Towards a European-wide harmonised transport-specific LCA Approach

TranSensus LCA

Coordinated and Support Action (CSA)
Grant Agreement Number 101056715

Start date of the project: January 1st, 2023, Duration: 30 months

Deliverable D 6.3

Report on transferability to other markets

Status: Final

Lead contractor for this deliverable:

Due date of deliverable: **30.04.2025**
Actual submission date: **21.05.2025**

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Project co-funded by the European Commission within Horizon Europe (2021-2027)		
Dissemination Level		
PU	Public, fully open	X
SEN	Sensitive, limited under the conditions of the Grant Agreement	
R-UE/EU-R	Classified: EU RESTRICTED under the Commission Decision No2015/444	
C-UE/EU-C	Classified: EU CONFIDENTIAL under the Commission Decision No2015/444	
S-UE/EU-S	Classified: EU SECRET under the Commission Decision No2015/444	

APPROVAL STATUS			
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REVISION Table		
Document Version	**Date**	**Modified sections - details**
0.1	17/12/2024	Template created
0.2	27/01/2025	Draft was finished
0.3	16/04/2025	WP3 review finished
0.4	14/05/2025	SC review finished
1.0	21/05/2025	Final version created

EXECUTIVE SUMMARY

The TranSensus LCA project is a European initiative aimed at developing a harmonized, transport-specific Life Cycle Assessment (LCA) methodology for zero-emission vehicles (ZEVs). Coordinated by the Fraunhofer Institutes LBF and IST, the project brings together 44 stakeholders from industry and research, including major automotive manufacturers, battery producers, and academic institutions.

TranSensus LCA seeks to establish a standardized LCA approach that encompasses environmental, economic, and social aspects of ZEVs. The project aims to:

- Conceptualize and demonstrate a unified, real-data-based LCA methodology for zero-emission road transport
- Harmonize existing methodologies, tools, and datasets to ensure consistency and comparability
- Develop an ontology and framework for a European-wide Life Cycle Inventory (LCI) database
- Establish protocols for LCI data management and updates throughout the vehicle life cycle and supply chain
- Address emerging technologies and evolving industry demands

The project covers the entire life cycle of ZEVs, including design, production, usage, and end-of-life stages. It considers various vehicle types, such as passenger cars and commercial vehicles, and technologies like battery-electric and fuel cell systems.

One major result of TranSensus LCA is deliverable D2.3 “Final harmonised approach”. It delivered a robust, transparent, commonly accepted and applied single life cycle assessment approach for zero emission vehicles, including environmental and social aspects. To reach such harmonised methodology, the work has been integrated in a consensus process including votes and feedback of associated partners. The TranSensus-LCA methodology proposed in D2.3 document consists in more than 137 requirements and covers all phases of life cycle assessment for zero emission vehicles.

Although TranSensus LCA focusses on road transport, the proposed LCA approach will probably be applicable (for most of its content) to other transport modes or for stationary applications like battery charging stations. A study on transferability to other industrial sectors was performed in WP6 to identify requirements from other markets, synergies and needs for adaptions of the proposed approach.

The TranSensus LCA task “Transfer to other industrial sectors” analysed applications including charging stations for battery electric vehicles and hydrogen refuelling, waterborne transport, airborne mobility, construction equipment, and railway vehicles (S-LCA/S-LCI).

The deliverable summarises findings on transferability, noting significant overlap in the project's insights, particularly in electricity modelling during production and use stages. While zero-emission technologies are the focus, sectors like waterborne transport and construction equipment may require sustainable fuels during the transition due to current limitations in zero-emission options.

EXECUTIVE SUMMARY

The life cycle impact assessment from TranSensus LCA can be applied to other applications, with impact categories classified into mandatory and optional groups. Inventory analysis parameters should be categorised similarly, with sensitivity analysis tailored to specific applications. The project's frontloading approach for integrating environmental considerations into product development can be adapted, along with adherence statements and result reporting.

For social life cycle inventory and assessment, the methodology is expected to align with zero-emission vehicles, though differences may need attention. A comparison with Hitachi Rail's SPD-PCR showed alignment in some components, highlighting areas for potential adaptation.

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Important abbreviations

BEV:	Battery Electric Vehicle
DQR	Data Quality Rating
EACs	Energy Attribute Certificates
EC	European Commission
EC-JCR	European Commission - Joint Research Centre
EF:	Environmental Footprint
eFuels	Electrofuels (synthetic fuels)
E-Mobility:	Electromobility
EoL:	end-of-life
EU:	European Union
EV:	Electric Vehicles
eV-TOL	electric vertical take-off and landing
FU	Functional unit
GHG	Green House Gas
H2	Hydrogen
H2/h	Hydrogen per Hour
HDV:	Heavy-Duty Vehicle
HEV:	Hybrid Electric Vehicle
HVAC	Heating, Ventilation, and Air Conditioning
GWP	Global Warming Potential
ICs	Impact Categories
ICE:	Internal Combustion Engine
ICEV:	Internal Combustion Engine vehicle
ISO	International Organisation for Standardisation
kWh/h	Kilowatt hour per hour
LCA:	Life Cycle Assessment
LCIA:	Life Cycle Impact Assessment

LNG	Liquefied Natural Gas
NGO	Non-Governmental Organisation
OEM:	Original Equipment Manufacturer
PAVs	Personal air vehicles
PEF:	Product Environmental Footprint
PEP	Product Environmental Profile
PCR	Product Category Rules
PREMISE	PRospective EnvironMental Impact asSEment
PSR	Product Specific Rules
PSILCA	Product Social Impact Life Cycle Assessment
ro-ro	Roll-on/roll-off vessels
RTOs	Research and Technology Organisations
SHDB	Sustainable Health Database
S-LCA:	Social Life Cycle Assessment
S-LCI:	Social Life Cycle Inventory
SPD	Social Product Declaration
SPCRs	Social Product Category Rules
TSLCA	TranSensus LCA
UAVs	Unmanned aerial vehicles
UNECE:	United Nations Economic Commission for Europe
V2X	Vehicle-to-Everything
WP:	Work Package
ZEV:	Zero Emission Vehicle

I. Introduction

I.1 Motivation and objectives of this deliverable

The TranSensus LCA project (funded by the EU's Horizon Europe programme) aims to develop a baseline for a European-wide harmonised, robust, transparent, commonly accepted and applied single life cycle assessment approach for zero emission road transport system, including environmental and social aspects.

This method should allow real-data-based LCA, be adaptative (depending on the goal, the practitioner and the level of knowledge), be comprehensive including all life cycle stages and relevant impact categories (not focusing only on global warming potential - GWP), cover a wide range of Zero Emission technologies, allow confidentiality, be standardized, differentiating, auditable [1].

TranSensus LCA (TSLCA) consists of six content-related work packages. These work packages are based on the necessary conceptualisation, harmonisation and communication efforts, as well as the different levels of stakeholder involvement. The tasks will be carried out with an iterative approach, ensuring information exchange at least every two months, overseen by the Project Steering Committee, which includes all WP Leaders.

The project started with WP1 & WP2, where a consensus LCA concept will be developed within the consortium, covering both retrospective and prospective assessments of vehicle and battery value chains, taking into account circular economy requirements, social aspects and cost considerations. The concept builds on existing activities beyond TranSensus LCA, covering different life cycle stages and assessment steps, with potential adaptation to other sectors and regions such as Asia and the US.

WP1 focuses on defining the context and objectives of the study, informing decisions on scope, methodology and data, and identifying knowledge gaps and needs. WP2 builds on the results of WP1 to create a comprehensive European LCA approach for electric mobility, assessing environmental, economic and social performance. This includes modelling recommendations and the improvement of LCA approaches for design phases and circular value chains.

WP 3 and WP4 start before the end of WP2, since they contribute to refine the approach developed in WP2 aiming to reach the consensus more efficiently. As the concept matures, harmonisation with advisory boards will be pursued in WP 3, followed by discussions with stakeholders such as industry, mobility providers, standardisation bodies, legislators and the EC in WP4. Experts will also participate in workshops and consultations across WPs 1-3, coordinated by WP4.

The results of the conceptualisation and harmonisation will be distilled into guidelines and recommendations for future standards in WP5.

In addition, synergies and transfer to non-road markets such as other transport modes, general engineering or consumer products will be analysed in WP6. All dissemination activities are also part of WP6.

Although TranSensus LCA focusses on road transport, the proposed LCA approach will probably be applicable (for most of its content) to other transport modes or for stationary applications like battery charging stations. A study on transferability to other industrial sectors was performed in WP6 to identify requirements from other markets, synergies and needs for adaptions of the proposed approach.

This deliverable sums up the results from the study on the transferability to other industrial sectors.

The project results were achieved through regular meetings, brainstorming sessions and feedback loops with TranSensus LCA project beneficiaries and associated partners from industry, academia and RTOs, and WP3 ensured that different perspectives were incorporated into the outcome.

I.2 Structure of the deliverable

This deliverable is divided into several sections:

First, a potential application is presented, such as charging stations for BEVs and H2 refuelling stations. Based on the aspects of goal and scope, life cycle inventory, life cycle impact assessment, life cycle interpretation, and social life cycle inventory / social life cycle assessment, each application is examined to determine to which extent it can be transferred to another application. At the end of the document, there is a concluding assessment of the transferability to other applications.

Figure 1: Requirements of TranSensus LCA methodology (Summary)

The basis for the transferability study in this document is deliverable *D2.3 TranSensus LCA final harmonised approach* [2], the building blocks of which can be seen in Figure 1.

