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Recommendations for a future global CO_2-calculation standard for transport and logistics

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ABSTRACT

A true global CO_2 emissions standard is still not available. EN16258 is currently the most internationally accepted standard for transport and logistics. Moreover, most emission standards have been developed by associations for a single mode of transport or for specific regions (e.g., North America). This research suggests recommendations for a global standard for all modes of transport based on EN16258 for freight/logistics transportation. First, the most relevant standards and methods are addressed and explained. Based on ISO IWA 16, they are then compared and combined into a single overview. A case study of the introduction of CarbonCare (emission calculator) and its global transport customers were taken into account to incorporate practical guidelines for a blueprint. Finally, the blueprint is discussed with experts from all modes of transport, culminating in recommendations not only for transport operation but also for harmonizing warehousing, cooling and transshipment - incorporating simplicity, accuracy, flexibility and feasibility.

1. Introduction and background information

In 2015, the share of global emissions from logistics and transport (24%) was the second highest (BDL, 2018). By the same token, projections based on the International Transport Forum's International Freight Model foresee an increase in trade-related freight transport emissions by a factor of 3.9 by 2050. In the base year, 2010, global emissions from trade-related freight transport were estimated to have been 2108 Mt, and could rise to 8131 Mt under the baseline scenario (OECD/ITF, 2016). Consequently, based on the Paris Climate Conference in 2015 (COP21) and as part of the European Green Deal, the EU Commission proposed in 2020 to raise the 2030 greenhouse gas (GHG) emission reduction target as follows (EU Commission, 2020):

- At least a 40% cut in greenhouse gas emissions (from 1990 levels)
- At least a 32% share for renewable energy
- At least a 32.5% improvement in energy efficiency

Logistic providers, transport operators, freight forwarders, shippers, etc., will all require a clear, global and transparent CO_2 calculation standard. Currently, there is a mix of state-supported standards, standards self-developed by associations, recommendations by research bodies, regional approaches, and standards for individual modes of transport, yet a harmonized, global standard is

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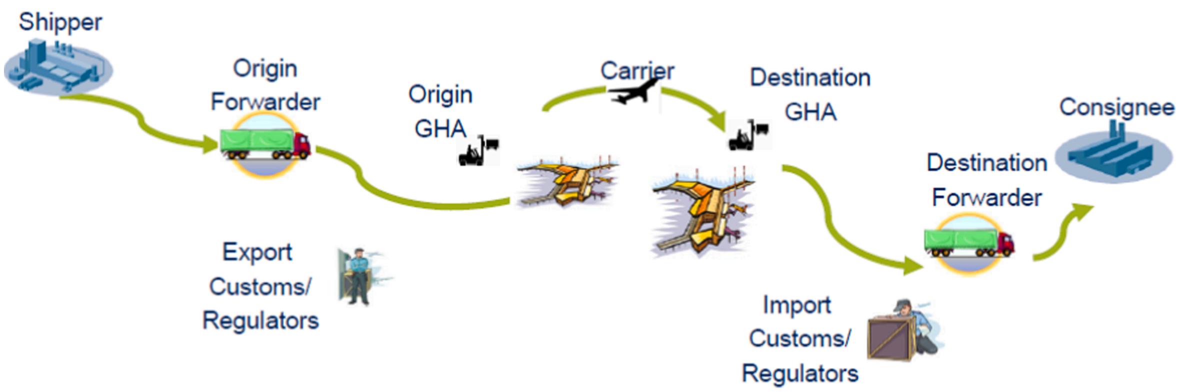

Fig. 1. Typical supply chain (IATA, 2013).

Table 1
Classification of Modes of Transport ().

Road freight transport **(ROAD)**	Full truck load (FTL)
	Less than truck load (LTL)
	Groupage shipment
	Distribution and/or pickup route
Rail freight transport **(RAIL)**	Block train shipment
	Single wagon load shipment
	Intermodal shuttle shipment
Inland waterways freight transport **(IWW)**	Direct (no intermediate stops)
	Inland waterways shipment with intermediate stops
Short sea freight transport **(SEA)**	Direct short sea shipment (no intermediate stops)
	Short sea shipment with intermediate stops
Deep sea freight transport **(SEA)**	Direct deep-sea shipment (no intermediate stops)
	Deep sea shipment with intermediate stops
Freight on a ferry **(SEA)**	Truck on ferry
	Train on ferry
Air freight transport **(AIR)**	Direct air freight shipment (no intermediate stops)
	Air freight shipment with intermediate stops
Terminals **(TRANSSHIPPING)**	Maneuvering (including shunting and taxiing)
	Transshipment (which could be from and to storage or vehicle) or internal transport & shuffle, sort
Warehouses and cross-docking locations **(TRANSSHIPPING)**	Unload & sort
	Unconditioned storage
	Refrigerated storage
	Deep freeze storage
	Order picking
	Preparing for dispatch
	(Re)packaging (as Value Added Logistics (VAL) operation) & load
Cooling chains **(COOL)**	Any transport operation which requires cooling

adapted from COFRET 2011, p. 24

missing (Kellner & Schneiderbauer, 2019). This creates challenges regarding compatibility and accuracy between standards, particularly for those who require standards for multiple modes of transport.

The current research will propose recommendations for future standardization efforts towards a global standard for all modes of transport, including transshipping. The recommendations are primarily focused on freight and logistics, but they can also be applied to passenger transport. The proposed recommendations are based on simplicity, accuracy, flexibility, transparency, and feasibility and are meant to foster discussion. COFRET (2010), Davydenko et al. (2014) and Auvinen et al. (2014) state that a standard should be based on transparency, simplicity, accuracy, and flexibility. We suggest the addition of feasibility. Accuracy means that a shipment should receive the share of emissions, for which it is responsible—the polluter-pays principle (Kellner & Schneiderbauer, 2019). Simplicity ensures that it will be understood and accepted by a wide range of users. Flexibility considers different users (e.g., consignee, shippers, operators, calculation tools, databases, associations, authorities, compensation providers etc.). A guideline might be simple, yet introducing it to a user might be challenging; the calculation of allocation weights for a shipper with hundreds of customers and several hundred thousand shipments annually is an example. Consequently, transparency is required for comparability reasons among the variety of users.

Throughout this paper, all modes of transport and logistics at hubs were classified according to the following scheme (Table 1):

Table 2
Normative Research Steps (Routio 2004a).

	Normative Steps	Application within this Research
1.	**Evaluative description** of the initial state including its earlier development and defining the need for improvements	Literature reviewComparative analysis ISO IWA 16
2.	**Analysis** of relationships and possibilities to change things	CarbonCare (Case Study)
3.	**Synthesis:** proposal for improvement	Preliminary recommendations
4.	**Evaluation** of the proposal	Expert interviews
5.	**Revised Model**	Final recommendations

- ROAD
- RAIL
- IWW (Inland Waterways)
- SEA (Maritime)
- AIR
- XSHIP (Transshipment, Warehousing)
- COOL (Cooling)

Normative research focuses on improvements; this means that it evaluates the present state of things and the direction of future development. By definition, evaluation is only possible from a personal perspective. It is therefore necessary to define the perspective being used in the evaluation. In this case, the user's perspective (Routio 2004a; Routio 2004b) was evaluated through the case of CarbonCare and interviews with its customers.

Hence, the normative approach that involves interviewing stakeholders is strongly supported by the Fourth Generation Evaluation approach of Guba and Lincoln (1989), which takes similar steps and is heavily underpinned by the constructivist paradigm. In conclusion, the methodology used here can be defined as normative exploratory research, based on existing methods and supported by Fourth Generation Evaluation (an inductive approach).

Therefore, the research starts by providing an overview of current standards, methods, tools, programs, and frameworks for emission calculation for transports and logistics. Thus, it will identify the most global and holistic guidelines which might play a role. As the next step, a comparative analysis of those existing guidelines is provided. This analysis is based on ISO IWA 16, which provides a sound basis, with further evaluation for finding universal elements for a global standard.

The central element of this research is a case study of CarbonCare (a global emission calculator based on the EN16258 standard) which offers calculation and compensation not only for all global modes of transport but also for warehousing, cooling, and transshipping.

The universal elements of the comparative analysis and the broad experiences provided by CarbonCare with its awareness of wishes and needs of customers (e.g., shippers, forwarders, transport operators, consignees) lead to the development of a set of recommendations for a future global CO_2–calculation standard for transport and logistics.

The recommendations are tested through interviews with a diverse group of their customers involved in all modes of transport, which will lead to final adjustments.

As an overview, the general approach (Table 2) in normative research, and in this research, takes the form of:

The typical supply chain involves several modes of transport and often several steps regarding transshipping and warehousing (see Fig. 1).

2. Current standards and methods in use

Presently, there are eighteen standards, programs, tools, frameworks, and methodologies for CO_2-calculation which are commonly in use. For simplicity, this research refers to them as "standards" (in the cases of EN16258 and ISO) or "methods." An overview may be found in Table 2 where the effective use is declared. These standards and methods are sorted below based on their focus on multimodal competencies and international applicability.

First, the European Standard EN16258 (CEN, 2012) establishes a common methodology for the calculation and declaration of energy consumption and GHG emissions related to any transport service (whether freight, passengers, or both). It specifies general principles, definitions, system boundaries, calculation methods, apportionment rules (allocation), and data recommendations, with the objective of promoting standardized, accurate, credible, and verifiable declarations regarding energy consumption and GHG emissions related to any transport service quantified (EN16258, 2012). This standard is the only international and multimodal (e.g., road, rail, ship. inland waterways, air) standard to date.

Second, SmartWay Transport is the US Environmental Protection Agency's (EPA) program for improving fuel efficiency and reducing GHG emissions and air pollution from the transportation supply chain industry. Developed jointly by the EPA and Charter Partners (represented by industry stakeholders, environmental groups, American Trucking Associations, and Business for Social Responsibility) in early 2003, this innovative program was formally launched in 2004. Supported by major freight industry associations, environmental groups, states, companies, and trade publications, SmartWay Transport is leading the way to improved fuel efficiency and lower emissions for the freight sector, while modeling government and industry cooperation for public and private benefits

(SmartWay, 2012). Similar to EN16258, the program is multimodal, but mainly focuses on North America.

Third, CE Delft is an independent research and consultancy specializing in developing innovative solutions to environmental issues. They have developed the "Study on TRansport Emissions of All Modes (STREAM)" project. STREAM was used to assess various modes of transport on an EU scale with the STREAM database. The study addresses all modes of transport except air transport. The study not only includes CO_2 emissions and air pollutants such as particulates (PM) and oxides of nitrogen (NOx) and sulfur (SOx), but also accounts for upstream and downstream transport (STREAM, 2016).

Fourth, the Greenhouse Gas Protocol initiative is a multi-stakeholder partnership between businesses, non-governmental organizations (NGOs), governments, and others, convened by the World Resources Institute (WRI), a US-based environmental NGO, and the World Business Council for Sustainable Development (WBCSD), a Geneva-based coalition of 170 international companies. Launched in 1998, the initiative's mission is to develop internationally accepted GHG accounting and reporting methods for companies, organizations, cities and countries.

