Decentralized and centralized transport and logistics carbon emission optimization and emission norms for the transport and logistics sector

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Abstract: Transport and logistics is one of the most important economic sectors contributing to the climate change. By the nature of transport and logistics operations, the sector is one of the most difficult ones to decarbonize. This paper proposes using carbon footprinting tools to optimize logistics operations with respect to emissions, and to setup government-led emission norms for the transport and logistics sector. Carbon footprinting can be used for operational decision making, such as those envisioned by the concept of physical internet, as well as in the classical operations research centralized optimization. The paper shows conceptually how carbon footprinting indicators are applicable for the traditional logistics optimization and for the decentralized optimization of operations. The governments can further speed up the process by setting emission norms for the transport and logistics. This paper shows that the carbon footprinting methods provide sufficient input for both logistics optimization and the norms. The carbon footprinting indicators are discussed and incorporated into the mathematical formulations of logistics optimization; the same carbon footprinting data is used for the setup of carbon emission norms in logistics.

Keywords: carbon footprint, carbon footprint minimization, emission monitoring, emission norms, transport and logistics optimization, centralized optimization, decentralized optimization

1. Introduction

A longer-term challenge of decarbonization of transport and logistics is huge. The climate change movement progresses from an acknowledgement of the problem to undertaking of actions. Depending on the ambition, decarbonization actions can be set to reduce emissions by 60% in 2050 compared with the baseline of 1990, effectively meaning a factor 6 increase in carbon productivity of the system (Smokers et al., 2019). A larger ambition can be set if 95% of emissions are to be reduced by 2050, which in essence means complete decarbonization of the system, or simply said, factor infinity. This means that for the long-term the transport and logistics sector has to be reorganized based on zero-emission technology.

A medium term goal of the European Commission is to reduce Greenhouse Gas (GHG) emissions by at least 40% in 2030 compared to the 1990 levels, as provided in the EU 2030 climate & energy framework. On a national level, the Netherlands the mobility sector is to achieve a 22% emission reduction by 2030 compared to a no action business as usual scenario (Klimaatakkoord, 2019; Hekkenberg and Koelemeijer 2018). Both the EU and national action plans confirm that for the medium term (action 2030), a complete decarbonization seems to be unfeasible due to a number of reasons, such as technological immaturity of zero emission vehicles, market unavailability of zero emission vehicles, insufficiently decarbonized generation of electricity, and lack of infrastructure. There are also some transport areas, such as aviation and long distance transport, which are hard to electrify. These considerations mean that in medium term a mix of carbon intensive and zero emission solutions will coexist.

Practically, decarbonization of transport and logistics operations can be facilitated by two forces: private and public parties. The first force comes from decision makers (e.g. planners and supporting software) working on behalf of private or corporate parties. These parties pursue the goal of logistics operations optimization within some certain boundary conditions. At this moment, the paradigm of operationalization of decision making in logistics, such as Synchromodality (e.g. Tavasszy et al., 2017; van Rissen et al., 2015) and physical internet (Montreuil, 2011) gain especial attention due to increased efforts on decarbonization of logistics operations.

The second force comes from the governmental bodies (public parties), who can influence the system by the fiscal means (e.g. fuel taxes, vehicle taxes), as well as by the means of permits and norms. For both private and public types of decision makers there is a need for objective information on GHG emissions, with a difference in the aggregation level: the private decision makers will mainly need more disaggregated and specific data, while the public decision makers will mainly need more system-wide aggregated data.

In this paper we do not consider cases in which all the needed information is available to the decision maker, as for instance, may be the case within a transport company. In that case the decision maker can, for instance, make sure that an optimum route, within business constraints, is driven by the fleet. We concentrate on the state-of-the-art where the GHG emission performance of third parties is not directly known to the users of the services and where there is no good aggregated information on the sector-specific GHG emission performance of constituting companies.

