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Technical Note

Materials Carbon Budget in Road Projects: A Case Study from The Greater Oslo Region

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Abstract: The estimation of carbon dioxide emissions in relation to the life cycle of road pavements is pivotal to quantify their sustainability at the design stage. This preliminary study assesses the carbon budgets concerning the production of aggregates and asphalt to build a new roadway stretch located close to Oslo (Norway), leveraging digital tools and environmental product declarations. First, the software Trimble Novapoint estimates the necessary quantity take-offs. Afterwards, the amounts of CO_2 generated during the production of the construction materials are appraised for the four main industries operating nearby. The results based on the corresponding environmental product declarations indicate that the carbon budgets show very small discrepancies among the considered suppliers.

Keywords: road pavement; carbon dioxide emission; environmental product declaration; production stage; building information modelling

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Citation: Khair, M.; Strzalkowski, P.; Faizi, A.Q.; Barkal, M.G.; Fawakherji, I.; Lima, M.; Adeysey, M.; Barbieri, D.M.; Lou, B. Materials Carbon Budget in Road Projects: A Case Study from The Greater Oslo Region. *Infrastructures* **2024**, *9*, 132. https://doi.org/10.3390/infrastructures9080132

Academic Editor: António Couto

Received: 4 July 2024
Revised: 31 July 2024
Accepted: 8 August 2024
Published: 10 August 2024

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1. Introduction

Traditionally, the design, construction, and maintenance of road pavements is mainly performed in view of technical and economic considerations [1,2]. At the same time, as the growing global population is facing the environmental burdens generated by anthropogenic activities [3], there is a shared consensus to curtail GreenHouse Gases (GHGs) and pollution in general [4,5]. Among the nations targeting such curtailment, Norway aims to achieve a 40% reduction in its GHG emissions compared to 1990 levels by 2030 [6]. In this context, transport agencies are increasingly shedding light on the sustainability aspects related to roads' life cycles [7,8] and, in particular, on the emission of carbon dioxide, which is a major driver of the greenhouse effect and climate change [9,10]. In many countries, the quantification of CO_2 is being spotlighted as a pivotal criterion for the public procurement of infrastructural projects by implementing various measures (e.g., carbon tax, emission trading system, CO_2 performance ladder) [11–13].

The two main natural resources employed to build the layered structure of a road pavement are aggregates and bitumen. Aggregates alone typically constitute the lower unbound courses, while they are mixed with bitumen to create Asphalt Concrete (AC), namely the black-coloured material forming the upper bound courses. In Europe, the total production of AC has been as high as 300 million tons per year since 2008 [14]. In general, the production of road construction materials faces challenges related to their availability, costs, and performance. Further, this industrial sector has long been recognized for its substantial environmental impact due to the extensive use of energy-intensive

processes [15,16], thus also encouraging the application of alternative and more sustainable technologies [17–20].

Life Cycle Assessment (LCA) evaluates the environmental burden (e.g., atmospheric emissions, solid wastes, hazardous by-products) associated with all the life stages of a service, process, or product, spanning from raw material extraction to end-of-life disposal [21,22]. Therefore, this technique can highlight the life stages that are the sources of the most impactful emissions. Even if the implementation of LCA in civil engineering is still in its infancy compared to other industrial sectors [23], there is an increasing amount of research specifically revolving around its application to road infrastructures [24–26].

By presenting a case study conducted in the Norwegian municipality of Bærum, the overarching goal of this work is to assess the CO_2 generated during the production stage of road construction materials (i.e., aggregates, AC) that can be supplied by the four major companies operating nearby. Leveraging the software Trimble Novapoint to estimate the necessary quantity take-offs and the Environmental Product Declarations (EPDs) to assess the carbon budget pertaining to each industrial supplier, this preliminary work highlights the importance of implementing the most sustainable decisions during road design [27,28].

2. Methodology

2.1. Road Design and Digital Tools

A typical road structure is composed of multiple layers to effectively distribute the traffic loads acting on the surface to the natural subgrade soil. Starting from the top, the courses laid on the soil are commonly denominated as the wearing, binder, base, and subbase layers, and their respective thicknesses generally increase [1]. The construction materials employed in each layer must meet stringent physical, geometrical, and mechanical requirements to ensure a well-performing pavement structure [29,30]. In Norway, these criteria are set by the design code "N200" developed by the Norwegian Public Roads Administration (NPRA), which implements a mechanistic–empirical design approach following the workflow depicted in Figure 1 [31].

