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Eco-labeling of freight transport services

Design, evaluation, and research directions

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Abstract

The idea of eco-labeling is to provide customers with an easy-to-understand signal regarding the ecological impact of using a product or service. With this paper, we propose an eco-labeling system for freight transportation. We discuss design options based on a common emission reporting standard and a related communication protocol. We further explain a procedure for deriving labels for shipments of goods and provide examples illustrating and evaluating the labeling process at selected land-based freight transport services. Results indicate that eco-labels can grade the environmental impact of a transport service reliably, even if heterogeneous goods are moved together. Finally, we outline challenges for future research associated with eco-labeling in freight transportation markets.

KEYWORDS

eco-labeling, emission allocation, EN 16258, GHG reporting standard, industrial economy, sustainable transportation

1 | INTRODUCTION

Passenger and freight mobility is responsible for about 14% of the global anthropogenic greenhouse gas (GHG) emissions, with a share of up to 25% in highly industrialized economies (IPCC, 2014). Prominent GHGs are carbon dioxide (CO_2), methane, nitrous oxide, ozone, chlorofluorocarbons, and other halogenated gases (EPA, 2021). To measure the negative effects of any GHG, its *global warming potential* (GWP) can be set in relation to the GWP of CO_2, which is then referred to in units of CO_2-*equivalents* (CO_2e). While the major part of mobility-related CO_2e emissions worldwide stem from passenger transportation, the role of freight transportation is still substantial. For example, road freight transportation emitted 2.4 Gt of CO_2e worldwide in 2018 (see Figure S1 in Appendix).

Diverse political initiatives aimed at limiting global warming by cutting transport-related GHG emissions. Noteworthy activities are stricter standards for exhaust systems of combustion engines, governmental promotions of electric vehicles, and CO_2 taxation. All this is discussed under the designation of green transportation in the literature with a focus often put on harmonizing environmental targets and traditional business objectives (see Dekker et al., 2012; Savelsbergh & Woensel, 2016).

This paper provides a novel view on green freight transportation, by asking how a transport service, that is, the movement of a good from a point of origin to a point of destination, should be organized to match a customer's ecological expectation. We develop a categorical labeling system, similar to eco-labels known in consumer product markets. The label generates a signal that shippers can use to express and adjust their ecological preferences. Along with an eco-label, a communication protocol illustrates the information flows of the labeling process. Checking whether or not a transport service's environmental performance is compatible with the shippers' ecological preferences is not an easy task, especially when different transport modes and vehicles with a changing degree of consolidation are involved.

To the best of our knowledge, the paper provides the first design for an eco-labeling system that targets logistic services and operations. It is organized as follows: Section 2 outlines reporting standard EN 16258, which forms the basis of the proposed eco-labeling system. In Section 3, we describe the communication flow between shippers and carriers necessary to measure a service's ecological footprint. Section 4 introduces the labeling system design. We define indicator values for measuring environmental performances of transport processes. The approach is evaluated in Section 5 by a study on different services. The paper ends with an outlook on future research topics related with eco-labeling in logistics in Section 6 and a conclusion in Section 7.

2 | EMISSION REPORTING STANDARD EN 16258

A major component of every eco-labeling system is a standardized procedure to ascertain the ecological impact of products or services, for example, in terms of GHG emissions caused by making the product or by consuming the service. For transport services, such a procedure has been proposed by the European Committee for Standardization (2013).

The European Norm EN 16258 defines a widely applicable GHG emission reporting standard for the transport industry. It prescribes (1) that carriers quantify the emissions that are caused by the conducted transport processes, (2) that they allocate these emissions to the transport orders moved in the processes, and (3) that they report the environmental performance to their customers (shippers).

A so-called *vehicle operation system* (VOS) forms the basis for calculating emissions according to EN 16258. It is constituted by physical movements of vehicles from some point of origin to some point of destination, also referred to as *vehicle trips*. Vehicle trips include loaded trips and empty trips necessary to reach customers or depots. The norm prescribes that the total energy consumption and GHG emissions associated with a VOS must be allocated completely to the involved transport orders. EN 16258 generally recommends to use *ton-kilometers* as allocation measure, but it allows other measures, if suitable, like *transport distance*, *loading weight*, *pallet-kilometer*, and even combinations thereof. If transport distance is considered in the emission allocation process, it should relate to crow-fly or shortest travel distances between the order's pickup and delivery locations, which provokes less bias than realized travel distances do (Davydenko et al., 2014; Kellner, 2016).

For each VOS, an allocation rule has to be applied consistently, meaning that transport orders carried together on a leg are treated the same way. Emission allocation starts with the amount of fuel or electricity a vehicle consumes when conducting a trip. For reporting purposes, the true energy consumption can be taken ex post, while for planning purposes, it has to be estimated. Various models are available to estimate the energy consumption of a vehicle trip at different scales of accuracy (see Demir et al. (2014) for an overview).

Given the true or estimated energy consumption f_i (in liters of fuel or kilowatt) for a vehicle serving leg i, the corresponding GHG emission e_i, measured in kg CO_2e, is calculated by:

$$e_i = f_i \times c_s^{GHG}. \tag{1}$$

Here, c_s^{GHG} denotes a *conversion factor*for the energy source s used in the process. For oil-based fuels, c_s^{GHG} indicates the GHG volume emitted by burning 1 L of fuel, measured in kg CO_2e/L. Corresponding emission coefficients for various fuels are provided by the European Committee for Standardization (2013).

Once the GHG emission e_i is determined for leg i, it is allocated in portions of e_{ij} to the transport orders $j \in J_i$ moved in the process. Let ω_j denote the value of the selected allocation measure regarding transport order $j \in J_i$. The allocation weight of order j is computed as the relative share of ω_j against the total value of all orders $k \in J_i$. Hence, the portion of emission e_{ij} assigned to order j is given by:

$$e_{ij} = \frac{\omega_j}{\sum_{k \in J_i} \omega_k} \times e_i. \tag{2}$$

An example is shown in Table S1 in the Appendix. Here, two orders are moved together by a van. The total emission produced on leg 1 is $e_1 = 60$ kg CO_2e. The table indicates that fairly different emission allocations are realizable for the process. An *egalitarian allocation* of emissions happens by the pallet-kilometer measure. According to EN 16258, an egalitarian allocation is also generally admissible.

In the case of a multi-leg transport process, the emission quantity e_j assigned to order j finally results from the sum of quantities assigned to j for each leg traveled. This yields:

$$e_j = \sum_{i \in I_j} e_{ij}, \tag{3}$$

where I_j denotes the set of legs used by transport order j.