This paper is structured as follows. Chapter 2 provides mathematical formulations on how to include GHG emissions into logistics optimization decisions. These formulations are applicable at the level of decentralized (and possibly distributed decision making) as being considered in the context of physical internet, as well as at the traditional level of centralized logistics optimization, as a well-established part of operations research. Chapter 3 provides formulations for indicators that can form a basis for the government-regulated norms for logistics emissions. The chapter further discusses the ways on how the norms can be formulated in practice. Chapter 4 provides ideas on data and governance infrastructure that need to be put in place to collect relevant data for both logistics optimization and setup of norms. Chapter 5 proposes a data collection and processing to service both logistics optimization and policy making purposes. Chapter 6 provides conclusions and outlines directions for further research to close still existing gaps in methodologies and knowledge.

2. Decentralized and centralized carbon optimization of transport and logistics by private parties

Optimization of transport and logistics is well studied and an integral part of Operations Research. For instance, a widely cited review of the literature on facility location and supply chain management (Melo et al., 2009), contains 139 references to the peer-reviewed works on this problem. The logistics and supply chain optimization traditionally balances two conflicting goals: provision of the clients with the desired service level, while minimizing expenses and costs associated with the logistics operations (Davydenko, 2015). The classical basic tradeoffs involved in logistics optimization are the balance between transport and stock keeping costs (e.g. economic order quantity, Blumenfeld et al., 1985, Goyal, 1985); the balance between the speed and cost of services (e.g. Tavasszy et al., 2011). In a broader sense, there is a tradeoff between the cost of sourcing products versus transport costs from the production locations to the consumption locations (e.g. Moses, 1958), as it can be more attractive to source products cheaply overseas and pay more for the transport services.

The logistics decisions lay mostly in the realm of private or corporate decision makers. Depending on the decision to be made, the choice set can be relatively small (e.g. the choice on transport mode to be used to transport goods) or the choice set can be relatively large (e.g. the choice on supply chain organization). The last one often involves solving a facility location problem.

This paper introduces explicit inclusions of GHG emissions into the optimization of logistics operation by private parties. The GHG emissions can be assigned a certain monetary value, proportionally to the volume of GHG emitted and the cost of one ton of the CO_2 or CO_{2eq} emissions. The inclusion of CO_2 costs into the decision process can be done at both operational and strategic levels. At the operational level, a set of transport options can be created, for example a set of possible ways to transport containers from the port using a direct road connection or using intermodal transport, involving inland navigation or train line haul with a subsequent last mile road leg from the intermodal terminal to the final destination. Another example is the choice that a parcel “can make” with respect to the vehicle in which the parcel will travel to the end destination. Equation (1) provides a simple formulation for the disutility function for a choice set that includes transport, time and emission related costs.

$$U_i = C_i + T_i * VOT + C_{CO_{2e}} * W_i, i = 1..n \quad (1)$$

Where:

U_i: total disutility of option i in €/unit (e.g. ton, m^3, container, parcel, …)
C_i: out-of-pocket cost of option i in €/unit paid to the service provider(s)
T_i: time it takes per transported unit to perform operations related to option i
VOT: value of time in € per time unit in accordance to T_i
$C_{CO_{2eq}}$: cost of a ton of CO_2 or CO_{2eq} emissions
W_i: total weight (ton) of CO_2 or CO_{2eq} emissions per transported unit related to option i

The cost C_{CO2eq} may be a fictive cost related to a company's internal accountancy. The total number of options is expressed as n. The decision maker chooses the option for which the U_i value is the smallest. For the purpose of illustration, the disutility function is kept to simplicity.

Equation (1) expresses the way on how to include the costs of CO_2 emissions into the operational environments. With the rise of self-organization and the concept of the physical internet, it is important to equip distributed decision makers with information about GHG emissions related to the choice set that these decision makers are to explore in the process of taking decisions. Equation (1) is also an example on how to incorporate the true costs of GHG emissions into the operational logic of distributed decision makers, which is a cornerstone of the concept of self-organizing logistics and the physical internet. This formulation is also suitable for incorporation into transport, using for instance, multinomial logit discrete choice model formulations (e.g. Bhat, 2000).