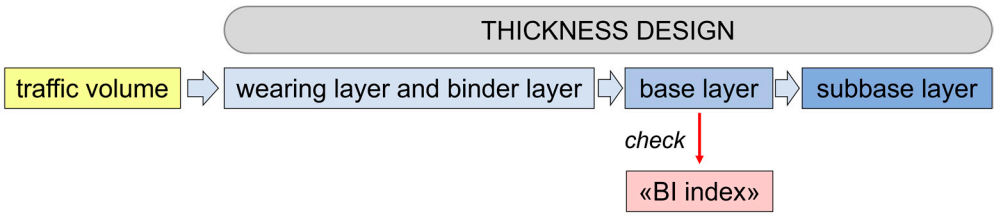

Figure 1. Road pavement design workflow according to the design code "N200", adapted from [32].

Such a design procedure initially considers the number of equivalent 10-ton axles corresponding to the Average Annual Daily Traffic of Heavy vehicles ($AADT_H$) anticipated for the road lifespan. The material types and thicknesses of the wearing and binder layers are directly decided considering the traffic volume, whereas the thickness of the base layer is designed based on the chosen construction material. The wearing, binder, and base courses are then assigned "load distribution coefficients" ("*lastfordelingskoeffisienter*" in Norwegian), which are used to appraise the corresponding "base layer index" ("*bærelagindeks*") (BI), assessed against a minimum threshold (BI_{min}). Eventually, the subbase course is designed based on the subgrade type.

Building Information Modelling (BIM), which is a digital semantic representation of planned or existing built facilities [33], was initially applied to buildings [34] and, at a later stage, to transport infrastructures [35,36]. As BIM was implemented early in the Nordic countries, Norway currently exhibits a wide distribution spanning across public and private stakeholders, as well as education institutions [37,38]. When it comes to the public agencies related to transport infrastructure, it is worthwhile to stress that guidelines have come forth for both roadway [39] and railway [40] design. Currently, the digital tools developed by the software house Trimble are largely employed in Norway owing

to their user-friendly working environment, cloud-based solutions, and attractive cost. As far as transport infrastructure engineering is concerned, Trimble Novapoint software can seamlessly develop georeferenced 3D models, perform various types of analyses (e.g., terrain, traffic, drainage), and share data with third parties in real time [41].

2.2. Environmental Product Declaration

From an LCA perspective, the life cycle of a road pavement can be broken down into four stages, which are further subdivided into modules: the production stage (A1–A3), the construction stage (A4–A5), the use stage (B1–B7), and the end-of-life stage (C1–C4) [21,22]. This study only focuses on the carbon dioxide emissions released during the production stage of road construction materials, namely aggregates and AC, as described in Section 1. The three corresponding modules A1, A2, and A3 deal with raw material supply, transport, and manufacturing, respectively (Figure 2).

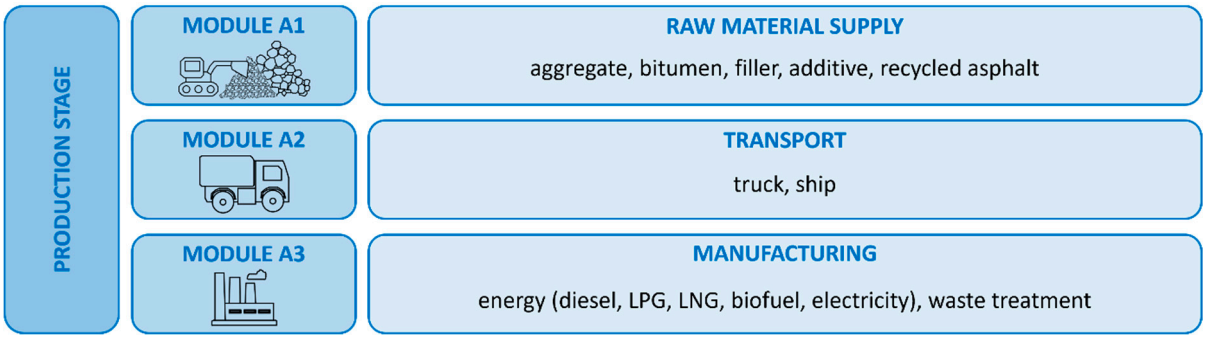

Figure 2. LCA production stage and corresponding modules A1, A2, and A3.