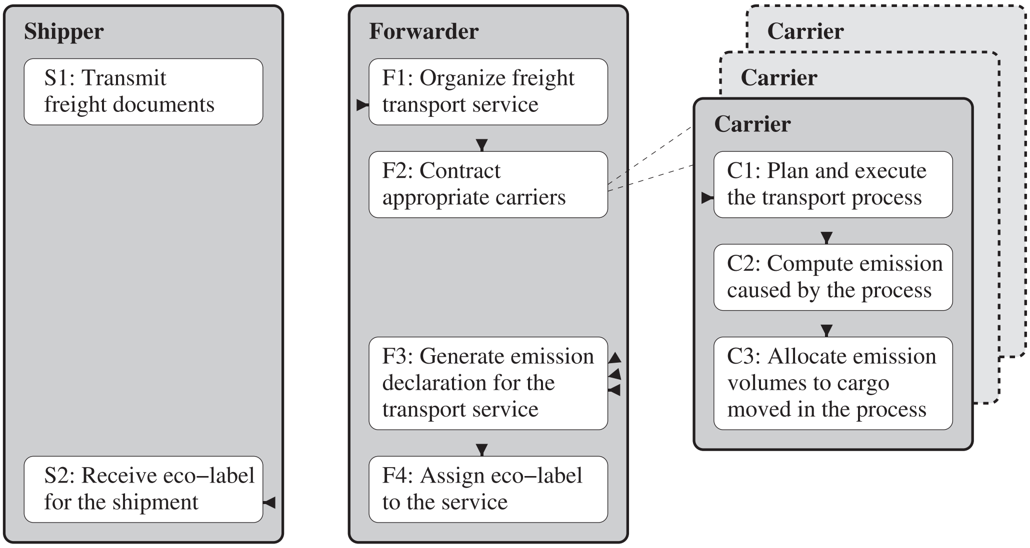


FIGURE 1 Communication protocol of an eco-labeling process

The reporting standard EN 16258 allows carriers to slightly affect the emission declaration process by selecting the allocation rule. This can evoke unequal treatment of shippers which is criticized in the literature (Davydenko et al., 2014; Kellner, 2016; Zhu et al., 2014). On the other hand, it enables carriers to balance heterogeneous customer preferences, for example, when some shippers accept a surcharge for low-emission services while others expect low transport rates (Kirschstein & Bierwirth, 2018).

3 | COMMUNICATION STRUCTURE

An eco-label for freight transportation aims at easing and improving the communication between shippers and carriers:

1. Looking for environmentally friendly transports, a shipper has to choose a shipping option for a specific good from a set of alternatives.
2. When shippers contract carriers, shippers would like to express their ecological preferences.
3. After a carrier has fulfilled an order, the shipper wants to assess the carbon footprint of the shipment.

To come up with an eco-labeling procedure for shipping options using different transport modes and services, we capture the communication between shippers and carriers by the protocol displayed in Figure 1. It illustrates a series of steps for data transformation and decision making on both sides. Some steps can be done by either party or by an intermediary forwarder. The protocol neglects price negotiation. We retrace this step by step below.

S1: Transmit freight documents.

Shippers prepare cargo, that is, specific sets of physical goods, to be transported according to spatial and temporal coordinates. Freight documents provide the data relevant for freight transportation like the loading weight of cargo (payload), space requirements, handling instructions, pickup-and-delivery locations, and time windows.

F1: Organize freight transport service.

The forwarder configures the *transport service* according to the requirements specified by the shipper. Often, a transport route is split up into a chain of transport *legs*. The physical movement of freight along a *transport chain* is done by vehicles like trucks or trains, which is called a *transport process*. Transport processes can be organized as *full truck- or trainload* (FTL) services or as part load services, called *less-than-full truck- or trainload* (LTL). In FTL mode, the shipper utilizes the entire vehicle capacity, whereas in LTL mode, goods of multiple shippers are moved together in the process. The forwarder has to select suitable transport processes for each leg of the transport chain. Moreover, logistic operations taking place at transshipment terminals are scheduled. In a planning procedure, the forwarder might choose a preferred transport service after receiving the estimated GHG emissions from the carriers (step F3) and calculating the associated eco-label (step F4). Thereby, the shipppers' preferences for eco-sensitivity, cost, time, etc., can be taken into account.

F2: Contract appropriate carriers.

To implement the projected transport service, the forwarder has to identify and contract appropriate logistic service providers. Apart from carriers, terminal and warehouse operators can be involved. For simplicity, the protocol neglects service operators other than carriers. The negotiations between forwarder and carriers may address pricing, service quality, and environmental compatibility of operations. As a result, the forwarder places a *transport order* for each leg of the transport chain with a particular carrier.

C1: Plan and execute the transport process.

Carriers typically receive many transport orders from shippers and forwarders in a period. To satisfy the agreed service quality at reasonable cost, they consolidate LTL services, combining general cargo at nearby destinations into larger entities. These entities are assigned to vehicles offering sufficient transport capacity before their routes and schedules are determined. To solve these complex problems, powerful planning tools are available, also with a scope on minimizing transport-related emissions see, e.g., Jabali et al. (2012), Fukasawa et al. (2016), or Dabia et al. (2017).

C2: Compute emission caused by the process.

From the viewpoint of carriers, a transport process generally starts and ends at a vehicle depot. Start depot and end depot, however, must not necessarily match. When the process is completed, the consumed energy is read off directly from the vehicles' fuel gauge or electricity meter. For planning purposes, the energy demand can be estimated by using a suitably calibrated, transport-mode-specific energy consumption model (see, e.g., Kirschstein & Meisel, 2015). We refer to Demir et al. (2014) and Heinold (2020) for reviews on emission estimation models for transporting freight using trucks and trains, respectively. Finally, Equation (1) calculates the emission volume e_i caused by the process on leg i from the spent energy and an associated GHG conversion factor.

C3: Allocate emission volumes to cargo moved in the process.

If a single transport order j is moved in a process, its emission volume is directly declarable by $e_{ij} = e_i$. Otherwise, the carrier selects an allocation rule and divides e_i among the jointly moved orders according to Equation (2).

F3: Generate emission declaration for the transport service.

The forwarder collects the GHG emission reports from the carriers engaged in the service and calculates the carbon footprint of the shipment using Equation (3). A certified emission declaration provides ecological information for the shipper on the entire service as well as on each of its legs.

F4: Assign eco-label to the service.

To provide a simple but qualified assessment of the emission declaration, the forwarder assigns an eco-label to the transport service, which is described in detail in Section 4.

S2: Receive eco-label for the shipment.

The shipper receives an emission declaration and an eco-label for the shipment carried out on its behalf.