Similarly to the operational decisions, the true costs of GHG emissions can be included at strategic level, for example when long term decisions are made on the location of facilities, such as warehouses, distribution centers, crossdocks, and other facilities. In line with the classical facility location formulations (Campbel, 1994; and Haug, 1985), this can be formulated as an integer programming problem as shown in equations (2) and (3). The choice set includes n possible locations where a facility can be placed with the goal of systemic total cost optimization. The cost function can include transport costs, facility costs and emission costs, as presented in equation (2), but other, more broad formulations are also possible.

$$\min\left(F_i + C_i^{in} + C_i^{out} + C_{CO_{2eq}} * W_i^{in} + C_{CO_{2eq}} * W_i^{out}\right) V_i * z_i,\ i = 1..n \quad (2)$$

$$\text{s.t.} \sum_{i=1}^{n} V_i * z_i = V \quad (3)$$

Where:

F_i: cost of facility i in € per volume of freight
C_i^{in}: inbound out-of-pocket transport cost for facility *i* in € per volume of freight
C_i^{out}: outbound out-of-pocket transport cost for facility *i* in € per volume of freight
$C_{CO_{2eq}}$: cost of a ton of CO_2 or CO_{2eq} emissions
W_i^{in}: inbound weight of CO_2 or CO_{2eq} emissions per volume of freight for facility *i*
W_i^{out}: outbound weight of CO_2 or CO_{2eq} emissions per volume of freight for facility *i*
V_i: volume of freight (annually) flowing through facility *i*
z_i: binary variable ($z_i = 0{,}1$) indicating whether facility *i* should be built
V: total volume that should be shipped through the system

This formulation ((2) and (3)) can be extended with other cost components and service requirements such as, for example, stock keeping costs and speed of service. Similarly to the disutility formulation (1), the integer program is kept to simplicity for the purpose of illustration.

In both operational (equation (1)) and strategic (equation (2) and (3)) cases, the amount of CO_{2eq} emitted (W_i, W_i^{in}, W_i^{out}) is not yet known as the transport operations will take place in the future. The ex-ante amount of CO_{2eq} to be emitted can be estimated in the following three ways:

1) Using assumptions about the organization of transport operations;
2) Using default data, such as industry average CO_2 emissions per ton-kilometer transported;
3) Using service provider specific emission factors based on the ex-post data of the service provider in question.

Emission estimation in accordance to option 1) is the least feasible among the three options. To provide better estimations for a specific organization than the industry average assessments of GHG emissions (option 2)), some knowledge and data on the organization of operations will be required. Moreover, there may be involved some computationally challenging tasks, such as determining the route and possibly solving a traveling salesman problem for each option. Such an approach is not feasible to be included into the integer program (equations (2) and (3)), nor is it reasonable to assume that distributed decision makers, as specified in equation (1), are capable of gathering the data and performing these computations. Option 2) is the easiest to apply, but has a drawback that it does not include any data on performance of specific service providers, nor can it take into account any local specifics. Option 3) allows using measured ex-post data for determining the future course of action – there is no guarantee that performance will be the same as measured in the previous period, but it is the best available approximation on a set of limited information for the future performance. Moreover, option 3) allows distinguishing between different service providers allowing to informatively choose the best performing one.

Private parties need information on GHG emissions for both operational (equation (1)) and strategic (equation (2) and (3)) decisions. Option 3) is the most suitable way to estimate the ex-ante amount of CO_{2eq} to be emitted. An additional advantage of option 3) is that this option can also be used as data input towards the formulation of GHG emission norms by public parties, as discussed in the following chapter.

3. Considerations on formulation of GHG emission norms by authorities

Decarbonization of transport and logistics is facilitated by two types of forces: private parties (as discussed in Chapter 2) and public forces (as discussed in this chapter). At the policy level, the question of regulation of transport and logistics emissions has gotten a new impetus. Similarly to the regulation of vehicle emissions, there is an ongoing discussion on an introduction of emission norms for the transport and logistics sector. Additionally to the political challenges, the policymakers face the technical challenge on how to set up a norming scheme. Specifically, what has to be the basis of a norm, i.e. what to measure, in what units and how? Once these questions have been answered, the policymakers will face the challenge of getting the baseline data right. Specifically, how to get adequate information about the current state of the industry with respect to quantitative data on the chosen measure? How to segment diverse logistics sectors into homogeneous segments where a norm can be applied?

