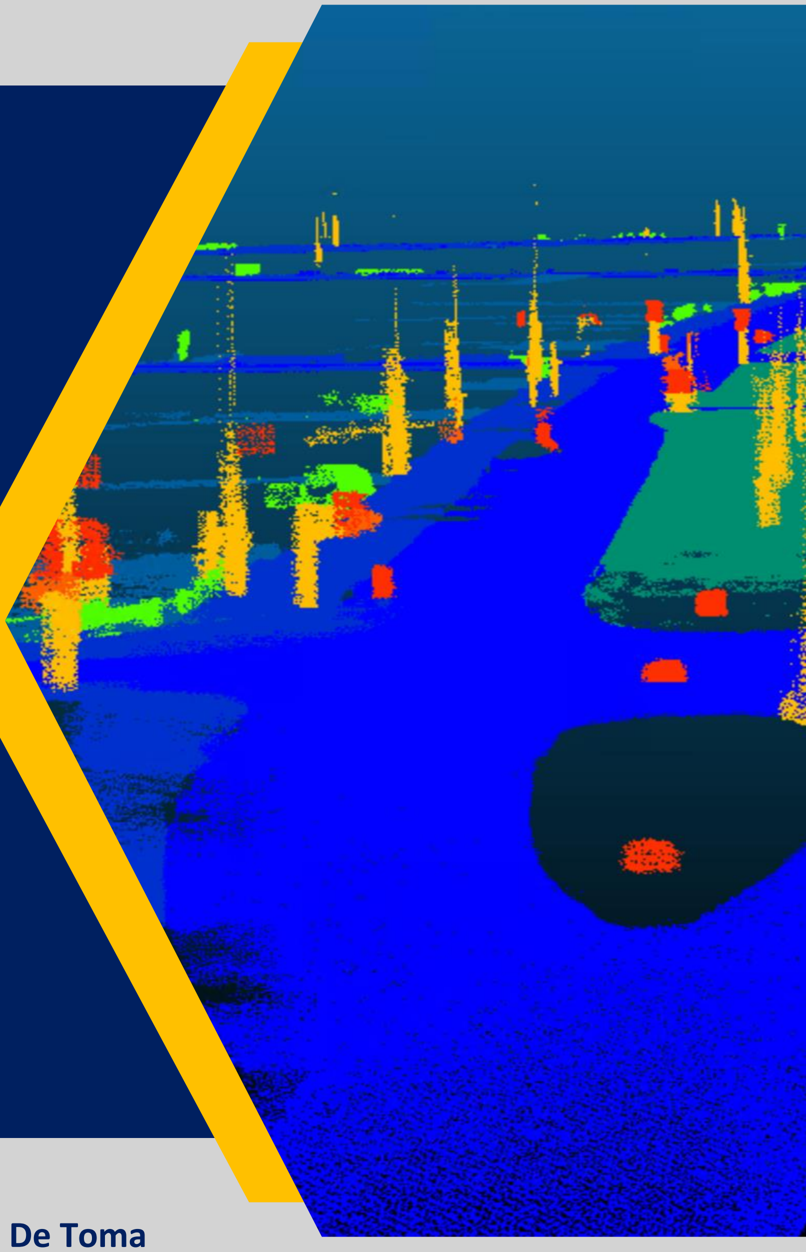
FUTURE ROADS

Building Trustworthiness in Carbon Data to Achieve Net-Zero Across the Life of Highway Assets



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1. The Problem

"Every year, the negative impacts of climate change become more intense. Every year, they bring more misery and pain to hundreds of millions of people across the globe. Every year, they become more a problem of the here and now, as well as a warning of tougher consequences to come. We are in a climate emergency. To get on track to limiting global warming to 1.5°C, we would need to cut 45 percent off current greenhouse gas emissions by 2030. For 2°C, we would need to cut 30 percent. A stepwise approach is no longer an option."