The following applications were analysed within this TranSensus LCA task:

- Charging stations for BEVs / H2 refuelling
- Waterborne transport
- Airborne mobility
- Construction equipment
- Railway vehicles (S-LCA/S-LCI)

II. Charging stations for BEVs / H2 refuelling

Life Cycle Assessment for charging stations and hydrogen refuelling stations is crucial in the transition towards sustainable transportation. As electric and hydrogen-powered vehicles become more prevalent, understanding the environmental impacts of their associated infrastructure is essential. Potential customers for a harmonised LCA could be manufacturers, infrastructure developers, automotive companies, government agencies, environmental consultants, investors and financial institutions, research institutions, NGOs and advocacy groups energy providers. LCA for electric charging stations for BEVs and hydrogen refuelling stations are performed using the standards ISO 14040:2006 [3] and ISO 14044:2006 [4]. Besides these standards there is a standard in development to assess the environmental impact according to the PEP ecopassport with the “PSR0018 - Specific rules for electric vehicle charging infrastructures” [5].

II.1 Goal and Scope

Regarding the goal of the LCA, it is more sensible to apply Retrospective and Prospective LCA to determine the impact of charging stations and refuelling stations for hydrogen. By also conducting OEM fleet life cycle assessments and macro fleet LCA, the practitioners can gain a comprehensive understanding of the environmental implications of charging and H2 refuelling stations within a larger context. The technologies in scope of this LCA, could vary significantly due to the application’s focuses on vehicle charging and refuelling. Therefore, there is a greater emphasis on charging speeds, stationary/mobile charging, battery swapping, wireless charging, Vehicle-to-Everything (V2X e.g., Vehicle-to-grid, Vehicle-to-building, Vehicle-to-vehicle, …) and smart charging, in the case of EV chargers. In the case of hydrogen refuelling, there is considerations needed regarding production delivery modes or on-site productions, fuel phase (gaseous or liquid) and dispensing approaches.

For hydrogen refuelling stations, the technologies considered should include public or private refuelling stations, those with on-site production facilities such as electrolysis, and both mobile and stationary applications, with integrated renewable power supplies, e.g., solar power or bulk hydrogen stations. The functional unit should measure the amount of energy delivered to a zero-emission vehicle over a specific period, e.g., kWh/h or kg H2/h.

The system boundaries can be adapted from the TranSensus LCA and should encompass the analysis from cradle to grave, including raw material extraction, manufacturing, transportation, installation, operation, and end-of-life (EoL) considerations.

In summary, the goal and scope can only be partially adapted from the TranSensus LCA; however, due to the exclusion of the vehicle itself, there is a minimal overlap.

II.2 Life Cycle Inventory

Regarding the production phase, the modelling approach from the TranSensus LCA can be applied here, including the data requirements for level 3 and the electric energy supply in the manufacturing phase. It must be verified whether these conditions are also valid for battery charging stations and H2 refuelling stations. This may prove to be specifically challenging for H2-refuelling due to the limited or no available accurate and complete databases for fuel cell and hydrogen technologies. Similarly, gathering information on the whole life cycle chain, including manufacturing, operation and end-of-life can be challenging due to highly limited commercial hydrogen supply chain operations.

The analysis of the use phase, in the case of EV charging stations should consider energy losses during charging, equipment energy consumption, the resulting charging efficiency (charging efficiency = energy delivered (total - losses) / total energy), maintenance, operational hours, emissions, grid interaction, and usage patterns, which differ significantly from those in the TranSensus LCA. Energy losses that occur while charging an EV, in conjunction with the efficiency factors previously discussed, can result in operational emissions, including the energy needed to operate and cool the charger. Variations or shifts in EV charging to period when the grid has lower greenhouse gas (GHG) intensity can also impact the overall operational emissions of the EV charger.

In the case of the hydrogen refuelling stations, life cycle emissions estimation can prove to be more complex. Besides the implications of a potential hydrogen production methods (i.e., electrolysis, steam methane reformation), there are leakages to be anticipated from storage and dispensing of the fuel. This is partly addressed by the methodology to account for fugitive H2 losses, the capacity of the refuelling stations to limit the release of these fugitive emissions needs to be accounted for.

It is crucial to ensure that there is no double counting of emissions during the use phase. Leakage of hydrogen during fuelling, storing, or processing should be considered during the use phase in regard to its Global Warming Potential.

The approach regarding end-of-life phase modelling can be adapted from the TranSensus LCA, including its data choices and the electric energy supply during the EoL phase. The approach to address multifunctionality problems can also be drawn from the TranSensus LCA with the necessary adaptations for specific applications.

Within these applications, it makes sense to perform some form of data quality assessment to ensure ISO compliance with criteria such as completeness, representativeness, transparency, consistency, temporal validity, source credibility and uncertainty assessment.

II.3 Life Cycle Impact Assessment

Regarding the life cycle impact assessment, it is reasonable to apply the TranSensus LCA approach, including its division of impact categories, calculation methods, and normalization of the results. The same categorization of mandatory impact categories (mandatory, optional, not recommended) can be applied here, with climate change, photochemical ozone formation, acidification, particulate matter, eutrophication (freshwater), cumulative energy demand, resource use, minerals and metals and also the land use impact as mandatory ones.

II.4 Life Cycle Interpretation

To analyse the robustness of the LCA results and to identify and quantify the most influential factors, it is recommended to perform scenario analysis, uncertainty analysis, and sensitivity analysis. As in the TranSensus LCA, the categorisation of certain parameters into mandatory, recommended, and optional parameters is a good approach to pursue. Similarly, it makes sense to define the type of analysis that should be performed (e.g., sensitivity analysis on the actual lifetime of the charging station potentially in both years, and lifetime energy delivered). The categorisation and the types of analysis must be defined with respect to charging stations and hydrogen refuelling stations.

The TranSensus LCA frontloading approach for the integration of environmental considerations into product development can be adapted.

Regarding the publication of the results, the TranSensus LCA approach can be partially adopted and adjusted to the needs of charging stations and hydrogen refuelling stations. If the results are to be publicly reported within any form of public communication of the Product LCA conducted, whether it is a public LCA report or a public summary, the following results can be published: absolute values scaled to the functional unit for the mandatory impact categories, contribution analysis for the mandatory impact results, and the main hotspots. The same applies to the scenario analysis, uncertainty analysis, and sensitivity analysis. During the application of the LCA, choices must be made, e.g., the decision on whether the lifetime values for the functional unit differ from the default values. These choices should be included in a public LCA report or public summary.

An approach has been developed that can be used to demonstrate how closely the TranSensus LCA methodology has been followed (adherence level "A" or "B"). Level "A" means that all mandatory requirements from TSLCA (including those on supporting information to report) are adhered to, while level "B" means that all mandatory requirements from TSLCA (excluding those on supporting information to report) are followed.

To ensure the LCA follows the requirements for Level 3 or 4 (UENCE) a 3rd party verification shall be conducted. For level 1 or 2 (UNECE) a 1st or 2nd party verification should be conducted.

Depending on the needs for battery charging stations and hydrogen refuelling stations, the approach for results and verification can be adopted.

II.5 Social Life Cycle Inventory / Social Life Cycle Assessment

With regard to Social LCI and LCA, it is expected that the approach for charging stations and H2 filling stations will not differ fundamentally from those that apply to zero-emission vehicles. In individual cases, it must be determined whether major differences will become apparent and need to be addressed.

III. Waterborne transport

This sector presents the life cycle assessment for waterborne transport, like container ships, ferries, cruise ships aiming to evaluate the environmental impacts throughout the lifecycle, from design and manufacturing to operation and end-of-life. The assessment is particularly focused on understanding how design improvements can enhance sustainability, thereby aiding manufacturers in making informed decisions. The scope of the assessment includes a cradle-to-grave approach, which captures all stages: raw material extraction, manufacturing, transportation, assembly, operation, and end-of-life disposal. The segments below are analysed based on active stakeholders of the maritime industry including but not limited to shipping companies, government, international organisations, classification societies, equipment manufacturers, shipbuilding companies, etc. Current standards for assessing the life cycle assessment of waterborne transport include the standards ISO 14040:2006 and ISO 14044:2006.

III.1 Goal and Scope

With the goal definition, for the purpose of analysis for a single ship, product LCA and prospective LCA are considered. Assessing LCA at the OEM fleet level and macro fleet level allows for a comprehensive understanding of the environmental impacts across all vessels, rather than individual ships in isolation. However, due to the complexity of container ships and typically assessed as part of larger fleets, and the impact from OEM fleet LCA which facilitates insights into design improvements and sustainability from manufacturer's perspective, these should be taken into consideration.

In terms of technology coverage, it considers various engine types, including hydrogen fuelled vessels, battery electric propulsion systems, hybrid systems, internal combustion engines who run on renewable fuels (biofuels, eFuels, methanol, ammonia, hydrogen, …) or wind-assisted propulsion. Various types of ships are part of the transferability study, including container ships, bulk carriers, tankers, cruise ships, ro-ro (roll-on/roll-off) vessels and ferries. The functional units are defined as the operation of a ship transporting a specified tonne-km for cargo ships (container ships, bulk carriers, tankers, …) and passenger-km for passenger ships. As highlighted in the introductory aspect, the entire cradle-to-crave (raw material extraction, manufacturing, transportation, assembly, operation, End-of-Life) should be considered in compliance with TranSensus LCA. A zero-emission vessel may incorporate charging infrastructure such as shore power systems and battery charging stations, along with bunkering/refuelling facilities for various fuel types, including hydrogen, liquid natural gas (LNG), biofuels, and ammonia, as well as renewable energy integration for sustainable operation. It is essential to ensure that emissions from these sources are included in some form of analysis, either within or outside the vessel's life cycle assessment.

