Assessing uncertainties in carbon footprint measurement

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Accuracy and transparency of assumptions are crucial when measuring and communicating carbon footprint estimations. The paper investigates the uncertainties underlying carbon footprint estimations of freight transportation, with a particular focus on trip-level assessment. The research identifies and classifies possible causes of these uncertainties, drawing from literature reviews, protocol analyses, field research, and interviews. Five sources of uncertainty (context, model structure, data input, parameter and model technical) are identified. Three methods are discussed to quantify uncertainties and their impacts: statistical analysis, sensitivity analysis and scenario analysis. Linked to different levels of uncertainty, different approaches can be identified to calculate the influence of uncertain inputs on the final footprint measure. Finally, a case study is done based on observed shipments of construction material to a building site.

The following conceptual framework describes the various types of uncertainty (Figure 1).

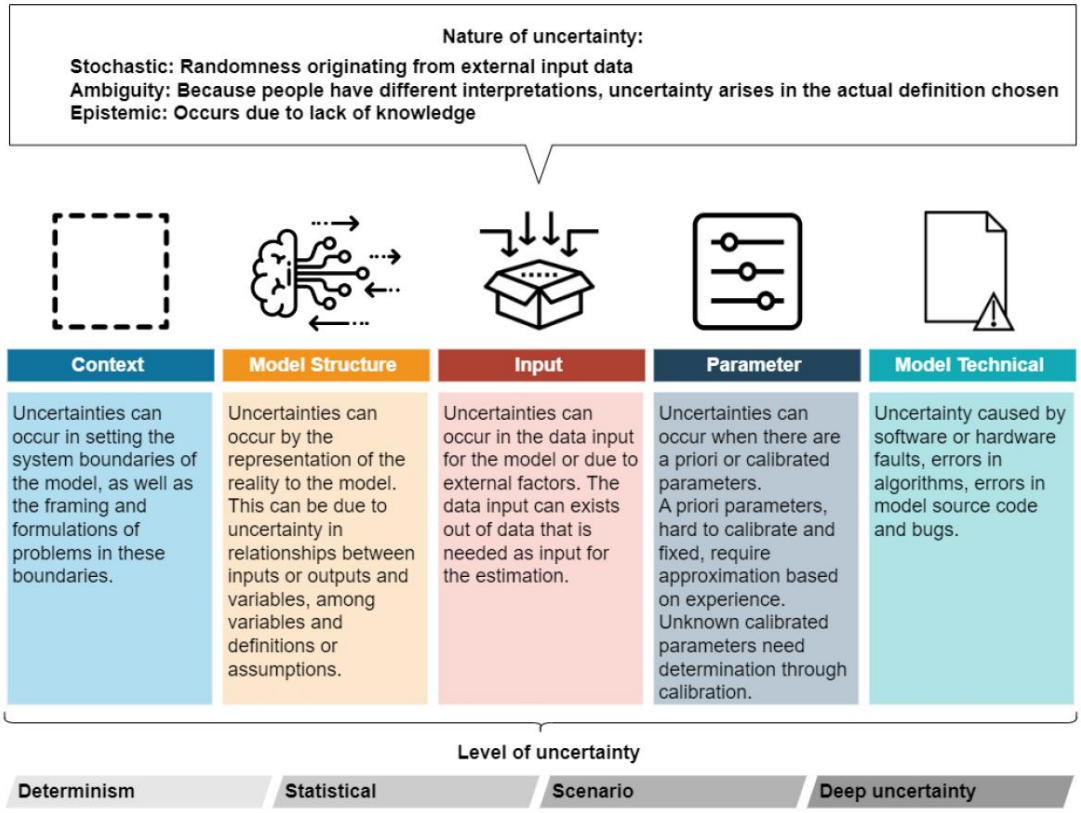

Figure 1 Classification of types of uncertainty

Important causes of uncertainty that were found to be relevant for the case of carbon footprinting included the following (Table 1).

