with Mass-Balance as Chain of Custody

If the TSP can only provide a PoC based on a mass-balance chain-of-custody system, the TSP must use the location-based CLEVER default emission factors. Under this approach, emissions must reflect the national natural gas grid mix, including the average country-specific biomethane share.

The above two cases are for guidance for compliance under CLEVER and *CountEmissions EU*, which recommends location-based reporting. Market based reporting may also be reported along with location-based reporting, but the respective international framework shall explicitly support such reporting.

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7 ANNEXES

Further supporting ANNEXES will be included within the final version of the methodology only.

7.1 ADDITIONAL CLIMATE IMPACTS FROM EMISSIONS AT HIGH ALTITUDES

The climate impact of aviation has an additional contributing factor in contrast to other modes of transport. Emissions (of a range of substances) at high altitudes substances lead to additional effects:

- NO_x increases ozone and decreases methane and water vapour concentrations, leading to a net warming effect.
- Water vapour in the stratosphere contributes to global warming.
- Condensation trails (contrails) and the cirrus cloudiness arising from them also have a warming effect.
- The same is true for soot emissions.
- In contrast to the above, sulphate aerosol production leads to cooling.

The climate impact of these additional effects depends highly on altitude, latitude, time of the day and environmental conditions, e.g., low-temperature ice-supersaturated air is a prerequisite for persistent contrail formation. Additionally, the metric used has an impact on the calculation of non-CO_2 effects (e.g., ATR100, GWP100 or GWP20[58]), since these effects are in general short-lived. This is why the quantification of non-CO_2 effects is in general subject to high uncertainties and involves subjective choices.

Additional climate impacts from non-CO_2 effects are very important, especially on a short-to mid-term time frame, and therefore need to be accounted for to obtain a serious estimate of the climate impact of aviation. According to (Lee et al. 2021), they contribute 40% of the total global warming potential of aviation on a 100-year time frame, increasing to 75% over 20 years.

Most databases and standards, e.g., CORSIA, the GREET aviation module (Argonne National Laboratory, 2023), the GLEC Framework, ISO 14083 (ISO, 2023) and base carbone, do not currently consider additional climate impacts from emissions at high altitudes, although there are some sources, e.g., UK GHG emission factors, EcoTransIT World and TREMOD[59], that do quantify these effects.

The ETS Directive was amended in 2023 (ETS II) to include, inter alia, the reporting of non-CO_2 aviation impacts from 1 January 2025 for flights within the European Economic Area and from January 2027 for all inbound and outbound flights to and from the EEA[60][61].

EcoTransIT World (and formerly TREMOD) treats additional climate impacts from emissions at high altitudes by multiplying the CO_2 emissions of the cruise phase (altitude > 9 km) by a fixed emission weighting factor (EWF) to obtain the total climate impact. Recently, a more detailed approach was developed by DLR and implemented in TREMOD. It divides flights up into several clusters. For each of these clusters, there is a different formula to calculate additional climate impacts based on the flight distance, the average degree of latitude, the fuel consumption and NO_X emissions (Allekotte et al. 2024). Among the sources that allow for the consideration of additional climate impacts from emissions at high altitudes, there is a significant difference in the emission weighting factor: UK Government uses and EWF of 1.7, uses an EWF of 2, whereas TREMOD used an EWF of 2.4 before switching to the cluster approach.

The MRV system established by the European Commission in the context of the ETS II directive calls for a weather-based flight-by-flight calculation. This calculation will be conducted using an IT tool called NEATS (Non-CO_2 Aviation Effects Tracking System) and is based on the following data: flight information, flight trajectory, weather data, aircraft properties, fuel properties and aircraft performance[62].

Since additional climate impacts from non-CO_2 effects are estimated to account for 40 to 75% of the total climate impact of aviation, it is not adequate to entirely omit these effects. Given the complexity of the issue,

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[58] ATR100: Average temperature response over 100 years; GWP100: Global warming potential over a 100-year period; GWP20: Global warming potential over a 20-year period

[59] TREMOD was developed by the ifeu institute on behalf of the German Federal Environment Agency and has been continuously updated for several years.

[60] Article 14(5)

[61] https://climate.ec.europa.eu/news-your-voice/news/new-monitoring-rules-agreed-eu-ets-including-non-co2-emissions-aviation-sector-2024-08-30_en

[62] https://climate.ec.europa.eu/document/download/2efafc7e-8b25-4763-906f-a7ba23b466d2_en?filename=policy_ets_avaiation_explainer_non-co2_mrv_tasks_for_ao_en.pdf

using an EWF is an easy way to obtain a rough estimate of the climate impact. If the correct value for the EWF is used, this approach can be adequate if one aims at calculating the additional climate impact for a high number of flights at once (deviations average out), especially if the flights were conducted in different geographical regions. However, this approach has several limitations. On the one hand, applying it to individual flights will not give an accurate result, since the additional climate impact is highly dependent on altitude, latitude, time of the day, environmental conditions and aircraft model. On the other hand, there are attempts to reduce additional climate impacts from emissions at high altitudes by optimizing flight routes (Matthes et al. 2024). However, because it relies on using a fixed factor, the EWF approach is not able to capture the resulting reduction in climate impact as there is no flexibility to factor in the aforementioned dependencies on a flexible basis. Furthermore, the EWF values currently being used were derived for airplanes fuelled with fossil kerosene. Blending kerosene with sustainable aviation fuels might change (possibly reduce) the EWF

The approach followed by the European Commission in the development of NEATS appears to be much more adequate and accurate for calculating the additional climate impacts from emissions at high altitudes for single flights.

