Sensor-based modelling of carbon dioxide emissions for trailer traffic

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Abstract: In this research work, the calculation of carbon dioxide emissions for trailer traffic based on sensor data is described. The data consist of trailer type, load, trip and route parameters. While the individual trailer parameters can be derived from the order management, the trip and route parameters are collected by frequently data. With this, the transport carbon footprint is calculated based on DIN EN 16258 by means of the *ProBas* database. The distributions of carbon dioxide emissions in trailer traffic are analysed and discussed. The results of the case study indicate that sensor-based modelling can be a useful tool for an improved transparency and estimation of carbon dioxide emissions.

Keywords: transport carbon footprint, trailer, telemetry data, logistics

1 Introduction

Anthropogenic climate change is currently one of the greatest threats to humanity. The earth is warming up due to anthropogenic carbon dioxide-equivalent (CO_2e) emissions and the resulting increase in the greenhouse effect. [RF09], [NO23]. The associated decline in agricultural yields, natural disasters, and water shortages are just a few of the causes leading to international conflicts [MKK21], [UB21]. In order to counteract these negative effects in the best possible way, savings in CO_2e emissions are required. Globally, the transport sector contributed to 20 % of CO_2e emissions in 2019 [St23]. Due to the restrictions during the corona pandemic, CO_2e emissions have temporary decreased significantly in the year 2020. In the area of road transport, this has even halved [Le20]. Since within the transport sector, road transport is responsible for 73% of global CO_2e emissions in 2018, this sector seems particularly suitable for considering improvements [La21]. While the reduction of CO_2e emissions due to the corona pandemic has been of short-term importance, long-term savings in the transport sector are mainly possible through more efficient fuels, means of transport or modal shifts [Bl20]. For this kind of

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more efficient transport management, which, for example, protects the environment by avoiding traffic congestions, the collection, analysis, and use of data is the basis [RM22]. Therefore, enhancement in transport efficiency and CO_2e emission reduction is mostly achieved by exploiting telemetry data, that became available due to Global Positioning System (GPS) traces from cell phones, vehicles and anonymized Call Detail Records (CDR) from cell phone providers [Ma19]. Based on these data, it is possible to develop models that represent the spatiotemporal CO_2e emissions [HZJ20].

2 Problem Statement and Scientific Question

Under consortium leadership of the Krone Group, Spelle with partners from industry and science, the three-year *EDNA* project (grant No.: 01MD22001C; funding program: "EDGE Datenwirtschaft") funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK) is exploring the potential of digital technologies for a more sustainable production in the transport and logistics sector (www.edna-projekt.de). One aspect of this project is the previously described calculation of the transport carbon footprint (TCF) caused by trailer traffic.

The trailers of Fahrzeugwerk Bernard KRONE GmbH & Co. KG regularly transmit telemetry data. Figure 1 shows a section of telemetry data from a trip. These data are periodically transmitted and contains, among other things, the location and movement data as well as the trailer type. The data discussed in this paper have been anonymised and contain only one customer of Krone fleet, the trailer rental service of the Krone Group. These data have been explicitly approved by Kemena GmbH and kindly provided for the analysis in this paper.