An Environmental Product Declaration (EPD) is a document that quantifies the environmental impact of a product based on an LCA performed by an independent party [21,22], thus enabling an apples-to-apples comparison between the different commercial alternatives a consumer or client can choose from [42]. The EPDs referred to in this study are supplied by EPD-Norway [43], which is an accredited programme operator with an established system for the verification, registration, and publication of approximately 3000 EPDs which also cover construction products [44,45]. In this work, the content of the consulted documents only pertains to the evaluation of CO_2 derived from modules A1, A2, and A3. Moreover, such quantification of carbon dioxide emissions may be subsequently imported into the VegLCA spreadsheet developed by NPRA to calculate the total carbon budget of road projects [46].

The database sources leveraged by EPD-Norway to create the EPDs used in this work derive from LCA.no [47], Eurobitume [48], and ecoinvent [49]. The production processes for the raw materials and energy flows accounting for less than 1% are not considered (such cut-off criterion does not apply to hazardous materials). Furthermore, even if this research only focuses on the assessment of CO_2 as the central parameter for sustainability rating [46], it may be worth mentioning that EPDs also quantify other relevant pollutants such as stratospheric ozone depletion (kg CFC-11 eq), tropospheric photochemical oxidants (kg C_2H_4 eq), acidification of land and water (kg SO_2 eq) and particulate matter (PM).

2.3. Case Study: "Gjønnes" Tunnel

The case study location is in the municipality of Bærum, which lies approximately 20 km west of Oslo. As illustrated in Figures 3 and 4, the project involves building a road pavement inside the new tunnel "Gjønnes" connecting highway E18 to the road "Bærumsvei" in addition to creating an open area with roundabouts and junctions [50,51]. The twin-bore tunnel has a length of 1950 m, and its cross-section corresponds to the T9.5 profile, with two 3.5 m wide lanes in each direction [52]. The road is designed to have a lifespan of 20 years, with the $AADT_H$ value being equal to 1000 units.