7.2 APPROACHES TO HANDLING OF FUEL AND ENERGY MIXES

Generally, it is easier for fuels to follow their characteristics throughout the supply chain than for electricity, as an electron cannot be traced, whereas for fuel mixes/ blends e.g. the exact amount of biogenic carbon in the fuel can be analysed (using the C14 method) and fuel batches can be kept separate from each other (at least for non-grid-based fuels). Still, most fuels today are supplied as already blended, average fuel mixes (with varying characteristics e.g. summer or winter grade or slightly different bio-content using a mixture of feedstocks for biofuel production).

The purpose of the CLEVER methodology is to ensure that double-counting of renewable or other low CI fuels is avoided (which can easily happen when someone uses a location-based fuel mix and someone else uses a specific fuel type) while balancing ease of use/ feasibility and fairness (“level playing field”) with the possibility to track improvements in the GHG emission factors of fuels (e. g. due to usage of different fuel carrier pathways).

In CLEVER, we have identified two options to account for non-grid-based fuel mixes:

1. **Exact fuel type/ blend**: In this option, fuel users would need to know the exact fuel type(s) they (physically) refueled with and could use this for their accounting. This can either be a specific fuel blend like B7 (diesel blended with 7% biodiesel) or E10 (gasoline blended with 10% ethanol) or a dedicated renewable fuel like HVO100. Whenever the exact fuel type is not known, a “worst case value” would be used to ensure that no double counting can occur (in most cases this would be the pure fossil fuel). Note: Even specific fuel blends would have to be based on average, representative real-world fuel mixes (valid for a certain timeframe and a specific geography) e. g. to determine the feedstock mix for biodiesel blended into the fossil diesel.

2. **Location-based fuel mixes with average biofuel shares:** The location-based fuel mixes are not linked to exact fuel blends but reflect the average amount of renewable fuel in the mix in the different EU countries derived from statistical data. Here fuel users do not need to know their exact fuel type/ blend and everyone must use the same location-based fuel mixes (regardless of whether they have proof of using a specific fuel type or not). This approach leads to a level-playing field for everyone but does not encourage usage of specific fuel types/ blends. It is aligned with the approach taken for grid-based fuels. However, in specific cases the statistical data allows to differentiate between blended biofuels and pure biofuels (this is currently the case for ethanol and biodiesel used in the EU). By using **location-based fuel mixes which do not include pure biofuels** it is possible to account for dedicated, pure biofuels (not yet included in the mix) without double-counting. However, users must use the location-based mix unless they can provide proof of directly having used a dedicated “pure” s renewable fuel (without taking mass-balancing into account).

To assess the chances and risks as well as the applicability of the options, an expert forum meeting was held where the experts (together with the consortium members) collected arguments for and against the different options. A short overview of these is shown in the table below. The majority of the experts were in favor of using location-based fuel mixes and including the possibility to account for dedicated, renewable fuels not yet captured in the mix separately which is why CLEVER will use this methodology.

	Pros	**Cons**
Exact fuel type/ blend	• Allows accounting for real fuel blends/ dedicated renewable fuels and gives maximum flexibility • Easy for users (if unknown: worst case) • Sets incentive for use of primary data (increased knowledge of actual fuel demand and types) • Can also facilitate accounting for specific biofuel pathways/ mixes	• Users need to know their exact fuel type/ blend (or use the worst-case default value) and provide proof (might be problematic for forwarders and carriers to get the necessary data)⍰ disadvantages for SMEs/ unfair as user´s who know less need to use worst case factors • Robust proof of use/ sustainability criteria and third-party verification is needed (to avoid cherry-picking) • May create an uneven playing field if some users cannot access detailed data • High granularity of data and issues with confidentiality • Number of EFs can be very high • Unclear whether increased demand of a specific fuel type actually leads to lower GHG

		emissions for the whole transport sector
Location-based fuel mixes with average biofuel shares	• Easy for users • “level playing field” for everyone (including SMEs with limited knowledge) • Alignment between electricity and fuel mixes	• No possibility to account for specific fuel blends/ pathways or dedicated renewable fuels (as they are already included in the mix) • Emerging fuel types might not (yet) be included into the mix as statistical data is only available for past years (usually around 2-year delay) • May discourage investment in advanced or emerging fuels • Exact location of refueling might be unknown • Gives no benefit (CO2-wise) if a specific, renewable fuel was used (even though it might be paid for) ⍰ consumer cannot claim lower GHG emissions
location-based fuel mixes which do not include pure biofuels	• Easy to use, with (limited) possibility to account for dedicated renewable fuels (currently available pure biofuels or emerging renewable fuels such as RFNBOs) • Encourages adoption of pure biofuels or advanced fuels where available • Balance between ease-of-use and incentive for specific fuel types	• Difficult to decide what a dedicated pathway is and what is already included in the mix (risk of double counting is higher) and only possible where statistical data is available • Needs a “residual” fuel mix (country mix must be changed based on renewable fuel directly consumed/ bought from market) • No possibility to account for different fuel blends (e.g. E85) (as they are already included in the mix) • Risk of inconsistent application across countries or modes • Exact location of refueling might be unknown