In this context, the GHG protocols focus on specific areas like corporate level, city-wide, national mitigation goals, value chains, policies and actions, product life cycles, and mitigation projects. However, the "Corporate Accounting and Reporting Standard" provides no specific calculation recommendations (GHG Reporting, 2014).

Fifth, the ISO has published several standards for calculating and dealing with GHG emissions. Published in 2006, the ISO 14,064 standard mainly defines basic ideas and harmonization of terms while ISO 14064–1 standard focuses primarily on organizations. ISO 14064–2 deals with guidance at the project level and 14064–3 with guidance for the validation and verification of GHG emissions (ISO, 2006). ISO 14,067 was published in 2013 and handles carbon footprinting at the product level focusing on the entire life-cycle (ISO, 2013).

Neither ISO 14,067 nor ISO 14064, or the GHG protocol specifically focus on transport (Davydenko et al., 2014). However, based on the Carbon Footprint of Freight Transport (COFRET) project's work, ISO IWA 16 delivers a comparison of existing methods and standards by mode of transport (ISO, 2015). It provides a comprehensive overview of current papers and their main assumptions. COFRET is a collaborative research and demonstration project, partially-funded by the European Commission. This has enabled industry, shippers, and logistics providers to remove the current uncertainty over calculating carbon footprint of freight transport (COFRET, 2014).

Sixth, Smart Freight Centre and a group of companies, associations, and programs formed the Global Logistics Emissions Council (GLEC) and together developed the first GLEC Framework in 2016 (GLEC Framework, 2019). The framework covers all modes of transport in addition to transshipping aspects. Furthermore, it aligns with Greenhouse Gas Protocol, the UN-led Global Green Freight Action Plan and Carbon Disclosure Project (CDP) reporting. The GLEC method, however, is mainly based on existing methods such as EN16258, SmartWay, IMO 2009 (International Maritime Organization), IATA RP 1678, the EcoTransIT platform and the Green Efforts/Green Logistics methods (Davydenko et al., 2019). Conversely, the GLEC method provides a first step towards a globally harmonized standard, although it is not an international, official standard. In this context, ISO intends to elaborate an official standard by ISO 14,083 and include assumptions from the GLEC approach (ISO, 2021)

Seventh, the EcoTransIT Initiative (EWI) is an independent, industry-driven, platform for carriers, logistics service providers, and shippers, dedicated to maintaining and developing a globally recognized tool and methodology for carbon footprint calculation and environmental impact assessment of the freight transport sector. In line with its vision of increasing transparency on the environmental impact of freight transport and demonstrating continuous improvement of EcoTransIT methodology and the EcoTransIT World (ETW) calculator, EWI members have commissioned their scientific and IT partners to provide an updated methodology report. EcoTransIT largely follows the EN16258 standard but has also implemented other standards for all modes of transport (EcoTransIT, 2014).

Eighth, BigMile, similar to EcoTransIT, is a software platform that collects and combines data from the day-to-day operations of shippers, logistics services providers, and carriers. It consists of three modules: Carbon Footprint—for computation of a certified carbon footprint; Carbon Analytics—for creating insights into the emissions and evidence-based improvement plans; and Profit Finder—for improvements in logistics performance. BigMile is aimed at both shippers and logistics services providers, covering all modalities and all possible fuels, including all important fossil fuels, different types of biofuels, electricity, synthetic fuels, etc. (Davydenko et al., 2019, p. 9).

Ninth, Lean and Green is an independent stimulus program being implemented by Connekt, a Dutch public–private network for sustainable mobility. The program encourages businesses to become more sustainable by taking measures that not only cut their costs but also reduce their environmental impact (Lean and Green, 2021). One of the initiators of the Lean and Green program is the Dutch Ministry of Infrastructure and the Environment. Over 400 public and private organizations in the Netherlands, Belgium, Germany, Italy, and Luxembourg participate in the Connekt/Lean and Green network. A primary goal is to reduce emission of participators by 20% over a five-year period.

Tenth, Green Freight Europe (GFE), launched in 2012, is the leading industry-driven program to support companies in improving the environmental performances of freight transport in Europe Green Freight Europe (2012). The program drives reductions of carbon emissions by:

- Establishing a platform for monitoring and reporting of carbon emissions, to assist in the procurement of transportation services, based on existing standards;
- Promoting collaboration between carriers and shippers in driving improvement actions and monitoring progress;
- Establishing a certification system to reward shippers and carriers who fully participate in the program.

Green Freight Asia is a non-profit organization that helps organizations to optimize their operations for better efficiency through six

Table 3
Overview of Standards and Methods.

Standards & Methods	Legal basis	GeographicScope	Modes of Transport	Trans-shipping	Remarks
EN16258	Official	Europe	All	–	
SmartWay	Program	North America	All	–	
CE Delft	Research	Global	Partly	–	
GHG Protocols	Method	Global	–	–	Several specific areas
ISO	NGO	Global	–	–	
GLEC	Framework	Global	All	–	Based and further developed on existing methods
EcoTransIT	Commercial	Global	All	–	Based on EN16258, GLEC
BigMile	Commercial	Global	All	✓	
IMO	Official	Global	SEA	–	United Nation
CCWG	Initiative	Global	SEA	–	
ICAO	Official	Global	AIR	–	
IATA	Association	Global	AIR	–	
Green Logistics	Research	Europe	–	✓	
Green Efforts	Research	Europe	–	✓	
Green Freight Europe/ Asia	Program				
ITEC	Initiative	Europe	–	✓	ECOHubs
CarbonCare	Commercial	Global	All	✓	

different programs (measuring, reporting, verification, certification, carbon offsetting, eco-driving, and awards) (Green Freight Asia, 2021)

The following methods consider only single modes of transport: maritime, inland waterway, air, and transshipping.

Eleventh, the IMO's Marine Environment Protection Committee (MEPC) has extensively considered the control of GHG emissions from ships and, in July 2009, finalized a package of specific technical and operational reduction measures. In March 2010, MEPC started to consider making technical and operational measures mandatory for all ships, irrespective of flag and ownership. This concluded in July 2011 with the breakthrough adoption of technical measures for new ships and operational reduction measures for all ships. Consequently, this was the first ever mandatory global GHG reduction regime for an entire industry sector. The adopted measures were added to MARPOL Annex VI as Chapter 4, titled "Regulations on energy efficiency for ships," making the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Plan (SEEMP) for all ships mandatory. The regulations entered into force through the tacit acceptance procedure on January 1, 2013 and apply to all ships of 400 gross tonnages and above. MEPC 67 approved the Third IMO GHG Study, providing updated emission estimates for greenhouse gases from ships (IMO, 2015).

Twelfth, the Clean Cargo Working Group (CCWG) is a global, business-to-business initiative of BSR, to improve environmental performance of marine container transport. BSR is a global nonprofit organization that works with its network of more than 250 member companies to build a just and sustainable world (CCWG, 2015). CCWG tools represent the industry method for measuring and reporting ocean carriers' environmental performance regarding CO_2 emissions and is based on the GHG protocol, EN16258, and IMO methodologies (CCWG, 2015).

Thirteenth, ICAO provides a carbon emission calculator, but only calculates CO_2-emissions (ICAO, 2014). This tool is primarily a calculator for passengers, and provides specific guidance for calculating comparable GHG emissions for accounting methods.

Fourteenth, IATA has published its IATA RP1678 (request for proposals) method, a valuable document for the air transportation sector. However, the guidelines include only CO_2 emissions and direct consumption (TTW: tank-to-wheel; see Glossary) whereas most methods will also consider upstream fuel consumption (WTW: well-to wheel) (IATA, 2014).

Fifteenth, Green Logistics was a joint project run by the EffizienzCluster LogistikRuhr, funded by the German Ministry for Education and Research and hosted at the Fraunhofer Institute. As part of the project, eleven industry project partners collaborated to conceptualize eco-efficient products and logistics systems. They planned to establish a CO_2 neutral airfreight hub, eco-efficient last-mile logistics, and efficient container management. Green Logistics published its latest paper "Green Logistics Method" in June 2015; however, it is not based on other methods (Green Logistics, 2015).

Sixteenth, Green Efforts, "Green and Effective Operations at Terminals and in Ports," is a collaborative research project, co-funded by the European Commission under the Seventh Framework Program, aimed at reducing energy consumption and improving the energy mix at seaports and terminals (Green Efforts, 2020). Since EN16258 does not cover transshipping energy consumption, Green Efforts published valuable insights into transshipping energy calculations and declarations.

Seventeenth, the "Intermodal Terminal Eco-Efficiency Calculator–ITEC" is a tool developed to calculate the energy use and GHG performance of intermodal terminals including all relevant operations. Additionally, it identifies the terminal's "hot spots" (i.e., the main energy consumers and processes), calculates the impact of "greening measures" implemented, and anticipates the effects of planned measures (ITEC, 2020). Therefore, ITEC helps to estimate transshipping emissions.

Eighteenth, CarbonCare is commercially calculation platform comparable to EcoTransIT or BigMile. From this perspective, its description should have been addressed in the first half of this introduction, however, the case of CarbonCare is essential to this research paper and is thus treated here at more length. CarbonCare is an advanced and holistic CO_2-emission calculator which estimates GHGs not only for all modes of transport, but also for transshipping/warehousing and for cooling chains. The tool calculates