---- IPCC Emissions Gap Report 2022

The transportation sector is responsible for nearly 40% of end-user carbon emissions. In 2019, direct carbon emissions from the transport sector were 8.7 Gt CO_2e (up from 5.0 Gt CO_2e in 1990), compromising 23% of global energy-related CO2 emissions[1]. Roads and highway transportation, as a sub-sector, are a major contributor, contributing to 75% of global transport sector emissions[2]. At the same time, they are a major contributor to society and economy. Roads and highways provide crucial infrastructure that connects people, goods, and services. For example, in the UK, 95 million miles are travelled on its strategic road network (SRN) each year; the SRN carries 3 times more people than UK rail network; the SRN is responsible for 77% of all domestic freight; 7.4 million people are employed in SRN-dependent industries[3]. **The decarbonisation of the transportation sector is critical to achieving a Net Zero Economy.**

Governments are recognizing the importance of reducing emissions in transport. Returning to the case of the UK, the government has introduced incentives for the use of electric vehicles and has invested in the development of charging infrastructure. The country has also made significant investments in the development of low-carbon highways, implementing energy-efficient design and construction standards, the development and use of low-carbon materials in the construction of new highways, and the retrofitting of existing highways to reduce emissions.

However, the pressure is on to progress and expand these efforts to meet aggressive decarbonisation targets and this requires coordinated effort. One major barrier is that development and management of road assets involves many stakeholders both across the sector and within large client organisations. **These stakeholders often rely on obtaining information from others to understand the carbon impacts of their decisions**. In response to this, *PAS 2080: Carbon Management in Infrastructure* was introduced in 2016 to guide the carbon management across infrastructure development value chains. The "value chain" encompasses any organisation involved in creating, operating, and managing assets. A revised and expanded version, *PAS 2080: Carbon management in buildings and infrastructure,* was released in March 2023, covering both infrastructure and buildings and including aspects from the materials to design, construction, as well as the use of a structure, including demolition and disposal. There is growing momentum of support for this welcome guidance on collaborative principles across the value chain. However, PAS 2080:2023's scope does not extend to covering ***how* the underlying collection, sharing, reporting, and analysis of data takes place**. Once an organization commits to PAS 2080, this is the necessary next step to address.

[1] Oladunni, O. J., & Olanrewaju, O. A. (2022). Effects of the Impact Factors on Transportation Sector's CO2-eq Emissions: Panel Evaluation on South Africa's Major Economies. *Atmosphere*, *13*(10), 1705.

[2] IEA, Global CO2 emissions from transport by sub-sector in the Net Zero Scenario, 2000-2030, IEA, Paris https://www.iea.org/data-and-statistics/charts/global-co2-emissions-from-transport-by-sub-sector-in-the-net-zero-scenario-2000-2030, IEA. Licence: CC BY 4.0

[3] Highways England Strategic Road Network Initial Report. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/666884/Highways_England_Strategic_Road_Network_Initial_Report_-_WEB.pdf

2. Data Trustworthiness in Carbon Management: The Issues and Value to the Industry

2.1. The Data Trustworthiness Issues

Carbon data is the fundamental prerequisite of evidence-based carbon management decision-making and actions. **Data trustworthiness refers to the degree to which data can be relied upon to be authentic, accurate, consistent, secure, and free from bias.** Highly trustworthy data needs to be accurate, up-to-date, and ideally verifiable. Without trustworthy data, governments, asset developers, and other value chain stakeholders risk making incorrect assumptions, setting unrealistic targets, taking unreasonable actions that may even lead to the contradictory direction of the Net-Zero target, and failing to achieve their carbon reduction goals.

Considering this in the context of carbon data trustworthiness, the Wall Street Journal recently report that a key problem facing regulators and companies is that: "**Some of the most important and widely used data is hard to both measure and verify**", especially for Scope 3 emissions, where "measurement, target-setting, and management of Scope 3 is a mess." Scope 3 emissions are the "result of activities from assets not owned or controlled by the reporting organization, but that the organization indirectly affects in its value chain"[4]. Meaningfully measuring, verifying and acting on Scope 3 emissions is indeed a future horizon for the highway sector (and likely wider infrastructure sectors in general). However, managing Scope 1 and 2 emissions is still a work in progress. **While there are efforts to measure, verify and manage Scope 1 and 2 emissions, this is not yet a mature and highly effective process**. Improvements are needed to address this, while bearing in mind the possibility of a greater focus on Scope 3 in the future.

There are several missing factors contributing to the low level of carbon data trustworthiness, including:

1) Lack of consistent and accurate data on carbon emissions and other relevant indicators.
2) Lack of coordination, collaboration, and integration across all levels of value chain, including the management, operations, and employees.
3) Lack of clear and consistent policies and regulations at international, national, and sector levels can make it difficult to collect trustworthy carbon data.
4) Lack of significant resources, including funding, technology, and expertise.