4 | ECO-LABELING SYSTEM DESIGN

We present a design for an eco-labeling of freight transport services, which is flexibly applicable to large-sized shipments, for example, several containers, as well as smaller units like pallets or even individual parcels. We discuss general requirements of such a labeling system in Section 4.1. Afterward, we derive reference emission rates and grading schemes in Sections 4.2 and 4.3.

4.1 | General requirements

Eco-labeling is a widely discussed market-based approach for grading the energy efficiency and sustainability of products and services (Prieto-Sandoval et al., 2016). The general interest in eco-labeling is based on the assumption that consumers can process ecological product information in the purchase decision more easily when it is systematically aggregated through a label (Heinzle & Wüstenhagen, 2012; Salzman, 1997). Likewise, scientific literature dealing with the effects of eco-labeling and GHG emission reporting in supply chains grows rapidly in recent years. Gopalakrishnan et al. (2020) assume that supply chain leaders who are motivated to reduce GHG emissions can leverage their knowledge on interrelated sources of GHG emission in their supply chains through reallocating emission volumes among suppliers in a footprint-balanced manner. A good deal of research concentrates on design questions for product-specific eco-labels and technical implementations. For an overview, we refer to Liu et al. (2016), who survey common standards for GHG reporting and the implementation of eco-labeling systems in selected industrial countries.

Previous work has demonstrated that emission reporting and eco-labeling can be effective in gaining eco-efficiency in face of heterogeneous technologies and information asymmetries between independent actors, but with regard to freight transportation markets, there are only a few recent studies addressing the applicability of eco-labeling to achieve a transparent grading of energy efficiency. Baumeister et al. (2020) analyze the impact of an eco-label in the booking decision of air passenger transportation. Results from a discrete choice analysis suggest that such labels indeed provide an incentive for passengers to choose flights that are considered to be more environmentally friendly. In this context, Baumeister and Onkila (2017) present results from 12 expert interviews highlighting criteria in the development of eco-labels in the airline industry. Similarly, Poulsen et al. (2017) assess best practices regarding eco-labels from several industries and state that the shipping industry falls short of meeting them.

Based on consumer and manufacturer responses, Banerjee and Solomon (2003) have evaluated several eco-labeling programs in the US. It was found that public programs are more successful in promoting energy efficiency than private programs because governmental support is capable of intensifying a program's credibility, financial stability, and long-term viability. More generally, Harbaugh et al. (2011) stress that eco-labels need to be designed and configured reliably and transparently. Otherwise, obliquity and mistrust may spoil the steering effect of the label information. In addition, Murali et al. (2019) argue that consistent eco-labeling standards foster eco-sensitive decision-making when actors face a lack of eco-credibility. Summarizing this analysis, we conclude that an eco-label for the transport industry should be certified by a public organization and possess the following properties:

- *Applicability*: The label must be applicable to all kinds of transport technologies.
- *Effectiveness*: The label must clearly address an ecological target figure.
- *Consistency*: The label must reflect the ecological impact of transport services consistently.
- *Simplicity*: The label must be sufficiently simple to apply and easy to interpret.

Applicability means that the labeling system works for all kinds of transport modes, vehicles, and types of traction. This is mandatory because different technologies may interact in a transport chain. Effectiveness means that the label catches a proper assessment of the environmental impact of a transport service (Salzman, 1997). Consistency ensures that the label allows decision makers to compare the ecological impact of transport services (Clift et al., 2005). Finally, simplicity means that the label is designed such that a third party can interpret it correctly without much effort.

According to Wiel and McMahon (2005), two types of eco-labels are distinguished, *endorsement labels* and *comparison labels*. Endorsement labels are single-grade labels signaling that a product or a service fulfills a set of criteria. Comparison labels are multi-grade labels based on an ecological performance measure. They allow a relative comparison between two or more entities. Wiel and McMahon (2005) further distinguish comparison labels as *categorical labels* and *continuous labels*. A categorical label uses discrete categories such that an entity falls exactly into one category. A *continuous label* positions the entity on a cardinal scale to indicate its ecological performance.

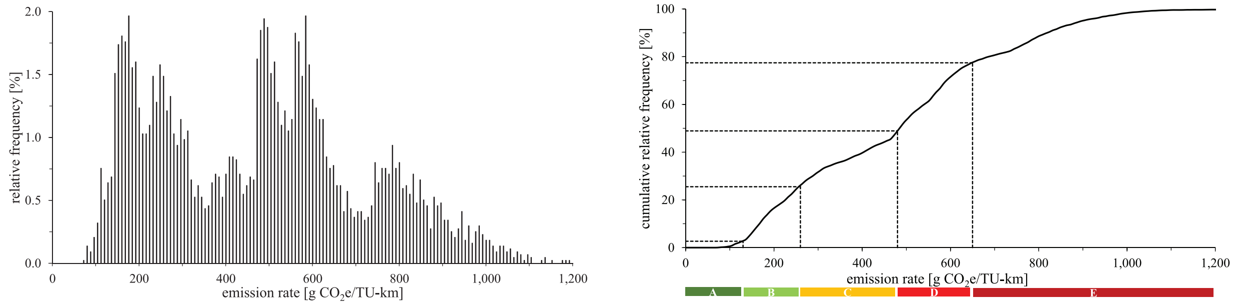
We propose a categorical label for an ecological assessment of freight transport services. A major advantage of categorical labels is that consumers can easily spot the relative performance gap between two compared entities. They indicate, in particular, the distance to the best-in-class entity with respect to a particular eco-measure.

4.2 | Reference base for transport emissions

An appropriate ecological assessment of freight transportation requires comprising the so called *tank-to-wheel* emission (TTW), which is produced while a vehicle is moved, and the *well-to-tank* (WTT) emission, which arises along the supply chains providing fuel and electricity. Both add up to the well-to-wheel (WTW) emission (Brinkman et al., 2005). For an ecological assessment of a transport service, the WTW emission caused by the involved transport processes is put into relation to the logistic performance achieved by the service. According to this ratio, a categorical labeling system can assign a service into one of a set of categories.

In order to determine reasonable category boundaries for a labeling system, we analyze CO_2e emission data reported for freight transportation processes within and between 27 European countries. The data have been recorded in a simulation study of Heinold and Meisel (2018). It involves a total of 4374 continental transport relations for shipping containerized transport units (TU), each with a payload of 6, 11, or 22 (metric) tons. For each relation, 500 shipments with individual pickup and delivery locations are routed in road-only mode and in rail-road mode. Based on the model of Kirschstein and Meisel (2015), the CO_2e emission is determined for each route. The underlying road and rail networks are based on Open Street Map (2021) and the Trans-European Transport Network (European Commission, 2021). Figure 2a shows the resulting distribution of GHG emission rates produced per TU and kilometer (TU-km).