Table 4
Comparative Analysis based on Appendix A

Investigated Aspect	General (all methods or modes)	Variation for specific method's modes
TTW/WTW	All use WTW or TTW or both	
CO_2/CO_2e	A majority uses CO_2e; some CO_2	
Allocation units in general	EN16258 uses tkm (tonne-kilometers); SmartWay CO_2/tsm, CO_2/vehicle mile or CO_2/cubic foot mile	SEA: CCWG uses CO_2/TEU AIR: in general mass and tkm XSHIP: TEU throughput, weight, space use or transported units
Specific allocation units	ISO claims that guidance is missing regarding maintenance, preparation and after-care and cleaning of transport units. For IWW, allocation rules for upstream, downstream transport are missing.	ROAD: tkm based on GCD (great circle distance) SEA: CCWG uses TEU AIR: EN16258 uses mass (passenger converted) ICAO/IATA uses for belly transports passenger + 50 kg for the seat
Energy consumption of auxiliary processes	EN16258 includes on-board processes (not specified).	SEA: CCWG respects reefer data (COOL) AIR: ICAO/IATA include auxiliary processes XSHIP: generally included. Green Logistics is specific as electricity, heating, packaging materials and refrigerants are included. Similarly, ITEC
Processes included	Empty trips included. Most for own fleet; EN16258 also for subcontractors	See above
VOS (vehicle operation system) descriptions	Most standards support the idea of a VOS. However, clear definitions for each mode of transport are required.	SEA: CCWG uses 25 trade lanes. XSHIP: ITEC has defined a certain VOS
Procedure for measured energy consumption data	EN16258 uses specific measured values, transport operator specific measured values and fleet values. SmartWay uses fuel/ CO_2 on measured data.	AIR: ICAO/IATA uses specific fuel measure protocols SEA: CCWG established on process on measured data. IMO uses own process which is vague on transport work done XSHIP: processes are vague
Procedure for absence of measured energy consumption data	EN16258: default data available	SEA: own IMO guidelines for conversions AIR: Default data from ICAO-CAEP or from IATA fuel measurement protocol XSHIP: guidelines are missing
Fuel-based vs. activity-based	Fuel-based	IWW: STREAM uses activity-based on vessel types XSHIP: ITEC uses a mixed approach
Default data	Guidelines in case of absence of measured data are not available	IWW: STREAM uses HBEFA data AIR: BADA & AEM data available SEA: CCWG own sources XSHIP: various options
Specific factors	EN16258 provides comprehensive tables SmartWay uses factors from Argonne Nat. Lab.	IWW: IMO has own factors and STREAM uses Defra factors AIR: IATA/ICAO uses IPCC SEA: IMO uses own factors XSHIP: ITEC uses Europ. Ref. Life Cycle database
Exiting gaps in coverage	More detailed clarification of sub modes in RAIL and SEA is required, as is better distinction between warehousing and transshipping.	
Allocation units	Use of mass/volume and TEU better unified	
Distances calculation	Actual distances (EN16258 uses GCD or shortest distances for allocation)	IWW: EN16258 allows GCD + 95 km for allocation AIR: EN16258/IATA allows GCD + 95 km for allocation. Green Logistics allows GCD + 50 km for allocation ICAO uses GCD + 50/100/125 km depending on distances SEA: CCWG uses direct distances + 15%
Reporting	EN16258 and SmartWay use CO_2e on TTW/WTW or CO_2/tsm Often not specified	XSHIP: Green Logistics uses size and throughput

consistently according EN16258, and considers data from STREAM and CCWG. All data were measured in collaboration with industry partners and compared with the literature. The calculator was funded during a five-year research period (started in 2014) by the Swiss Federal Department of the Environment, Transport, Energy and Communications (DETEC) and examined by the Swiss Federal Office of Civil Aviation (FOCA). Furthermore, the whole calculator was validated for consistency according to EN16258, and the results are correct for all modes of transport. Primarily, CarbonCare is intended for shippers, forwarders, and transport operators, with a focus on freight. Few customers use the platform only for compensation.

Table 3 provides an overview of the discussed standards and methods. It reveals that an official global standard, combining all modes of transport and offering transshipping, is currently missing.

3. Comparative analysis

Initially, this paper assesses the valuable work carried out by ISO IWA 16 (Appendix A) which analyzed all standards and methods for each mode of transport and logistics hubs (transshipping). Tables from that have been revised (e.g., EcoTransIT's/BigMile's approach was deleted, since their method is based on other methods) and extended with additional standards (e.g., for AIR). For the analysis, the comparative analysis approach suggested by Walk (2020) was used for a point-by-point analysis. Hence, we used the ISO's approach for "investigated aspects" (first column). Boxes like "Allocation notes," "Harmonization notes," and "General comments" have not been specifically addressed since they are included in other boxes or addressed later through the preliminary recommendations.

Table 4 summarizes common aspects in all cases, whereas the last column shows differences.

4. Operational experiences from CarbonCare case study

The comparative analysis provides a solid foundation for discussions and identifies universal aspects. Hence, using the normative exploratory research design, the views of the transport operators, users of the policies, and emission calculator operators are taken into account. The experiences from CarbonCare were included to develop preliminary suggestions.

CarbonCare is an advanced, holistic CO_2-emission calculator which estimates GHGs not only for all modes of transport but also for transshipping/warehousing and for cooling chains (www.carboncare.org). CarbonCare calculates consistently according EN16258, and considers data from STREAM and CCWG. All data were measured in collaboration with industry partners and compared with the literature.

The CarbonCare calculator was funded during a five-year research period by the Swiss Federal Department of the Environment, Transport, Energy and Communications (DETEC) and examined by the Swiss Federal Office of Civil Aviation (FOCA). Furthermore, the whole calculator was validated for consistency according to EN16258, and results are correct for all modes of transport.

Therefore, the experiences from CarbonCare may provide valuable operational insights from customers. The following discussion is organized according to the structure presented in Table 4 above.

4.1. *TTW/WTW/CO_2/CO_2e*

Transport operators are mainly interested in their TTW values and in pure CO_2 emissions. However, WTW and CO_2e results are central in assessing climate impact. Therefore, CarbonCare, although consistent with EN16258, provides CO2e emissions for TTW/WTW as well as the pure CO_2 (TTW) emissions for information purposes. Consequently, the calculation of additional pure CO_2 does not require significant extra effort, since it is based on a distinct factor.

Any compensation should be based on CO_2e for TTW whereas previous standards have used a variety of approaches. With equivalents based on TTW, the compensator takes care of all greenhouse gases for transport operations. Therefore, this should be the preferred approach.

4.2. *Allocation units in general*

The research proposes a different approach in terms of allocation units than EN16258, which generally foresees mass per tonne-kilometers. Similar to SmartWay, the paper recommends an allocation based on CO_2 per tonne-kilometer, but based on last year's historical data. Therefore, transport operators should measure their complete transported goods (mass), actual travel distances, and consumed fuel on a yearly basis. This results in a specific emission factor for the company or the respective transport service category (e.g., a specific fleet) (Eq. (1)). Apparently, GLEC adopted a similar approach. Specific emission factor allows simple and quick calculation for planning reasons (ex-ante) and post-delivery (ex-post). Furthermore, the specific emission factor is a stable index which takes into account variations from load factors, different traffic situation, meteorological influences, etc. based on the previous year. Measurements other than mass, such as volume, pallets, or TEUs or even mixed approaches (e.g., 85% kilometers + 15% tonne-kilometers), will dilute comparability due to density or variable effective load. Kellner and Schneiderbauer (2019) report that allocation rules should be simple since a wide range of users have to apply them. The study and simulation for road transports by Kellner and Schneiderbauer (2019) analyzed the best allocation unit in respect to EN16258. They mainly evaluated weight, volume and distances. The result was that the most accurate allocation unit is distance. However, distances do not account for operator efficiency. CO_2 per tonne-kilometer measures the efficiency of the network of the carrier with respect to carbon emissions (Davydenko et al., p. 12, 2019). The cargo load factor may highly influence the emission factor based on emissions per tonne-kilometer. Consequently, the best example is the comparison between a widebody cargo aircraft with approximately 400 g CO_2 per tonne-kilometer and a widebody belly aircraft which accounts for 700 g CO_2 per tonne-kilometer. A detailed discussion for belly and freighter aircrafts can be found under "specific allocation units-AIR" below. Moreover, the tonne-kilometer approach motivates operators to improve their efficiency and lets them directly compare the results over historical years. The literature also mentions multidimensional capacity allocation methods (Davydenko et al., 2014), revenue driven allocation (Davydenko et al., 2019), and game-theoretical allocation approaches (Naber et al., 2015). However, considering simplicity, the tonne-kilometer approach has clear advantages and is also recommended by GLEC. Therefore, the following proposed approach for all modes of transport allows for calculating the specific emission factor for a company, a transport service category (TSC) (e.g., specific fleet; group of vehicles with similar characteristics) or a single vehicle in grams (CO_2 or CO_2e) per tonne-kilometer. For simplicity, the formula I is presented as "Specific Emission TSC."

$$\text{SpecificEmissionTSC} = \frac{total\ fuel\ consumned(year) \times emission\ factor}{total\ mass\ transported(year) \times total\ distances\ performed(year)} \quad (1)$$

The advantages are as follows:

- The results allow comparison to competitors
- Operators are challenged to improve the specific emission yearly (natural challenge due to awareness)
- Empty trips and positioning are included
- The specific factor includes operational efficiencies (e.g., utilization factors, seat load factors, cargo load factors, efficient use of vehicles, etc.)
- Operational improvements are measured and quantified
- Changes in engines, replacements of complete vehicles (e.g., new vehicles) or changes in fuels (e.g., electrification, hydrogen, sustainable fuel, or bio-fuels) do not affect the calculation and still allow a comparison to previous states
- Due to a yearly measurement, seasonal and meteorological changes (e.g., wind, temperatures, pressure systems, changing conditions of streets, different drivers, different VOS patterns, (currents, mountainous areas, etc.) are included
- It provides a certain transparency, not only to customers, but also to environmental agencies and emissions calculators (e.g., commercial calculators, shippers, industry associations)
- The formula serves the needs of "Simplicity, Flexibility and Feasibility" since it serves the needs of shippers/forwarders when the transport operator provides specific emission factor. Even smaller shippers/forwarders may calculate the emissions with Google Maps (e.g., shortest distances) or with online GCD calculators (masses are known to the shipper/forwarder).
- Furthermore, the results are accurate since it is based on solid historical data and reflects the specific capacity of a fleet or a company.
- Finally, the formula may be sued for planning purposes (ex-ante) and after delivery (ex-post). Since such data are based on solid fundaments, only minor changes are expected between planning and effective operation, except the mode of transport, the TSC, or the routing is altered.

However, the requirement is that operators establish such data on a yearly basis and for each cluster of TSC (e.g., for the same aircraft fleet, truck categories, type of vessels, trains, etc.).

Basic cluster TSC's must, as a minimum, include the weight/size of vehicles, the engine fuel type, and the operation type.

For the first year of emission evaluation, associations or state agencies may provide data from competitor groups. Transport operators should be allowed to interpolate historical data (e.g., for the previous year) if there have been investments in new vehicles and/or new fuels which result in significantly lower emission factors.