	BD_GPS_LATITUDE	BD_COUPLED	67	BD_DOOR_OPEN	69	BD_GPS_LONGITUDE	BD_GPS_LOCATION	83	84	BD_GPS_DIRECTION
634	53.08438	True	nan	False	nan	8.73477	Georg-Henschel-Straße 3, 28197 Bremen, DE	nan	nan	0
635	53.08437	True	nan	False	nan	8.73480	Georg-Henschel-Straße 3, 28197 Bremen, DE	nan	nan	0
636	53.08439	True	nan	False	nan	8.73480	Georg-Henschel-Straße 3, 28197 Bremen, DE	nan	nan	0
637	53.08437	True	nan	False	nan	8.73488	Georg-Henschel-Straße 3, 28197 Bremen, DE	nan	nan	0
638	53.08438	True	nan	False	nan	8.73482	Georg-Henschel-Straße 3, 28197 Bremen, DE	nan	nan	0
639	53.08438	True	nan	False	nan	8.73483	Georg-Henschel-Straße 3, 28197 Bremen, DE	nan	nan	0
640	53.08436	True	nan	False	nan	8.73480	Georg-Henschel-Straße 3, 28197 Bremen, DE	nan	nan	136
641	53.08437	True	nan	False	nan	8.73480	Georg-Henschel-Straße 3, 28197 Bremen, DE	nan	nan	242
642	53.08437	True	nan	False	nan	8.73488	Georg-Henschel-Straße 3, 28197 Bremen, DE	nan	nan	318
643	53.08434	True	nan	False	nan	8.73494	Georg-Henschel-Straße 3, 28197 Bremen, DE	nan	nan	5
644	53.08439	True	nan	False	nan	8.73488	Georg-Henschel-Straße 3, 28197 Bremen, DE	nan	nan	5
645	53.08438	True	nan	False	nan	8.73491	Georg-Henschel-Straße 3, 28197 Bremen, DE	nan	nan	5
646	53.08435	True	nan	False	nan	8.73494	Georg-Henschel-Straße 3, 28197 Bremen, DE	nan	nan	5
647	53.08802	True	nan	False	nan	8.73605	Bremen Georg-Henschel-Straße, 28197 Bremen, DE	nan	nan	69
648	53.07462	True	nan	False	nan	8.76165	A281, 28197 Bremen, DE	nan	nan	125
649	53.08601	True	nan	False	nan	8.79601	Landwehrstraße 4, 28217 Bremen, DE	nan	nan	39
650	53.09567	True	nan	False	nan	8.79471	Parallelweg 49, 28219 Bremen, DE	nan	nan	195
651	53.05992	True	nan	False	nan	8.76180	Emslandstraße 22, 28259 Bremen, DE	nan	nan	243
652	53.04625	True	nan	False	nan	8.70130	B75, 27751 Delmenhorst, DE	nan	nan	259
653	53.03507	True	nan	False	nan	8.62124	Schlutterweg 6, 27755 Delmenhorst, DE	nan	nan	273
654	53.05779	True	nan	False	nan	8.52816	E22, 27777 Ganderkesee, DE	nan	nan	275
655	53.05926	True	nan	False	nan	8.42537	E22, 27798 Hude, DE	nan	nan	264
656	53.07263	True	nan	False	nan	8.32730	E22, 26209 Hatten, DE	nan	nan	315
657	53.12310	True	nan	False	nan	8.27532	A29, 26135 Oldenburg, DE	nan	nan	5
658	53.18635	True	nan	False	nan	8.25922	A29, 26125 Oldenburg, DE	nan	nan	332
659	53.23211	True	nan	False	nan	8.18460	A29, 26180 Rastede, DE	nan	nan	318
660	53.29376	True	nan	False	nan	8.14751	A29, 26180 Rastede, DE	nan	nan	348
661	53.35885	True	nan	False	nan	8.12381	Aeropark 1, 26316 Varel, DE	nan	nan	354
662	53.41644	True	nan	False	nan	8.08824	A29, 26316 Varel, DE	nan	nan	307
663	53.46425	True	nan	False	nan	8.01762	A29, 26452 Sande, DE	nan	nan	354
664	53.52688	True	nan	False	nan	8.00755	A29, 26419 Schortens, DE	nan	nan	36

Figure 1: Snapshot of a telemetry data frame

This telemetry data is not yet used for the consideration of CO_2e emissions. Theoretically, CO_2e emissions can be derived manually from the fuel consumption of logistics service providers. However, as the CO_2e emissions are to be calculated automatically, this method is not suitable for this purpose. The motivation on the part of Fahrzeugwerk Bernard KRONE GmbH & Co. KG is to make logistics more sustainable and to limit and monitor the emissions generated in the process. The first step towards achieving this goal is to determine CO_2e emissions. Therefore, this paper deals with the implementation of a transport carbon footprint calculator using telemetry data.

This paper is structured as follows. First, the general methodology of the transport carbon footprint calculation is explained. This is subsequently illustrated by means of an example. Next, the telemetry data is explained in more detail and the calculation of the transport carbon footprint based on this data is presented. The paper concludes with a summary and an outlook for further studies.

