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Review

An updated literature review of CO_2e calculation in road freight transportation

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ABSTRACT

In recent decades, increasing emphasis is being placed on sustainable freight transport. The aim of this study is to discern how detailed the calculation of CO_2e emissions in road transport is. For this, the study conducted a sample review with 53 scientific sources and 121 annual reports. Only 14 out of the 53 scientific sources incorporated emissions that occur as a by-product of energy supply. Not more than 14 of the 121 companies included emissions from transportation activities of both the upstream and downstream processes. Therefore, the study highlights the necessity for new and validated models to support decision-making processes that sustainably reduce CO_2e emissions.

Introduction

In 2016, the international community set a goal to limit global warming to below 2°C by 2050. (United Nations, 2015) An evaluation by the Intergovernmental Panel on Climate Change (IPCC) that considered 6,000 studies revealed that this target will not be met; instead, an increase of 3.2°C is likely to occur (Figueres et al., 2018, United Nations Environment Programme, 2019). The main driver of this anthropogenic climate change is an increase in the amount of greenhouse gases (Le Quéré et al., 2018). In order to facilitate better comparison of the effects of various greenhouse gases, they are expressed in a common metric measure called CO_2 equivalent (CO_2e). Road transport, for example, is responsible for 11.9% (5.88 Gt of CO_2e out of 49.4 Gt of CO_2e) of global CO_2e emissions (Ge and Friedrich, 2020). According to the International Energy Agency, road freight accounted for approximately 40% of the total road transport emissions in 2018 and was responsible for 2.4 Gt of CO_2e (Teter, 2020).

The above facts suggest that emissions from freight transport should be reduced to achieve climate targets. Technical and organizational approaches to this end exist, however, to ascertain which approaches have a high impact, we need to know where and how much CO_2e is emitted. The objective of this study is to provide a literature review of the methods used for calculating the emissions from road freight transportation and to analyze and appraise scientific papers and annual reports regarding their evaluation of emissions in the transportation sector. Additionally, our objective is to investigate how the different calculation methods vary from each other. Therefore, our review systematically covers the complete range of emissions, from direct emissions to emissions that occur in connection with administrative tasks.

An overview of the methods used is provided in Section 2, followed by a literature review in Section 3 where we link the system boundaries (SB) (Greene and Lewis, 2019, McKinnon and Piecyk, 2010) for calculating transport-related emissions with the relevant factors influencing the emission from road freight transportation (EcoTransIT World Initiative, 2019). Subsequently, we analyze

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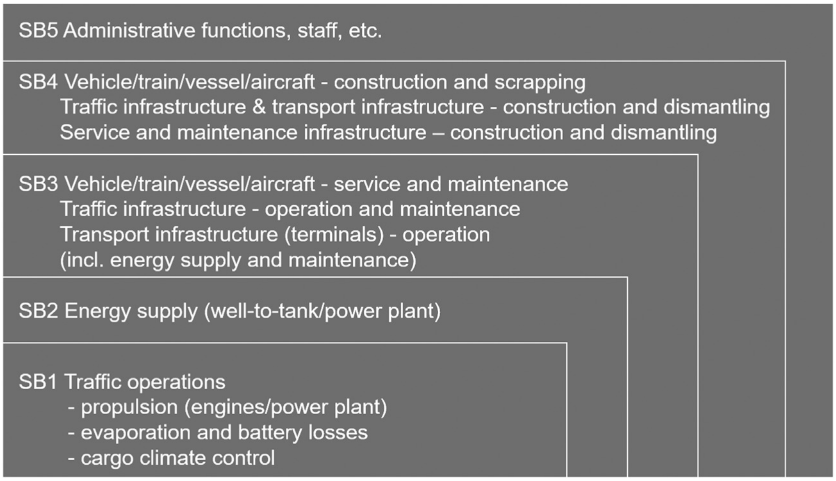

Fig. 1. System Boundaries 1 to 5 concerning transport operations for carbon calculation (McKinnon and Piecyk, 2010).

the extent to which the regulations, guidelines, calculation tools, scientific articles, and company publications take the SB and the influencing factors into account for their emission prediction. In Section 4, we present our conclusion, and identify the need for future research.