Logistics performance with respect to GHG emissions can be measured as the amount of CO_{2eq} emitted per unit of transport activity. Different indicators exist that are aimed at different types of stakeholders, however, two large classes of the indicators can be distinguished (Davydenko et al., 2019).

1. Carbon efficiency of a service provider: gCO_{2eq} per unit of freight per unit of distance, for instance gCO_{2eq} per ton-kilometre or gCO_{2eq} per m^3-kilometre of transport carried.
2. Carbon efficiency of a shipper: gCO_{2eq} per unit of freight, for instance gCO_{2eq} per ton or gCO_{2eq} per m^3 shipped.

Specifications of the unit of freight are usually limited to the weight (tonnes), volumes (cubic meters), TEU or containers, pallets and packages, although other units of freight may be used. The most common among them is the weight unit. The unit of distance is kilometer (Imperial unit is mile) and there are different ways to measure the distance, which is discussed in more detail in Chapter 4.

Based on these considerations, there can be two types of norms proposed. The first type of norm is related to the operations of service providers who work within the logistics industry. The service providers' related norm will be expressed in gCO_{2eq} per ton-kilometre transported. The second type of norm is related to the operations of shippers – the users of transport and logistics services. The shippers' indicator will be expressed in gCO_{2eq} per ton shipped. The shippers' indicator combines the service provider's carbon efficiency with the overall organization of the shipper's supply chain. In other words, the less spatially stretched the shipper's supply chain and the more efficient the service provider of their choosing, the better is the shipper's indicator.

The process of setting the norms includes determining the carbon performance of market parties in the segment. A possible approach to setting up the norms is to determine the distribution of the emission values by the companies active in the segment and to set the targets such that the worst performing companies will have to improve or go out of business. Concentration on the worst performing companies has two advantages: first, it removes the worst performing operators (i.e. those that emit disproportionally more gCO_{2eq} per ton-kilometre or per ton shipped) and second, by removing the worst performing operators from the market, the total emissions will be lowered, as well as the average level of emissions. The process of target setting can be organized in a way that, for instance, performance of worse than two standard deviations over the mean is forbidden, affecting around 5% of the company population, depending on the form of distribution. Once the new norm is set, it can be revised over a period (e.g. one year) in a similar way, thus creating the pressure on continuous improvement in the market, see figure 1 for an illustration.