The observed emission rates for land-based containerized transportation range between 70 and 1200 g CO_2e/TU-km. The overall distribution shows three peak regions at 200, 550, and 800 g CO_2e/TU-km, respectively. We recognize five categories of emission rates for TU-shipments. The first category A is reserved for a few shipments with emission rates lower than rates belonging to the first peak region of the distribution. The



(a) Distribution of GHG emission rates.

(b) Cumulative relative frequency of emissions rates.

FIGURE 2 Frequency and cumulative frequency of emissions rates in European land-based container transportation (Heinold & Meisel, 2018). Underlying data for this figure are available in supporting information S1. (a) Distribution of GHG emission rates; (b) cumulative relative frequency of emissions rates

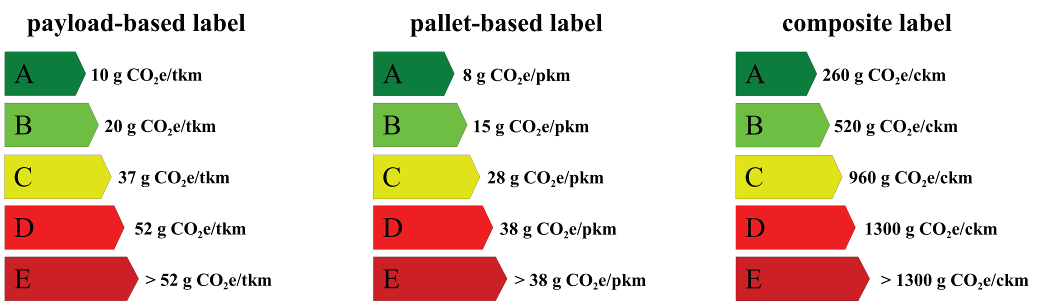


FIGURE 3 Three eco-labeling systems for freight transport services

second category B addresses those shipments that fall into this region. The third category C covers the range of shipments falling between the first and the second peak region, while the fourth category D addresses shipments belonging to the second peak region. Category E takes up the rest of the shipments, including those of the third peak region.

The chosen number of categories is in line with other transport-related eco-labeling systems; for example, Baumeister and Onkila (2017) review cases of five to seven categories in the aviation sector. The boundaries between the categories become evident by the cumulative distribution of the emission rates shown in Figure 2b. About 3% of the shipments fall into category A, with emission rates of at most 130 g CO_2e/TU-km. The further boundaries are set to 260, 480, and 650 g CO_2e/TU-km for labels B to E, comprising about 22%, 23%, 28%, and 23% of the shipments, respectively. Note that the proposed setting reflects a reached state of technology. Boundaries need to be adjusted when technological, infrastructural, or organizational innovation succeeds.

4.3 | Grading eco-performance of transport services

An often used ecological performance indicator for a transport service divides the volume of CO_2e allocated to the service by the payload of cargo given in metric tons, and the direct travel distance given in kilometer. Measuring the ecological transport performance in g CO_2e per ton-kilometer (tkm) seems appropriate for heavy goods, whereas for volume goods, emissions are better accounted by a volume-based (m^3km) or pallet-based (pkm) measure.

To address this issue, we transfer the category boundaries shown in Figure 2b into corresponding eco-labels for heavy goods and volume goods. In line with Heinold and Meisel (2018), we assume that an average TU represents 12.5 tons of payload and 17 pallets which utilizes a heavy truck with a capacity of 25 t and 34 pallets by 50%. For payload capacity, the boundary of category A (130 g CO_2e/TU-km) results in $\frac{130\,\text{g}\,CO_2\text{e}}{12.5\,\text{t}} \approx 10$ g CO_2e/tkm, and for pallet space in $\frac{130\,\text{g}\,CO_2\text{e}}{17\,\text{pal.}} \approx 8$ g CO_2e/pkm. The boundaries of the remaining categories are computed accordingly. This leads to the payload-based and the pallet-based labeling systems shown in Figure 3.

As an illustrative example, we consider two shipments that are moved together for a distance of 100 km. Shipment 1 (2) weighs 1 ton (0.5 tons) placed on a single pallet (two pallets). In the process, 3 kg of CO_2e is allocated to each shipment. For payload-based labeling, Shipment 1 achieves an emission rate of $\frac{3000\,\text{g}\,CO_2\text{e}}{1\text{t}\cdot 100\text{km}} = 30$ g CO_2e/tkm and is labeled as C. Accordingly, Shipment 2 achieves a rate of = 60 g CO_2e/tkm labeled by E. Under pallet-based labeling, the rates are $\frac{3000\,\text{g}\,CO_2\text{e}}{1\text{p}\cdot 100\text{km}} = 30$ g CO_2e/pkm and 15 g CO_2e/pkm, which corresponds to labels D and B, respectively. Note that the payload–pallet ratio of Shipment 1 exceeds the TU's critical ratio of $\frac{12.5}{17}$ ton per pallet, which is why it is better off under payload-based eco-labeling. On the contrary, shipments that underscore the critical ratio benefit from pallet-based eco-labeling.

A way to unify different performance indicators has been proposed by Davydenko et al. (2014). Let c_i denote the vehicle capacity of type $i \in$ {payload, pallets, space, volume, …}. Furthermore, let m_{ij} denote the percentage of capacity i, which is occupied in the vehicle by transport order j. Then,

$$u_j = \max_i \left(\frac{m_{ij}}{c_i} \right) \tag{4}$$

represents the demand of capacity critical for shipment j in a transport process involving arbitrary goods. For an ecological assessment of the shipment, its emission declaration can be normalized by the value of u_j. The resulting emission rate is measured in g CO_2e per ckm (*percentage of the composite capacity utilization and kilometer*).

The right-most picture of Figure 3 shows the transition of the composite performance measure into a labeling system. Due to the assumption that an average TU exploits the container capacities by 50%, the boundary of label A calculates to $\frac{130\,\text{g}\,CO_2\text{e}}{50\%} \approx 260$ g CO_2e/ckm. Suppose $c_{payload} = 25$ ton and $c_{pallet} = 34$ pallets hold in our example, we obtain $u_1 = \max(1/25, 1/34) = 1/25$ for Shipment 1, and $u_2 = \max(0.5/25, 2/34) = 1/17$ for Shipment 2. The corresponding composite emission rates reveal $\frac{3000\,\text{g}\,CO_2\text{e}}{1/25\,\text{c}\cdot 100\text{km}} = 750$ g CO_2e/ckm and 510 g CO_2e/ckm for the shipments, labeled as C and B, respectively. This is in accordance with the stronger labels achieved by the shipments under a payload- or pallet-based labeling system. As the composite-capacity-based labeling system generally selects the strongest label obtainable for a shipment, it is applied in the rest of the paper, if not stated otherwise.