Overview of the Applied Research Methodology

Categorization of Literature Sources

Many different methods exist to define SB for emissions. For example, the Greenhouse Gas (GHG) Protocol with its three "scopes" is suitable for all industries, including logistics and transportation companies (World Resources Institute, 2011, Greene and Lewis, 2019) However, the GHG Protocol is not sufficiently specific to be applied in logistics. Therefore, the Network for Transport Measures (NTM) has created a GHG-Protocol-compliant methodology to assess emissions from road freight transportation (McKinnon and Piecyk, 2010). The NTM defines five SB (SB1 to SB5) for transportation-related CO_2e emissions (see Fig. 1):

- SB1 comprises direct emissions from actual transport operation.
- SB2 includes well-to-tank emissions (DIN EN 16258).
- SB3 includes emissions caused by service and maintenance of the vehicle as well as operation and maintenance of the traffic and transport infrastructure.
- SB4 is broader in scope and encompasses construction and scrapping of the vehicle as well as construction and dismantling of the traffic, transport, service, and maintenance infrastructure.
- SB5 includes emissions due to administrative functions, personnel, and others.

Not all SB are required for every type of decision. SB1 ought to be considered for operational decisions such as route planning. SB2 needs to be considered when deciding on the fuel types to be purchased. SB3 plays a part in tactical decisions such as consolidating within logistics hubs or intermodal transport using transshipment points. SB4 and SB5 are factored in for strategic decisions such as the supply chain network design or road freight infrastructure projects.

For direct emissions, which the NTM reports in SB1, a more detailed method of calculation exists:

Fifteen influencing factors for CO_2e emissions from transportation were identified as part of the EcoTransIT.(EcoTransIT World Initiative, 2019) They are listed in Table 1.

As the focus of this literature review is on the transportation of a single shipment between two locations by truck, the factors of length of landing and take-off/drive cycle, intermodal transfer, and trade-line-specific ships are irrelevant. This leaves 12 influencing factors for consideration. The literature sources can be reviewed in full using the SB of the NTM with details on the influencing factors of EcoTransIT within SB1.

Conducting the Literature Review

The query contains the keywords "transport," "road," "CO_2," "cost," and "freight" and were entered in the search engines Scopus and Google Scholar. In addition to "CO_2," "CO_2e" and "CO^*" were also searched. Only publications from 2010 or later were considered. The first 100 results of each query were checked for relevance. This procedure uncovered 53 relevant scientific sources:

- 11 guidelines,
- 3 tools,

Table 1
EcoTransIT—main factors influencing energy consumption (EcoTransIT World Initiative, 2019).

Group	Influence Factor
Vehicle, vessel	Type, size, payload capacity
	Drive, energy
	Technical and emission standard
Traffic route	Road category, waterway class
	Gradient, water/wind resistance
Driving conditions	Speed
	No. of stops, acceleration
	Length of landing and take-off cycle/cruise cycle
Transport logistics	Load factor
	Empty trips
	Cargo specification
	Intermodal transfer
	Trade-lane specific vessels
Transport work	Cargo mass
	Distance traveled

- 2 literature reviews, and
- 37 scientific articles.

Although we have identified the most relevant publications for road freight transport focusing on CO_2 using this approach, we do not claim that our research is exhaustive.

In addition to reviewing scientific articles, the review includes the annual reports of

- 30 DAX companies,
- 30 Dow Jones companies,
- 50 Euro Stoxx companies, and an additional
- 26 major logistics companies not listed on DAX, Dow Jones, or Euro Stoxx.

Our goal was to examine whether and to what extent annual reports apply the standards and scientific classifications of CO_2e assessment. Since it was already clear from a rough survey that the level of detail about CO_2e emission in the annual reports is significantly lower than in the scientific sources, the following simplified questions were asked:

- According to which standard is the CO_2e calculation performed?
- Does the report show CO_2e emissions from logistics operations?
- If CO_2e emissions from logistics operations are reported, are they divided into emissions from ocean, road, and air transport?
- Does the report address the accuracy of the company's CO_2e calculations?
- By reviewing annual reports as well as scientific contributions, we were able to map the extent of the applications of different considerations of CO_2e calculation in logistics.