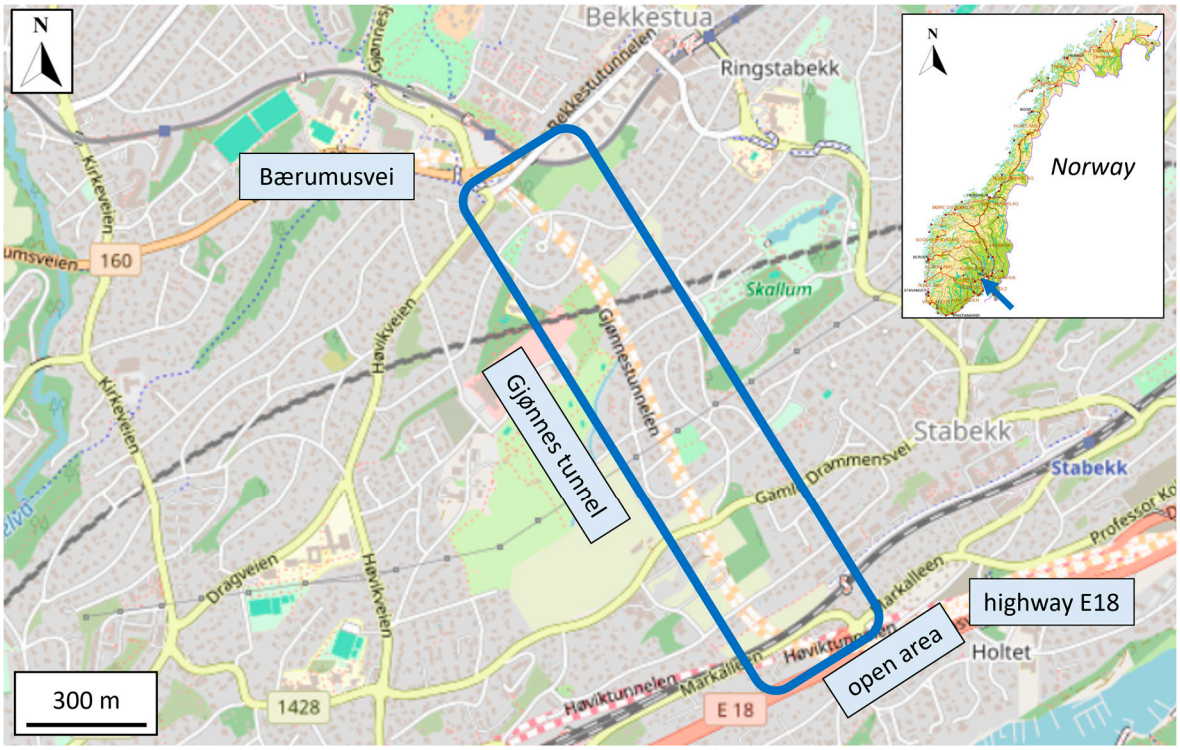

Figure 3. Location of the road project [53].

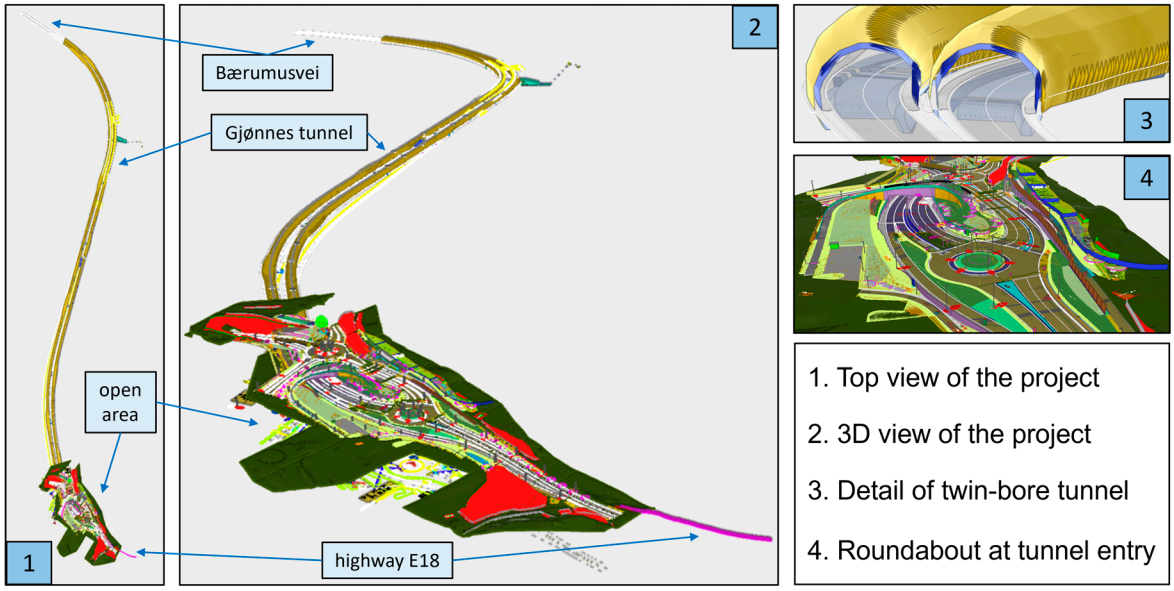

Figure 4. General overview of the project, obtained with the use of Trimble Novapoint **(tunnel structure in yellow, open areas in green and red)**.

This study appraises the carbon budget related to the production of road construction materials. In this regard, the four main industrial suppliers operating in the greater Oslo region are considered (Figure 5), namely NCC, Peab, Veidekke, and Velde, which are denominated as Supplier A, Supplier B, Supplier C, and Supplier D, respectively.