Furthermore, TEU should be converted into masses and logistics hubs should aim for consistency in weight allocation since weight often corresponds to size (i.e., heavier items require more energy for loading and unloading). GLEC uses a standard weight of 10 tonnes (Davydenko et al., 2019)

Davydenko et al. (2014) and Auvinen et al. (2014) criticized EN16259, highlighting the following three major weaknesses of the standard:

- There is an ambiguity as to how the VOS is defined. Specifically, it allows calculation for the whole fleet over one year, all return journeys between two locations in a quarter, or a single leg in a collection and/or delivery round trip. This approach makes comparison difficult. Thus, they recommend tailoring to a micro level (on basis of the vehicle), a meso level (basis of a trade lane, corridor or a network), or a macro level (basis region or a company). However, those assumptions lead to additional ambiguity as the they state "definition of trade lane or a corridor is relatively sensitive to arbitrary choices" (Davydenko et al., p. 368, 2014). The specific emission approach simplifies the approach by mirroring the TSC (e.g., define clusters) to the specific needs of the operator.
- Further, they point out that the mass and tonne-kilometer (tkm) approach may distort the allocation, since it may allocate high emissions for a single shipment for a fixed network (e.g., in the case of detour for other shipments or network optimizations). Moreover, the emission proportion of lightweight materials (e.g., volume specific materials like fur) and heavy weight materials (e.g., lead) in the same shipment result into higher allocation to the heavy-weight material. Therefore, they propose an allocation weight approach. This approach takes into account the vehicle capacity and several dimensions like weight, volume, floor space passengers, pallets, etc. This approach is not only complex for shippers and transport operators to calculate, it also distorts comparability. Furthermore, shippers and transport operators do not always know what materials are included in shipments (e.g., TEU) and heavy-wight materials need more energy (e.g., fuels) to be transported (Kellner & Schneiderbauer, 2019). In an extreme case like a transport in widebody aircraft, an additional tonne of weight leads to 25% additional fuel consumption (Wild, 2020). Considering feasibility, the specific emission calculations allow for simplicity and feasibility.
- Finally, it may not be feasible to calculate the emissions for each chain element for shippers, since required information may not be available and different standards are applied. However, this is not an issue with EN16258 but more a global problem due to the lack of harmonization and clear guidelines. As discussed above, the proposed formula may offer shippers a realistic chance to calculate their greenhouse gases.

Jevinger and Parsson (2016) discussed the use of a dedicated distance proportion allocation (DDPA), which recommends the use of dedicated distances and a limiting factor in the transport chain, such as truck volume. However, this approach further complicates the calculation with no significant benefit.

4.3. Specific allocation units

Within the explicit modes of transport, the following allocation rules should be applied:

Table 5
Suitability of Distance Metric (Davydenko et al., 2021, p. 12).

Criterion / Distance Metric	GCD	ADD	PD	SFD
1. Adequacy for estimation of fuel used	–	++	+	+/-
2. Adequacy for allocation of emission to individual shipment and customers	++	–	–	+/-
3. Adequacy and ease of auditing results by accountants	++	–	–	+/-
4. Data requirements and ease of data gathering for calculations	++	–	–	+/-
5. Use of comparison of different networks and/or modalities	++	–	–	–
6. Use of analysis of potential improvement measures and for GHG optimization	++	+	+	+/-
7. Use for combining data from multiple subcontractors	++	–	–	–
8. Commercially sensitive information shared	+/-	–	–	+/-

Table 6
Default data Sources.

	ROAD	RAIL	IWW	SEA	AIR
Source	HBEFA	–	STREAM	CCWG(25 trade lanes)	ICAO Fuel data

Table 7
Reporting Standard.

TTW	CO_2 and CO_2e
WTW	CO_2e

Table 8
Assessment of Requirements.

Simplicity	The formula is simple, understandable and it assess the network efficiency of the carrier. Further and importantly, it encourages carriers to lower their emission (e.g., comparison of the previous years for each TSC).
Accuracy	Wide variations exist in the literature about best allocation method. Whereas some argue about allocation weight or distance are best, GLEC, CarbonCare, EN16258 give preference to tonne-kilometer. Allocation weight is often not used since it is not simple and not feasible, especially for large forwarders/carriers. Distance does not consider the network efficiency. Thus, tonne-kilometer and shortest distances seem to be not widely accepted, but also simple, feasible and the best option (trade-off) for accuracy.
Flexibility	The model is flexible since it fulfils the need of wide range of users.
Feasibility	Feasibility might be a challenge in the first year when no data is available. Therefore, default data are required. However, with the first assessment of the emissions, further assessment might be routinely done. Default data for warehousing and transshipping by global regions would simplify the process enormously.
Transparency	The advantage is that the same formula might be applied for all modes of transport and all TSC. This provides for comparability within companies, among competitors and authorities.

Table 9
Interview partners.

Element	Experts
ROAD	Operational manager of a medium size trucking organization
	General manager of a large trucking organization
RAIL	Secretary General of a freight railway association
IWW	General Manager of a medium-size IWW company
	General manager of a port organization
SEA	Senior environment manager of a large, global SEA shipping company
	General manager of a large SEA shipping company
AIR	President of an air cargo association
	Senior operational manager of a passenger airline
	Senior operational manager of a cargo airline

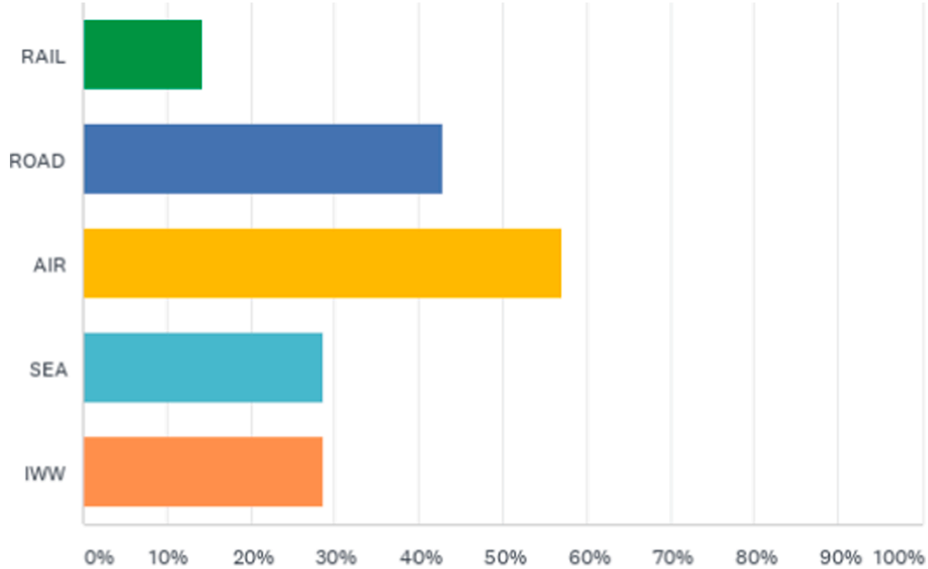

Fig. 2. Experts experiences in transport elements.

ROAD: Allocation on shortest direct routes or GCD. Typically, truck operators operate on VOS and serve several customers a day. As stated by Davydenko et al. (p. 15, 2019), the GCD is the most suitable measure for distance for the purpose of carbon foot printing as it considers the net transport work independent of the chosen modality, infrastructure density, and routing of the goods flow. It is the only measure that leads to a correct calculation of the impact of changes in routing or modalities on the carbon footprint. It is also the "easiest" distance measure from administration and data requirements perspectives, as keeping track of the routes that the vehicles travelled is not required. Furthermore, specifically when lorries have to leave the direct route (e.g., the highway, for example when they have to enter a remote area like a village in a valley) to deliver a parcel, they have to rejoin the node of direct access for the next parcel. This may lead to additional distances for the following deliveries which incur more emissions than for a direct transfer. Therefore, shortest distances and GCD offer a fairer treatment.

RAIL: There are essentially two types of rail transport—diesel and electric driven locomotives. Considering these types, there are huge variations in mass, from 6000 t to less than 900 t. Therefore, clear clustering is necessary.

IWW: The requested allocation guidelines by ISO IWA 16 for upstream and downstream operations are obsolete, compared with the general allocation policy above.

AIR: Passengers should be strictly converted into masses. EU-OPS (European Regulation for commercial air transport) foresees in Subparts J 1.620 (d) and (f) 84 kg for adults and 11–15 kg for baggage (e.g., depending on flights: domestic; intra-EU, intercontinental) (EC 859, 2008). Therefore, airlines often use 100 kg for each passenger including baggage as a rule of thumb to convert passengers into mass. This approach is also supported by GLEC (Davydenko et al., 2019). Further, IATA/ICAO (in particular, IATA RP1678) recommends allocation of seats (e.g., 50 kg per seat) to passengers for belly aircraft. This not only dilutes the share of payload, but is also inconsistent with the general approach above. Additionally, when it comes to decision-making for a shipper or a forwarder, freighter aircraft benefit from these rules, that is, passengers in belly aircraft take over a larger share of emissions for the same mass. Principally, emissions should be handled as revenue payload for which certain energy is necessary. To be consistent with those assumptions, it would therefore be difficult to allocate additional installed vehicle equipment for a group of payloads (e.g., a heavy ENVIROTAINER for cooled transports, gas tanks on gas ships, etc.). The guidelines should be uniform and fair considering each shipment's emissions. Nevertheless, freight aircraft have a distinctly lower specific emission factor, approximately 400 g per tonne-kilometer, compared to passenger aircraft due their higher efficiency (e.g., mass) (Wild, 2019). A belly aircraft and cargo aircraft are also different types of TSC with characteristics similar to different vessels.

4.4. *Energy consumption of auxiliary processes*

EN16258 foresees that on-board process are included, but are not defined. CCWG established specific reference tables (i.e., for cooling), and IATA/ICAO includes consideration of additional fuel matters, such as Auxiliary Power Usage (APU; for cooling and electricity generation on ground). Green Logistics and ITEC intend to include electricity, heating, packaging materials, and refrigerants.

With the specific emissions approach, all fuels are included (e.g., APU) for operational activities. CarbonCare measures cooling separately, and for transshipping they include heating and electricity, but packaging and refrigerants are not calculated. Cooling is common in the supply chain and it requires additional energy. Therefore, it should also be assessed for transshipping together with electricity (e.g., for lighting and heating). Similarly, GLEC includes not only cooling and handling of goods in the vehicles but also emissions from handling, and storage of goods (ambient and temperature controlled) at storage and transshipment points (Davydenko et al., 2019). Allocation of packaging, however, is complicated, since packaging could be carried out by the shipper, or the customer, and it might be changed several times during the shipment chain. Hence, the research recommends allocation of such emissions at the company level. Consequently, only energies required for the direct operation should be considered, such as fuel for transport, energy for cooling and warehousing, etc.

CarbonCare also measured the emissions for transshipping between the chain elements for loading/unloading (for example, unloading goods in a port from a vessel and loading the same parcels onto a train). As practiced by CarbonCare, such emission could be measured globally and allocated as fixed values (e.g., 5 kg CO_2 for a transshipment from airlines to trucks). However, as the empirical measures from CarbonCare reveal, such fixed values have to be measured at regional levels. There are differences between an airport transshipment in Europe and in Asia. Consequently, minor variations will exist, but such differences in emissions will be negligible in a complete supply chain. Therefore, transshipping emissions represent a minor share of all emissions (e.g., normally in the magnitude of 100 g CO_2 per tonne to 5 kg per tonne handled depending on the transshipment) (Wild, 2019).

4.5. Processes included

With the yearly fleet model, all empty trips and subcontractors are included.

4.6. VOS descriptions

These have been discussed under "TTW/WTW/CO_2/CO_2e." CarbonCare uses TSEs according to "weight/size," "fuel," and VOS specific operations (e.g., cooled services, specific patterns) where feasible. CCWG's approach with specific trade lanes in this particular case is robust and simple. Thus, clusters should be further defined by global committee.