2.2. An Example of Carbon Data Trustworthiness Issue

Data trustworthiness in carbon management is a shared challenge across infrastructure sectors, this example exploring just one broad use case observing data flowing from a major capital project into a wider asset monitoring system. This case is informed by observations of the highway sector but could generally reflect any situation where there is a new asset being built that is becoming part of a wider existing network.

We can see that, from this single use case in Figure 1, **data availability and data quality are two major problems**. The heterogenous data sources, prolonged value chain, and segmented stages of sharing all present possible hurdles. Data validation procedures can be time-consuming and costly, and it can be difficult to ensure data quality. Organizational level reporting for a major asset owning client requires accumulating data from across its project portfolio, and any compatibility and security problems in earlier phases will affect the ability to create meaningful datasets.

[4] https://www.epa.gov/climateleadership/scope-3-inventory-guidance#:~:text=Scope%203%20Resources-,Description%20of%20Scope%203%20Emissions,scope%201%20and%202%20boundary.

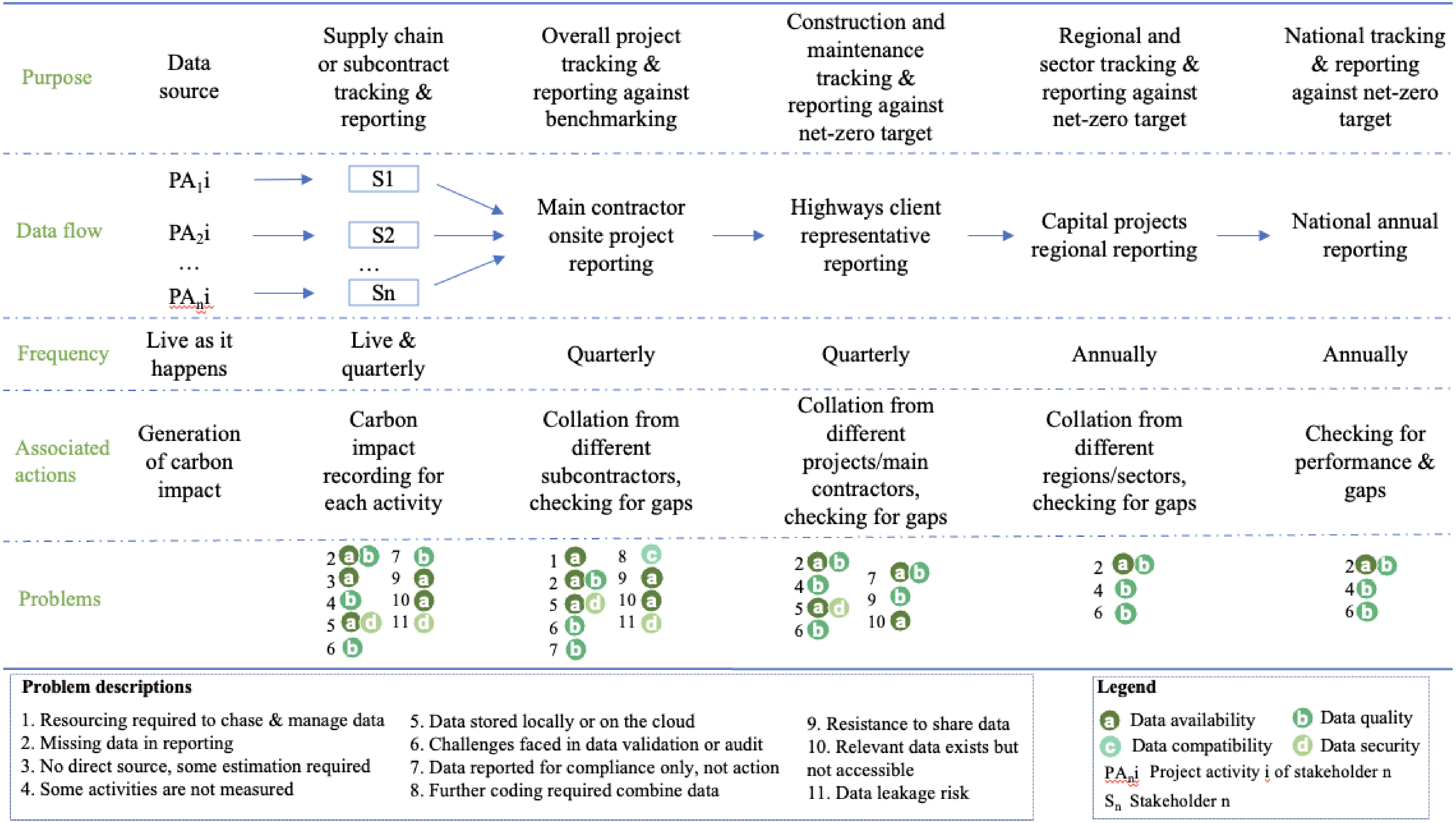

Figure 1. A use case of carbon data flow through a construction project to highway owner reporting