3 Methods and Techniques

DIN EN 16258, developed by the German Institute for Standardisation, includes not only specific calculation and allocation procedures, but also basic definitions as well as regulations regarding system boundaries [De13]. In this context, the standard serves "to calculate and declare energy consumption and greenhouse gas emissions for any transport service" [De13]. The basic requirement is that energy quantities are reported in Joule and Greenhouse Gas (GHG) emissions in gram CO_2e or multiples thereof [De13]. For the evaluation of a system, all consumptions and emissions during the system's usage are to be included [De13]. This involves, among other things, the expenses for the on-board electronics, the propulsion power as well as any additional services required, such as the operation of cooling units [De13]. This applies to both, the loading journeys and any resulting empty journeys [De13]. Additionally, fuels as well as electricity and their corresponding emissions from extraction to provision must be considered [De13]. Excluded from the system boundaries are, for example, emissions originated by spills or short-term support such as navigation by tugboats - an overview of all exceptions can be found in Ref. [De13]. Emissions trading and compensation cannot be a direct part of the transport carbon footprint, so that these are not considered in the calculations. [De13].
The derivation of the transport carbon footprint is divided into three steps. First, the different partial routes and the means of transport used are to be identified based on the activity data. [De13]. The next step is the determination of the following values for each lag of the journey: Well-to-wheel energy consumption, Well-to-wheel GHG emissions, Tank-to-wheel energy consumption, Tank-to-wheel GHG emissions [De13]. In addition to the activity data, emission factors are also required for this. The activity data includes the distance, the truck type and the weight of the load, which finally leads to the fuel consumption [De13]. Ideally, these data together with emission factors are determined by real-time measurements. However, the use of default values from databases is well-aligned with norms and guidelines [De13].

The aforementioned emission values could be calculated as follows:

1. $E_w = F * e_w$ [4]
2. $G_w = F * g_w$ [5]
3. $E_t = F * e_t$ [6]
4. $G_t = F * g_t$ [7]

The third substep of the calculation includes the addition of the partial results to one total result per value [De13]. However, if statements are not to be made for an entire transport unit, but only for a transported good, allocations are to be carried out [De13]. Results according to DIN EN 16258 may be publicly reported to increase transparency about the CO_2e emissions. These analysis results of the transport carbon footprint may be published in a declaration [De13]. The prescribed formulation of such a declaration can be found with more derails in DIN EN 16258 on pages 20 and 21.

DIN EN 16258 specifies the average fuel consumption of a truck by 35 litres per 100 km. Thus, the fuel consumption F can be calculated from the distances travelled and the average fuel consumption. This results in emission values (TCF) for the route, as exemplary shown for three sections of a route in Table 2 (each section is 49, 32 and 23 km long).

4 Application and Results

By adapting this procedure, CO_2e emissions can now be calculated using telemetry data. Since the transmitted telemetry data contain values for the trailers' type and load, it is possible to determine the trucks' load. This load in turn enables databases such as *ProBas* (https://www.probas.umweltbundesamt.de/php/index.php) to include more granular emission factors in the calculation of the TCF. The solution presented in this paper uses the *ProBas* database, which yields emission factors for truck utilisation intervals of 10 %. For example, for the truck types used in this paper, *ProBas* gives the values as presented in Table 3 [Um23d], [Um23e], [Um23c], [Um23a], [Um23b]. Since the value of e_t is not available in the *ProBas* database, the value of DIN EN 16258 is still used for this calculation.

For the calculation of the distance travelled by the trucks, the GPS coordinates are converted into a Geo-JSON file. This Geo-JSON file is used to determine the distance

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[4] E_w = Well-to-Wheel-Energy-Consumption (MJ), F = Fuel consumption (l), e_w = Well-to-Wheel-Energy-Factor (fuel) (MJ/l)

[5] G_w = Well-to-Wheel-Greenhousegas-Emissions ($kg\ CO2e$), g_w = Well-to-Wheel-Emission-Factor (fuel) ($kg\ CO2e/l$)

[6] E_t = Tank-to-Wheel-Energy-Consumption (MJ), e_t = Tank-to-Wheel-Energy-Factor (fuel) (MJ/l)

[7] G_t = Tank-to-Wheel-Greenhousegas-Emissions ($kg\ CO2e$), g_t = Tank-to-Wheel-Emission-Factor (fuel) ($kg\ CO2e/l$)

travelled via the API of *Openrouteservice* (https://maps.openrouteservice.org/). Figure 2 shows the 137 km route travelled as measured by telemetry GPS coordinates based on the *Openrouteservice* API.