4.7. Procedure for measured energy consumption data

The measurement guidelines for a "general allocation" are simple, transparent, and allow comparisons between specific categories within transport elements.

4.8. Procedure for absence of measured energy cons. Data/Default data

As previously discussed, default data should be provided by globally harmonized standards for clustered vehicles (TSE). This approach could be used for the first year of reporting, for comparison and for decision-making for customers and shippers.

4.9. Fuel-based vs. activity-based

Primarily, fuel-based approach provides accurate results since it is directly related to emissions. However, such fuel-based approaches should be clustered on activity. Activity-based means herewith based on available data on categories of vehicles (Lapini, 2021). Thus, it allows comparing the specific emission factor for different vehicle categories (i.e., trucks, vessels, aircrafts etc.). This approach is used by STREAM.

4.10. Specific factors

It is vital that this is the first area of harmonization due to large differences between countries and regions.

4.11. Allocation units

A standard must focus strictly on emissions (e.g., CO_2/CO_2e) per tonne-kilometer.

4.12. Distance calculation

Besides "general allocation," this is one of the most important areas of harmonization. EN16258 takes into account actual travelled distances. Davydenko et al. (2019), Auvinen et al. (2014), Davydenko et al. (2014), and Kellner and Schneiderbauer (2019) promote using shortest distances in general. Conversely, Davydenko et al. (2019) brings up the idea of the planned distance. The planned distance is not the shortest distance, but the planned distance (ex-ante) when optimizing the VOS (mainly, trucks) and available in the database. On one hand, this contradicts the statements that great circle distances are best (see specific allocation units above) and the statements about the shortest distances, and on the other hand, another calculation method dilutes additionally comparability.

Davydenko et al. (2021) took this topic up in a recently published research paper with a main focus on distance, in which they analyzed all options and compared their suitability for different purposes. The findings and arguments clearly support the overwhelming strengths when applying great circle distances for allocation of units (Table 5 below).

Additionally, there are some specialties to be observed within each mode.

ROAD: For multiple deliveries, which is the normal case, great circle distances predominately support simplicity and fairness (based on Davydenko et al., p. 15, 2019; refer to specific allocation units above for discussion).

RAIL: It is important to distinguish between diesel and electric trains. Emissions from electricity should be estimated from national grid values. However, these calculations are nearly impossible without a professional and reliable carbon calculator with its own mapping programs. Even the International Union of Railways in Paris, UIC, has no comprehensive knowledge of the global train routes. CarbonCare invested one year in developing this aspect.

IWW: No additional assumptions.

SEA: CarbonCare evaluated eighteen programs for the calculation of SEA routes. The differences regarding distances were significant.

AIR: EN16258, IATA, ICAO, and Green Logistics propose adders to the GCD in the range of 50 to 125 km. However, the pure GCD without any addition harmonizes the application of distances and allows also comparability between modes of transport.

4.13. Reporting

Reporting should be based on TTW (CO_2 and CO_2e) and WTW (CO_2e). The basis of reporting should be the specific emission factor for modes of transport and CO_2/CO_2e per mass for warehousing/transshipping.

4.14. Preliminary recommendations

At the heart of a globalized standard should be realistic figures, based on transported masses (realistic load factors including empty trips and sub-contractors), used energy (e.g., fuels), and performed kilometers based on the previous year. This culminates in the specific emission factor for the company or the transport service category (TSC).

$$\text{SpecificEmissionTSC} = \frac{total\ energy\ consumned(year) \times emission\ factor}{total\ mass\ transported(year) \times total\ distances\ performed(year)} \quad (2)$$

The result is a measure of emissions as CO_2 or CO_2e per tonne-kilometer.

Cooled transports must be provided with separate tables, or a be assigned a specific mark-up. Similarly, for warehousing, energy (e.g., fuels/electricity used) must be included for lighting, cooling, and heating (direct operation emissions). Dobers et al. (2019) recommend to allocate energy where it is needed. Therefore, energy for refrigerating equipment should be allocated only to refrigerated shipments, whereas, for example, energy for lighting must be allocated to all shipments. Such emissions shall be reassessed on a yearly basis. Other energy usage shall be allocated at the company emission level.

For transshipping (e.g., loading/unloading) from one mode of transport to another or to the warehouse, specific standard figures shall be developed. Emissions from warehousing (WH) and transshipping (XS) shall be allocated based on mass. A comparable procedure is proposed by Dobers et al. (2019). Thus, a specific emission factor for warehousing and transshipping is established based on data from the previous year. Further, this provides another, second universal approach besides the specific emission factor for vehicles and is based on the same approach:

$$\text{SpecificEmissionWH} \Big/ \text{XS} = \frac{total\ energy\ consumned(year) \times emission\ factor}{total\ mass\ transhipped(year)} \quad (3)$$

This results in measuring emissions as CO_2 or CO_2e per tonne or kilogram.

For comparability and in order not to dilute specific emission factors, vehicles should be clustered in categories (TSEs) based on:

- Similar weights/sizes (e.g., 40 t truck)
- Similar engines/fuels (e.g., diesel)
- Similar VOS (transport patterns) (e.g., cargo train)

As discussed above, a common application of great circle distances for all modes of transport will enormously harmonize the calculation and allocation of emissions.

Included Processes: These should comprise all on-board processes which require energy (fuel/electricity for operation and cooling) for direct operation. Other energy required for maintenance, cleaning, or preparation should be accounted for at the company emission level.

Default data/Specific Factors: For the first year of operation and for comparability, default data should be provided. Especially, for warehousing and transshipping, default data would simplify calculations. Furthermore, specific factors for conversion must be globally harmonized. The default data presented in Table 6 are often used.

Reporting: This should be done as CO_2 or CO_2e, as shown in Table 7.

The preliminary recommendations might be sued for planning reasons (ex-ante) and for operational reasons (ex-post). As previously discussed, the suggestions fulfil aspects of simplicity, accuracy, flexibility, feasibility and transparency. Table 8 reviews all requirements in -Globo.

4.15. Assessment of preliminary recommendations

Expert interviews have been conducted with the European participants shown in Table 9, who have a combined industry experience of 279 years. Their relative experience in the transport elements of interest is illustrated in Fig. 2. All experts have experience in carbon foot printing and were not involved in CarbonCare.

The interviewees were presented the suggestions; eight main aspects of the work were discussed during the interviews:

1) The basic calculation principle
2) Allocated cooling values
3) Warehousing and transshipping allocation
4) Distance allocation
5) Included on-board processes
6) Harmonization of standard values and standard emission factors
7) Reporting of emissions
8) Missing facts and assumptions

Generally, there was overwhelming support for the blueprint. The blueprint was praised for its simplicity, feasibility and transparency. The research highlights and, where appropriate, addresses the discrepancies and concerns reported in the interviews below.

- The historical, annual timeframe was generally supported; however, one participant (IWW) preferred a semi-annual data collection. Operators are not precluded from updating their emissions semiannually and may tighten conditions.
- Some interviewees, largely from IWW and SEA, mentioned that it would be difficult to separate main energy consummation from the energy required for cooling. However, addressing this requires only organized data gathering and conscious measurement of energy flows.
- Questions were raised regarding the proper allocation of energy for transshipments and the workload for processing respective data.
- Partners agreed on the classification for TSEs in the various transport elements with different engines, fuels, and weight classes. However, they pointed out that data for newer fuels, such as gas-to-liquid, biodiesels, hydrogen, etc., are difficult to source.
- Generally, great circle distances were accepted, though there were still some minor uncertainties in this area, such as the harmonized allocation of distances for ports. If adders would still be respected in a future standard, then interviewees suggested an addition also for SEA operation comparable to that for AIR (e.g., GCD + 95 km).
- Most partners were supportive of included processes where only on-board processes such as cooling and operational energies are included. Energy for cleaning, maintenance, and preparation for transports should be not included. It was felt that such allocations would dilute the comparison and promote misuse of calculations.
- A majority of interviewees reported that WTW should be used for compensation, although it results in remarkably higher emission values than TTW. Considering compensation, TTW CO2e would encourage more carriers, forwarders, and shippers to buy in.
- It was pointed out that global standard values are difficult to source for the first year of reporting and for comparisons, particularly for Asia and Africa.

5. Final recommendation for a global emission standard

Based on the strong results of supporting interviews, only minor adjustments were required to the preliminary recommendations and details of the revised elements are provided below.

At the heart of a globalized standard should be:

- Realistic figures, based on transported masses (realistic load factors including empty trips and sub-contractors), used energy (e.g., fuels) and performed kilometers based on data from the previous year (this could be updated semi-annual).
- A calculation is based on Eq. (2) and results reported as CO_2 or CO_2e per tonne-kilometer.
- Cooled transports must be provided with separate tables or a specific mark-up, which are normally measured by the carrier.
- Similarly, for warehousing, energy (e.g., fuels/electricity) must be included for lighting, cooling, and heating (direct operation emissions). Such emissions shall be assessed on a yearly basis. Other energy usage shall be allocated to at the company emission level.
- For transshipping (e.g., loading/unloading) from one mode of transport to another or to the warehouse, specific standard figures shall be developed. Emissions from warehousing (WH) and transshipping (XS) shall be allocated based on mass. Thus, a specific emission factor for warehousing and transshipping is established based on data from the previous year, as per Eq. (3) and results reported as CO_2 or CO_2e per tonne or kilogram.
- Further, specific emission factors for vehicles should be clustered in categories (TSEs) based on:
    - Similar weights/sizes (e.g., 40-tonne truck)
    - Similar engines/fuels (e.g., diesel)
    - Similar VOS (transport patterns) (e.g., cargo train)
- Distances should be simply calculated on great circle distances for all modes of transport.

- Included processes: all on-board processes which require energy (fuel/electricity for operation and cooling) must be considered for direct operation. Other energy usage required for maintenance, cleaning, or preparation should be accounted for at the company level.
- For the first year of operation and for comparability, default data should be provided. Nevertheless, specific factors for conversion must be globally harmonized. Additionally, most publications lack emissions conversion for sustainable fuels like hydrogen, GTL (gas-to-liquid), or mixed fuels.
- Reporting must be based on TTW (CO_2 and CO_2e) and WTW (CO_2e).
- Emission compensation should be based on TTW CO_2e or on WTW CO_2e.
- The proposed elements are usable ex-ante and ex-post.

6. Conclusions and recommendations

The research stated that a useable, global emission standard should be based on four factors:

- Simplicity
- Accuracy
- Flexibility
- Feasibility

and

- Transparency.

The presented recommendations provide a transparent, simple approach with several universal elements. This was confirmed by all interviewed experts. Through the recommended approach's simplicity, operators have a realistic chance for implementation (feasibility), and it allows for a certain flexibility, while guaranteeing comparability.

Future research should examine applicability in Asia and North America, and refine calculation practice for warehousing and transshipping with different real-life examples, since operators still feel that there are large uncertainties in these areas.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Declaration of Interests.