2.3. The Value of Data Trustworthiness

Albeit there are many issues, in the context of carbon management, data trustworthiness is critical to the success of carbon reduction initiatives and the accuracy of the results of those initiatives. It can enable governments to precisely monitor the emission reduction performance in meeting the Net-Zero Target, monitor how the policies are executed and whether they are sufficient, through the supply of good data. It allows asset developers to accurately measure and track their carbon footprint, set meaningful targets for reduction, and report on their progress. It also facilitates contracting requirements setting clear targets for performance, through the ability to accurately determine if required performance levels have been met. The benefits of having trustworthy carbon data in the infrastructure sector are numerous:

1) Better decision-making: trustworthy data helps to ensure that evidence is sound and comprehensive as the starting point for informed decisions.
2) Improved project planning: Accurate carbon data can inform project planning, reducing the risk of errors, unexpected costs, and delays in achieving net-zero targets.
3) Cost savings: By reducing carbon emissions, infrastructure projects can often save money on energy costs, as well as avoid potential penalties for exceeding emissions limits.
4) Regulatory compliance: Many jurisdictions have regulations related to carbon emissions, and trustworthy carbon data can help infrastructure projects stay in compliance with these rules.
5) Improved reputation: Infrastructure projects that demonstrate a commitment to carbon reduction can enhance their reputation with investors, customers, and the public.
6) Better collaboration: trustworthy data can provide a strong belief among value chain stakeholders that strategies and plans can be trusted and valued, providing a solid basis for collaborations.

3. The 4 Pillars of Carbon Data Trustworthiness

We suggest that there are four key pillars of carbon data trustworthiness: data availability, data quality, data compatibility, and data security. Each pillar is supported by key attributes that collectively contribute to improving carbon data trustworthiness, see Figure 2.

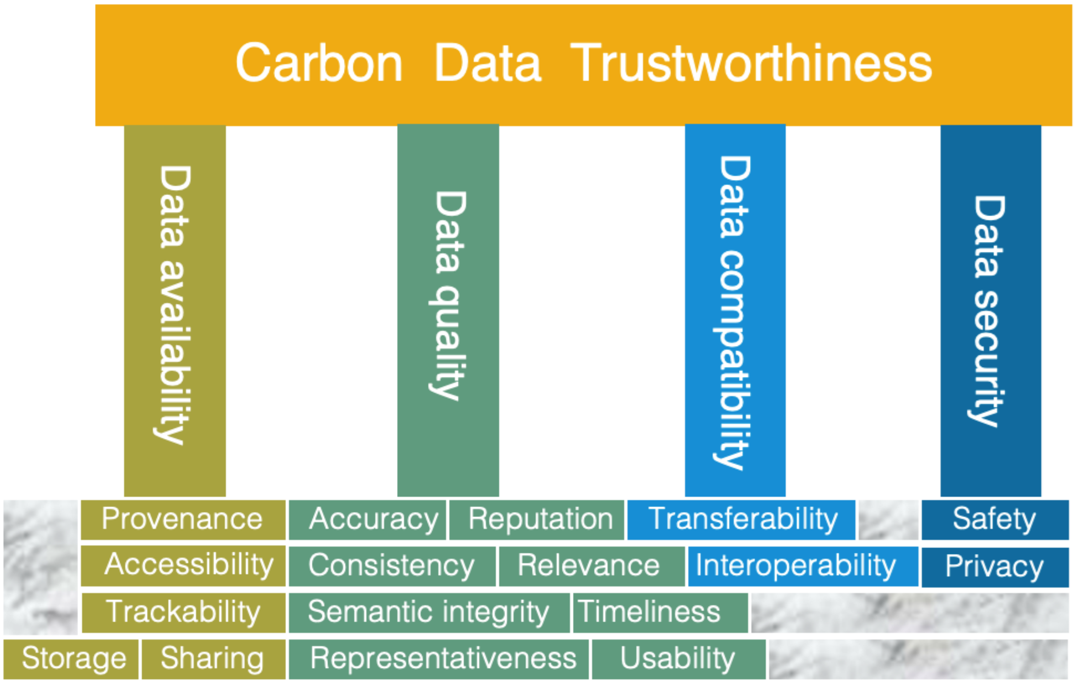

Figure 2. The four pillars of carbon data trustworthiness

3.1. Data Availability

Data availability concerns the ability to obtain the data to measure what one needs. Carbon data availability enables stakeholders to access, use, and analyse the data for various purposes, such as sustainability reporting, benchmarking, and carbon management decision-making.