Descriptive Statistics

This section presents the results of the analysis of the literature sources identified as described in Section 2.2. The sources were compared using the classification described in Section 2.1. Emissions within the five SB were considered individually in their respective subsections; only SB4 and SB5 were combined to ensure a critical mass of publications. The results of the evaluation of the annual reports are presented in the last subsection.

Guidelines and Tools

Guidelines

The Global Logistics Emissions Council (GLEC) framework has highlighted that its guideline is mostly compliant with the NTM factors (Greene and Lewis, 2019). The impact factor of speed is the only factor that is not considered. The Science-Based Targets (SBTi) (Luna and Villasana, 2018) have the same main authors as the GLEC framework and cover the same impact factors. Since the EcoTransIT(EcoTransIT World Initiative, 2019) standard is the source for the SB1 breakdown, all factors are considered in EcoTransIT.

The European Norm (EN) 16258(DIN EN 16258) does not consider road category, gradient, speed, acceleration, or load specification. The French standard 2011-1336(Direction de l'information légale et administrative 2011) has the same SB as EN 16258 but unlike EN 16258, it specifies uniform default values.

The Federal Association for Freight Forwarding and Logistics Germany's (DSLV) guidance "Calculating GHG Emissions for Freight Forwarding and Logistics Services" in accordance with EN 16258 (Schmied and Knörr, 2013) includes the same EN 16258 factors as those found in SB1.

The German federation of the chemical industry (VCI) (VERBAND DER CHEMISCHEN INDUSTRIE e.V., 2010) and the SmartWay guidance by the Environmental Protection Agency (EPA) (EPA, 2020) differ in their focus on SB1. The EPA focuses on vehicular factors, whereas the VCI focuses on transportation logistics factors.

In their report on the measurement and management of CO_2 emissions from European chemical transportation, (McKinnon and Piecyk, 2010) accurately highlight the importance of the SB and provide examples of their effects. Although the authors mention all five SB, they apply SB1 in their report.

Tools

In order to assess emissions from transport operations, the NTM has developed the (NTM Calc. 4.0 2020). This tool takes into account most (nine out of 12) influencing factors. Speed, number of stops, empty runs, and cargo specifications are the only factors that are not directly considered. However, emissions from empty runs can be calculated separately and can be added later. Besides, empty runs are already considered in the master data.

The EcoTransIT calculation tool (Siefer and Radtke, 2020) does not directly consider the road gradient, speed, nor the number of stops or accelerations. With the Planning Transport Traffic (PTV) Map&Guide tool, (PTV MAP & GUIDE, 2020) all EcoTransIT influencing factors can be taken into account.

Scientific Sources

Literature Review

Two literature reviews were identified in the literature search: one by Soysal et al. (2012) and one by Demir et al. (2014). Soysal et al. have reviewed 36 quantitative models for sustainable food logistics management, and five of the 36 publications include emissions from transportation (Soysal et al., 2012): These five publications were by Gebresenbet and Ljungberg (2001), Akkermann et al. (2009), van der Vorst et al. (2009), You et al. (2012) and Oglethorpe (2010).

The comprehensibility of the calculation of emissions in road freight transport varies. Akkermann et al. for example include environmental effects in their model, but do not specify how CO_2 emissions are evaluated. They refer to Hauschild et al. (2005) who wrote about life cycle assessments but did not specify how transport emissions are evaluated.

The literature review by Demir et al. (2014) focuses on direct factors influencing fuel consumption. They identify 24 influencing factors such as vehicular, environmental, traffic, driver, and operational factors and review 25 emission models to determine which of the 24 influencing factors were included: None of the emissions models covered every factor, but each influencing factor was included in at least one of the 25 models.