III.2 Life Cycle Inventory

Similar to the recommendation given in TranSensus LCA regarding data requirement, and for Level 3 LCA for a ship life cycle assessment, the following minimum cradle-to-gate data requirements can also be applied:

- The practitioner shall select ship components that together account for a minimum threshold of a certain percentage of the production phase Global Warming Potential, in addition to the propulsion system components that the relevant maritime regulations cover. Given the substantial amount of steel and other materials required to produce a ship, it would be reasonable to suggest a higher threshold for selecting ship components in the assessment of the production phase Global Warming Potential than the 20% TranSensus LCA suggested.
- The selected components shall be modelled using company-specific data from at least their tier 1 suppliers, while secondary data may be utilized to cover the remaining components' supply chain.
- A list of the chosen components (specific to GWP) shall be provided by the practitioner.

On the energy requirement, similar to the approach given by TranSensus LCA, to satisfy the varying preferences for energy supply modelling in the production phase of vessels, a flexible approach is established, incorporating location-based, market-based, and mixed-method strategies. The default modelling choice is a location-based approach, utilizing either sub-national grid mixes or national grid mixes when available. In the absence of these, a supra-national grid mix is employed.

For industries opting to utilize Energy Attribute Certificates (EACs), a 100% market-based approach can be adopted, where electricity consumption is modelled based on specific contractual agreements. If no contract is available, a residual consumption mix—either at a national or sub-national level—should be used. Recognizing that many companies face challenges in implementing a 100% market-based approach due to data availability and the complexity of their global supply chains, a mixed-method approach is also permitted. This method involves using location-based electricity mixes as a default while integrating specific processes reflecting the electricity mix from contractual instruments.

It is crucial that all chosen modelling approaches are transparently documented and justified to ensure consistency in comparative LCAs, adhering to ISO 14044 guidelines. Regardless of the selected approach, industries must avoid dual reporting and ensure compliance with defined safeguards concerning contractual instruments used in their assessments. In addition to the energy requirement, operational emissions and maintenance should be included in within the Use Phase modelling in compliance with ISO 14044 guidelines and TranSensus LCA recommendations. Operational emissions include fuel combustion emissions from internal combustion engines (ICEs) if applicable, emissions associated with onboard electricity generation, such as from auxiliary engines or generators, emissions related to activities at ports, including loading and unloading, and any auxiliary power used while docked, as well as ballast water management and waste management. Passenger ships like cruise ships generate special emissions from unique onboard activities, including wastewater treatment, food waste management, and the operation of recreational facilities like spas and water parks. Additionally, increased emissions stem from heating, ventilation and air conditioning (HVAC) systems and luxury services that cater to passengers, reflecting the energy-intensive nature of cruise ship operations.

The maintenance for vessels is distinct to those for road vehicles considered in TranSensus LCA. Maintenance involves large-scale systems such as hull integrity, deck equipment maintenance, environmental systems maintenance (waste management, ballast water treatment, …) or maintenance of recreational facilities (for cruise ships). Unlike road vehicles vessels usually undergo refits during the lifetime. That can mean major overhauls or renovations that can involve significant modifications to the vessel's structure, layout, or systems, aimed at enhancing performance, compliance with new regulations, or adapting to changing operational needs. This type of maintenance is not only intended to ensure or restore seaworthiness but can also have an influence on relevant LCA parameters such as energy consumption, emissions, or maximum permissible payload.

The TranSensus LCA approach could be applied for end phase modelling with its data choices and energy supply at the end-of-life phase. In dealing with multifunctionality problems, appropriate allocation methods, substitution approach, perform Sensitivity analyses, Stakeholder Engagement shall be considered. The steps to address these problems shall align with recommendations given by TranSensus LCA. Criteria such as completeness, representativeness, transparency, consistency, temporal validity, source credibility and uncertainty assessment shall be considered for data quality rating (DQR) for the life cycle inventory.

III.3 Life Cycle Impact Assessment

While widely adopted, inconsistencies in methodology affects accurate and reliable impact assessment. Through the methodological standardization by TranSensus LCA on the key elements (including impact categories, impact indicators, impact assessment methods, and normalisation), similar standardization can be applied with container ships since the recommendation stays same for Fleet LCA. The adaptation of the mind map highlighting the requirements for LCIA is also crucial for specific demands when performing for container ships. Regarding calculation of LCIA results, since mandatory ensures compliance with regulatory requirements and industry standards while Optional offers a more comprehensive view of the environmental impacts, both can be applied here. A thorough review of impact categories of maritime specific parameters should be highlighted e.g., due to the movement of the ship in water and its direct interaction with the marine environment, there is a greater potential for pollution in the sea, such as contributing to acidification and marine eutrophication. Normalisation factor, under normalisation may be used to contextualise and compare impact results by translating them into a common scale of reference, further helping to prioritize ICs as most significant.

Once results are achieved, analysing it can enable the LCA practitioner to realise significant differences (where necessary) between data sourced from primary databases. The proposal by TranSensus LCA where a reversed-engineering approach is employed to investigate the discrepancies can reveal what contributes to the total impact. This is essential for validation and concise analysis. The findings at the end may enable one to understand the relevance of the methodology and data quality in accurately assessing environmental impacts in for the container ship production process.

III.4 Life Cycle Interpretation

The approach defined for the interpretation phase of LCA (part A) and S-LCA (part B) including the proposal of recommendations for conducting sensitivity analysis, scenario analysis, and/or uncertainty analysis may enable the conceptualization of how decision-making and frontloading processes should be implemented into industrial product development processes along the supply chain. As a result, similar approach can be implemented to enable engineers and managers according to their profile (shipping industry, regulatory bodies, academia, policy, etc.) to select solutions and technologies (both existing and emerging) based on their environmental and social impacts in view of the overall objective to pave the path towards an LCA-driven product development for container ships.

On the topic of scenario analysis, uncertainty analysis and sensitivity analysis, specific parameters such as fuel consumption, operational profile, technology innovations, etc as well as specific methods focusing on maritime (maritime traffic patterns, environmental impact assessment) have to be considered for mandatory, recommended and optional parameters.

Regarding integration into the product development process, the TranSensus LCA frontloading approach for integration of environmental considerations in design, decision-making support, harmonized process development may be applied.

In addition to reporting the results of the LCA study, choices made along the requirement application of TranSensus LCA methodology and mandatory supporting information to understand the results, recommendations to be followed when reporting, operational profiles including information on typical operational conditions, technological innovations following the use of alternative fuels, efficiency measures, etc should be reported as they can significantly have environmental impacts. On public reporting, as recommended to follow choices made along the

TranSensus LCA, the methodology mandates specific reporting requirements to ensure transparency and comparability in lifecycle assessments, which is also crucial for container ships as they present unique environmental challenges. In addition to the key choices that must be publicly reported, use stage modelling should encompass energy consumption specifics and degradation factors, while end-of-life considerations must address the choice between company-specific or generic secondary data. These choices must be justified and documented to facilitate indirect comparability across studies. Given the variable operational profiles of container ships, including route efficiencies and technological innovations, it is essential to communicate these factors clearly to enhance the credibility and relevance of LCA results within the maritime sector.

On adherence statement, for the purpose of flexibility in reporting, encouraging transparency and contribution to industry objectives, the concept of adherence statement as outlined in TSLCA can be applied here. However, due to its complexities, clear guidelines, industry-specific examples and collaborative frameworks should be considered for its implementation. Verification process approach can as well be applied. However, much attention needs to be initially given to Level 2 for detailed assessment, key impact identification and foundation for further analysis in Level 3 or Level 4.

III.5 Social Life Cycle Inventory / Social Life Cycle Assessment

For the relevance of stakeholder impact assessment, regulatory compliance etc, the TSLCA approach is ideal to be implemented. The product scales outlined as well as established by PSILCA (Product Social Impact Life Cycle Assessment) and SHDB (social hotspots database) should be followed. However, comprehensive understanding of all regulations, standards, norms and pertinent need to be considered for the collection of data for reference scales. The mind-map can be followed with specific consideration to factors on maritime applications. This should serve as a mind-map to guide the implementation and assessment of Social LCA in the container ship applications.

IV. Airborne mobility

The airborne mobility sector is growing due to rising urbanisation, technological advancements, and a shift towards sustainable transport solutions. As demand for efficient and environmentally friendly transportation increases, Life Cycle Assessment becomes crucial in evaluating the environmental impacts of airborne vehicles throughout their entire lifecycle.

IV.1 Goal and scope

In terms of the purpose of LCA, it makes sense to apply retrospective and prospective LCA to determine the impact of air mobility solutions. By also assessing OEM fleet LCA and macro-level fleet LCA, stakeholders can optimise individual contributions and understand the aggregated impact on sustainability and environmental goals. The technologies covered by this LCA could include electric vertical take-off and landing (eVTOL) aircraft for short trips, unmanned aerial vehicles (UAVs) e.g., for delivery and surveillance, air taxis providing on-demand air transport services for urban and suburban areas, personal air vehicles (PAVs) for individual or small group travel, or hybrid airships combining lighter-than-air technology with traditional aircraft features for cargo or passenger transport. Drones can serve a variety of purposes beyond transporting cargo or people, including surveillance and security, agricultural tasks like crop monitoring and spraying, capturing aerial photography and videography, and inspecting infrastructure such as bridges and power lines. Due to the enormous dynamics of this sector, new applications and technologies are constantly being introduced, so the list of technologies covered is not exhaustive. These vehicles can be powered by electric, hybrid, hydrogen fuel cell, internal combustion engines, hybrid engines, turboprop and turbofan engines.