3.1.1 Data provenance

Data provenance relates to the ability to trace back the complete history of data sources. The key attributes of carbon data provenance typically include information about the origin, such as the project, the activity, the location and time, and the basis on which it was generated, as well as information about its ownership and any transfers or sharing it has undergone. This information could be recorded in a carbon registry or database for transparency and accountability in carbon calculation and reporting.

3.1.2 Data accessibility

Data accessibility is the ability to access the collected data. This issue is a prevalent concern that has been widely reported by both practitioners and researchers. Most of the data required for carbon reporting and accounting already exists in some direct or indirect forms, the challenge lies in how and where to access such data. There is a paradox that value chain stakeholders want to access data from others but are concerned and reluctant to share their own data to others. A clear data access mechanism is needed for easier accessibility while avoid repeated data collection.

3.1.3 Data trackability

Data trackability is the ability to trace and verify the movement of carbon emissions data through the value chain. Data tracking enhances transparency and accountability in the carbon reporting process. However, the lack of standardized processes for reporting carbon emissions at a livelier manner makes it difficult to track data across activities and organizations. Timestamps and involved persons for reporting data are two factors that should be recorded to enable data trackability.

3.1.4 Data storage and sharing

Carbon management requires the disclosure and sharing of carbon data among the value chain stakeholders. In the highway sector, there is a long list of value chain stakeholders. Current data silos and privacy concerns make it challenging to share data across them. Data storage should be secure so that data owners can feel confident in their ability to protect sensitive information, while also providing a means to share carbon data for informed carbon reporting and data interrogation for better decision-making across the value chain.

3.2. Data Quality

Data quality refers to the degree to which data meets the required standards of accuracy, reliability, and completeness. It is critical for ensuring the trustworthiness of carbon data as it impacts the quality of data-informed decisions about sustainability performance, risk management, and regulatory compliance. To ensure data quality, it is important to consider several key factors, including accuracy, reputation, adaptability, consistency, timeliness, relevance, representativeness, and usability.

3.2.1 Data accuracy

Data accuracy refers to the degree to which data precisely reflects the real-world. In the case of carbon data, it is about the carbon emissions produced by construction, operation, and maintenance activities. Ensuring accurate carbon data is important for quantitatively analysing the environmental impact of highway infrastructure and making informed decisions about how to reduce that impact. To achieve accurate carbon data, standardized carbon accounting methodologies and advanced data collection technologies can help. Carbon data may be generated through manual reporting of information or through automatic capture via devices that are directly monitoring activity. Direct and automated recording is ultimately the desirable goal where this will both reduce the possibility of error created in manually inputting data into spreadsheets and relieve personnel tasks at repeated intervals.

3.2.2 Data consistency

Data consistency refers to the uniformity of data across different stages, systems, or applications. This involves ensuring that the data is structured, formatted, and validated in a way that is consistent and reliable. Consistency over time ensures that data is properly attributed from its final use to its source along the data flow. Good data consistency practice ensures the consistent allocation of responsibility for those involved in the data flow with the carbon management policies and procedures, and that any issues or errors in data are properly documented and addressed. Consistency is a highly aligned term with trackability under the pillar of Data availability, but trackability is focused on the ability to trace the movement of data, while consistency is the uniformity of the data itself.

3.2.3 Data timeliness

Timeliness in data collecting, accounting, reporting, sharing, and analysing requires establishing the ideal frequency of these activities, which should be based on the purposes of carbon management. For a company to generally report carbon in a yearly manner, the data can be collected and reported in a less timely manner than the monthly and quarterly report. Also, if the purpose is to actively manage carbon emissions on a construction site, then quarterly retrospective reporting that is delayed through manual data collection, review and approval presents a significant barrier. In this case, ad-hoc data collection and analysis would better meet the timeliness requirement.