None.

Glossary.

Carbon offsetting: Carbon offsetting refers to the achieved reduction in emissions of carbon dioxide or other greenhouse gases to compensate for emissions generated elsewhere.

CO_2 equivalent: CO_2 equivalent is a measure used to compare the emissions from various greenhouse gases on the basis of their global warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential.

Paris Agreement: The Paris Agreement is a legally binding international treaty on climate change. It was adopted by 196 Parties at COP 21 in Paris, on December 12, 2015, and entered into force on November 4, 2016.

Tank-to-Wheel: Tank-to-Wheel considers the effective chain from absorbed energy (fuel, electrical energy, hydrogen etc.) to conversion into kinetic energy in motor vehicles.

Well-to-Wheel: Well-to-Wheel is an analysis method in the field of vehicles. It examines the entire chain of effects for locomotion, from the generation and provision of drive energy to its conversion into kinetic energy.

Appendix A

Table A1-A7

Table A1
ROAD Transports (ISO IWA 16 2015, p. 6).

Investigated Aspect	EN16258	SmartWay	Identified Gaps & Comments
TTW/WTW (Tank-To-Wheel/ Well-To-Wheel)	TTW/WTW	TTW	Consistency of approach Reliable information about upstream processes
CO_2/CO_2e	CO2e	CO_2	Consistency of approach
Allocation units in general	Preferred unit is tkm, but other units can be used if they are justified. Marginal accounting is not allowed	CO_2/ton mile. Also, CO_2/vehicle mile and CO_2 per cubic foot mile	Unified allocation units per type of cargo and/or transport service
Specific allocation units	Preferred allocation unit for collection and distribution: tkm based on Great Circle Distance	–	use of this allocation unit in practice (recommendation: uniform calculation unit for every service type: dense network transport, loose network transport, point-to-point-transport)
Energy consumption of auxiliary processes	Only on-board processes are included, they are not specified in detail	Not specified	Treatment of temperature control/reefer to be consistent across all modes
Processes included	Loaded and unloaded (empty) trips, subcontractor transports, on-board handling if measured	Own fleet Empty running included	Auxiliary processes (e.g., non-onboard handling), secondary energy used for temperature-controlled processes, maintenance, preparation and aftercare of vehicle and transportation units (e.g., cleaning of tank containers)
Allocation notes	–	–	–
Vehicle operation systems (VOS) descriptions	Concept of VOS and fleet is introduced	This is taken into account through benchmarking by service type in which the information is presented	STD categories of descriptions for VOS would help comparability. General internationally applicable clustering of vehicles into categories needs to be specified, granularity of data.
Procedure for measured energy consumption data	The standard categorizes data into the groups of specific measured values, transport operator specific values and transport operator fleet values. It is not specified how these values are generated	Fuel and CO_2 based on measured data. Other pollutants modelled using national emissions factors and protocols	Guidelines for measurement and use of measured data are needed. Guidelines on uncertainties
Procedure for absence of measured energy consumption data	Procedures and sources for default data referenced in annex, use not specified	Not applicable	Guidelines for use and selection of data in case of absence of measured data are needed
Fuel-based versus activity based	Fuel-based preferred but other approaches accepted	Fuel-based	Fuel (including electricity) as desired base, other approaches need to be accepted in the meantime
Data sources (default data)	–	–	Guidelines for use and selection of data in case of absence of measured data are needed
Specific factors	Given in EN16258, Annex A	National emission factors from Argonne National Laboratory	Need a standard procedure for the approach to emission factors across all modes
Gaps in existing coverage/ comments	–	–	–
Allocation unit and intensity	–	–	Mass/volume relation and distances need to be unified
Calculation of distances	Actual distance travelled. For allocation: Great Circle Distance or shortest feasible distance	Actual distance driven	Harmonized approach to consideration of distance is required
Reporting	Energy use and CO_2e on both TTW and WTW basis	Benchmarked reporting based on 5 groups ranked according to CO_2 per ton mile within each of several operational business sectors	Definition of reporting factors for the specific purpose required (for all modes)
Accuracy labels	–	–	Accuracy labels for reporting to be developed.
Harmonization note	It is recommended that national or regional regulations take into account the transnational dimensions of transport	Wide range of perfectly logical/ reasonable ways of doing things is confusing. Harmonization must serve a purpose for people to adopt or change what they are doing	Standard(s) need(s) to specify clearly the following three levels for coherent quantification of CO_2e emissions of freight transport (total and intensity): (1) Level of operation of TCE; (2) Level of network including company level; (3) Level of cargo
General comments and thoughts	Use of TCEs to allow disaggregation of supply chain into manageable, consistent, discrete elements is widely acknowledged across all Action Group areas, although the way that this is done and described varies greatly.		

Table A2
RAIL Transports (ISO IWA 16 2015, p. 8).

Investigated Aspect	EN16258	SmartWay	Identified Gaps & Comments
TTW/WTW	TTW/WTW	TTW (rail module)	Consistency of approach Reliable information about upstream processes
CO_2/CO_2e	CO2e	CO_2	Consistency of approach
Allocation units in general	Preferred unit is tkm, but other units can be used if they are justified. Marginal accounting is not allowed	g CO_2/ton mile Also g CO2/vehicle mile	Only uses several average values for gross weight and payload
Specific allocation units			Special Case: allocation rules in case of combined passenger and freight trains
Energy consumption of auxiliary processes	Only on-board processes are included, they are not specified in detail	Not specified	Treatment of temperature control/reefer to be consistent across all modes
Processes included	Loaded and unloaded (empty) trips, subcontractor transports, on-board handling if measured	Own fleet empty running included Fuel used by main power source	Auxiliary processes (e.g. non-onboard handling), sec. energy used for temperature-controlled processes, maintenance, preparation and aftercare of vehicle and transportation units (e.g. cleaning of tank containers)
Allocation notes			Emissions of shunting processes need to be considered
Vehicle operation systems (VOS) descriptions	Concept of VOS and fleet is introduced	Reporting according to overall fleet operations and also disaggregated by bulk and other operations	Standard categories of/ descriptions for VOS would help comparability. VOS for rail transport have to be specified and included in a calculation methodology
Procedure for measured energy consumption data	The standard categorizes data into the groups of specific measured values, transport operator specific values and transport operator fleet values. It is not specified, how these values are generated	Fuel and CO_2 based on measured data Other pollutants modelled using national emissions factors and protocols	Guideline is needed for railway operators for calculation of trip or round trip (e.g., for block trains or shuttle trains in intermodal transport) related emissions
Procedure for absence of measured energy consumption data	Procedures and sources for default data referenced in annex, use not specified	Not applicable	Fuel (including electricity) as desired base, other approaches need to be accepted in the meantime
Fuel-based versus activity based	Fuel-based preferred but other approaches accepted	Fuel-based	Fuel (including electricity) as desired base, other approaches need to be accepted in the meantime
Data sources (default data)	–	–	A regularly updated process of data or data sources needs to be considered. (Many data are not published and are not validated by neutral bodies)
Specific factors	Given in EN16258, Annex A	–	Need a standard procedure of approach for emission factors across all modes
Gaps in existing coverage/ comments	–	–	Database should become more transparent and extended to different train types (block, trains, intermodal trans- port trains, single wagon load trains). Further, empty runs should be measured and allocated more transparency
Allocation unit and intensity	–	–	Mass/volume rel. & distances need to be unified. For intermodal trains, emissions per load unit (i.e., TEU) should be added
Calculation of distances	Actual distance travelled. for allocation: Great Circle Distance or shortest feasible distance	Actual distance travelled	Not clear how resistance factors were calculated; Empty return trips need to be transparently calculated; Number of additional stops are only considered on average in default data sources, but the real energy consumption greatly depends on the number of stops, e.g. due to siding tracks to be crossed by faster trains. This is harmonized for rail transport; for further standardization developments, harmonization across modes is needed
Reporting	Energy use and CO_2e on both TTW and WTW basis	Reporting according to CO_2 per ton mile	Definition of reporting factors for the specific purpose required (for all modes)
Accuracy labels	–	–	Accuracy labels for reporting to be developed
Harmonization note		Wide range of perfectly logical/ reasonable ways of doing things is	Standards(s) need(s) to specify clearly the following three levels for coherent

(*continued on next page*)

Table A2 (*continued*)

Investigated Aspect	EN16258	SmartWay	Identified Gaps & Comments
	It is recommended that national or regional regulations take into account the transnational dimensions of transport	confusing Harmonization must serve a purpose for people to adopt or to change what they are doing	quantification of CO_2e emissions of freight transport (total and intensity): (1) Level of operation of TCE (2) Level of network including company level (3) Level of cargo
General comments and thoughts	Use of TCEs (transport chain element) to allow disaggregation of supply chain into manageable, consistent, discrete elements is widely acknowledged across all Action Group areas, although the way that this is done and described varies greatly.		

Table A3
IWW Transports (ISO IWA 16 2015, p. 12).

Investigated Aspect	EN16258	SmartWay	IMO MEPC.1 /circ.684	STREAM International	Identified Gaps & Comments
TTW/WTW	TTW/WTW	TTW	TTW	TTW/WTW	Consistency of approach. Reliable information about upstream processes
CO_2/CO_2e	CO2e	CO_2	CO_2	CO2e	Consistency of approach
Allocation units in general	Preferred unit is tkm, but other units can be used if they are justified. Marginal accounting is not allowed	gCO_2/ton mile gCO_2/ vehicle mile gCO_2/cubic foot mile	gCO_2/unit for transport work done (usually tkm, but others are possible)	g CO_2e/tkm	Consistency of reporting
Specific allocation units	–	–	–	–	Allocation rules for inland water- ways need to be clarified regarding specifics of loaded/ unloaded upstream (up river) and down-stream (down river) transports
Energy consumption of auxiliary processes	Only on-board processes are included, they are not specified in detail	Not specified	Not specified	Not specified	Treatment of temperature control/reefer to be consistent across all modes
Processes included	Loaded and unloaded (empty) trips, subcontractor transports, on-board handling if measured	Own fleet Empty running included Fuel used by main power source	Own fleet All fuel used by main power source in operation, so empty running included by default	Empty running included by use of utilization factor	Auxiliary processes (e.g. non-onboard handling), secondary energy used for temperature-controlled processes, maintenance, preparation and aftercare of vehicle and transportation units (e.g. cleaning of tank containers)
Allocation notes	–	–		–	–
Vehicle operation systems (VOS) descriptions	Concept of VOS and fleet is introduced	Reporting according to overall fleet operations and also dis-aggregated by bulk and other operations	Reporting according to different types of cargo operation	Reporting according to different types of cargo operation	Standard categories of descriptions for VOS would help comparability
Procedure for measured energy con- sumption data	The standard categorizes data into the groups of specific measured values, transport operator specific values and transport operator fleet values. It is not specified how these values are generated	Fuel and CO_2 based on measured data. Other pollutants modelled using national emissions factors and protocols	–	–	Default database should be completely publicly available/ accessible to ensure transparency and trust
Procedure for absence of measured energy consumption data	Procedures and sources for default data referenced in annex, use not specified	Not applicable	–	–	Guidelines for use and selection of data in case of absence of measured data are needed
Fuel-based versus activity- based	Fuel-based preferred but other approaches accepted	Fuel-based	Fuel-based	Activity-based. Energy use and pollutant emissions modelled on	Fuel (including electricity) as desired base, other approaches need to be accepted in the meantime