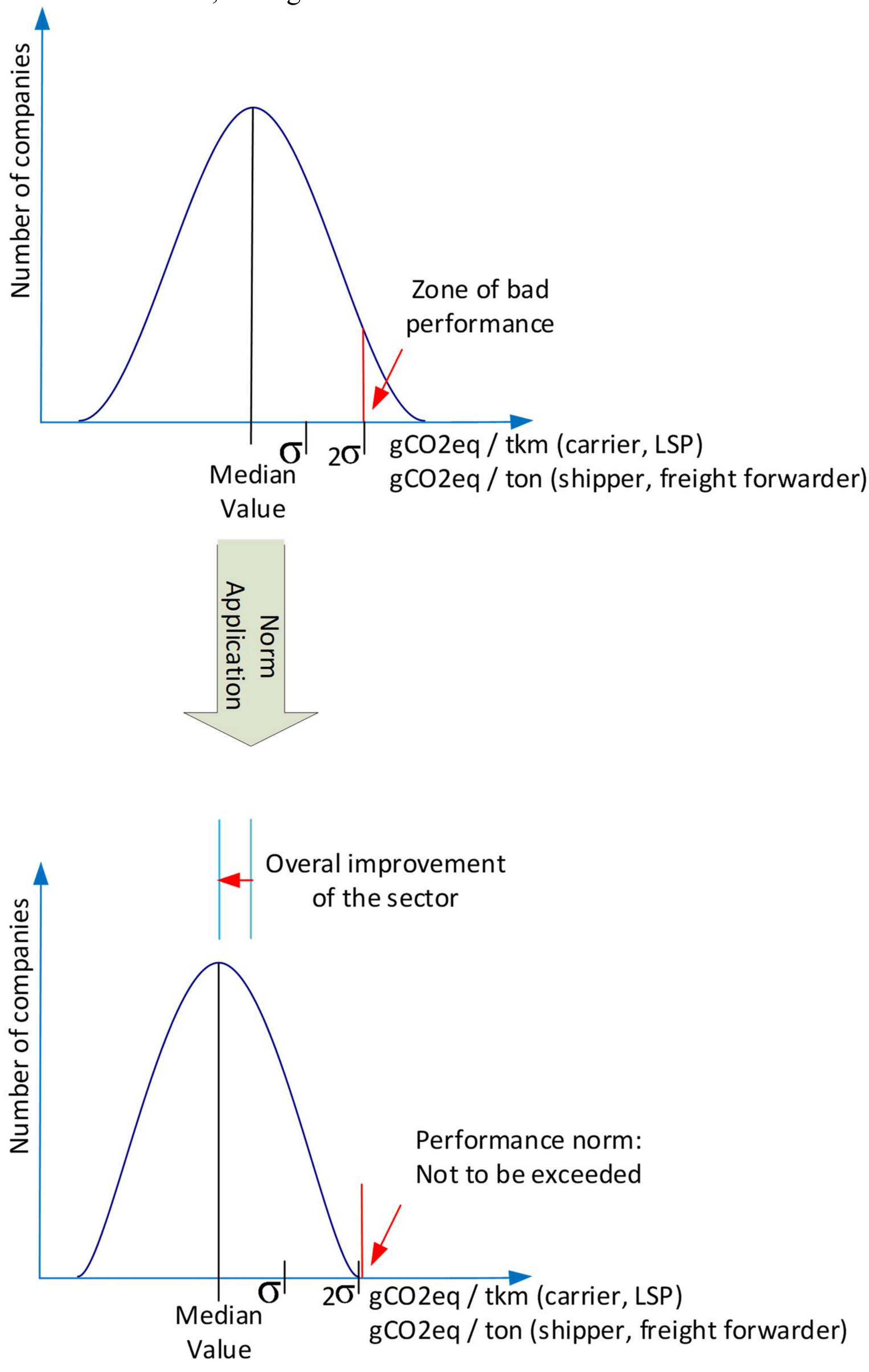

Figure 1. Example of a way for norm set up

This paper is discussing the issue of logistics segmentation that is related to the fact that logistics operations are heterogenous in their nature. The different segments are not directly comparable with each other in terms of CO_2 emissions. For instance, the average fuel consumption per ton-kilometer of goods shipped in a van is 10 times bigger than the same indicator for the goods transported in a 40-ton truck (Greene and Lewis, 2016). Therefore, a proper segmentation of the transport market is a condition for a norming scheme and deserves a dedicated consideration.

4. Data infrastructure for GHG emission optimization and GHG emission norms

As we discussed in chapters 2 and 3, for both logistics process optimization and policy applications, a measure of GHG emissions related to transport activity is the needed input into the decision making process.

4.1. Transport activity

Transport activity is measured in terms of freight units transported over distance units.
Units of distance. Five fundamental distance measures can be distinguished:

1) **Great Circle Distance (GCD).** The great circle distance is the shortest distance between two points on the surface of the Earth, measured along the surface of the Earth. It is also known as the “as the crow flies” distance: this distance does not consider any infrastructure, so two points are connected directly, as if there is a straight road between them. The GCD is the most suitable measure for distance for the purpose of carbon footprinting as it looks at 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 an administration and data requirements point of view, as there is no need to keep track of the routes that the vehicles travelled (Davydenko et al, 2019);

2) **Actually Driven Distance (ADD).** The actually driven distance is the distance travelled by the vehicle. This distance can be measured by the vehicle’s odometer. The ADD is the most intuitively understandable distance: for this reason it has deep usage roots. For instance, transport statistics is expressed in ton-kilometres actually driven and the companies are used to reporting to the statistics bureaus in this manner. Also, some transport companies charge their clients based on travelled distances (Davydenko et al). The ADD has a number of drawbacks with respect to establishing GHG emission performance indicators. First, the ADD does not reflect on efficiency of the routes, as for instance, unnecessary kilometres are not penalised. The ADD can even encourage more kilometres to be driven in case emissions made while making those kilometres are less than the average emissions. Second, for the logistics optimization purposes, as discussed in Chapter 2, the ADD is not known ex-ante, estimation of this distance requires assumptions and optimization, which are not possible or desirable in the distributed decision environment, nor it is suitable for the integer programming. Third, the ADD has to be logged and stored by the carrier; this distance measure is not generally available to any other party than the carrier. Despite the fact that the ADD is often

used in carbon reporting and accountancy, the abovementioned drawbacks make the ADD distance unit an inferior unit compared to the GCD.