3.2.4 Data relevance and usability

Carbon data relevance refers to the degree to which the data is applicable to the decision-making process, while carbon data usability refers to the degree to which the data can be effectively analyzed and interpreted for carbon management purposes. The identification of the purpose of data, the choice of appropriate data collection and analysis technologies, the availability of data on all relevant emissions sources, the use of standardized carbon accounting methodologies, the ability to effectively transfer and interpret heterogenous data, as well as engaging stakeholders in a standardised data collection process can help achieve higher carbon data relevance and usability in the highway infrastructure sector.

3.2.5 Data representativeness

Carbon data representativeness refers to the extent to which the data accounts for the real carbon generation. The generation of carbon is a complex process that involves many variables and factors, and the data used to represent this process should ideally accurately reflects the reality of the situation. This is generally simplified through establishing standardized assumptions for the rate of emissions associated with processes and material use. While material embodied carbon is easier to represent, the construction and operation activity carbon is still hard to be accurately and comprehensively represented with simpler methods.

3.2.6 Data reputation

Data reputation refers to the credibility of data reported. Carbon data reputation has the potential to influence the credibility of an organization's sustainability claims and can impact its reputation in the eyes of investors, customers, and other stakeholders. This potential will increase alongside increasing requirements to manage and report on carbon emissions. Data reputation is established through achieving other attributes in this pillar and can be assessed by the extent to which organisations achieve other attributes.

3.3. Data Compatibility

Data compatibility concerns different data sources and systems to be shared and integrated seamlessly, and exchange data in a sensible and accurate manner. Data transferability and interoperability are its two significant attributes.

3.3.1 Data transferability

Data transferability is the ability to move data between different systems, platforms, and stakeholders without losing any information. It requires systems and platforms to be able of exporting data to different transferable formats and importing data from different sources and formats. Its significance to carbon management lies in its ability to improve collaboration, efficiency, and accuracy in the carbon reporting process, leading to improved visibility across stakeholders, reduced duplication, less data loss, and faster decision-making. Some problems associated with carbon data transferability are the limited functions of systems and platforms, diversity of data sources and formats, data privacy and security concerns, and the complexity of data transfer between organizations, particularly for smaller ones with limited resources and technical expertise.

3.3.2 Data interoperability

Data interoperability is the ability of different data systems and platforms to communicate data seamlessly. It is focused on ensuring that data can be used and understood by different systems without significant modifications of its structure and formats. It is an attribute on top of data transferability. With numerous data being created, data interoperability concerns how to ensure the data, either from different versions of hardware or software, or from different systems developed by different vendors, can be integrated easily, not just to be transferred. However, the lack of standardization in the carbon data structure and carbon reporting process makes it difficult to interoperate data across different stages, organizations, and industries. The diversity of data sources and formats can also pose challenges in data integration and standardization, leading to inconsistencies and inaccuracies in reported data.

3.4. Data Security

Data security is a crucial pillar to ensure the trustworthiness of carbon data. It refers to the protection of data from unauthorized access, use, modification, or destruction, and involves measures to protect the confidentiality, integrity, and availability of data. Data security is significant because it helps to build trust among stakeholders by ensuring that data is accurate, reliable, and protected against potential threats. We include data safety and data privacy as two key attributes of data security.

3.4.1 Data safety

Data safety focuses on protecting data from accidental or intentional loss, corruption, or destruction, and involves measures such as backup systems, data redundancy, and disaster recovery plans. Effective data safety measures can help organizations comply with data protection regulations and prevent reputational damage, financial losses, or legal liabilities that can arise from data breaches or cyber-attacks. The complexity of implementing and maintaining effective data safety measures, the diversity of data sources, formats, and stakeholders, and the increasing sophistication and frequency of cyber-attacks and data breaches pose constant threats to carbon data safety, highlighting the need for continuous monitoring and improvement of data safety measures.

3.4.2 Data privacy

Data privacy focuses on protecting personal or sensitive information from unauthorized access or disclosure, and involves measures such as access controls, encryption, and data anonymization. The diversity of data sources and formats involved in the carbon reporting process can make it difficult to ensure that personal and sensitive information is adequately protected across different systems and platforms. On the other hand, data privacy regulations can create barriers to data sharing and hinder effective collaboration among stakeholders, particularly when dealing sensitive information. How to balance the data privacy protection and data sharing is an important issue for carbon data trustworthiness.

4. Key Success Factors for Achieving Data Trustworthiness

This whitepaper proposes an idealized model for achieving trustworthiness through a combination of well-designed standardized data models, reliable data sources, automatic data collection methods, strict data quality control, regular validation procedures, transparent data management systems, and robust data protection. The six key success factors are mapped against with the four pillars of data trustworthiness in Table 1 to highlight the relevance of each pillar to the success factors.