5 | EVALUATION OF ECO-LABELING SYSTEMS

In this section, we evaluate the proposed eco-labeling systems with numerical examples. For this, we present the corresponding data in Section 5.1 and four transport scenarios in Sections 5.2 to 5.5.

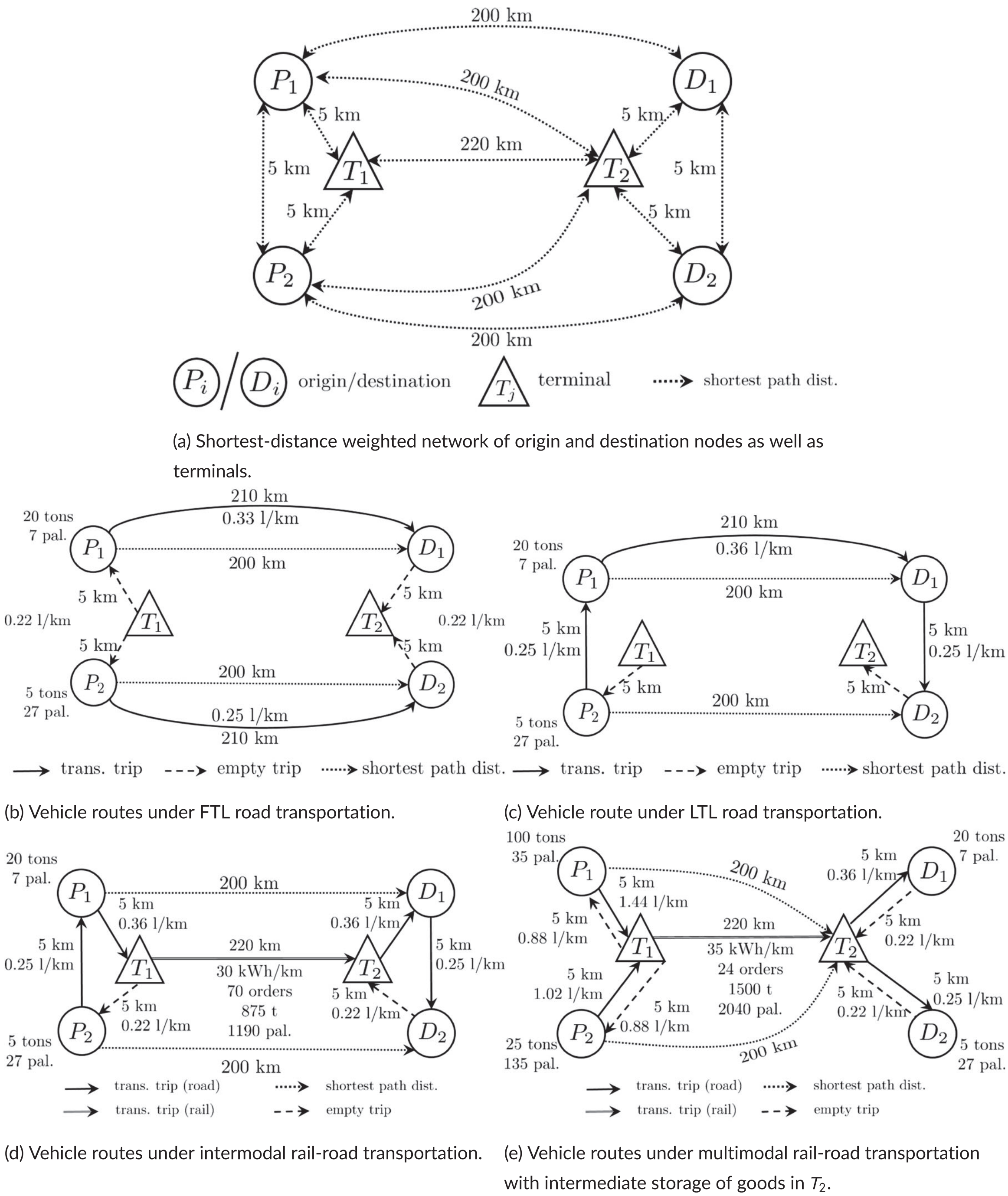
5.1 | Transport order data and transport services

For an evaluation of the eco-labeling system displayed in Figure 3, we consider two transport orders carried out by four different transport services. Order HG consists of a heavy good with a loading weight of 20 tons placed on seven pallets. Order VG represents a volume good of 5 tons placed on 27 pallets. The values have been chosen such that both orders can be considered for an individual carriage by a standard truck as well as for a joint carriage, which will perfectly exploit the truck capacities. Table S2 in the Appendix summarizes the order data together with the required transport performances and capacity utilization levels.

Transport orders HG and VG have pickup locations P_1 and P_2 within the same region (the pickup region) and delivery locations D_1 and D_2 within the same delivery region. The pickup and delivery locations are only reachable by road. The direct road transport distances are 200 km for each order. We further assume that a terminal T_1 is available in the pickup region within a 5 km distance to the pickup locations P_1 and P_2. This terminal serves for transshipping cargo from the road mode to the rail mode and as start and end point of truck routes that collect the cargo. In the delivery region, terminal T_2 is at a distance of 5 km to the delivery locations D_1 and D_2. The terminals are connected by a rail line of 220 km length that is regularly served by rail trains. Figure 4a shows the transport network connecting the pickup places P_1 and P_2 with each other and with the rail terminals T_1 and T_2 as well as the delivery places D_1 and D_2.

Freight transport services for the two transport orders must realize a door-to-door transport chain. The chain can utilize a single vehicle or multiple vehicles combining a single or multiple modes of transport, and involves several transshipment processes of goods. If no transshipment is involved, we refer to it as a *direct transport service*. As mentioned in Section 3, direct services are further classified as FTL services, where goods of a single shipper ride alone, and as LTL services, where the carrier consolidates goods of multiple shippers to improve vehicle utilization.

For transport services involving transshipment of goods, we refer to definitions provided by the Economic Commission for Europe (2001). A service is referred to as *multimodal* if the movement of goods is realized by two or more modes of transport, and *unimodal* otherwise. Multimodal services generally allow for handling and storing goods when changing modes. In case the movement of goods happens in one and the same loading unit, the transport is called *intermodal*. A multimodal transport service with intermediate storage can be advantageous if transport orders are given on a regular basis. To achieve economies of scale, shippers can bundle multiple orders into larger shipments.



(a) Shortest-distance weighted network of origin and destination nodes as well as terminals.

(b) Vehicle routes under FTL road transportation.

(c) Vehicle route under LTL road transportation.

(d) Vehicle routes under intermodal rail-road transportation.

(e) Vehicle routes under multimodal rail-road transportation with intermediate storage of goods in T_2.