The functional units from TranSensus LCA can be used with tonne-km for cargo drones and passenger-km for passenger drones. For drones who can carry more than one person, the occupancy rates shall be taken into account for the calculation respectively sensitivity analysis. UAVs can perform a variety of tasks that do not include just carrying payload or passengers. For these cases, the functional unit can be based on the type of service delivered: being "hectares of crops treated" for agricultural drones, or "flight hours" for a videography UAV.

The system boundaries can be adapted from the TranSensus LCA and should encompass the analysis from cradle to grave, including raw material extraction, manufacturing, transportation, installation, operation, and end-of-life considerations.

In summary, the goal and scope can be adapted from the TranSensus LCA with few changes.

IV.2 Life Cycle Inventory

Regarding the production phase, the modelling approach from the TranSensus LCA can be applied here, including the data requirements for level 3 and the electric energy supply in the manufacturing phase. It must be verified whether these conditions are also valid for airborne mobility. This may prove to be specifically challenging due to the limited or no available accurate and complete databases for this sector. Similarly, gathering information on the whole life cycle chain, including manufacturing, operation and end-of-life can be challenging due to limited number of manufacturers, due to the novelty of the technologies, and the highly dynamic nature of the market.

In the life cycle assessment of small aircraft, modelling of the use phase is a critical component that captures the environmental impacts during the operational life of the aircraft. This phase includes the assessment of energy consumption, which can vary significantly depending on flight time, distance and payload weight. It also involves estimating emissions, whether direct emissions from fuel combustion for fuel-powered drones or indirect emissions from the production of the energy carrier. Routine maintenance and repairs are considered, taking into account the resources and environmental impacts associated with these activities. Operational efficiency is assessed by looking at the area covered, or data collected per unit of energy consumed. The life cycle of the battery is another important consideration for battery powered vehicles, considering charging cycles, degradation and the impact of replacement. Weather and environmental conditions such as wind, temperature and altitude are also considered as they can affect energy consumption and performance. Finally, the impact of different payloads, such as cameras or sensors, on energy consumption and operational efficiency is also analysed.

The approach regarding end-of-life phase modelling can be adapted from the TranSensus LCA, including its data choices and the electric energy supply during the EoL phase. The approach to address multifunctionality problems can also be drawn from the TranSensus LCA with the necessary adaptations for specific applications.

Within these applications, it makes sense to perform some form of data quality assessment to ensure ISO compliance with criteria such as completeness, representativeness, transparency, consistency, temporal validity, source credibility and uncertainty assessment.

IV.3 Life Cycle Impact Assessment

For the LCA, it is useful to apply the TranSensus LCA approach, including its categorisation of impacts, calculation methods and normalisation of results. The same categorisation of mandatory impact categories (mandatory, optional, not recommended) can be applied here: climate change, photochemical ozone formation, acidification, particulate matter, freshwater eutrophication, cumulative energy demand, resource use, minerals and metals and H2 emission flow and GWP sensitivity impacts as mandatory.

IV.4 Life Cycle Interpretation

It is recommended to perform scenario analysis, uncertainty analysis, and sensitivity analysis also on airborne mobility. As in the TranSensus LCA, the categorisation of certain parameters into mandatory, recommended, and optional parameters is a good approach to pursue. Similarly, it makes sense to define the type of analysis that should be performed (e.g., sensitivity analysis on the lifetime in hours). The categorisation and the types of analysis must be defined with respect to airborne mobility.

The TranSensus LCA frontloading approach for the integration of environmental considerations into product development can be adapted.

Regarding the publication of the results, the TranSensus LCA approach can be partially adopted and adjusted to the needs of airborne mobility. If the results are to be publicly reported within any form of public communication of the Product LCA conducted, whether it is a public LCA report or a public summary, the following results can be published: absolute values scaled to the functional unit for the mandatory impact categories, contribution analysis for the mandatory impact results, and the main hotspots. The same applies to the scenario analysis, uncertainty analysis, and sensitivity analysis. During the application of the LCA, choices must be made, e.g., the decision on whether the lifetime values for the functional unit differ from the default values. These choices should be included in a public LCA report or public summary.

An approach has been developed that can be used to demonstrate how closely the TranSensus LCA methodology has been followed (adherence level “A” or “B”). Level “A” means that all mandatory requirements from TSLCA (including those on supporting information to report) are adhered to, while level “B” means that all mandatory requirements from TSLCA (excluding those on supporting information to report) are followed.

To ensure the LCA follows the requirements for Level 3 or 4 (UENCE) a 3rd party verification shall be conducted. For level 1 or 2 (UNECE) a 1st or 2nd party verification should be conducted.

Depending on the needs for airborne mobility, the approach for results and verification can be adopted.

IV.5 Social Life Cycle Inventory / Social Life Cycle Assessment

With regard to Social LCI and LCA, it is expected that the approach for charging stations and H2 filling stations will not differ fundamentally from those that apply to zero-emission vehicles. In individual cases, it must be determined whether major differences will become apparent and need to be addressed.

V. Construction Equipment

This section presents the Life Cycle Assessment for construction equipment such as Cranes, Excavators, bulldozers, Loaders, concrete mixers, etc, aiming to evaluate the environmental impacts throughout the lifecycle, from design and manufacturing to operation and end-of-life. The assessment is particularly focused on understanding how design improvements can enhance sustainability, thereby aiding manufacturers, suppliers and government in making informed decisions. The scope of the assessment includes a cradle-to-grave approach, which captures all stages: raw material extraction, manufacturing, transportation, assembly, operation, and end-of-life disposal. The segments below are analysed considering active stakeholders of the construction equipment industry to fit into the overall objective. These stakeholders include but not limited to: Governments, owners, managers, employees, suppliers, creditors, customers, citizens, etc.

V.1 Goal and scope

Regarding goal definition, during the development stage when the bill of materials is not fully defined or accurate, a prospective LCA is suitable to estimate its potential environmental impacts before production. Further on, the Product LCA is essential to evaluate the environmental impact. Since most construction equipment are not fully zero-emission equipment, looking into this aspect would be budding, and thus essential to consider their impact within sub-national and international contexts, regarding policy making and economy scale strategies. Macro Level Fleet is therefore essential in this category. OEM fleet analysis may be necessary here considering the fact that it facilitates insights into the design improvement.

Considering the caveat "The technology coverage in the prospective LCA is open for all new and emerging technologies as long as they meet the definition of the ZEV", construction equipment can fit into the TSLCA's technology coverage in addition to the technology types. Here, power train technologies (battery-electric systems, fuel cell systems, and grid-connected equipment), energy supply and infrastructure (renewable energy sources, battery charging infrastructure, onsite energy storage solutions, etc), material and manufacturing (sustainable material sourcing, manufacturing emissions etc), operation and maintenance etc. should be taken into account for its technology coverage. All stages in LCA processes needs to be considered for the system boundary without exception (cradle-to-grave including raw material extraction, manufacturing, transportation, assembly, operation, maintenance, end-of-life). Unless specified, specific explanations should be given why a particular stage should be ignored. The functional unit is defined as the operational use of a construction equipment performing its specific task under standard workload conditions for a specific period of time.

V.2 Life Cycle Inventory

Within this second phase of the LCA, for production phase modelling, the construction equipment may deviate from the guidelines provided by TSLCA due to the choice of prospective LCA for the electric energy supply in manufacturing stage. However, the deviation guideline for energy supply, residual mix modelling and on-site electricity production processes should be considered in its implementation. Further on in the production phase, the energy supply for manufacturing phase and data requirements should be considered in alignment with the guidelines for production phase modelling. Before this, the exact time frame for prospective LCA before production phase should be specified. Hypothesis such as Power Purchase Agreements (PPAs) should also be specified. Here Energy Attribute Certificate (EAC) cannot be used since such contractual instruments are dedicated to past electricity production. The guidelines for electricity modelling should not also be ignored in this perspective.

For use phase modelling, the EU regulatory type-approval/certification values should be the basis for defining the energy consumption, based on certified energy consumption values according to the vehicle energy consumption calculation tool (VECTO) [6] developed for the European Commission (European Commission, 2023) [7], and used in whole-vehicle certification in the EU for construction equipment. Same as in production phase, the deviation guideline for energy supply and on-site electricity production processes should be considered in its implementation. All deviations for electric energy supply in use phase guidelines should as well be considered in addition to the guidelines laid. Categorically, the residual mixes used for prospective LCA should be modelled as national mixes to reflect the future development of Energy Attribute Certificate (EAC). As a recommendation, future electricity mixes may be done with the results of the PREMISE (PRospective EnvironMental Impact asSEment) project [8], which offers a streamlined approach to producing databases for prospective life cycle assessment using integrated assessment models. However, it ends, the electricity modelling chosen for the use phase construction equipment should be clearly justified and documented.