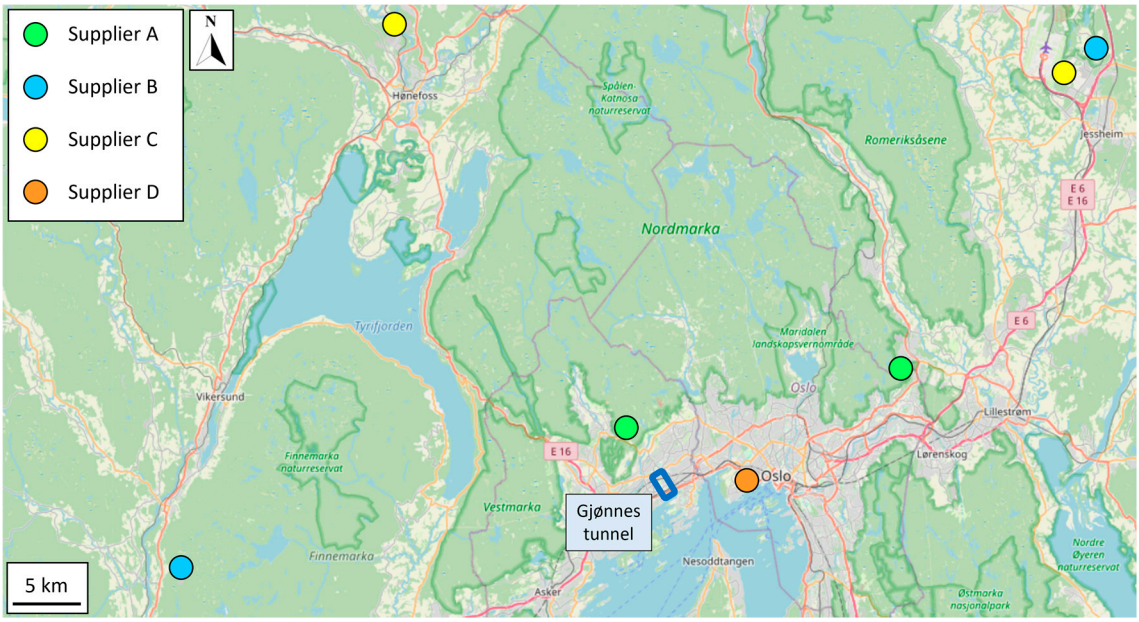

Figure 5. Location of the asphalt plants pertaining to the industrial suppliers [53].

3. Results and Discussion

The road pavement is dimensioned according to the design procedure outlined in Section 2.1. The number of equivalent 10-ton axles anticipated during the road lifespan is between 3.5 and 10 million, which corresponds to traffic group "E" [31]. The construction materials used for the wearing and binder layers are Asphalt Concrete (AC, "*asfaltbetong*" in Norwegian). In this regard, the maximum aggregate size is 16 mm, and Polymer-Modifed Bitumen (PMB) is applied to enhance durability. The base layer comprises Asphalt Gravel (AG, "*asfaltert grus*") with a particle dimension up to 16 mm. Lastly, the subbase layer is made of crushed rock ("*pukk*") with an aggregate size between 4 mm and 90 mm. Table 1 summarizes the information regarding material type and thickness for each road layer [31]. It is worth highlighting that the material specifications deriving from the road pavement design code "N200" are in line with the European standards [54,55]. The software Trimble Novapoint automatically assesses the corresponding quantity take-offs.

Table 1. Overview of construction materials and their thicknesses and quantities.

Road Layer	Construction Material	Thickness (cm)	Quantity (ton)
Wearing	AC 16 PMB	5	11,549
Binder	AC 16 PMB	5	11,549
Base	AG 16	12	34,959
Subbase	Crushed rock 4/90	25	73,989

Information about the environmental impact of the selected materials produced by the four suppliers is contained in the respective EPDs [43]. In this study, the emission factor refers to the amount of CO_2 in kg generated during the production of one ton of material for modules A1 (raw material supply), A2 (transport), and A3 (manufacturing). As displayed in Table 2, the emission factor related to the production of AC, which entails a high energy demand to heat bitumen and aggregates, is one order of magnitude higher than for aggregates alone [56,57]. Further, it is possible to observe that the emission factors related to the subbase layer are similar (the difference between the maximum and minimum values is 0.57 kg_{CO_2}), whereas considerable variations can be observed for asphalt materials (the difference between the maximum and minimum values is 15.88 kg_{CO_2} for AG and 20.60 kg_{CO_2} for AC). The discrepancies between the values of the emission factors

pertaining to the industrial suppliers can be naturally ascribed to all the different material and technological solutions (e.g., material sources, type of machinery), logistic choices (e.g., geographical location of the providers of raw materials, transport mode), and asset management plans (e.g., maintenance of production plants) that are implemented during the production process of the construction materials, as depicted in Figure 2.

Table 2. Emission factors and total CO_2 emissions for different material suppliers.