Table 1. Mapping key success factors to the four pillars of data trustworthiness

Key pillars / Key success factors	Data availability	Data quality	Data compatibility	Data security
1. Standardized Data Model	✓	✓	✓	
2. Reliable Data Sources	✓	✓		
3. Automatic Data Collection Methods	✓	✓	✓	
4. Data Quality Control		✓		✓
5. Transparent Data Management System			✓	✓
6. Robust data protection		✓		✓

4.1. Standardized Data Model

A standardized data model includes standardized data protocols, schemes, formats, and exchange mechanisms. This helps to ensure that data can be easily transferred, combined, compared, and analysed between different systems, and that the data remains accurate and consistent, even as it is passed from one system to another. In designing a standardized carbon data model, a key consideration is the compatibility of the data protocol, scheme, and formats with that of the existing systems and infrastructure by using data mapping and data integration tools that allow data from different systems to be shared, transferred, and integrated.

4.2. Reliable Data Sources

Reliable sources are essential in ensuring that the data used is reliable and can be trusted to inform decisions. Such data sources include updated and verified carbon factor databases, quantity and activity data collected using reliable methods, and advanced technologies that collect data in a reliable way. It is important to validate the data sources using expert review and other cross verification methods to ensure the quality and accuracy of data. To meet the data requirements, it may be necessary to combine data from multiple supplementary sources and get a comprehensive picture of carbon emissions across the infrastructure lifecycle. In such cases, the reliability of each data source should be weighted so that their impact on the final decision-making can be considered.

4.3. Automatic Data Collection Methods

The trustworthiness of carbon data is largely dependent on the quality of the data collection methods used. This includes the consistent use of standardized measurement instruments and their calibration, as well as the appropriate data collection protocol. In the case of highway infrastructure sector, it is important to use a combination of direct and indirect measurement methods to collect carbon data. Manual input can be laborious, prone to error, lacking efficiency and cost-effectiveness. Comparatively, automatic data collection methods, making the most of existing sensors, monitoring systems, and other measurement tools, can be more accurate, consistent, efficient, standardized, and therefore, more trustworthy. It needs to be addressed that many current automatic data collection methods for the purpose of safety, progress, and quality, can be used for carbon data collection as well. The initial financial and technical investment would not be overwhelming, but its potential benefits are huge.

4.4. Data Quality Control

Quality control is essential throughout the data collection, processing, and analysis stages. Data quality control procedures include: (1) establishing clear guidelines for data collection and entry; (2) using data profiling, data testing, and data reconciliation techniques to ensure data completeness, accuracy, and consistency; (3) developing and implementing data management policies and procedures to ensure that carbon data is stored, processed, and managed in a consistent and secure manner; (4) continuously monitoring the data to identify and correct any data quality issues, and to detect and prevent data corruption and loss; (5) establishing data governance processes to ensure that data is managed, used, and shared in a responsible and ethical manner, and that data privacy and security are protected; (6) regularly reviewing, verifying, and updating the data, data collection and analysis processes to ensure that it is accurate and consistent, and to identify and resolve any issues; (7) developing and implementing data archiving and preservation processes to ensure that data is properly stored and preserved for future use.

4.5. Transparent Data Management System

Carbon data should be managed in a secure, controlled, and transparent environment to ensure its trustworthy storage, sharing and usage over time. Organizations should invest in transparent and auditable data management systems to make it easy to share data, while still maintaining data security and privacy. Some potential directions of effort include permission-based data access mechanism, common data environment (CDE), and tools that allow for the tracking and management of data sharing activities.

4.6. Robust Data Protection

Robust encryption algorithms and other protective measures can keep stored data safe from unauthorized access or tampering. This includes measures such as access control, firewalls, the use of checksums or hashes to validate the data, the use of backup and recovery procedures, and the implementation of data auditing and version control processes to ensure that information can be retrieved in the event of a security breach or other unexpected event.

5. How Can Technology Help

For organizations to set meaningful targets for carbon reduction, they must have the means to collect the required data in a form where it can be accessed and analysed.

Our observations of current industry practice in the road and highway sector highlight the use of an up-to-date carbon factor database and environmental production declarations for reference data. Project bill of quantities, Excel-based records and some form of certification or assurance methods are used for project carbon data collection and reporting. These processes are maturing and provide a certain level of detail. New software applications are emerging to improve the overall data collection and management process. However, the collection of carbon-related data predominantly relies on on-site manual input and is typically stored across different organisations and systems. It is the heterogenous nature of this data, and its varying levels of accuracy, which contributes to issues of trustworthiness.