3) **Planned Distance (PD).** The planned distance is the distance that a shipment is expected to follow in a vehicle as the route of the vehicle is determined by the planning software. The PD as a distance unit measure for the GHG emission measure indicator is equivalent to the ADD and, thus despite wide use in carbon reporting and accountancy, it is inferior compared to the GCD unit measure.

4) **Shortest Feasible Distance (SFD).** The shortest feasible distance is the shortest distance between two places on a mode-specific network. The SFD can be computed by any party having access to the network specifications and software capable of computing shortest path. The SFD is a physical distance over infrastructure, thus more similar to the GCD distance measure. Compared to the GCD, it has three drawbacks: 1) it is mode-dependent, 2) it needs special software to be computed and 3) it changes when the network is adjusted. This makes the use of SFD slightly less attractive than the GCD.

5) **Fastest Distance (FD).** The fastest distance is the distance of the route that allows travelling from the departure point to the arrival point at a minimum time. The FD is essentially equal to the SFD, with the only difference that instead of distance, travel time is minimized while determining the FD. The GCD is more preferable unit than the FD due to the same drawbacks as those of the SFD.

Units of freight. Units of freight can be characterized by their physical properties, such as weight and volume, as well as specific industrial conventional load units.

1) **Weight (tons).** Weight is the most common unit of freight. Weight is relatively easy to obtain by weighing the goods; if it is not practical to weigh the goods, then the total weight is the sum of weights of individual items.

2) **Volume (m^3).** The volume of goods is also a common measure of freight, especially in case of volume-limited operations, or freight with a high volume to weight ration. Volume is not as often measured as weight, however, for some operations like parcel deliveries, volume is more common than weight.

3) **Load units.** The most used load unit is container, measured in 20-foot container equivalents (TEU) for shipping, and in LD-3 and other containers in aircraft operations. Other load units, such as pallets and individual SKU's or parcels can also be used. The load unit measures are common for arrangement of pallet and shipping container transport.

As we considered different measures to determine transport activity, the measure based on the Great Circle Distance and weight transported can be considered the most useful for logistics optimization and a setup of logistics emission norms. In case other than weight units of freight are universally used across the segment, it can be acceptable to use m^3 * distance GCD as the common transport activity measure for that specific segment.

4.2. GHG emission measures

Green House Gas emissions are measured as the weight of CO_2-equivalent emissions made while carrying out certain transport activity. The measured GHG emissions should include all vehicle operations, including empty runs, repositioning and other non-revenue use that is essential for conduction of primary business activities.

In practice, the GHG emission weight is determined by multiplication of volume of fuel burned (or the amount of electricity used) by an emission factor, which specifies the weight of CO_2-equivalents released into the atmosphere by burning one liter or one kilogram of fuel, or by using one kilowatt hour of electricity. A practical way to determine the weight of GHG emissions is to get fuel purchasing data (or charging data if applicable) over a period and to multiply the amount of fuel or electricity used in that period by a relevant emission factor. As in many cases tanking does not happen every day, relatively large rounding error may occur if aggregated over a short period, in many cases it is reasonable to aggregate fuel and electricity use for periods of at least one month. Fuel and electricity use aggregation of one year has an advantage of smoothing out seasonal patterns of energy use and seasonal patterns of transport service demand.

For determination of logistics emission performance indicators, as discussed in Chapter 2 and 3, the emission data has to be normalized per unit of transport work. It is important to ensure that there is a unique and unambiguous match between transport activity carried out and fuel (or electricity) use. In other words, it must be ensured that the vehicles are used only for services falling within the scope of transport activities, and that transport activities are carried out only within the scope of measured fuel or electricity use.