For end-of-life phase modelling, company-specific data may only be used if it already possesses partnerships, owns facilities in that field, or the practitioner is certain about the fate of the End-of-life of the equipment in the future (e.g., one central treatment facility in the geographical scope of the study where all the End-of-Life treatment may occur). If not, the LCA practitioner should use secondary generic data [2]. In addition to the proposition for electric energy supply, the decision tree proposed for electric energy supply in the EoL phase should also be adhered to since the general guidance for prospective LCA deviates from the production LCA EoL phase. Similar to the use phase, the residual mixes used for construction equipment EoL phase should be modelled as national mixes (whether dynamic future electricity national grid mixes or static current national mixes) from which all the renewable production (hydroelectricity, wind power, photovoltaic and biomass energy) as well as nuclear electricity production has been taken out (conservative approach that reflects the future development of Energy Attribute

Certificate (EAC)). Future electricity mixes may as well be done with the results of the PREM-ISE project, which offers a streamlined approach to producing databases for prospective life cycle assessment using integrated assessment models. the electricity modelling chosen for the use phase should be clearly justified and documented. Regardless of the difference, the rules for construction equipment under prospective LCA in general should be the same rules followed in Product LCA even though some discrepancies may exist.

For multifunctionality problems, substitution approach, sensitivity analyses, stakeholder engagement should be considered. Notwithstanding, the deviations for Multifunctionality for prospective LCA such as the additional considerations of system expansion and both physical and economic allocations should be followed to ascertain the respective questions to be considered. Cut-off method should be used in regarding the EoL phase for multifunctionality. In addition., Change in recycling technologies in the future and change in incineration technologies (e.g. lower emissions) should be considered.

Data quality assessment should be ISO compliant. Specific attention to checklist, peer review, sensitivity, scenario and statistical analysis for proper validation through third party verification.

V.3 Life Cycle Impact Assessment

Inconsistencies in methodology affect accurate and reliable impact assessment. Through the methodological standardization provided by TranSensus LCA [2] - including impact categories, impact indicators and impact assessment methods similar approach can be applied to other zero-emission construction equipment. Since the recommendations remain consistent for prospective LCA, no major deviations are required in this regard.

The adaptation of the mind map highlighting LCIA requirements is crucial for addressing specific demands when conducting LCA for electric construction equipment. Regarding the calculation of LCIA results, the mandatory approach ensures compliance with regulatory requirements and industry standards, while the optional approach provides a more comprehensive view of environmental impacts. Both should be applied to ensure a balanced assessment.

Additionally, a thorough review of impact categories such as global warming potential, resource depletion, acidification potential, etc, for electric construction equipment is necessary, even though they fall under zero-emission vehicles. This is to ensure that all hidden environmental burdens - such as resource depletion, battery production impacts, water consumption, and end-of-life disposal - are accurately assessed, preventing a false perception of zero-emission sustainability in construction equipment, thus key impact categories such as battery life-cycle emissions and embodied energy in material production should be considered.

For normalization, the global planetary boundary-based normalization factor, as recommended by TranSensus LCA, should be used. This approach contextualizes and compares impact results by translating them into a common scale of reference, further aiding in the prioritization of impact categories based on significance.

V.4 Life Cycle Interpretation

Since Prospective LCA is covered by the TranSensus LCA methodology, a similar approach can be applied to construction equipment with necessary adaptations. Additional parameters that may not yet be captured in Product LCA - such as equipment durability, operational efficiency, and alternative material compositions - should also be assessed.

For a comprehensive understanding of LCA reliability, it is crucial that all stakeholders, including manufacturers, suppliers, and policymakers, can make informed decisions along the value chain. This requires a detailed impact analysis that considers construction equipment-specific factors.

- Scenario Analysis is essential for evaluating future technological shifts, regulatory changes, and market conditions, helping to assess how the choice of design and operational strategies of the construction equipment influence the overall environmental footprint.
- Sensitivity Analysis should complement scenario analysis to determine how outcomes vary with key assumption changes in technology advancements, energy sources, or raw material use.
- Uncertainty Analysis is necessary to assess the reliability of input data and assumptions, ensuring transparency and robustness in LCA results.

Scenario analysis should be a primary focus in this section given the long lifespan and evolving technological landscape of construction equipment. However, a balanced integration of the three forms of analysis should be considered for a robust decision-making and data variability.

While the mandatory and optional parameters suggested by TSLCA largely apply to construction equipment, additional parameters must be incorporated. Specifically, factors like technological innovations, market demand, equipment lifespan, and material composition should be considered for zero-emission construction equipment.

Regarding environmental considerations in design, decision-making support, and harmonized process development, the TSLCA approach remains ideal for application. Additionally, the recommendation to apply prospective LCA to support the early engineering product development process (adapted from the V model) should be directly implemented for construction equipment, with well-defined conditions tailored to this sector.

For flexibility in reporting, promoting transparency and alignment with industry objectives, the adherence statement concept can be applied. However, due to its complexity, its implementation should be supported by clear guidelines, industry-specific case studies, and collaborative frameworks.

Finally, for verification and validation, the recommendation to integrate Prospective LCA into the verification process should be adopted to ensure credibility and accuracy in environmental impact assessment for construction equipment.

V.5 Social Life Cycle Inventory / Social Life Cycle Assessment

For the relevance of stakeholder impact assessment, regulatory compliance etc, the TSLCA approach is ideal to be implemented. The reference scales outlined and established by PSILCA and SHDB [2] should be followed when considering a specific reference scale for construction equipment. However, comprehensive understanding of all regulations, standards, norms and pertinent need to be considered for the collection of data for reference scales. The mind-map can be followed with specific consideration to factors on construction applications. This should serve as a mind-map to guide the implementation and assessment of Social LCA in the construction equipment applications.

VI. Railway Vehicles

The integration of Social Life Cycle Assessment (S-LCA) methodologies with existing frameworks, such as Hitachi Rail's SPD (Social Product Declaration) and SPD-PCR (Product Category Rules) [9], alongside the TranSensus Framework, offers a unique opportunity to explore synergies in advancing social sustainability within the rail sector. This section highlights how these established tools can complement each other to provide a comprehensive evaluation of social impacts across the lifecycle of railway systems. By leveraging the SPD and SPCR's structured approach to sustainability declarations and combining it with the TranSensus Framework's emphasis on stakeholder engagement and social impact pathways, this analysis aims to identify overlapping strengths and address gaps. The goal is to create a cohesive methodology that enhances decision-making processes for manufacturers, operators, and policymakers while aligning with global social sustainability goals. This synergy strengthens the assessment of social dimensions and contributes to the broader adoption of socially responsible practices in rail transport systems.

VI.1 Goal and Scope

Stakeholder Categories and Impact Categories

The main stakeholder categories considered in the SPD-PCR for rolling stock are workers, local community and consumers, whereas for TranSensus they are workers, local community and society. The table below shows the mandatory impact sub-categories to be considered for the SPD-PCR rolling stock and TranSensus LCA.

Table VI-1 : Stakeholder Categories and Impact Categories

Stakeholder Categories: SPD-PCR Rolling Stock	Workers	Local Community	Consumers
Mandatory Impact Sub-categories: SPD-PCR Rolling Stock	Health and safety, Wages, Social benefits, Working conditions, Discrimination, Freedom of association and collective bargaining	Local employment	Health and safety, Feedback mechanisms, Consumers privacy, Transparency for consumers
Stakeholder Categories: TranSensus	Workers	Local Community	Society
Mandatory Impact Sub-categories: TranSensus	Freedom of association and collective bargaining, Child Labour, Fair salary, Social Benefits /Social Security, Forced Labour, Working Hours, Health and Safety	Respect of Indigenous Rights	Corruption

Functional Unit

According to the SPD-PCR rolling stock, the functional unit is the transport of 1 passenger per km or 1 tonne of cargo per km depending on its function. Whereas for TranSensus it is the amount (example: 190,000) of passenger-km (if only one passenger, which then equals vehicle km) driven over a lifetime (example: 15 years) by a small passenger car.

System Boundary

Mandatory stages which are included in the system boundary of SPD-PCR rolling stock are upstream processes (extraction, manufacturing of components) and the core stage which includes vehicle manufacturing including components if internally manufactured. Use stage and end of life stage are optional. But for TranSensus the system boundary shall include the raw material extraction; material, components (battery and fuel cell included) and energy production; vehicle production; use and end-of-life scenarios.

Besides functional unit, system boundary, stakeholder categories and impact subcategories TranSensus also discusses determining the Application of S-LCA, activity variable, standard/guideline followed, and geographical scope relevant to ZEVs.

VI.2 Social Life Cycle Inventory

TranSensus documents data requirements and electricity supply for the manufacturing stage, use stage and end of life stage as well as the Well to Tank modelling and maintenance considerations for the use stage. Also, TranSensus provides the rules for data quality rating and handling multifunctionality problems including cut-off rules in all life cycle stages including end of life. Also, TranSensus provide recommendations on secondary databases, data collection procedures and types of data needed to be collected.

SPD-PCR for rolling stock recommends doing a social hotspot analysis of the main raw materials as a step to do in social life cycle inventory analysis. It also provides in detail the data that needed to be collected in each stage of the life cycle for related social indicators with the procedures and sources to collect social data. Like TranSensus SPD-PCR also provide guidance on cut-off rules and data quality requirements.

VI.3 Social Life Cycle Impact Assessment

Both SPD-PCR and TranSensus recommends the Reference Scale approach.

VI.4 Life Cycle Interpretation

No interpretation parameters are recommended in SPD-PCR whereas TranSensus LCA recommends certain parameters to evaluate different scenarios or sensitivity for example locations of material supply.

VII. Summary

While TranSensus LCA primarily targets road transport, the suggested LCA and S-LCA methodology is likely relevant (for most of its aspects) to other modes of transport or even stationary applications like battery charging stations. A study was conducted to assess the transferability to different industrial sectors and transport modes, aiming to pinpoint requirements from other markets, identify synergies, and determine necessary adaptations to the proposed TranSensus LCA approach. This deliverable summarises the findings from the study on transferability to other industrial sectors and transportation modes.