FIGURE 4 General transport network and vehicle routes for all transport services along with energy demand rates. (a) Shortest-distance weighted network of origin and destination nodes as well as terminals; (b) vehicle routes under FTL road transportation; (c) vehicle route under LTL road transportation; (d) vehicle routes under intermodal rail-road transportation; (e) vehicle routes under multimodal rail-road transportation with intermediate storage of goods in T_2

The following services are taken into consideration:

1. FTL road transportation
2. LTL road transportation
3. Multimodal rail-road transportation without intermediate storage of goods (intermodal)
4. Multimodal rail-road transportation with intermediate storage of goods

TABLE 1 Emission declarations and eco-labels under FTL road transportation

Order	Declaration ($kg\ CO_2e$)	Payload-based label ($g\ CO_2e/tkm$)	Pallet-based label ($g\ CO_2e/pkm$)	Composite label ($g\ CO_2e/ckm$)
HG	225	56 E	161 E	1,406 E
VG	172	172 E	32 D	1,083 D
Σ	397			

For road transports, a diesel-powered heavy truck is used. Its fuel consumption per kilometer is defined by $f(p) = 0.22 + 0.14 \times \frac{p}{c}$, where 0.22 is the baseline fuel consumption of the empty truck and 0.14 is the marginal fuel consumption of a fully loaded truck, p is the carried payload, and $c = 25$ ton is the payload capacity of the truck (see Schmied & Knörr, 2013). Next to transport trips, repositioning trips of empty trucks are included in each scenario. For rail transports, electrified freight trains are used. Two service types are offered by a rail company. Short trains operate in the general cargo market where a shipment must be at least a pallet. Long-train services are reserved for shipments of complete truckloads. The energy consumption for short trains is 30 kWh per kilometer and for long trains 35 kWh per kilometer, reflecting the trains' different total weights (Schmied & Knörr, 2013). Emission coefficients of 3.15 kg CO_2e per liter of diesel and 0.5 kg CO_2e per kWh electricity are applied (Schmied & Knörr, 2013). Details on the energy demands for the transport services are outlined in Figure 4. Technical parameters of the vehicles considered in the following scenarios are summarized in Table S3.

5.2 | FTL road transportation

In the baseline scenario, orders HG and VG are served individually by two heavy trucks. These trucks start their tours empty at T_1, pick up load at P_1 and P_2, respectively, deliver it at D_1 and D_2, respectively. Afterward, they return empty to terminal T_2. Usually, shortest routes to a destination cannot be realized exactly due to breaks, refueling stops, etc. This is reflected by a detour of 10 km such that a traveling distance of 210 km results for the transport leg of the trip. Figure 4b displays the activities along with the relevant data.

A heavy truck spends $f(0) = 0.22$ L of diesel per kilometer if going empty, $f(20) = 0.22 + 0.14 \times \frac{20}{25} \approx 0.33$ L while moving HG, and $f(5) = 0.22 + 0.14 \times \frac{5}{25} \approx 0.25$ L while moving VG. Hence, fuel consumption is $5 \times 0.22 + 210 \times 0.33 + 5 \times 0.22 = 71.5$ L along the route that serves HG and $5 \times 0.22 + 210 \times 0.35 + 5 \times 0.22 = 54.7$ L for the route that serves VG. The corresponding CO_2e emissions are $71.5 \times 3.15 \approx 225$ kg and $54.7 \times 3.15 \approx 172$ kg, respectively, leading to a total emission of 397 kg CO_2e for both orders.

Eco-labels are derived for the transport services by calculating the corresponding CO_2e emission rates per ton kilometer (tkm), pallet kilometer (pkm), and composite capacity kilometer (ckm) (see Table 1). It indicates that label E is awarded in most cases. Road mode is obviously not an eco-friendly solution for long-haul transports. However, the pallet-based system still awards label D to the service of VG. Recall that the composite-based system always selects the capacity maximally utilized by an order. For order VG, this is pallet-space with a relative utilization of $\frac{27}{34}$. This yields an emission rate of 1083 g CO_2e/ckm (= 172 kg/CO_2e divided by $\frac{27}{34}$ and 200 km direct distance) corresponding to label D just like the pallet-based labeling system.

5.3 | LTL road transportation

A better consolidation of freight is reached when orders HG and VG are shipped together. Figure 4c shows the route taken by the LTL service. A single empty truck starts at terminal T_1, picks up load successively at P_2 and P_1, delivers it at D_1 and D_2, before returning empty to terminal T_2. For the longest part of the journey, the truck is fully occupied in terms of payload and pallet space. The fuel consumption on this leg accounts for $f(25) = 0.22 + 0.14 \times \frac{25}{25} \approx 0.36$ L of diesel per kilometer. In total, the truck consumes 80.3 L of diesel and emits 253 kg CO_2e.

Following EN 16258, the emission quantity of 253 kg CO_2e is allocated to orders HG and VG either in proportion to payload, pallets, or egalitarian (see Table 2). The emission declarations are lower for the LTL service than for the FTL service with the only exception of order VG. It receives a declaration of 201 kg CO_2e from pallet-proportional emission allocation. Obviously, when heavy and volume goods are moved together, the CO_2e share of heavy goods benefits from a pallet-based emission allocation while volume goods benefit from a payload-based allocation. Supposed that the involved parties are likewise eco-sensitive, egalitarian allocation balances shares most fairly.

Note that composite labeling systems generally award stronger labels to the LTL service than to the FTL service. Either HG or VG can reach label B at the expense of the other order, which achieves label D. In case both shippers are eco-sensitive, they can jointly reach label C with the LTL service.

TABLE 2 Emission declaration, allocation, and eco-labels under LTL road transportation

Allocation	Payload		Pallets		Egalitarian	
order	(kg CO_2e)	(g CO_2e/ckm)	(kg CO_2e)	(g CO_2e/ckm)	(kg CO_2e)	(g CO_2e/ckm)
HG	202	1263 D	52	325 B	127	793 C
VG	51	321 B	201	1266 D	127	800 C
Σ	253		253		253	

TABLE 3 Emission declaration, allocation, and eco-labels under intermodal rail-road transportation

		On rail					
	On road	payload		Pallets		Egalitarian	
Order	allocation	(kg CO_2e)	(g CO_2e/ckm)	(kg CO_2e)	(g CO_2e/ckm)	(kg CO_2e)	(g CO_2e/ckm)
HG	Payload	96	600 C	40	250 A	68	425 B
	Pallets	81	506 B	25	156 A	53	331 B
	Egalitarian	89	556 C	33	206 A	60	375 B
VG	Payload	24	151 A	80	504 B	52	327 B
	Pallets	40	252 A	96	605 C	68	428 B
	Egalitarian	32	202 A	88	554 C	60	378 B

5.4 | Multimodal rail-road transportation without intermediate storage of goods (intermodal)

An intermodal rail-road transport service divides the transport chain of the orders into three legs, the pre-, main-, and post-carriage. During pre-carriage, the movement of goods is executed by a single truck that starts its tours empty at the depot in T_1 and ends there for transshipping the cargo onto a train. Post-carriage of both orders is performed by a truck that starts its route in T_2 where it picks up the goods from the train and delivers them before returning empty to T_2. The routes of the vehicles are shown in Figure 4d. The total fuel consumption of the trucks is $2 \times 5 \times (0.22 + 0.25 + 0.36) = 8.3$ L of diesel, leading to an emission of 26.2 kg CO_2e.