Scientific Papers

Thirty-three of the 37 identified scientific papers use driving distance as an influencing factor. We could not classify the remaining four scientific papers—by Sadeghi Rad and Nahavandi (2018), Vierth et al. (2019), Jonkeren et al. (2019) and Stenico de Campos et al. (2019)—using the classification presented above, because it was unclear how the CO_2 emissions were calculated.

For instance, Stenico de Campos et al. use fuel consumption to determine the CO_2 emission value and claim that this method is more accurate than modeling CO_2 emissions directly in most cases. However, Stenico de Campos et al. employ an average time-based diesel consumption for different payload classes within different vehicle fleets and do not link this value to the transportation performance.

Of the remaining 33 scientific papers, Zhang et al. (2015) is the only one that uses travel distance as the sole influencing factor. Six other papers use driving distance along with a second influencing factor. In 2011, Paksoy et al. (2011) use a default value taken from a 1999 source, referring to a 1995 publication. Unfortunately, we could not access this source in order to clarify the origin of the parameter values. Binh and Tuan, (2016), Figliozzi, (2011), Guajardo, (2018), Cadarso et al., (2010), and Park et al., (2012) also use a second influencing factor.

Four of the remaining 26 papers refer to three influencing factors. As a third influencing factor, Lättilä et al., (2013) and Kengpol et al., (2014) refer to the cargo mass. Regmi and Hanaoka, (2015) and Pålsson et al., (2017) are the remaining two studies.

Four more papers consider four influencing factors: In addition to travel distance, Fan Y.V. et al., (2018), Shimizu and Sakaguchi, (2013) and Mrabti et al., (2020) consider the cargo mass and loading factors. Craig et al. Craig et al., (2013) use empty runs, propulsion, and emission standards.

Three of the remaining 18 scientific papers consider five factors. Zanni and Bristow, (2010) and Rahimi et al., (2017) take into account energy and speed. Fridell et al., (2019) use the road categories and loading factors, among others.

Three other scientific papers use six influencing factors. Cenek et al., (2012) include road slope, while Ozen and Tuydes-Yaman, (2013) consider the engineering standards and emission standards and thus differ from Piecyk, (2010) who uses propulsion and energy. Another four papers consider seven factors, and Harris et al., (2011) have even assessed eight influencing factors. Kim et al., (2009) differ significantly from Rizet et al., (2012), Boer et al., (2011) and Wygonik and Goodchild, (2011) by considering the road gradient.

Three papers— Soysal et al., (2018) Cavallaro et al., (2013) and Liimatainen et al., (2014)—include nine influencing factors. Nocera and Cavallaro, (2016), De and Giri, (2020) and Ballot and Fontane, (2010)—take into account 10 influencing factors, and Odhams et al., (2010) assess 11 influencing factors.