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Table A3 (*continued*)

Investigated Aspect	EN16258	SmartWay	IMO MEPC.1 /circ.684	STREAM International	Identified Gaps & Comments
				different types of vessel	
Data sources (default data)	–	–	–	EcoTransIT HBEFA Dutch national stats. EU Averages	A regularly updated process of data or data sources needs to be considered. (Many data are not published and are not validated by neutral bodies)
Specific factors	Given in EN16258 Annex A	National emission factors from Argonne National Laboratory	Uses international factors sourced by IMO	Uses Defra factors	Need a standard procedure for the approach to emission factors across all modes
Gaps in existing coverage/ comments	–	–	–	–	–
Allocation unit and intensity	–	–	–	–	Mass/volume relationship and distances need to be unified
Calculation of distances	Actual distance travelled. For allocation: Great Circle Distance + 95 km or shortest feasible distance	Actual distance travelled	Actual distance travelled	Actual distance travelled	–
Reporting	Energy use and CO_2e on both TTW and WTW basis	Reporting according to CO_2 per ton mile	–	–	Definition of reporting factors for the specific purpose required (for all modes)
Accuracy labels	–	–	–	–	Accuracy labels for reporting to be developed
Har-monisation note	It is recom-mended that national or regional regulations take into account the transnational dimensions of transport	Wide range of perfectly logical/ reasonable ways of doing things is confusing. Har-monisation must serve a purpose for people to adopt or change what they are doing	–	–	Standard(s) need(s) to specify clearly the following three levels for coherent quantification of CO_2e emissions of freight transport (total and intensity): (1) Level of operation of TCE; (2) Level of network including company level; (3) Level of cargo
General comments and thoughts	Use of TCEs to allow disaggregation of supply chain into manageable, consistent, discrete elements is widely acknowledged across all Action Group areas, although the way that this is done and described varies greatly.				

Table A4
Maritime Transports (ISO IWA 16 2015, p. 15).

Investigated Aspect	EN16258	Clean Cargo Working Group	IMO MEPC.1 /circ.684	Identified Gaps & Comments
TTW/WTW	TTW/WTW	TTW	TTW	Consistency of approach. Reliable information about upstream processes
CO_2/CO_2e	CO2e	CO2e	CO_2	Consist. of appr.
Allocation units in general	Preferred unit is tkm, but other units can be used if they are justified. Marginal acc. is not allowed	g CO_2/TEU km	g CO_2/unit for transport work done (usually tkm but others are possible)	Transfer into CO_2e for TEU is needed across all containerized transport
Specific allocation units	–	Use of TEU for containerized maritime transport is beneficial due to uncertainty over leading of individual containers	No	Recognized, specific industry guidance is beneficial, currently exists for containerized transport (all types of ships); needs to be expanded to other maritime sectors, e.g., bulk, tanker
Energy consumption of auxiliary processes	Only on-board processes are included, they are not specified in detail	Includes a factor to allow for the energy consumption of reefers	Not specified	Treatment of temperature control/reefer to be consistent across all modes
Processes included		Own fleet Empty running included	Own fleet All fuel used	Auxiliary processes (e.g. non-onboard handling), secondary

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Table A4 (*continued*)

Investigated Aspect	EN16258	Clean Cargo Working Group	IMO MEPC.1 /circ.684	Identified Gaps & Comments
	Loaded and unloaded (empty) trips, subcontractor transports, on-board handling if measured	Fuel used by main power source Industry average loading factor for TEU per vessel	by main power source in operation, so empty running included by default	energy used for temperature-controlled processes, maintenance, preparation and aftercare of vehicle and transportation units (e.g. cleaning of tank containers). Load factor process needs to be defined
Allocation notes	–	–	–	–
Vehicle operation systems (VOS) descriptions	Concept of VOS and fleet is introduced	A trade lane approach is taken for vessels travelling on the most common journey combinations	Reporting according to different types of cargo operation	VOS needs to be defined for transport segments which are not containerized
Procedure for measured energy consumption data	The standard categorizes data into the groups of specific measured values, transport operator specific values and transport operator fleet values. It is not specified how these values are generated	Fuel and CO_2 based on measured data wherever possible using information supplied through the CCWG data collection process	Raw data input: fuel used, distance travelled, transport work done (transport work not defined and therefore not comparable)	Harmonization of the use of measured data is needed
Procedure for absence of measured energy consumption data	Procedures and sources for default data referenced in annex, use not specified	Industry STD factors for the main trade lanes based on the CCWG data collection process	Industry standard factors for conversion of fuel into CO_2 based on IMO guidelines	Default database should be publicly available/ accessible to ensure transparency and trust
Fuel-based versus activity based	Fuel-based preferred but other approaches accepted	Fuel-based	Fuel-based	Fuel (including electricity) as desired base, other approaches need to be accepted in the meantime
Data sources (default data)	–	CCWG industry-derived values	–	A regularly updated process of data or data sources needs to be considered. (Many data are not published and are not validated by neutral bodies.)
Specific factors	Given in EN16258, Annex A	Uses international factors sourced by IMO.	Uses international factors sourced by IMO.	Need a standard procedure for the approach to emission factors across all modes
Gaps in existing coverage/ comments	–	Focused on container shipping only - IMO guidelines provide the opportunity for other maritime sectors	IMO guidelines provide the opportunity for other time sectors (not container) but more specific guidance is needed within these segments to ensure comparability	Need to develop maritime sectors other than containerized transport
Allocation unit and intensity	–	–	–	–
Calculation of distances	Actual distance travelled. For allocation: Great Circle Distance or shortest feasible distance	Direct distance + 15 %	Actual distance travelled	Gap between shortest distance (applied by users) and actual distance (applied when calculating emission factors) for segments other than container vessels
Reporting	Energy use and CO_2e on both TTW and WTW basis	–	–	CO_2e and WTW need to be aligned. Definition of reporting factors for the specific purpose required (for all modes)
Accuracy labels	–	–	–	Accuracy labels for reporting to be developed.
Harmonization note	It is recommended that national or regional regulations take into account the transnational dimensions of transport	Important to consider how the application to container transport through terminals and on rail or road feeder journeys can be addressed in a consistent manner	–	Standard(s) need(s) to specify clearly the following three levels for coherent quantification of CO_2e emissions of freight transport (total and intensity): (1) Level of operation of TCE; (2) Level of network including company level; (3) Level of cargo
General comments and thoughts	Use of TCEs to allow disaggregation of supply chain into manageable, consistent, discrete elements is widely acknowledged across all Action Group areas, although the way that this is done and described varies greatly.			

Table A5
AIR Transports (ISO IWA 16 2015, p. 17).

Investigated Aspect	EN16258	IATA RP1678	Identified Gaps & Comments
TTW/WTW	TTW/WTW	TTW	Consistency of approach. Reliable information about upstream processes
CO_2/CO_2e	CO2e	CO_2	Consistency of approach
Allocation units in general	Preferred unit is tkm, but other units can be used if they are justified. Marginal accounting is not allowed	Allocation based on mass and tkm	Unified allocation units per type of cargo and/or transport service
Specific allocation units	Allocation for belly freight uses actual mass of passengers and baggage or allowance for passengers	Allocation for belly freight uses mass of passengers plus an allowance for each seat, even if not occupied	Consistency of approach is crucial
Energy consumption of auxiliary processes	Only on-board processes are included, they are not specified in detail	Auxiliary power usage included (as defined in the IATA Fuel Measurement Protocol)	Treatment of temperature control/reefer to be consistent across all modes
Processes included	Loaded and unloaded (empty) trips, subcontractor transports, on-board handling if measured	Empty running and repositioning included in network approach. Subcontractor transports included	Auxiliary processes (e.g. non-onboard handling), secondary energy used for temperature-controlled processes, maintenance, preparation and aftercare of vehicle and transportation units (e.g. cleaning of tank containers)
Allocation notes	–	–	–
Vehicle operation systems (VOS) descriptions	Concept of VOS and fleet is introduced	Can be taken on a leg-based or network approach	VOS has to be defined including alignment of terminology across all modes of transport
Procedure for measured energy consumption data	The standard categorizes data into the groups of specific measured values, transport operator specific values and transport operator fleet values. It is not specified, how these values are generated	IATA fuel measurement protocol	Recognized, specific industry guidance is beneficial
Procedure for absence of measured energy consumption data	Procedures and sources for default data referenced in annex, use not specified	IATA fuel measurement protocol	Default database should be publicly available/accessible to ensure transparency and trust
Fuel-based versus activity-based	Fuel-based preferred but other approaches accepted	Fuel-based following IATA fuel measurement protocol	Recognized, specific industry guidance is beneficial; Fuel (including electricity) as desired base, other approaches need to be accepted in the meantime
Data sources (default data)	–	–	A regularly updated process of data or data sources needs to be considered. (Many data are not published and are not be validated by neutral bodies.)
Specific factors	Given in EN16258, Annex A	CO_2 emission factor taken from IPCC	Need a standard procedure for the approach to emission factors across all modes
Gaps in existing coverage/ comments	–	–	–
Allocation unit and intensity	–	–	–
Calculation of distances	Actual distance travelled. For allocation: Great Circle Distance + 95 km or shortest feasible distance	Great Circle Distance (GCD) GCD + 95 km is allowed	consistency of approach (and with other modes)
Reporting	Energy use and CO_2e on both TTW and WTW basis	–	CO_2e and WTW needs to be aligned. Definition of reporting factors for the specific purpose required (for all modes)
Accuracy labels	–	–	Accuracy labels for reporting to be developed
Harmonization note	It is recommended that national or regional regulations take into account the transnational dimensions of transport	–	Standard(s) need(s) to specify clearly the following three levels for coherent quantification of CO_2e emissions of freight transport (total and intensity): (1) Level of operation of TCE; (2) Level of network including company level; (3) Level of cargo
General comments and thoughts	Use of TCEs to allow disaggregation of supply chain into manageable, consistent, discrete elements is widely acknowledged across all Action Group areas, although the way that this is done and described varies greatly.		

Table A6
AIR Transports (own development).