Table VII-1 summarises the major synergies between TranSensus LCA and the new applications and the most relevant adaptations that are necessary.

While charging stations for BEVs and hydrogen refuelling stations differ from the transport modes addressed in the TranSensus LCA, there is significant overlap in the project's findings. Although TranSensus LCA focuses exclusively on technologies with zero tailpipe emissions, sectors such as waterborne transport and construction equipment are unlikely to transition solely to zero-emission technologies in the near future. Current zero-emission options are not yet commercially viable or reliable for larger vessels, and alternatives like batteries and hydrogen lack the energy density of traditional fuels, which limits their range and efficiency. Therefore, it is essential to consider fuels from sustainable sources, such as e-fuels, during the transition period [10].

A significant element from the TranSensus LCA that can be applied across all applications is the electricity modelling, especially concerning the production and use stages. However, a notable distinction in the modelling of the use stage is maintenance, as it varies considerably between vessels and road vehicles addressed in the TranSensus LCA. The maintenance of ships differs from that of road vehicles, mainly due to the extensive refits that ships typically undergo, often involving significant changes to their structure and systems, which can affect aspects such as fuel consumption [11].

The life cycle impact assessment from the TranSensus LCA can be utilised for the other mentioned applications, including the classification of impact categories into mandatory and optional groups. If an application significantly contributes to issues such as acidification and marine eutrophication, as seen in waterborne transport, the impact of these factors and its categorisation will need to be reassessed.

Following the TranSensus LCA approach, categorising inventory analysis parameters into mandatory, recommended, and optional groups, along with defining the appropriate types of inventory analysis is essential for all proposed applications. The parameters that need to be analysed have to be determined based on the application such as sensitivity analysis on e.g., the lifetime of charging stations and their energy delivery. The TranSensus LCA frontloading approach for the integration of environmental considerations into product development can be adapted. The adherence statement from TranSensus LCA can also be adopted for other applications with few modifications as well as the result display and public reporting.

Concerning social life cycle inventory and social life cycle assessment, it is anticipated that the methodology for e.g., airborne transport will largely align with that used for zero-emission vehicles. However, in specific instances, it will be necessary to identify any significant differences that may arise and require attention. As part of this deliverable S-LCA approach proposed in TranSensus LCA is also compared with the SPD - PCR from Hitachi rail. This comparison showed that certain components suggested in SPD - PCR is aligned with TranSensus whereas some others are not aligned.

Table VII-1 : Summary of the results of the study on applicability

		Goal and Scope	Life Cycle Inventory	Life Cycle Impact Assessment	Life Cycle Interpretation	Social Life cycle Inventory / Social Life Cycle Assessment
Charging stations for BEVs / H2 re-fuelling	**Synergies**	Defined system boundaries, macro and OEM fleet level can be adopted	Electricity modelling, EoL modelling	Division of impact categories	Approach for data assessment, frontloading and report	Can be adopted from TSLCA
	Adaptation needed	Different functional units, different technologies (battery swapping, …)	Energy consumption of equipment	Impact categories might vary slightly	Different parameters relevant for analysis and reporting	-
Waterborne transport	**Synergies**	Defined system boundaries, Technology coverage.	Component Level Data Prioritization	Utilizes Mandatory and Optional LCIA	Applies frontloading approach, Follows reporting standards	TSLCA assessment framework, Follows PSILCA & SHDB product scales
	Adaptation needed	Different lifetime, combustion fuel dependency	Energy modelling complexity	Maritime specific Impact Categories.	Maritime focused verification methods needed.	Maritime labour standards and specific regulations needed for reference data

Airborne mobility	**Synergies**	Functional units for cargo and passenger transport	Electricity modelling, EoL modelling	Division of impact categories	Approach for data assessment, frontloading and report	Can be adopted from TSLCA
	Adaptation needed	ICEs still needed (from renewable sources), functional unit for UAVs performing non-transport tasks	High influence of weather and environmental conditions	Impact categories might vary slightly	Different parameters relevant for analysis and reporting	-
Construction equipment	**Synergies**	Prospective LCA for early Phase, Technology coverage	Multifunctionality rules, leverage PREMISE assessment	Standardized methodology, Mindmap adaptation, Planetary Boundary normalization.	Integration and Decision support tools, Adherence statement,	TSLCA assessment framework, Follows PSILCA & SHDB product scales
	Adaptation needed	Clear Transport Impact in System Boundary	Construction equipment specific operational profiles	Hidden burdens on Impact reviews, Optional approach for comprehensive Impact reviews.	Tailored V-Model Adaptation, Sector specific factors for parameter structure	Heavy machinery Labour standards, Upstream visibility needed.
Railway vehicles (S-LCA/S-LCI)	**Synergies**	Stakeholder Categories and Impact Categories	Guidance on cut-off rules and data quality requirements	Use of reference scale approach	-	-
	Adaptation needed	Harmonisation with SPD / PCR from e.g. Hitachi needed, Different functional unit	-	-	SPD-PCR does not recommend analysis of certain parameters (harmonisation needed)	-

Glossary

Note:

1) The glossary for Environmental Life Cycle Assessment was primarily adopted from Product Environmental Footprint Guidelines (PEF) [12]. Methodological points which are PEF-specific are re-formulated for general applicability. Any new term that did not come from PEF or deviates even slightly from the definition reported in PEF will be written in *Italic*.
2) The terms for Social Life Cycle Assessment were adopted from UNEP guidelines [13]
3) If same term was found to apply for both methodologies, the methodology intended is highlighted between parentheses next to the term
4) The list of definitions is not limited to the terms appearing in the report since the other terms were thought to be helpful to the reader as well like some basic terms.

This glossary is adapted from a former deliverable and should be checked for consistency. Definitions that are not needed here should be deleted.

***Acidification** – EF impact category that addresses impacts due to acidifying substances in the environment. Emissions of NOx, NH3 and SOx lead to releases of hydrogen ions (H+) when the gases are mineralised. The protons contribute to the acidification of soils and water when they are released in areas where the buffering capacity is low, resulting in forest decline and lake acidification.*

Activity variable - An activity variable is a measure of process activity or scale which can be related to process output. Activity variables, scaled by the output of each relevant process, are used to reflect the share of a given activity associated with each unit process. A relevant activity variable is worker-hours. Process-specific coefficients of worker-hours per unit of process output are used to estimate the share of total life cycle worker-hours associated with each unit process. The activity variable is useful to represent the product system in a way that gives an idea of the relative significance of each unit process in the whole system.

***Additional environmental information** – environmental information outside the EF impact categories that is calculated and communicated alongside LCA results.*

***Additional technical information** – non-environmental information that is calculated and communicated alongside LCA results.*

Aggregated dataset - complete or partial life cycle of a product system that – next to the elementary flows (and possibly not relevant amounts of waste flows and radioactive wastes) – itemises only the product(s) of the process as reference flow(s) in the input/output list, but no other goods or services. Aggregated datasets are also called 'LCI results' datasets. The aggregated dataset may have been aggregated horizontally and/or vertically.

Aggregation - The action of summing or bringing together information (e.g., data, indicator results, etc.) from a smaller scope into a larger scope, e.g., from inventory indicator to sub-category. In S-LCA, aggregation of data may be done at the life cycle inventory or impact assessment phase of the study and should not be done in a way that leads to loss of information about the location of the unit processes.

Allocation – an approach to solving multi-functionality problems. It refers to 'partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems '.

Application specific – generic aspect of the specific application in which a material is used. For example, the average recycling rate of PET in bottles.

Attributes [see "Life cycle attribute assessment"]- Properties or characteristics of a process, which are of interest to stakeholders. These are different from conventional quantitative input/output flows of processes but are of a qualitative nature, e.g. gender discrimination or safety as a whole, and thus also coincide with qualitative parameters of social issues in the context of S-LCA.

Attributional – process-based modelling intended to provide a static representation of average conditions, excluding market-mediated effects.

Attributional LCA – a type of LCA focusing on one specific functional unit of the system/product under study, while assuming that the system/product itself does not alter the larger system into which it is embedded/deployed. (e.g., an LCA of one EV, without considering the effects that a large-scale roll-out of EVs may be expected to have on: (i) the demand for LIB metals, and hence on the changing impacts of their supply chains, and (ii) the increased total demand for electricity due to the vehicle's use phase, which may necessitate deployment of new generators and changes in grid mix composition).

Benchmark – a standard or point of reference against which any comparison may be made. In the context of PEF, the term 'benchmark' refers to the average environmental performance of the representative product sold in the EU market.

Bill of materials *– a bill of materials or product structure (sometimes bill of material, BOM or associated list) is a list of the raw materials, sub-assemblies, intermediate assemblies, sub-components, parts and the quantities of each needed to manufacture the product. In some sectors it is equivalent to the bill of components.*

Classification – assigning the material/energy inputs and outputs tabulated in the life cycle inventory to EF impact categories, according to each substance's potential to contribute to each of the EF impact categories considered.

Classification (S-LCA) - The classification step is the step where the Inventory results are assigned to a specific Stakeholder Category and/or Impact (sub)Category.

Climate change – EF impact category considering all inputs and outputs that result in greenhouse gas (GHG) emissions. The consequences include increased average global temperatures and sudden regional climatic changes.

Company-specific data – refers to directly measured or collected data from one or more facilities (site-specific data) that are representative for the activities of the company (company is used as synonym of organisation). It is synonymous to 'primary data'. To determine the level of representativeness a sampling procedure may be applied.

Company-specific dataset – refers to a dataset (disaggregated or aggregated) compiled with company-specific data. In most cases the activity data is company-specific while the underlying sub-processes are datasets derived from background databases.