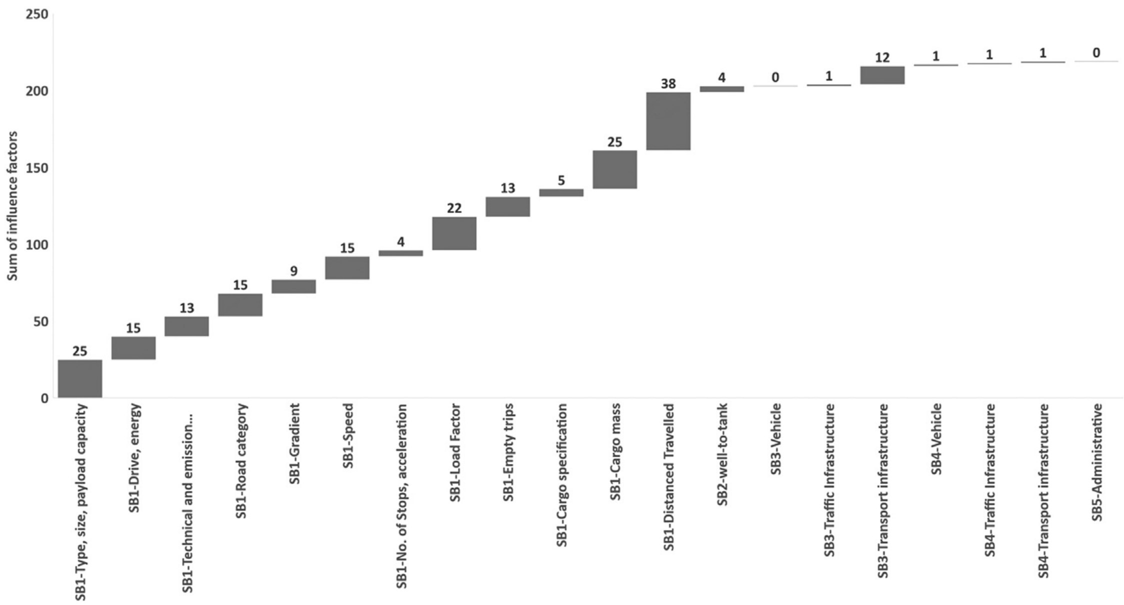

Fig. 2. Sum of influencing factors from SB1 to SB5.

Additional Evaluation of Emissions within SB2

The calculation of well-to-tank emissions (definition explained in Greene and Lewis, (2019)) is an integral part of seven out of 10 guidelines and tools. Only four of the 37 scientific papers consider well-to-tank emissions and all four sources use different methodologies and parameters to determine well-to-tank emissions.

Additional Evaluations of Emissions within SB3

In contrast to emissions within SB2, emissions within SB3 are predominantly not considered in the guidelines and tools, except in the NTM (Network for Transport Measures, 2015). The GLEC (Greene and Lewis, 2019) and SBTi (Luna and Villasana, 2018) even recommend that emissions from the transportation infrastructure be evaluated in terms of logistics locations. The GLEC framework specifically considers emissions from fuel and electricity used to store or transport goods within the facility. It also recommends including direct losses from refrigerants.

Ten out of 37 scientific papers consider CO_2 emissions within SB3. Fridell et al., (2019) is the only source that considers emissions from the operation and maintenance of traffic infrastructure, which identified the main factors influencing emissions from a road and determined the primary energy required for maintenance and operation.

Additional Evaluation of Emissions within SB4 and SB5

Table 2 illustrates an overview of the SB as mentioned in the respective sources. The scientific papers are listed according to the number of SB influencing factors they use. Fig. 2 depicts the frequency with which individual influencing factors are used in the 37 scientific articles.

Impact of Factor Influences

This study illustrates in Section 0 that the influencing factors are taken into account in varying degrees. Within this section, we demonstrate with the following examples, the impact of each factor on CO_2e emissions:

- SB1 Road category: up to 40% of total emissions (Schmied and Knörr, 2013)
- SB1 Fuel: 6.74% decrease using biodiesel in place of diesel (DIN EN 16258)
- SB1 Emission class: 3% decrease using Euro V as a replacement for Euro III (DIN EN 16258)
- SB1 Gradient: +/-6% depending on the gradient (Notter et al., 2019)
- SB1 Speed: 9.5% decrease by slowing down from 90 km/h to 80 km/h (Kim and van Wee, 2014)
- SB2 Well-to-tank: 21.49% of SB1 value (DIN EN 16258)
- SB3 Traffic infrastructure: 1 to 7% of SB1 and SB2 combined (Fridell et al., 2019)
- SB4 Traffic infrastructure: 0.45% from SB1 and SB2 combined (Fridell et al., 2019)

Table 2
Overview of SB1 to SB5 based on the sources.