Digitalisation and automation technologies have a core role to play in resolving current issues. Although the potential of such technologies has been widely discussed, the capabilities that exist in principle have not yet been fully leveraged for carbon management. For example, building information modelling (BIM) is claimed to have the ability to generate a bill of quantities, the cost, and carbon impacts automatically. But the current application BIM in the road and highway sector does not yet fully harness these capabilities. Efforts to develop BIM and digital twin technologies for road and highway development and management need to account for carbon quantification requirements. In addition, to solve the manual input problems, auto-identification technologies, sensor technologies, and computer vision might be used. This is the starting point in terms of data collection but needs to be integrated into an enterprise-wide system (with the ability to support compatibility across the supply chain).

To store and manage data, cloud-based solutions need to be explored. The solution will require the ability to federate data across systems as well as analyse possible sensitive data will protecting privacy. This will support the data availability and security pillars of the data trustworthiness concept. Machine learning might then be adopted to cleanse and integrate data from multiple sources to ensure the required data quality.

The next step in our research is to use standard provided by PAS 2080 as a starting point to build supporting engineering and business technology capabilities to collect, share, report, and analyse carbon utilization in a trustworthy manner. The objective is to (A) resolve the issues explored under the four pillars of carbon data trustworthiness (Figure 1), with a focus on the highway sector in the UK, and (B) demonstrate how technology can provide accurate and reliable insights on progress towards net zero targets. We invite other stakeholders to work with us to create the basis on which a coordinated system of technologies could work for the sector.

SAP are collaborating as a partner of the Future Roads research programme, to explore how their existing solutions might be adapted to this purpose. The SAP HANA database[5] provides the capability to federate data across systems and cloud as well as to analyse sensitive data while protecting privacy. This will support the data availability and data security pillars of the data trustworthiness concept. We will evaluate how solutions such as SAP Datasphere[6], which leverages machine learning, and is used to cleanse, and integrate data from multiple sources to ensure the required data quality. And we will assess how Costain's Intelligent Infrastructure Control Center (IICC)[7] solution and SAP sustainability solutions can ensure data compatibility across the value chain according to PAS 2080 standards and enable carbon accounting[8] and management reporting[9].

[5] https://www.sap.com/products/technology-platform/hana.html
[6] https://www.sap.com/products/technology-platform/datasphere.html
[7] https://www.sap.com/about/customer-stories/costain.html
[8] https://www.sap.com/sustainability/climate-action.html
[9] https://www.sap.com/sustainability/esg-reporting.html

6. Summary

The trustworthiness of carbon management data is critical to the success of carbon reduction initiatives. By defining data trustworthiness, identifying the key factors that contribute to it, discussing its importance, and providing recommendations to achieve carbon data trustworthiness, this white paper is intended to help organizations strategically advance their carbon data management capabilities. By doing so, organizations can set meaningful targets for carbon reduction, accurately track their progress, make more informed data-driven decisions, meet their pressing net-zero targets, and contribute to a more sustainable future.

About the Digital Roads for the Future Programme

The Digital Roads of the Future Initiative (https://drf.eng.cam.ac.uk/) is a collaboration between the University of Cambridge, Costain, and National Highways. It encompasses two major, multi-million-pound research programmes: "Digital Roads" and "Future Roads". This white paper has been published through the Future Roads programme. The Future Roads Fellowships (FUTUREROADS) is a £5.9m programme supported by EU MSCA COFUND over 60 months. It offers 27 experienced researcher fellowships linked to the thematic areas; digital twins, data science, smart materials, automation and robotics, and sustainability, all in the context of the roads network. There are 24 industry partners supporting this programme.

This white paper is associated with a project exploring *Data Science and advanced technologies for carbon management in the highway asset lifecycle*. The project aims to develop a fundamental carbon data (metadata) model of a digitalized platform to increase the automation, timeliness, trustworthiness of carbon data reporting to support optimized carbon management. It will explore the application of advanced technologies including BIM/digital twin, IoT, and machine learning to digitalise and automate the carbon management in road and highways. This is the first whitepaper of the series of three as planned, the second one will be about the fundamental carbon data (metadata) model and the third one will be a use case. Interested practitioners and scholars are welcome to collaborate in this project by contacting Dr Jinying Xu via jx314@cam.ac.uk.

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