GCD as the optimal distance metric for CO_{2e} allocation in freight transport

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Emission intensity factor

The emission intensity factor, kg CO_{2e} per tonne[1]-kilometre shipped, is the most important key performance indicator for a carbon footprinting methodology.

This booklet summarizes the analysis of four distance metrics for computing transport activity: the great circle distance (GCD), the actually driven distance (ADD), the planned distance (PD) and the shortest feasible distance (SFD). For more detailed information, we refer to the full version of the report, which can be found here.[4] The analysis is based on a framework consisting of eight criteria to assess suitability of each of the four distance metrics for carbon footprinting. On the basis of this analysis, the great circle distance is the distance metric that shall be used for determining transport activity as denominator in the emission intensity factor.

The comparative analysis assesses the suitability of each of four distance metrics for the eight criteria that are relevant.

The summary of the analysis is presented in Table 1, where we denote '++' as the most suitable, '+' as suitable, '+/-' as neutral, '-' as unsuitable, and '--' as the most unsuitable.

Table 1
Suitability of distance metrics for different purposes: summary of comparative analysis

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

Below we explain the most important reasons that lead to the conclusions with respect to the eight analysis criteria.

1. Adequacy for estimation of fuel used[2].

This criterion relates to the nominator of the network emission intensity KPI. In an ideal situation, the primary data on fuel or energy use should be used. Moreover, as fuel is one of the main cost components of transport, the fuel data is generally well collected and stored, and thus actual fuel data must be used when available. However, in the absence of these data, the actually driven distance, combined with a default fuel consumption or emission factor, can be used to estimate fuel use[3]. PD and SFD may also be used for this purpose, where PD is generally closer to the ADD, SFD is usable in case of point-to-point transport, but it becomes unusable if a journey involves multiple stops. The GCD is not suitable for the purpose of estimation of fuel use as it takes no account of actual network distances.

In practice most transport companies have accurate records of measured fuel consumption, eliminating the need to estimate fuel consumption.

1 For volume-limited transport a volume dimension should be used instead of tonne.
2 The adequacy for estimation of fuel use is the single criterion that relates to the nominator of the carbon footprinting GHG intensity KPI. Criteria 2-8 relate to the denominator of this KPI, namely transport activity measured as a unit of freight displaced over a unit of distance (e.g. tonne-kilometers).
3 The use of ADD to estimate fuel use is applicable for the road vehicles. Other modalities have a weaker relationship between (projected on the Earth surface) distance driven and fuel use.
4 I.Y. Davydenko, R.T.M. Smokers, W.M.M. Hopman, H. Wagter (2021), Great circle distance as the optimal distance metric for CO2 allocation in freight transport, TNO report 2021 P11077

2. Adequacy for allocation of emissions to individual shipments and customers.

This criterion relates to the process of emission allocation (also known as emission assignment) to the shipments, customers/entities that cause them or are responsible for them. The GCD is the most suitable one for this purpose: it allocates emissions proportionally to the geographic displacement and is independent of operational details, while truly reflecting on the overall carbon efficiency within the scope of computation.

The KPIs based on GCD can be communicated with the customers such they can compute absolute emissions related to their shipments. It is the most objective indicator of the total network efficiency. The SFD is the second best choice and can be used in case of unimodal transport, but it also has a number of disadvantages compared to the GCD, of which the most important one is ambiguity in SFD computation. The PD metric is not suitable for allocation[5] as it is problematic in distribution (such as milk runs, groupage networks or LTL operations) as results vary a lot depending on assumptions. The PD also hides information on network efficiency. The ADD is not suitable metric, in distribution rounds or other routes with multiples stops allocation becomes arbitrary depending on the sequence of stops, require assumptions to carry out, and can often lead to directionally wrong results.

3. Adequacy and ease of auditing results by accountants.

The GCD distance metric used for determining of transport activity is the most suitable one for accountancy as it is immutable and can always be verified. Coupled with shipment data, the GCD metric presents easy to verify data on transport activity. The SFD is less suitable for this purpose as it requires additional information to be stored, such as routing software and network definitions. Furthermore the SFD can change over time, which leads to irreproducible results. The ADD is not suitable, as it requires a lot of detailed information to be supplied. Theoretically it is possible that the driven routes are collected and stored, but the amount of data, data consistency and complexity of the checks make auditing very difficult (i.e. more detailed information means more work). The PD is the least suitable, as auditing will require access to the software by which the planning was made, which is not realistic to expect, as software can be embedded, proprietary and evolve over time.