																		Scientific Papers ordered by the number of influence factors incl. in SB1																																									
SB	Infl. Factors	Guidelines										Tools				Lit. Review		0						1-2									3			4						5			6				7-8				9					10		11	
		DIN EN16258	Fr.Nr. 2011-1336	GLEC	IPCC	SBTi	VCI-Leitfaden	DSLV	McKinnion	McKinnon	EPA Smart Way	NTM	NTM Calc. 4.0	EcoTransit	PTV Map &	Demir	Soysol	Bilgen	Akkerman	Rad	Stenico	Vierth	Jonkeren	You	v. d. Voerst	Cadarso	Paksoy	Park	Zhang	Binh	Figliozzi	Guajardo	Lättila	Kengpol	Regmi	Palsson	Oglethrope	Fan	Shimizu	Mrabti	Craig	Pan	Rahimi	Zanni	Fridell	Cenek	Ozen	Piecyk	Rizet	Den Boer	Wygonik	Kim	Harris	Gebres	Soysol	Cavallaro	Liimataien	Nocera	De	Ballot	Odhams
SB1	Type, size,	Y	Y	Y	Y	Y	Y	Y	Y	-	Y	Y	Y	Y	Y	(48/58)	(3/36)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	Y	Y	-	Y	Y	Y	-	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	Y	Y	Y	Y	Y	Y	Y	Y	Y
SB1	Drive, energy	Y	Y	Y	Y	Y	-	Y	Y	-	Y	Y	Y	Y	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	Y	-	Y	Y	-	Y	-	Y	-	-	Y	Y	Y	-	Y	Y	Y	Y	Y	-	Y
SB1	Tech & emmis.	Y	Y	Y	Y	Y	Y	Y	Y	-	Y	Y	Y	Y	Y	(12/58)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	Y	-	-	Y	-	Y	Y	Y	-	Y	-	Y	Y	Y	Y	Y	-	Y
SB1	Road category	-	-	Y	Y	Y	-	-	Y	-	Y	Y	Y	Y	Y	Y	(1/36)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	Y	Y	Y	-	Y	Y	-	Y	Y	Y	Y	Y	Y	Y	Y	Y
SB1	Gradient	-	-	Y	Y	Y	Y	-	Y	-	-	Y	Y	-	Y	(12/58)	(1/36)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	Y	-	Y	Y	Y	-	Y	Y	Y	Y
SB1	Speed	-	-	-	Y	-	-	-	Y	-	Y	Y	-	-	Y	(46/58)	(2/36)	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	Y	Y	Y	-	-	-	-	Y	-	Y	Y	Y	Y	Y	Y	-	Y	Y	Y	Y
SB1	No. stops,	-	-	Y	Y	Y	-	-	Y	-	-	Y	-	-	Y	(16/58)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	Y	Y	Y
SB1	Load factor	Y	Y	Y	Y	Y	Y	Y	Y	-	Y	Y	Y	Y	Y	Y	(3/36)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	Y	Y	Y	Y	Y	-	Y	-	-	Y	-	Y	Y	Y	Y	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
SB1	Empty trips	Y	Y	Y		Y	Y	Y	Y	-	Y	Y	-	Y	Y	Y	(1/36)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	Y	-	-	-	-	Y	Y	Y	Y	Y	Y	-	-	Y	-	-	Y	Y	-	Y	Y
SB1	Cargo spec.	-	-	Y		Y	Y	-	Y	-	-	Y	-	Y	Y	Y	(1/36)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	Y	-	Y	-	-	Y	-	-	Y	-
SB1	Cargo mass	Y	Y	Y		Y	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	(4/36)	-	-	-	-	-	-	-	Y	Y	Y	Y	-	Y	-	-	Y	Y	-	Y	Y	Y	Y	Y	-	Y	Y	-	Y	-	-	-	Y	-	-	Y	-	Y	Y	Y	Y	Y	Y	Y	Y
SB1	Distanced trav.	Y	Y	Y		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	(5/36)	-	-	-	-	-	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
SB2	Well-to-tank	Y	Y	Y		Y	-	Y	Y	-	-	Y	Y	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	Y	-	Y	-	-	-	-	-	Y	-	-	-
SB3	Vehicle	-	-	-		-	-	-	Y	-	-	Y	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SB3	Traffic infrast.	-	-	-		-	-	-	Y	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SB3	Transport	-	-	Y		Y	-	Y	Y	-	-	Y	-	-	-	-	(3/36)	-	-	-	-	-	-	Y	Y	-	-	Y	Y	-	-	-	Y	-	-	-	Y	-	-	Y	-	-	Y	-	-	-	-	-	-	Y	-	Y	Y	-	-	-	-	-	Y	-	-
SB4	Vehicle	-	-	-		-	-	-	Y	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SB4	Traffic infrast.	-	-	-		-	-	-	Y	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SB4	Transport	-	-	-		-	-	-	Y	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SB5	Administrative	-	-	-		-	-	-	Y	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Y= included; - = not included