Consumer – an individual member of the general public purchasing or using goods, property or services for private purposes.

Cradle to gate – a partial product supply chain, from the extraction of raw materials (cradle) up to the manufacturer's 'gate'. The distribution, storage, use stage and end of life stages of the supply chain are omitted.

Cradle to grave – a product's life cycle that includes raw material extraction, processing, distribution, storage, use, and disposal or recycling stages. All relevant inputs and outputs are considered for all of the stages of the life cycle.

Cut-off criteria - Specification of the amount of material or energy flow or the level of significance associated with unit processes or product system to be excluded from a study. Adapted from ISO 14040 (2006).

Data quality – characteristics of data that relate to their ability to satisfy stated requirements. Data quality covers various aspects, such as technological, geographical and time-related representativeness, as well as completeness and precision of the inventory data.

Data quality rating (DQR) - semi-quantitative assessment of the quality criteria of a dataset, based on technological representativeness, geographical representativeness, time-related representativeness, and precision. The data quality shall be considered as the quality of the dataset as documented.

Ecotoxicity, freshwater – EF impact category that addresses the toxic impacts on an ecosystem, which damage individual species and change the structure and function of the ecosystem. Ecotoxicity is a result of a variety of different toxicological mechanisms caused by the release of substances with a direct effect on the health of the ecosystem.

EF-compliant dataset – dataset developed in compliance with the EF requirements, regularly updated by DG JRC2.

E-LCA - Environmental Life Cycle Assessment (E-LCA) is a methodology for assessing environmental impacts associated with all the stages of the life cycle of a product, service or organization.

Impact assessment *– phase of the LCA analysis aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product. The impact assessment methods provide impact characterization factors for elementary flows, to aggregate the impact so as to obtain a limited number of midpoint indicators*

Impact assessment method *– protocol for converting life cycle inventory data into quantitative contributions to an environmental impact of concern.*

Impact category *– class of resource use or environmental impact to which the life cycle inventory data are related.*

Impact category indicator *– quantifiable representation of an LCA impact category.*

Environmental impact – any change to the environment, whether adverse or beneficial, that wholly or partially results from an organisation's activities, products or services.

Eutrophication *– Impact category related to nutrients (mainly nitrogen and phosphorus) from sewage outfalls and fertilised farmland that accelerate the growth of algae and other vegetation in water. The degradation of organic material consumes oxygen, resulting in oxygen deficiency and, in some cases, fish death. Eutrophication translates the quantity of substances emitted into a common measure, expressed as the oxygen required for the degradation of dead biomass.*

Focus group - A focus group is a type of group interview organized to acquire a portrait of combined local perspective on a specific set of issues. What distinguishes the focus group technique from the wider range of group interviews is the explicit use of the group interaction to produce data and insights that would be less accessible without the interaction found in a group. Focus groups with a range of actors can be used to identify relevant stakeholder groups and indicators. Finally, focus groups can also be used in impact assessment when defining the relative importance (weight) of each impact (sub)category.

Functional unit (E-LCA) – defines the qualitative and quantitative aspects of the function(s) and/or service(s) provided by the product being evaluated. The functional unit definition answers the questions 'what?', 'how much?', 'how well?', and 'for how long?'.

Functional unit (S-LCA)- Quantified performance of a product system for use as a reference unit in a life cycle assessment study, and also valid for an S-LCA. ISO 14040 (2006)

Gate to gate – a partial product supply chain that includes only the processes carried out on a product within a specific organisation or site.

Gate to grave – a partial product supply chain that includes only the distribution, storage, use, and disposal or recycling stages.

Global warming potential (GWP) – An index measuring the radiative forcing of a unit mass of a given substance accumulated over a chosen time horizon. It is expressed in terms of a reference substance (for example, CO2- equivalent units) and specified time horizon (e.g. GWP 20, GWP 100, GWP 500 – for 20, 100 and 500 years respectively). By combining information on both radiative forcing (the energy flux caused by emission of the substance) and on the time it remains in the atmosphere, GWP gives a measure of a substance's capacity to influence the global average surface-air temperature and therefore subsequently influence various climate parameters and their effects, such as storm frequency and intensity, rainfall intensity and frequency of flooding, etc.

Goal and scope -The first phase of an LCA or S-LCA; establishing the aim of the intended study, the functional unit, the reference flow, the product system(s) under study and the breadth and depth of the study in relation to this aim. For S-LCA, a unique aspect in practice is the specification of the stakeholder group(s) of interest and the type of assessment (type I or type II).

Impact category - A social impact category is a class that covers certain social issues of interest to stakeholders and decision makers. In practice, impact categories are logical groupings of S-LCA (subcategory) results.

Impact indicator / Impact (sub)category indicator - An indicator that represents a (social) impact, linked to a particular impact category, and in that context, can be called an "impact (sub)category indicator".

Impact pathway approach / Type II approach / Impact pathway (IP) S-LCIA approach -Impact pathway S-LCIA assesses potential or actual social impacts by using causal or correlation/regression-based directional relationships between the product system/organizations' activities and the resulting potential social impacts – a process called "characterization". Here, the analysis focuses on identifying and tracking the consequences of activities possibly to longer-term implications along an impact pathway.

In particular in S-LCIA, aggregation is a way of combining various elements and synthesizing complex phenomena in order to achieve a better understanding and for the communication of results. As such, it may involve the construction of a single, possibly synthetic, score with two or more subcomponents. Single indices or scores are a powerful way to combine and summarize multi-dimensional information.

Indicator - An indicator is a measurement or value which gives you an idea of what something is like.

Input - Product, material, or energy flow that enters a unit process. ISO 14040 (2006)

Land use – *EF impact category related to use (occupation) and conversion (transformation) of land area by activities such as agriculture, forestry, roads, housing, mining, etc. Land occupation considers the effects of the land use, the amount of area involved and the duration of its occupation (changes in soil quality multiplied by area and duration). Land transformation considers the extent of changes in land properties and the area affected (changes in soil quality multiplied by the area).*

Life cycle – consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal.

Life cycle assessment (LCA) – compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.

Life cycle attribute assessment [See "attribute"] - A method that enables to express the percentage of a supply chain that possesses (or lacks) an attribute of interest. Norris (2006)

Life cycle impact assessment (LCIA) – phase of life cycle assessment that aims to understand and evaluate the magnitude and significance of the potential environmental impacts for a system throughout the life cycle. The LCIA methods used provide impact characterization factors for elementary flows to aggregate the impact, to obtain a limited number of midpoint and/or damage indicators.

Life cycle impact assessment / Social life cycle impact assessment (S-LCIA) - Phase of an S-LCA that aims at understanding and evaluating the magnitude and significance of the impacts for a product system throughout the life cycle of the product. Adapted from ISO 14040 (2006)

Life cycle inventory (LCI) - the combined set of exchanges of elementary, waste and product flows in a LCI dataset.

Life cycle inventory (LCI) dataset - a document or file with life cycle information of a specified product or other reference (e.g., site, process), covering descriptive metadata and quantitative life cycle inventory. A LCI dataset could be a unit process dataset, partially aggregated, or an aggregated dataset.

Life cycle inventory / Social life cycle inventory (S-LCI) - Phase of an S-LCA where data are collected, the systems are modelled, and the LCI results are obtained.

Loading rate – ratio of actual load to the full load or capacity (e.g. mass or volume) that a vehicle carries per trip.

Materiality assessment - Materiality assessment is a process to select topics that are more important because of their impact on stakeholders and/or on the business. The Global Reporting Initiative consider material issues to be the ones that reflect the organization's significant social impacts; or that substantively influence the assessments and decisions of stakeholders. This is also recommended by ISO 26000.

Materiality principle - Materiality (principle) constitutes social matter (information, data, performance, impact, stakeholder) that is of such relevance and importance that it could substantially influence the conclusions of the study, and the decisions and actions based on those conclusions. In the Interpretation section, we follow this definition.

Material-specific – a generic aspect of a material. For example, the recycling rate of polyethylene terephthalate (PET).

Method - Specific procedure within a technique.

Methodology - Coherent set of methods.

Models: *mathematical description/formula*

Multi-functionality – if a process or facility provides more than one function, i.e. it delivers several goods and/or services ('co-products'), then it is 'multifunctional'. In these situations, all inputs and emissions linked to the process will be partitioned between the product of interest and the other co-products, according to clearly stated procedures.

Normalization – after the characterization step, normalization is the step in which the life cycle impact assessment results are divided by normalization factors that represent the overall inventory of a reference unit (e.g. a whole country or an average citizen). Normalised life cycle impact assessment results express the relative shares of the impacts of the analysed system, in terms of the total contributions to each impact category per reference unit. Displaying the normalised life cycle impact assessment results for the different impact topics next to each other shows which impact categories are affected most and least by the analysed system. Normalised life cycle impact assessment results reflect only the contribution of the analysed system to the total impact potential, not the severity/relevance of the respective total impact. Normalised results are dimensionless, but not additive.

Organization - Company, corporation, firm, enterprise, authority, or institution, or part or combination thereof, whether incorporated or not, public or private, that has its own functions and administration. ISO 14001 (2004)

Particulate matter – *Impact category that accounts for the adverse effects on human health caused by emissions of particulate matter (PM) and its precursors (NOx, SOx, NH_3).*

Performance reference point (PRP) - Performance reference points (PRPs) are thresholds, targets, or objectives that set different levels of social performance or social risk. PRPs allow to estimate the magnitude and significance of the potential social impacts associated with organizations in the product system. The PRPs are context-dependent and are often based on international standards, local legislation, or industry best practices – Comparing inventory indicator data with PRPs allows to qualify performance on a scale.