Based on these distances, the CO_2e emissions can be calculated with the load data, truck type and the average fuel consumption. Exemplary results are shown in Figure 3 for the CO_2e emissions of one truck for four trips, whereas the purple curve shows the CO_2e emissions for the distance travelled in Figure 2. Accordingly, it is now possible to analyse the CO_2e emissions along the route.

Mode of transport	e_t (MJ/l)	e_w (MJ/l)	g_t (kg CO_2e/l)	g_w (kg CO_2e/l)
Truck	35,9	42,7	2,67	3,24

Table 1: Energy and emission factors according to DIN EN 16258

Route	E_w (MJ)	G_w (kg CO_2e)	E_t (MJ)	G_t (kg CO_2e)
Part 1	732,305	55,566	615,685	45,791
Part 2	478,24	36,288	402,08	29,904
Part 3	343,735	26,082	288,995	21,494
Total	1554,28	117,94	1306,76	97,19

Table 2: Exemplary calculation of the TCF

Utilization rate	e_t (MJ/1000km)	e_w (MJ/1000km)	g_t (kg CO_2e/1000km)	g_w (kg CO_2e/1000km)
0 %	-	7,49	0,554	0,643
10 %	-	4,22	0,312	0,362
30 %	-	1,59	0,118	0,137
50 %	-	1,07	0,0789	0,0915
70 %	-	0,839	0,0621	0,072

Table 3: Selected emission factors in relation to the utilisation rate

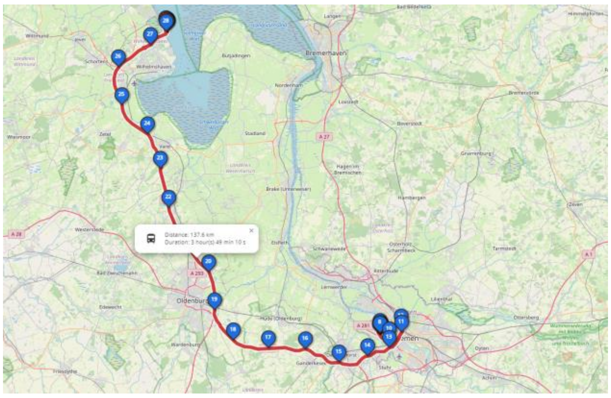

Figure 2: Exemplary travelled Route

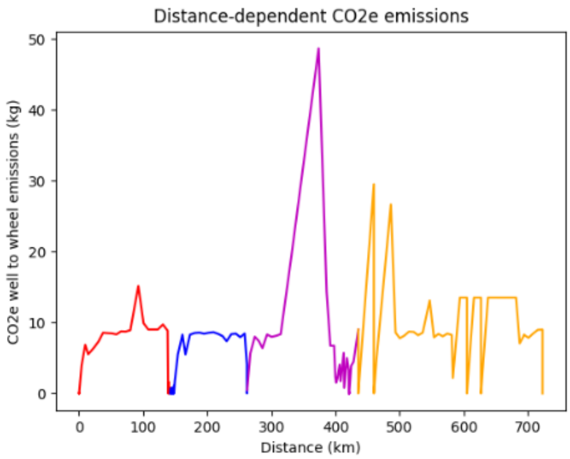

Figure 3: Distance dependent CO_2e emissions

5 Summary and Outlook

In this paper, a model has been proposed which can determine the CO_2e emissions of trailers based on telemetry data. In this proposed model, the routes travelled by the trailers are calculated using an API from Openrouteservice together with the GPS coordinates gathered by telemetry. The CO_2e emissions are then calculated according to DIN EN 16258, considering route length, truck type, load factor and fuel consumption. This will improve the transparency of CO_2e emissions for the logistics of the Krone Group and its customers in the future.

In the further development, an extension of this model will consider the elevation profile of the route and a model-based calculation of the fuel consumption based on the trailer data to further improve the quality of the transport carbon footprint calculation. This enables an even more precise representation of CO_2e emissions and therefore a realistic transport carbon footprint dashboard of trailer logistics in real-time. In addition, it will be possible to offer the service of CO_2e emissions monitoring to customers in the future.