4. Data requirements and ease of data gathering data for calculations.

Similarly to the auditing requirements, GCD requires the least data gathering requirements and efforts, can be computed for any given two addresses using the Haversine formula[6] implemented in any software, leading to exactly the same results. The SFD will require using network definitions and applications of the shortest path algorithm (Dijkstra algorithm). As network definitions evolve over time (e.g. due to software updates and infrastructure changes), the use of SFD will require more data storage, making it less suitable from the data gathering point of view. The ADD at the level of shipments is difficult to collect as it requires complete logging of the routes travelled by the individual shipments[7]. The PD is the least suitable metric requiring logging of the plans and inaccessibility of these data to the 3rd parties - for the 3rd parties access to the planning data is in most cases impossible.

5 Note that the PD is not the shortest distance for a shipment, but a distance that the shipment is planned to travel within a vehicle.

6 The Haversine formula is known from the beginning of the 19th century in the context of navigation, e.g. Robusto (1957).

7 The ADD at the level of road vehicle is easy to collect, as it is equal to the odometer data.

5. Use for comparison of different networks and/or modalities

The GCD as distance metric in the denominator is suitable for comparison of network GHG efficiencies and between different modalities. As the GCD distance is the same for all transport options, GHG intensity based on transport performance calculation using GCD provides a sound basis for comparison of networks and across different modalities. All other types of distance metrics are mode- specific and do not provide any basis for comparison across modalities.

Within the same modality, the PD does not provide any basis for comparison as it is vehicle-level journey specific and cannot be reproduced by a third party to have a meaningful comparison between networks. The ADD-based comparison of the emission intensity KPIs only reflects on the load and vehicle efficiency, while overall network organization efficiency is not reflected when ADD is used to determine transport activity. The SFD metric is possible to use for emission intensity comparison within the same modality, but it is not problem-free.

6. Use for analysis of potential improvement measures and for GHG optimization.

The GCD provides a very good basis for optimization: minimizing GHG emissions per tonne-km GCD will result in the best real world result for a given flow of goods. The minimization of kilometers driven (ADD) is an often used optimization strategy, but it is limited to one modality. The ADD minimization results in an optimal PD, such that for a given goods flow an optimal planned route is determined, so in essence these two are equivalent. The minimization of emissions per tonne-km SFD is similar to the GCD-based optimization, but it is only possible within one modality and is more difficult or cumbersome to implement.

7. Use for combining data from multiple subcontractors.

In case GHG data is provided in absolute volumes by subcontractors in a network to the shippers, specifically for the information exchange, the distance metric matters for verifiability and auditing. If the data is shared in the form of network GHG intensity[8], the distance metric matters a lot, making analysis for this criterion similar to the one conducted for point 2 on emission allocation. If emissions are computed on the basis of GHG intensity, both the transport service provider and the user of transport services must be using the same distance metric and the same tool to calculate it in case of SFD and PD. Therefore, GCD is an ideal metric in this situation. The SFD is the second best, but much less preferable due to the fact that it cannot be defined unambiguously. The PD is utterly unsuitable as this distance is not known to the party who receives the GHG intensity data and cannot be independently assessed. The ADD can only be used if complete data on driving routes is shared, which is not practical and given availability of better options is not necessary.

8 Sharing of network GHG intensity is not the preferred way to provide carbon footprint data by the carrier to the user of transport. In an ideal situation the absolute footprint information should be provided. But in case the user of transport requires this data or for the purpose of verification, the network GHG intensity data can be an important element.

8. Commercially sensitive information shared.

Sharing carbon footprint data or GHG network intensity data leads to a degree of commercial information sharing. For conventional transport solutions based on fossil fuels, GHG data can be directly converted into fuel use and thus monetary expense. However, some distance metrics can only be used for general derivative data on network cost efficiency, such as GCD and SFD. The ADD and PD based data reveal more information about network organization and distances travelled for specific customers. If audited, the ADD and PD based computation will require network disclosure to the auditor, making them less attractive from this point of view[9].

This leads to the following conclusions on the suitability of the four analyzed distance metrics for carbon footprinting:

- *The ADD is a clear winner for estimation of fuel use and GHG emissions in case primary fuel consumption data is not available. In many cases this fuel consumption data is measured separately so there is no need to make estimates: in case real world fuel data is available it must be used in computations, and not the estimates.*

- *For all other purposes, and especially for determining of the transport activity, transport performance and for emission allocation as well as for the goals of sharing emission intensity data, minimum data requirements and auditing, the GCD distance metric is the only fundamentally correct option among the analyzed distance metrics. For these purposes the SFD metric is a second-best choice, when used for calculating and comparing carbon footprints within one transport modality. The SFD metric is however mutable, software-dependent and can lead to directionally incorrect decisions. This makes it generally less suitable compared to the GCD.*

9 The accountant can be obliged to keep the audited source data confidential.

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