The main carriage is performed by an electrified short train. It spends 220 km × 30 kWh/km = 6600 kWh of energy on the rail leg which causes a CO_2e emission of $6600 \times 0.5 = 3300$ kg. We further assume that the train moves 70 transport orders with a total of 875 tons and 1190 pallets between the two terminals. This means that both the average demand of payload capacity and the average demand of pallet capacity of both orders exactly meet the average capacity demand of all orders moved in the process. Hence, a share of $2 \times \frac{3300}{70} = 94.3$ kg CO_2e falls upon orders HG and VG for the rail leg, no matter what allocation rule the rail carrier applies. Thus, a total of $26.2 + 94.3 \approx 120$ kg CO_2e is assigned to both orders by the intermodal service, which is less than in FTL and LTL services.

Since the intermodal service involves multiple transport processes, the allocation rules selected by the carriers can vary. We assume that the road carriers apply the same rule. Various emission declarations are yet possible for orders HG and VG. Table S4 in the Appendix shows corresponding emission declarations for road and rail legs. Nine combinations of emission allocation rules are possible and assessed by the composite labeling system in Table 3. It indicates that the allocation rule used in the main carriage shows a larger impact than the rule used for pre- and post-carriages. As before, HG benefits from pallet-based allocation and VG from payload-based allocation. Both orders can achieve the strongest label A on their own, provided the allocation rule on the rail leg is chosen to their advantage. With egalitarian allocation applied to the rail leg, both achieve label B, no matter which allocation rule is used on the road legs. This signals the environmental compatibility of rail freight transportation.

5.5 | Multimodal rail-road transportation with intermediate storage of goods

To study multimodal transportation, we regard the order quantities of HG and VG as a regular customer period demand. We further assume that a warehouse is available at terminal T_2 which can be used for an intermediate storage of goods. This setting enables shipping goods in larger amounts leading to a better transport consolidation such that larger and more energy-efficient vehicles like long trains can be used.

TABLE 4 Emissions declaration, allocation, and eco-labels under multimodal transportation

		Declaration (kg CO_2e) on			(kg CO_2e)	
Order	**Allocation**	**Leg 1**	**Leg 2**	**Leg 3**	**Total**	**(g CO_2e/ckm)**
HG	Payload	7.3	51.4	9.2	68	340 B
	Pallets	7.3	13.2	9.2	30	150 A
	Egalitar.	7.3	32.1	9.2	49	245 A
VG	Payload	6.0	12.8	7.4	26	131 A
	Pallets	6.0	51.0	7.4	64	322 B
	Egalitar.	6.0	32.1	7.4	46	232 A

For an evaluation of the multimodal rail-road service, we consider transport quantities for both goods, which are a fivefold of the period demand. These quantities can be moved to T_1 by four complete truckloads each. The trucks are fully utilized regarding either payload ($4 \times 25 = 5 \times 20$ tons) or pallet space ($4 \times 34 = 5 \times 27 + 1$ pallets) in seven of the eight trips. Merely, a single pallet storage place is not occupied in one of the trips. As road transportation on leg 1 takes place in FTL mode, GHG emissions are directly declarable for pre-carriage. To get rid of emission allocation for post-carriage, we suppose that the road transport from T_2 to the delivery places is done in unconsolidated FTL mode, too. On this, leg capacity is utilized by 80%. An allocation of transport emissions is only necessary on the rail leg, which comprises the long-train rail transport between T_1 and T_2. Figure 4e displays the outlined logistic activities for the multimodal service.

The total GHG emission produced by the service is calculated as follows: Leg 1 of the transport chain comprises four fully utilized truck transports for each good. Those four trucks cause $3.15 \times 5 \times (0.88 + 1.44) \approx 37$ kg CO_2e for HG and $3.15 \times 5 \times (0.88 + 1.02) \approx 30$ kg CO_2e for VG. The electrified long train operating on leg 2 consumes 220 km × 35 kWh/km = 7700 kWh of energy. It causes total emissions of $7700 \times 0.5 = 3850$ kg CO_2e. We assume that 24 orders with a total of 1500 tons and 2040 pallets are moved together in the rail process with an average of 62.5 tons and 85 pallets per order. Like for the short train, this is in line with the joint capacity demand of the heavy and the volume good. Consequently, a share of $2 \times \frac{3{,}850}{24} \approx 321$ kg CO_2e falls upon both orders, whatever allocation rule is selected. To attribute GHG emissions to the periodic orders, the emission volumes calculated for leg 1 and 2 are divided by five periods. Emissions on leg 3 are directly declarable to the orders as for leg 1. They account for $3.15 \times 5 \times (0.22 + 0.36) \approx 9.2$ kg CO_2e for the heavy good and $3.15 \times 5 \times (0.22 + 0.25) \approx 7.4$ kg CO_2e for the volume good and are respected in every period.

Table 4 shows the emission declaration of the orders on each leg and the eco-labels achievable by the multimodal transport. Emission allocation only takes place on leg 2, which represents the major part of the transport. The multimodal service improves the eco-performance of the transport operations once more. Allowing for an intermediate storage, it allocates 96 kg CO_2e to HG in the maximum, which is a 29% reduction against intermodal transportation. The eco-labels signal this trend very clearly. Whatever emission rule the rail carrier selects, the transport orders receive at least label B. With the egalitarian allocation rule, the service even achieves label A for both orders. It must be noted, however, that GHG emission caused by warehousing operations is disregarded in the analysis.

5.6 | Evaluation summary

For an evaluation of the proposed approach, we recall the requirements formulated in Section 4.1. To overcome the limitation of labeling approaches that are based on single performance measures (like ton-kilometers or pallet-kilometers), a composite-capacity-based label has been developed for the transport industry. It supports shippers in finding eco-compatible transport options and makes searches for a best-fitting label redundant. The proposed label design relies on a consistent calculus regarding energy generation, transformation, and consumption. Regarding *applicability*, it supports an appropriate consideration of vehicle classes driven by electric or combustion engines, and it covers future technologies like fuel cells as well. It is likewise *effective* by addressing the release of GHG on a unique and quantitative basis.