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Bibliography

[Bl20] Blok, K. et al.: Assessment of Sectoral Greenhouse Gas Emission Reduction Potentials for 2030, 2020.

[De13] Deutsches Institut für Normung e. V. (Hrsg.): DIN EN 16258:2013-03, Methode zur Berechnung und Deklaration des Energieverbrauchs und der Treibhausgasemissionen bei Transportdienstleistungen (Güter- und Personenverkehr); Deutsche Fassung EN_16258:2012. Beuth Verlag GmbH, Berlin, 2013.

[HZJ20] He, Z.; Zhang, W.; Jia, N.: Estimating Carbon Dioxide Emissions of Freeway Traffic: A Spatiotemporal Cell-Based Model. IEEE Transactions on Intelligent Transportation Systems 5/21, pp. 1976–1986, 2020.

[La21] Lamb, W. F. et al.: A review of trends and drivers of greenhouse gas emissions by sector from 1990 to 2018. Environmental Research Letters 7/16, p. 73005, 2021.

[Le20] Le Quéré, C. et al.: Temporary reduction in daily global CO2 emissions during the COVID-19 forced confinement. Nature Climate Change 7/10, pp. 647–653, 2020.

[Ma19] Markovic, N. et al.: Applications of Trajectory Data From the Perspective of a Road Transportation Agency: Literature Review and Maryland Case Study. IEEE Transactions on Intelligent Transportation Systems 5/20, pp. 1858–1869, 2019.

[MKK21] Malhi, G. S.; Kaur, M.; Kaushik, P.: Impact of Climate Change on Agriculture and Its Mitigation Strategies: A Review, 2021.

[NO23] NOAA Climate.gov: Global Temperature Anomalies - Graphing Tool. https://www.climate.gov/maps-data/dataset/global-temperature-anomalies-graphing-tool, accessed 30 Apr 2023.

[RF09] Ramanathan, V.; Feng, Y.: Air pollution, greenhouse gases and climate change: Global and regional perspectives. Atmospheric Environment 1/43, pp. 37–50, 2009.

[RM22] Ravi, S.; Mamdikar, M. R.: A Review on ITS (Intelligent Transportation Systems) Technology: 2022 International Conference on Applied Artificial Intelligence and Computing (ICAAIC). IEEE, pp. 155–159, 2022.

[St23] Statista: CO2-Ausstoß weltweit nach Sektoren | Statista. https://de.statista.com/statistik/daten/studie/167957/umfrage/verteilung-der-co-emissionen-weltweit-nach-bereich/, accessed 2 May 2023.

[UB21] Uexkull, N. von; Buhaug, H.: Security implications of climate change: A decade of scientific progress, 2021.

[Um23a] Umweltbundesamt: ProBas - Prozessdetails: LKW oder Lastzug. https://www.probas.umweltbundesamt.de/php/prozessdetails.php?id={11E18C8C-AAB0-5835-A30C-70023B2A8D21}, accessed 13 May 2023.

[Um23b] Umweltbundesamt: ProBas - Prozessdetails: LKW oder Lastzug. https://www.probas.umweltbundesamt.de/php/prozessdetails.php?id={11E18C8C-AAB0-5830-A30C-90023B2A8D20}, accessed 13 May 2023.

[Um23c] Umweltbundesamt: ProBas - Prozessdetails: LKW oder Lastzug. https://www.probas.umweltbundesamt.de/php/prozessdetails.php?id={11E18C8C-AAB0-5835-A30C-70023B2A8D27}, accessed 13 May 2023.

[Um23d] Umweltbundesamt: ProBas - Prozessdetails: LKW oder Lastzug. https://www.probas.umweltbundesamt.de/php/prozessdetails.php?id={11E18C8C-AAB0-5835-A30C-70023B2A8D23}, accessed 13 May 2023.

[Um23e] Umweltbundesamt: ProBas - Prozessdetails: LKW oder Lastzug. https://www.probas.umweltbundesamt.de/php/prozessdetails.php?id={11E18C8C-AAB0-5835-A30C-70023B2A8D25}, accessed 13 May 2023.