Primary data (E-LCA)*– data from specific processes within the supply chain. Such data may take the form of activity data, or foreground elementary flows (life cycle inventory). Primary data are site-specific, company-specific (if multiple sites for the same product) or supply chain specific. Primary data may be obtained through meter readings, purchase records, utility bills, engineering models, directmonitoring, material/product balances, stoichiometry, or other methods for obtaining data from specific processes in the value chain. In this report, primary data is a synonym of 'company-specific data' or 'supply chain specific data'.*

Primary data (S-LCA)- Refers to data that has been directly collected by the practitioner, via interview, survey, or participant observation for instance.

Product (S-LCA) - Any good or service offered to members of the public either by sales or otherwise. ISO 26000 WD4.2 (2008)

Product (E-LCA) – any good or service.

Product category – group of products (or services) that can fulfil equivalent functions.

Product category rules (PCRs) – set of specific rules, requirements and guidelines for developing Type III environmental declarations for one or more product categories.

(PEFCRs) – product category-specific, life cycle-based rules that complement general methodological guidance for PEF studies by providing further specification for a specific product category. PEFCRs help to shift the focus of the PEF study towards those aspects and parameters that matter most, and hence increase the relevance, reproducibility and consistency of the results by reducing costs, compared to a study based on the comprehensive requirements of the PEF method. Only PEFCRs developed by or in cooperation with the European Commission, or adopted by the Commission or as EU acts, are recognised as being in line with this method.

Product flow – products entering from or leaving to another product system.

Prospective LCA: A prospective LCA is conducted in the development stage and aims to estimate environmental impacts before the start of production (several years). The TRL is low (TRL<6) and the BOM is not completely defined.

Raw material – primary or secondary material used to produce a product.

Reference scale - Reference scales are ordinal scales, typically comprised of 1 to 5 levels, each of which corresponds to a performance reference point (PRP).

Reference scale approach / Type I approach / Reference scale (RS) S-LCIA - Reference scale S-LCIA assesses the social performance in the product system. More specifically, it assesses the social performance of activities of organizations in the product system (e.g. the practices implemented to manage social impacts) based on specific reference points of expected activity (called performance reference points - PRPs).

Releases – emissions to air and discharges to water and soil.

Representative product (model) – this may be a real or virtual (non-existing) product. The virtual product should be calculated based on average European market sales-weighted characteristics for all existing technologies/materials covered by the product category or sub-category. Other weighting sets may be used, if justified – for example weighted average based on mass (ton of material) or weighted average based on product units (pieces).

Representative sample – a representative sample with respect to one or more variables is a sample in which the distribution of these variables is exactly the same (or similar) as in the population of which the sample is a subset.

Resource use, fossil – EF impact category that addresses the use of non-renewable fossil natural resources (e.g. natural gas, coal, oil).

Resource use, minerals and metals – EF impact category that addresses the use of non-renewable abiotic natural resources (minerals and metals).

Retrospective LCA: A retrospective LCA aims to evaluate environmental impacts slightly before or after the start of production. A nearly finalised bill of materials of all parts is available to the OEM.

Review – procedure intended to ensure that the process of developing or revising a PEFCR has been carried out in accordance with the requirements provided in the PEF method and part A of Annex II.

***Reviewer** – independent external expert conducting the review of the PEFCR and possibly taking part in a reviewer panel.*

Scope of the study -The scope is defined in the first phase of the study. It encompasses issues of depth and breadth of the study. It defines the limits placed on the product life cycle (that can be infinite) and on the detail of information to be collected and analysed. It defines where the data will be coming from, how up to date the study will be, how information will be handled, and where the results will be applicable.

Secondary data (E-LCA) – data that is not from a specific process within the supply-chain of the company performing a PEF study. This refers to data that is not directly collected, measured or estimated by the company, but rather sourced from a third party LCI database or other sources. Secondary data includes industry average data (e.g., from published production data, government statistics and industry associations), literature studies, engineering studies and patents) and may also be based on financial data and contain proxy and other generic data. Primary data that go through a horizontal aggregation step are considered to be secondary data.

Secondary data (S-LCA)- Refers to data that has been initially collected and manipulated by another person/institution than the practitioner or collected for another purpose than the one being currently considered or, often a mix of the two. For example, a publication, third party audit, or a database.

Sensitivity analysis – systematic procedures for estimating the effects of the choices made regarding methods and data on the results of a PEF study.

Sensitivity analysis (S-LCA) -Systematic procedures for estimating the effects of the choices made regarding methods and data on the outcome of a study.

Single overall score – sum of the weighted EF results of all environmental impact categories.

Site-specific data – directly measured or collected data from one facility (production site). A synonym of 'primary data'.

S-LCA - A social and socio-economic Life Cycle Assessment (S-LCA) is a social impact (actual and potential impacts) assessment technique that aims to assess the social and socio-economic aspects of products and their positive and negative impacts along their life cycle encompassing extraction and processing of raw materials, manufacturing, distribution, use, re-use, maintenance, recycling, and final disposal.

Social impact assessment (SIA) - Social Impact Assessment (SIA) is the process of identifying the social consequences or impacts that are likely to follow specific policy actions or project development, to assess the significance of these impacts and to identify measures that may help to avoid or minimize adverse effects.

Social impact pathway [The term "Social mechanism" can be used as a synonym] - An impact pathway that covers the propagation of the cause-effect chain from social LCI results to impact, and is specified per social impact (sub)category.

Social impacts - Social impacts are consequences of positive or negative pressures on social endpoints of area of protection (i.e., well-being of stakeholders).

Social indicators - Social indicators are evidence, subjective or objective, qualitative, quantitative, or semi-quantitative being collected in order to facilitate concise, comprehensive and balanced judgements about the condition of specific social aspects with respect to a set of values and goals. In LCA social indicators are indicators of a social LCI result (inventory indicators) or represent impact per social impact (sub)category.

Social performance - Social performance refers to the principles, practices, and outcomes of businesses' relationships with people, organizations, institutions, communities, and societies in terms of the deliberate actions of businesses toward these stakeholders as well as the unintended externalities of business activity measured against a known standard (Wood, 2016). Commonly, social performance is measured at the inventory indicator level.

Social significance / significant - Social significance is a judgment on the degree to which a situation or impacts are important. It is highly dependent on context, based on criteria, normative, contingent on values, and entails considering trade-offs.

Social themes / Social issues - Social themes or issues are considered as threatening social well-being or that may contribute to its further development. Social themes of interest include but are not restricted to: human rights, work conditions, cultural heritage, poverty, disease, political conflict, indigenous rights, etc.

Socio-economic - Which involves a combination of social and economic factors or conditions.

Specific data – directly measured or collected data representative of activities at a specific facility or set of facilities. A synonym of 'primary data'.

Stakeholder category / Stakeholder group - Cluster of stakeholders that are expected to have similar interests due to their similar relationship to the investigated product system.

Stakeholder -Individual or group that has an interest in any activities or decisions of an organization. (ISO 26000, 2008)

Subcategory / Impact subcategory - It is a constituent of an impact category that is assigned to a stakeholder group, for example "Health and Safety" for the stakeholder group "Workers". Multiple subcategories, possibly across various stakeholder groups, may be part of an overarching impact category.

Supply chain - A supply chain, or logistics network, is the system of organizations, people, technology, activities, information, and resources involved in moving a product or service from supplier to customer. Supply chain activities transform natural resources, raw materials, and components into a finished product that is delivered to the end customer. In sophisticated supply chain systems used products may re-enter the supply chain at any point where residual value is recyclable. Supply chains link value chains. Nagurney (2006

System boundary – *definition of aspects included or excluded from the study. For example, for a 'cradle-to-grave' LCA analysis, the system boundary includes all activities ranging from the extraction of raw materials, through processing, distribution, storage and use, to the disposal or recycling stages.*

System scope / System boundary - System scope = system boundary: set of criteria specifying which unit processes are part of a product system. ISO 14040 (2006)

Tool (S-LCA) - Instrument used to perform a procedure.

Tools (E-LCA) - *software or applications supporting the analysis (e.g. LCA software or excel based tool)*

Uncertainty - Uncertainty refers to the lack of certainty e.g. in the prediction of a certain outcome, in a measurement, or in an assessment's results. It is a general term used to cover any distribution of data caused by either random variation or bias. In LCA and S-LCA, evaluation or measurement of uncertainty is an on-going process and relates to all the elements of data quality as well the aggregation model used and to the general aims of the study as set in the Goal and Scope.

Uncertainty analysis *– procedure for assessing uncertainty in the results of a PEF study due to data variability and choice-related uncertainty.*

Upstream – occurring along the supply chain of purchased goods/ services prior to entering the system boundary.

User of the PEFCR – stakeholder producing a PEF study based on a PEFCR.

Validation *– confirmation – by the environmental footprint verifier – that the information and data in the PEF study, PEF report and communication vehicles are reliable, credible and correct.*

Value chain *– a synonym of 'supply chain'*

Verification (in PEF context) – conformity assessment process carried out by an environmental footprint verifier to demonstrate whether the PEF study has been carried out in compliance with Annex I

Verification report – documentation of the verification process and findings, including detailed comments from the verifier(s), as well as the corresponding responses. This document is mandatory, but it may be confidential. The document shall carry the electronic or handwritten signature of the verifier or (where a verification panel is involved) the lead verifier.

Waste – substances or objects which the holder intends (or is required) to dispose of.

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