Consistency means that a labeling system signals the ecological impact of different transport services adequately, which is not that straight to judge for the composite-capacity-based labeling system. Four services have been investigated. Even though their environmental ranking is straightforward, the responded signals are not that definite in every single case. The reason is that freight consolidation complicates emission allocation. For one and the same transport order and service, not a single but a range of different labels is achievable depending on the allocation rule selected. Table S5 in the Appendix summarizes the ranges of labels assignable to the two transport orders in view of the four services. Selecting an allocation rule gives carriers an important instrument at hand to enhance the performance of eco-sensitive shippers. Supposing all shippers are equally sensitive, the question arises with which rule the best common label is obtained. For the transport orders in our example, this is the egalitarian allocation rule. The last line of Table S5 shows the best labels that HG and VG can obtain together in a consolidated transport service. A clear grading is recognizable between LTL road transportation, intermodal transportation, and multimodal transportation, which is consistent with the services' total emission quantities for both orders.

Regarding *simplicity*, our approach is not that clear yet. While its application is technically controllable and reliable, the outcome is not always simple to interpret regarding the unit of composite capacity. This might be a subject of future research, next to the research opportunities that we outline in the following.

6 | RESEARCH DIRECTIONS

We present a list of research opportunities that might be investigated in the context of eco-labels for freight transportation. Clearly, we can only touch these issues here, and the provided list is certainly not complete.

Operations management and integration into planning systems: Eco-labels can be used as a way to communicate a customer's environmental preference regarding a shipment. Then, this information, that is, the eco-label, needs to be considered proactively in the operational planning and decision-making of logistics service providers. For this purpose, it needs to be investigated how labels can be incorporated into optimization models and solution methods for vehicle routing problems, inter- and multimodal transportation planning, service network design, transport mode selection, and further related problems. We refer to Bektaş et al. (2009) for a general overview on the role of operations research in green freight transportation. In this context, it will be interesting to investigate different ways of integrating eco-labels in optimization models. For example, labels might be considered as soft or hard constraints as well as (part of) the objective with which the fulfillment of eco-labels would work as a customer-related service level. On this basis, it would be interesting to compare a setting in which shipments are either in accordance with their eco-label, or not, with a setting considering also the magnitude of not fulfilling a label. For this, eco-labels can be converted to emission limits that state a shipment's absolute amount of emissions resulting from the corresponding eco-label (Heinold & Meisel, 2020).

Emission allocation: As illustrated in Section 5.5, choosing an emission allocation rule is a crucial decision for the implementation of a labeling system, especially if heterogeneous goods share the same service. Our example captured just a few out of many available allocation rules (see, e.g., Kellner & Otto, 2012) and highlighted their effects in an illustrative way. Therefore, more detailed analyses of product-specific allocation rules as well as their (game-)theoretic properties and practical effectiveness are due.

Adjustment of the label's reference base: A weak spot of categorical labels is that it suffices to underscore the upper bound of a category just marginally in order to achieve it. Hence, services may receive the same label even if they have quite diverse environmental performances. This effect may be compensated partly by defining a larger number of categories, but it remains unclear whether this is a proper countermeasure in general. It is also known that labels can become a victim of their own success (Heinzle & Wüstenhagen, 2012) if best-in-class categories are achieved more and more easily due to technological progress. This raises a need for regularly re-assessing the category boundaries to push companies toward more eco-friendliness in the long run.

Political implications and steering effects: Politics pursues eco-initiatives to foster green transportation, for example, by implementing policies to shift freight from road to rail. This raises the question of how a transport-related eco-label as proposed by this paper can support such policies. More generally, it is important to evaluate the overall environmental effect to be expected at a local and global scale. In particular, it might be interesting to analyze how overall emissions are affected by the introduction of eco-labels and to compare this change with other eco-oriented policies like emission reduction targets or carbon taxes. This is, we expect some interesting findings regarding research on how eco-labels affect more sustainable transport solutions.

Competitive advantage, business models, and consumer behavior: If shippers and logistic service providers express eco-friendliness of their products and services by an eco-labeling system, it is worth analyzing the competitive advantage they gain. Corresponding research could comprise, for example, investigating how customers value a better eco-label category and whether this can be turned into a higher willingness-to-pay such that a carrier's profit increases. In this context, an open question is what new business models could emerge from the introduction of such labels and how companies incorporate eco-labeling when negotiating with business partners or in pricing decisions for their products and services. For instance, Agatz et al. (2021) analyze the interactions between price and eco-labeling incentives for time slot selection in a home delivery service. They conclude from experiments and simulations that eco-labels are more effective than price incentives in fostering more sustainable customer decisions.

Label propagation in supply chains and inclusion of further processes: Almost any industry-made product consists of a wide range of materials and components that usually stem from a large number of spatially distributed suppliers. Nowadays, many supply chain parties determine and report the carbon footprint of their products. What are still lacking are mechanisms for consolidating such information along horizontal and vertical partnerships. This also calls for new tasks and roles such as the one of an environmentally oriented supply chain leader (see Gopalakrishnan et al., 2020). The required transactions may call for an adaptation of the logistics-oriented communication protocol from Section 3. From this, a better understanding could be obtained on how to propagate and harmonize eco-labels of converging and diverging material flows. The adaptation might also strive for an inclusion of emissions caused by the involved transshipment and warehousing processes. However, communication flows and labeling procedures should be kept as simple as possible ensuring a comprehensible and trustworthy labeling of products and services.

7 | CONCLUSION

The paper proposes a categorical, comparison eco-label for the freight transportation industry. The label fosters transparency of the eco-friendliness of transport processes with regard to their emitted GHGs. The gained transparency can be exploited by freight forwarders to differentiate their services from those of (less eco-friendly) competitors, by shippers to express their eco-friendliness, and by other stakeholders for further purposes like reporting or statistics. We have discussed design issues of such a label and procedures of the labeling process for transport services and orders. We derived three labeling systems. The first one assesses emissions per ton-kilometer, which is particularly useful for shipments involving heavy goods. The second system assesses emissions per pallet-kilometer, which is most suitable for volume goods. The third system flexibly adapts the labeling to the most intensively used capacity dimension of a transport process. This system is generally applicable even for processes that involve a mix of heavy goods and volume goods.

We provided examples of how to implement the label in different transport management settings. Our analyses showed that choosing an emission allocation rule and labeling system can yield very different labels for a particular shipment. Still, the labels fulfill general expectations as consolidated transports achieve better labels than non-consolidated transports.

Finally, we proposed directions for future research, including topics in operations management and also further topics that address policy issues, incentives, and others. We have sketched those challenges that we consider most relevant, which might be considered subjective.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in the supporting information of this article.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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