Road Layer	Supplier A		Supplier B		Supplier C		Supplier D	
	Emission Factor [a]	CO_2 Emission [b]	Emission Factor [a]	CO_2 Emission [b]	Emission Factor [a]	CO_2 Emission [b]	Emission Factor [a]	CO_2 Emission [b]
Wearing	37.40	432	46.90	542	26.30	304	35.89	414
Binder	37.40	432	46.90	542	26.30	304	35.89	414
Base	19.49	681	18.16	635	34.04	1 190	25.66	897
Subbase	2.32	171	2.11	156	2.68	198	2.34	173
TOTAL		1716		1874		1995		1899

[a] kg of CO_2 released during production of one ton of material (LCA modules A1, A2, A3). [b] total tons of CO_2 considering the material quantities reported in Table 1.

By multiplying the emission factor for the quantity take-offs reported in Table 1 and summing the results for each road layer, the total CO_2 emissions can be appraised for every industrial company, as detailed in Table 2. The mean value among all the companies is 1871 t, and the emissions generated by each of them are approximately within ± 8% (150 t) of the average amount. From an engineering point of view, the discrepancies are very small for the material quantities needed in this case study: this outcome documents that the carbon budgets related to the suppliers' industrial production are similar. Therefore, a possible criterion that could cause the engineer to choose a specific supplier instead of another could be related to the CO_2 released along the transport route between the production plant and the construction site (module A4 of construction stage). This matter could represent an interesting topic for future research.

4. Conclusions

Policymakers and engineers need to assess road projects against their environmental impacts in addition to technical and economic requirements to ensure that the road designs align with sustainability goals. In this regard, Life Cycle Assessment (LCA) is a pivotal technique for ascertaining the carbon footprint associated with all the life cycle stages of a pavement.

This concise study has revolved around the creation of a new roadway stretching for more than 2 km in the municipality of Bærum in the greater Oslo region, Norway. The structural design has been carried out according to the Norwegian pavement design code "N200", which is in line with European standards when it comes to material selection and designation. Further, the BIM software Trimble Novapoint has performed the project georeferencing and estimated the necessary quantity take-offs.

The main goal of this preliminary research was to achieve the quantification of the CO_2 emissions generated during the production of road construction materials, namely aggregates and asphalt (LCA modules A1, corresponding to raw material supply, A2, corresponding to transport, and A3, corresponding to manufacturing). In this regard, this study considered the Environmental Product Declarations (EPDs) pertaining to the main four industrial suppliers operating in the greater Oslo region. The average carbon budget was found to be 1871 t. The results show that the carbon budgets pertaining to all the companies are very similar for the material quantities needed in this case study.

Future research could encompass the other life cycle stages of roadways not addressed in this preliminary research, namely the construction, use, and end-of-life stages, in addition

to considering transport distances. In this way, a more comprehensive carbon budget framework could shed light on the least sustainable stages, thus enabling the implementation of the most convenient technological or management strategies.

Author Contributions: M.K.: Data Curation, Formal Analysis, Investigation, Methodology, Software, Visualization, Writing—Original Draft. P.S.: Data Curation, Formal Analysis, Investigation, Methodology, Software, Visualization, Writing—Original Draft. A.Q.F.: Data Curation, Formal Analysis, Investigation, Methodology, Software, Visualization, Writing—Original Draft. M.G.B.: Data Curation, Formal Analysis, Investigation, Methodology, Software, Visualization, Writing—Original Draft. I.F.: Data Curation, Formal Analysis, Investigation, Methodology, Software, Visualization, Writing—Original Draft. M.L.: Conceptualization, Project Administration, Resources, Supervision, Writing—Review and Editing. M.A.: Conceptualization, Data Curation, Methodology, Project Administration, Resources, Supervision, Visualization, Writing—Review and Editing. D.M.B.: Conceptualization, Data Curation, Methodology, Project Administration, Resources, Supervision, Visualization, Writing—Original Draft. B.L.: Conceptualization, Data Curation, Methodology, Project Administration, Resources, Supervision, Visualization, Writing—Original Draft. All authors have read and agreed to the published version of the manuscript.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data Availability Statement: Dataset available on request from the authors.

Conflicts of Interest: Authors Martina Lima and Mohammed Adeysey were employed by the company AFRY Norway AS. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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