Investigated Aspect	Green Logistics (Air)	ICAO	GHG & Aerospace	Identified Gaps & Comments
TTW/WTW	TTW/WTW	TTW (point-to-point transport contribution)	TTW/WTW	Consistency of approach. Reliable information about upstream processes
CO_2/CO_2e	CO2e	CO_2	–	Consist. of appr.
Allocation units in general	Allocation based on mass and tkm	Allocation based on mass and tkm	Allocation based on mass and tkm (operational control approach)	Unified allocation units per type of cargo and/or transport service
Specific allocation units	Allocation for belly freight uses actual mass of passengers and baggage or allowance for passengers	ICAO: Allocation for belly freight uses mass of passengers plus an allowance of 50 kg for each seat, even if not occupied.	–	Consistency of approach is crucial
Energy consumption of auxiliary processes	Only on-board processes are included, they are not specified in detail	Auxiliary power usage included (as defined in the ICAO Engine Exhaust Data Bank)	Scope 3 for leased (also rented) buildings for the company pays the utility bills; business travel from airfare, rental car, bus and rail travel	Treatment of temperature control/reefer to be consistent across all modes
Processes included	Loaded and unloaded (empty) trips, subcontractor transports, on-board handling if measured	empty running and repositioning included in network approach Subcontractor transports included	Scope 1–3	Auxiliary processes, secondary energy used for temperature-controlled processes, maintenance, preparation and aftercare of vehicle and transportation units. Empty/ subcontractor should be included.
Allocation notes	–	–	–	–
Vehicle operation systems (VOS) descriptions	Concept of VOS and fleet is introduced	Can be taken on a leg-based or network approach	–	VOS has to be defined including alignment of terminology across all modes of transport
Procedure for measured energy consumption data	The standard categorizes data into the groups of specific measured values, transport operator specific values and transport operator fleet values. It is not specified how these values are generated	ICAO Engine Exhaust Emissions Data Bank (available, reliable and transparent based on regular updates)	The problem regarding a regular update process of data sources is not mentioned or considered to be relevant	Default database should be publicly available/ accessible to ensure transparency and trust. This is the case for all ICAO databases
Procedure for absence of measured energy consumption data	Procedures and sources for default data referenced in annex, use not specified.	Default databases are publicly available /accessible from ICAO/CAEP		Default database should be completely publicly available/ accessible to ensure transparency and trust
Fuel-based versus activity-based	Fuel-based preferred but other approaches accepted	Fuel based. Load factors per region available	Fuel-based preferred but other approaches accepted	Recognized, specific industry guidance is beneficial; Fuel (including electricity) as desired base, other approaches need to be accepted in the meantime
Data sources (default data)	–	In addition: fuel consumption per city-pair or leg and distances (ESAD) from the available & validated Eurocontrol data base BADA4 & Advanced Emission Model (AEM)		A regularly updated process of data or data sources needs to be considered. (Many data are not published and are not validated by neutral bodies)
Specific factors	Given in EN16258, Annex A	CO_2 emission factor taken from IPCC	–	Need a standard procedure for the approach to emission factors across all modes
Gaps in existing coverage/ comments	–	–		–
Allocation units and intensity	–	–		–
Calculation of distances	Actual distance travelled. For allocation: Great Circle Distance + 50 km or shortest feasible distance	Great circle distance (GCD) + 50 (<550 km), +100 (550–5500 km) or + 125 km (>5500 km)	Actual fuel and distance	consistency of approach (and with other modes)
Reporting	Energy use and CO_2e on both TTW and WTW basis	–	–	Reporting is not very clear, especially not for the case of a

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Table A6 (*continued*)

Investigated Aspect	Green Logistics (Air)	ICAO	GHG & Aerospace	Identified Gaps & Comments
				complete network. Consistency of approach is crucial
Accuracy labels	–	–		Accuracy labels for reporting to be developed
Harmonization note	It is recommended that national or regional regulations take into account the transnational dimensions of transport	–	–	–
General comments and thoughts	It is neither specified, nor clear how an implemented application should acquire the appropriate input data. ICAO/CAEP (in close collaboration with IATA/FAA and airframe/engine manufacturers) is the future for a globally accepted standardization in the airline industry. The problem regarding a regularly updated process of data sources is neither mentioned nor considered to be relevant. In addition, data sources and default data (e.g., calculation of distances) are not transparent.			

Table A7
Transshipping (ISO IWA 16 2015, p. 19).

Investigated Aspect	Green Efforts	Green Logistics	ITEC	Identified Gaps & Comments
TTW/WTW	TTW/WTW	TTW	WTW (TTW possible, not desired)	–
CO_2/CO_2e	CO2e	CO2e	CO2e	–
Allocation units in general	TEU throughput	Transshipment centers: allocation based on weight (tons). Warehouses: allocation based on space use (average stock level)	Transported Loading Unit (Transported = transshipped in the intermodal terminal from one mode to the other; Loading Unit = freight container > 20′, i.e., according to ISO 668, EN 284, EN 452 and semi-trailer)	No harmonized allocation units Need to distinguish between transshipment centers and warehouses Consistency of reporting
Specific allocation units	Focused on maritime container terminals. The focus has been on throughput rather than a measure of dwell time or number of processes within the terminal due to practicality considerations	Green Logistics project has considered a range of logistics facilities (air freight terminals, letter/parcel sorting centers, storage/*trans*-shipment centers for general cargo)	Internally: different units depending on the process group, e.g., trains, trucks, loading units, which are finally transferred into "Loading Unit" using measured figures of the intermodal terminal	Allocation rule for temperature control/reefers of high practical relevance and should be consistent with maritime
Energy consumption of auxiliary processes	Generally included, depending on what data are available	Electricity, heating, packaging materials, refrigerants	Included in main process groups, e.g., offices, lighting	Treatment of temperature control/reefer to be consistent across all modes
Processes included	No reliable method for the consumption by reefers while at the terminal as yet	All warehouses/ transshipment centers of logistics network	Main process groups inside the functional boundaries of the intermodal terminal: transshipment operations (different types of RMG, RTG, Reach Stacker), rail operations (last mile, incl. shunting, different types of line and shunting locomotives), truck operations, additional services (e.g., depot, reefer, internal movement), supply/disposal	
Allocation notes	–	–		–
Vehicle operation systems (VOS) descriptions	not applicable (n/a) - not based on VOS	n/a - not based on VOS	VOS described within main process groups (distances, times, specific energy consumption)	Definition of boundaries especially with regard to onshore power supply (OPS)
Procedure for measured energy consumption data	Collect as much original fuel use data as possible May require data to be collected for many different processes and separate operating bodies	Operators have access to original fuel use data and material consumption data on a yearly basis. In general, no further measurement or sampling is needed. Data collection must be specific for each warehouse/transshipment center	Collect as much as possible real process data and energy use from terminal (terminal operating company, terminal owner, service partners)	Default database should be publicly available /accessible to ensure transparency and trust
Procedure for absence of	–	We are aiming to develop indicators to model energy	Technical data sheets of all kinds of vehicles and engines	Guidelines for use and selection of data in case of

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Table A7 (*continued*)

Investigated Aspect	Green Efforts	Green Logistics	ITEC	Identified Gaps & Comments
measured energy consumption data		consumption based on size, operation type, goods type and processes	used in terminals as well as experience values from other comparable terminal processes by process group and specific energy consumption	absence of measured data are needed
Fuel-based versus activity-based	Fuel (energy) based	For privately-owned warehouses and transshipment centers: fuel (energy) based. For external warehouses and transshipment centers: estimate based on size, operation type, goods and processes (see above)	Mixed approach: activity based and fuel-based for details as well as comparison of results	Fuel (including electricity as desired base, other approaches need to be accepted in the meantime
Data sources (default data)	Electricity consumption is an important element of terminal energy use, so consistency of approach and values with rail (and other modes) is important	Electricity: important to differentiate between various options of electricity generation. General approach (e.g., WTW) must be in line with other elements of logistics network (rail, road etc.) Default values will differ from rail transport, because of rail specific electricity production. Heating: important to differentiate between various options of heat generation. Default values should be in line with other elements of logistics network (e.g., use of natural gas for heating and trucks)	Background data on trucks (by type), country-specific electricity data, European Diesel data, different types of heating; Self-learning database on intermodal terminals	A regularly updated process of data or data sources needs to be considered. (Many data are not published and are not validated by neutral bodies.)
Specific factors	–	–	Emission factors compliant with the European reference life cycle database	Need a standard procedure for the approach to emission factors across all modes
Gaps in existing coverage/ comments	Non-container terminals not directly covered, but it should be straightforward to consider similar approach using appropriate measure of throughput	Indirect emissions of use of packaging materials should not be neglected. Especially if warehouse/transshipment center does not need heating and has low emissions due to the use of green energy. Distinction between warehouse and transshipment center is needed	Intermodal terminals rail/road covered; barge/ road tested, others could be included following the same methodology. Total life-cycle-approach, including energy and materials used to build the equipment as well as the terminal infrastructure not yet applied	Ports and associated terminals are important due to the large throughput and significant localized influence. Warehousing is also important due to its high frequency in most transport chains
Allocation unit and intensity	–	–	–	–
Calculation of distances	n/a	n/a	Measures distances for the different process groups, if applicable	–
Reporting	–	information on size and throughput of transshipment/ warehouse center required	I-Report, with values on entire terminal and differentiate by main process groups	CO_2e and WTW needs to be included. Definition of reporting factors for the specific purpose required (for all modes)
Accuracy labels	–	–	As accurate as possible	Accuracy labels for reporting to be developed
Harmonization note	Need to ensure consistent approach to boundaries between transshipment centers and transport elements for all modes. E.g., fuel used by vehicles that primarily operate outside the terminal will most probably be recorded under the transport mode and should not be double counted	Need to ensure consistent approach to boundaries between transshipment centers and transport elements for all modes. E.g., fuel used by vehicles that primarily operate outside the terminal will most probably be recorded under the transport mode and should not be double counted In contrast, vehicles that only run on the ground of transshipment/ warehouse	Functional (VOS- based) definition of intermodal terminal; "external vehicles", e.g., barges, wagon sets, trucks operating inside the functional boundaries of the terminal (defined by quay wall, reception/ departure track, terminal gate) is included. Double counting is however possible if external modes of transport include these as an "overhead" on their transport	Need to consider what processes to include and exclude Standard(s) need(s) to specify clearly the following three levels for coherent quantification of CO_2e emissions of freight transport (total and intensity): (1) Level of operation of TCE; (2) Level of network including company level; (3) Level of cargo

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Table A7 (*continued*)

Investigated Aspect	Green Efforts	Green Logistics	ITEC	Identified Gaps & Comments
		cannot be neglected (e.g., reach stackers, lifting truck for swap bodies)	part of the transport chain. Nevertheless, it is meaningful to include this into the terminal functional boundaries due to their inter-dependency. Example: the far distance rail operator is unlikely to know about local shunting operations	
General comments and thoughts	It would be helpful to have standard estimates to use for vehicle operations (e.g., fork lift truck operations) based on tonnes of goods handled in typical warehousing operations. All logistics hubs, e.g., airport and air cargo logistics hubs should be taken into account.			

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