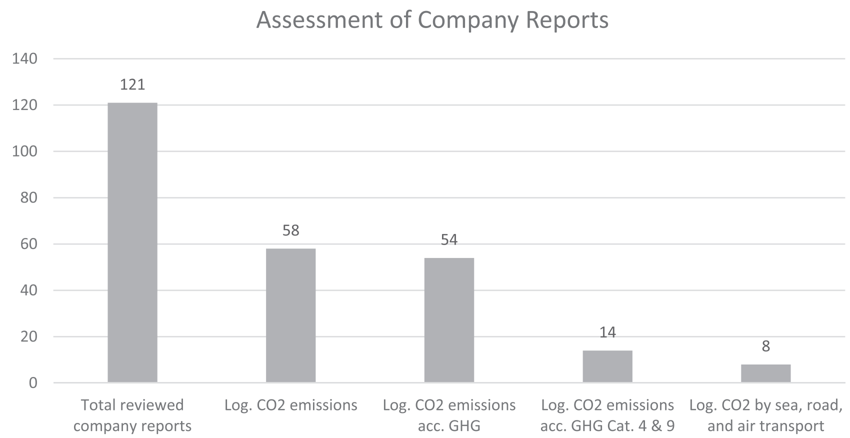

Fig. 3. Assessment of Company Reports.

Assessment of Company Reports

A total of 121 annual reports from 2019 were evaluated. Among all the reports, 115 mapped out future targets and activities to reduce their greenhouse gas footprints in their reporting, 96 published a sustainability report, and 25 companies included their corporate social responsibility reporting in their annual reports or other media. The remaining four companies did not publish any report on corporate social responsibility nor did they include emission figures in any other published report.

Fifty-eight of the 121 companies reported logistics-related CO_2 emissions, and 55 out of these followed the GHG Protocol. However, only 14 companies reported upstream and downstream processes according to categories 4 and 9 of the GHG Protocol; Linde plc. and Siemens AG only reported downstream processes. In contrast, 3M and Nokia Corporation only reported upstream processes. Eight of the 121 companies divided their CO_2 emissions into sea, road, and air transport emissions. There is no information in any of the annual reports about the calculation accuracy or meaningfulness of the CO_2 accounting, and it remains unclear whether the companies have calculated their fuel consumption. In Fig. 3 the assessment of the scrutinized company reports is visualized.

Conclusions

Based on the SB system and the influence factors included, we have analyzed guidelines, tools, scientific papers, and annual reports of firms. Most guidelines consider SB1. Only 14 out of the 53 scientific sources incorporated emissions that occur as a by-product of energy supply and some highlight the importance of SB3 to SB5 but do not provide any specific method to calculate them. All influencing factors in SB1 and SB2 can be calculated with the PTV tool. Scientists have applied SB1 incompletely and SB2 to SB5 poorly. Only a few companies have taken the CO_2e emissions of road freight transport into account in their reports. Those that did so did not indicate which SB were considered.

Simultaneously, we also find that within SB1, depending on the selection of the influencing factors taken into account, the result of the calculated CO_2e emissions can vary by more than 50%, or, when SB2 to SB5 are also considered, by more than 29%. Under no circumstances can this deviation be considered an acceptable basis for decision-making aimed at reducing CO_2e emissions. We therefore conclude that there is an urgent need for the scientific community to provide models that support decision-making on operational, tactical, or strategic levels with the corresponding SB1 to SB5 to reduce CO_2e emissions in a sustainable manner. These models must be validated, and prediction errors must be calculated.

Declaration of Competing Interest

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

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