Table 1 Key causes of uncertainty

CONTEXTUAL	
Definition	e.g. what is carbon, what is a footprint?
Logistics System boundary	scope, number of clients, trip, tour etc.
MODEL STRUCTURE	
Allocation Methods	when co-loading, how to distribute
Functional forms	linear/non-linear
Activity assumptions	trip modelling constructs
VARIABLES	

Fuel used	fuel type and consumption
Trip characteristics	origin, destination, distance, shipment
Vehicle characteristics	size and weight, payload
PARAMETERS	
Emission factors	averages, WTT/TTW/WTW, sources
Conversions	shipment to payload to vehicle, etc.

The different uncertainties were brought together in an emission calculation framework, allowing to assess their final impact on carbon emissions. A case study analysing three individual freight movements to a building site was conducted. Based on a quantification of uncertainties around each trip, input data was prepared (Figure 2) and variations around a mean carbon footprint estimate could be provided (Figure 3), combining statistical and scenario-based approaches.

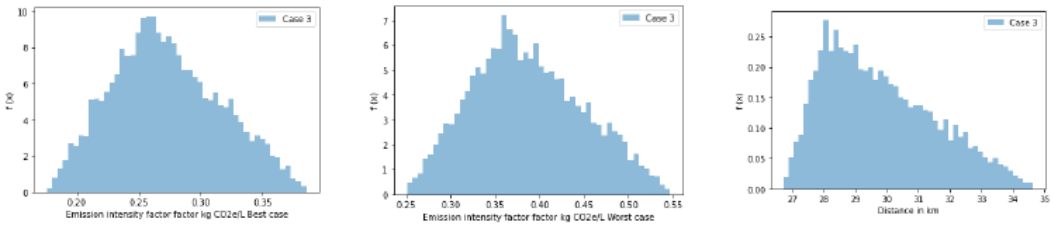

Figure 2: Visualisation of typical uncertainties in inputs

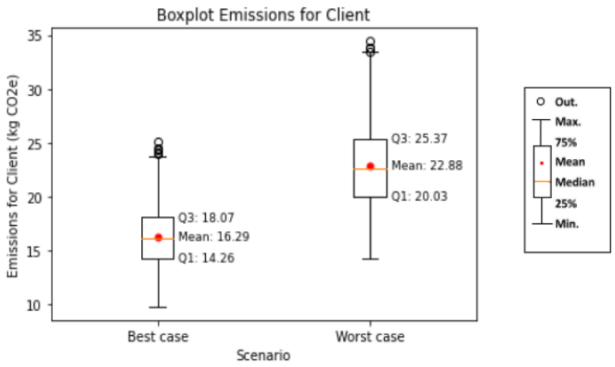

Figure 3: Results of carbon emitted at trip level

The results show that simple and unavoidable uncertainties can significantly impact the carbon footprint estimate. This effect is particularly evident when uncertainties are quantified using best and worst-case scenarios. The validation process conducted with experts in the field demonstrated a general consensus on the identified uncertainties. This shared appreciation highlights the need for further exploration, as outcomes depend heavily on the amount and level of detail of the available information. An important point of discussion among the experts was that this research focused on estimating the carbon footprint at the trip level, while the new ISO standards recommend an aggregated level of emission assessments. It is unclear what aggregation would do to the effect of essentially micro-level uncertainties.

The study suggests various opportunities for further research. Firstly, there is a need to establish accurate probability density functions based on existing research and data. Secondly, the development of an extended methodology is required, that aligns with the new ISO standard for carbon footprint assessment. Thirdly, an interesting direction for future research is the examination of uncertainties in well-to-tank emission factors. Fourthly, an analysis of the impact of uncertainties in carbon footprint assessments on the selection of logistics service providers or carriers during the tender process could be worthwhile. Fifthly, many uncertainties arise due to a lack of data, stemming from inadequate data storage systems or difficulties in data retrieval. The impact of this is understudied. Lastly, expanding the investigation of uncertainties into other modes of transport, such as rail, sea, and air, could greatly enhance the usability of the approach. This could contribute to a comprehensive understanding of uncertainties in carbon footprint assessments across all transport chains.