5. Proposal for data collection process and data processing design

The logistics emission calculation tools (e.g. BigMile, EcoTransIT World, EPA's SmartWay, TK'Blue and others) together with the public data collection institutes, such as the Dutch Statistics Bureau CBS, can provide the necessary physical and institutional infrastructure for emission data collection, processing and analysis. At the micro level, where decisions are made on the optimization of operations, and the macro (policy) level, where the emission norms are to be set, the emissions are computed and normalized to the indicators discussed earlier in the paper. The following can be considered as the main data collection requirements.

1. **For micro level decisions**, such as those discussed in Chapter 2, the data collection arrangement should provide an easy to use computation of GHG emissions related to certain logistics choices based on primary data of service providers. This this can be realized by 3rd party platforms that collect micro data from the businesses and which, authorized by the data owners, can share emission data with intended recipients or the public.

2. **For macro (policy) level decisions on emission norms**, such as those discussed in Chapter 3, the data collection process should provide sufficiently aggregated data on the GHG performance of businesses. This can be done through comprehensive survey(s) of transport and logistics.

The basis GHG emission KPI in the transport networks of carriers is gCO_{2eq} per ton-kilometer GCD transported, and for the shippers the basis KPI is gCO_{2eq} per ton of goods shipped, which can be determined in accordance to the discussion in Chapter 4. The carriers are in principle capable to compute this indicator by themselves and subsequently publish it in a form as, for instance, proposed by the GLEC declaration. In some cases, the carriers are not possessing all the data necessary to compute this KPI (see more details on the absence of cargo weight data by the carriers in LEARN D4.4 (Davydenko et al., 2018) – the analysis of around 30 carbon footprint implementations at industrial companies). In this case tools that help collect data (e.g. electronic bill of lading, aggregation of different data sources, intercompany links) may solve the problem.

Another challenging issue that needs to be overcome is the sensitivity of GHG emission data. From the emission data the amount of fuel used can be determined, and thus fuel costs, which is one of the most important expenses of the service providers. Some of them may not be willing to share this information broadly. Therefore, for the purpose of policy-related data collection, the Statistics Bureaus (e.g. CBS) can be asked to collect emission performance data, in addition to the data they collect on, for example, goods flows. This may use the existing organizational and survey infrastructure with strict data privacy norms.

For the operational and strategic decisions by the users of transport services, the logistics emission calculation tools can be extended towards data services (e.g. SmartWay can be considered one of those, although it does not compute the specific indicators discussed in this paper) that allow communication of emission performance data between market parties. In this way the data owners can restrict and specify the list of other parties who may be provided limited access to their data. For instance, for a specified origin and destination, the service may return a number of options (e.g. modalities and carriers) with the emission data related to each of the choices.

6. Conclusions and outline for further research

This paper has provided a discussion on how to include GHG emissions in logistics decisions and optimization of logistics operations. The optimization of logistics processes can be done locally and operationally, possibly by the distributed decision makers, such as it is foreseen in the concept of physical internet. The optimization can be done in a classical way, globally or centrally, where integer programing can be used for determining an optimum supply and transport chain designs. The added value of this discussion is that, in addition to the usual optimization goal of cost reduction and maximization of the service level, the resulting GHG emissions are taken explicitly into account and directly impact the outcome of operational and strategic decisions. Depending on the costs of a ton of CO_2 emission constant used, the formulations provided in the paper may shift decisions from the cheapest solutions within service constraints to the least polluting ones within the same constraints.

Similarly to the emission norms for vehicles, there is an ongoing discussion on regulating logistics emissions through formulation of emission norms for logistics operations. This paper provides a discussion on how to set up logistics GHG emission norm regulations using carbon footprinting methods developed for the micro level, i.e. bringing carbon footprinting to the macro level, at which policy makers work.

To realize both logistics optimization and to set up norms for GHG emissions in logistics operations, the emission data need to be collected. The paper provides a discussion on what data need to be collected and how it should be processed to realize the stated goals. Established commercial platforms can be used as the gateways for data collection and processing for the logistics optimization purposes, as well as national and international statistics bureaus for the independent data collection and processing related to the policy making process.

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