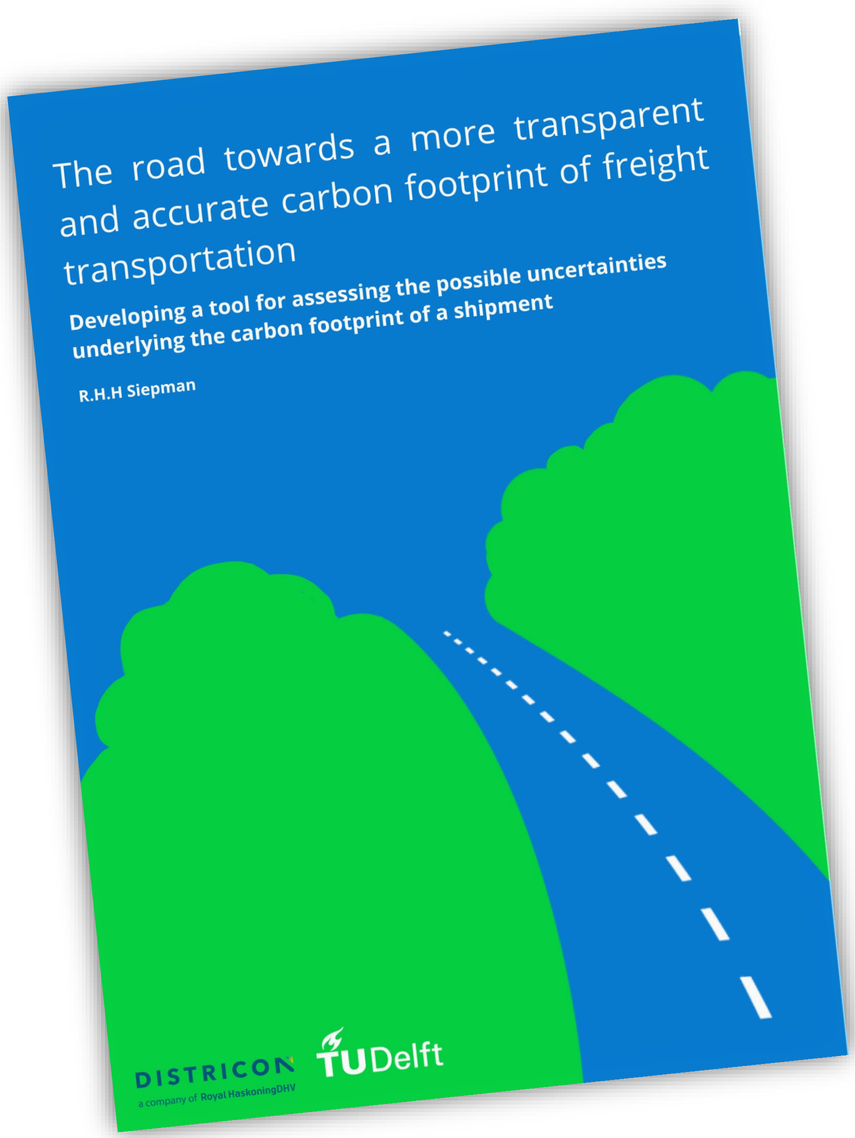

TU Delft MSc Thesis Renee Siepman
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Assessing uncertainties in carbon footprint measurement in road freight transport

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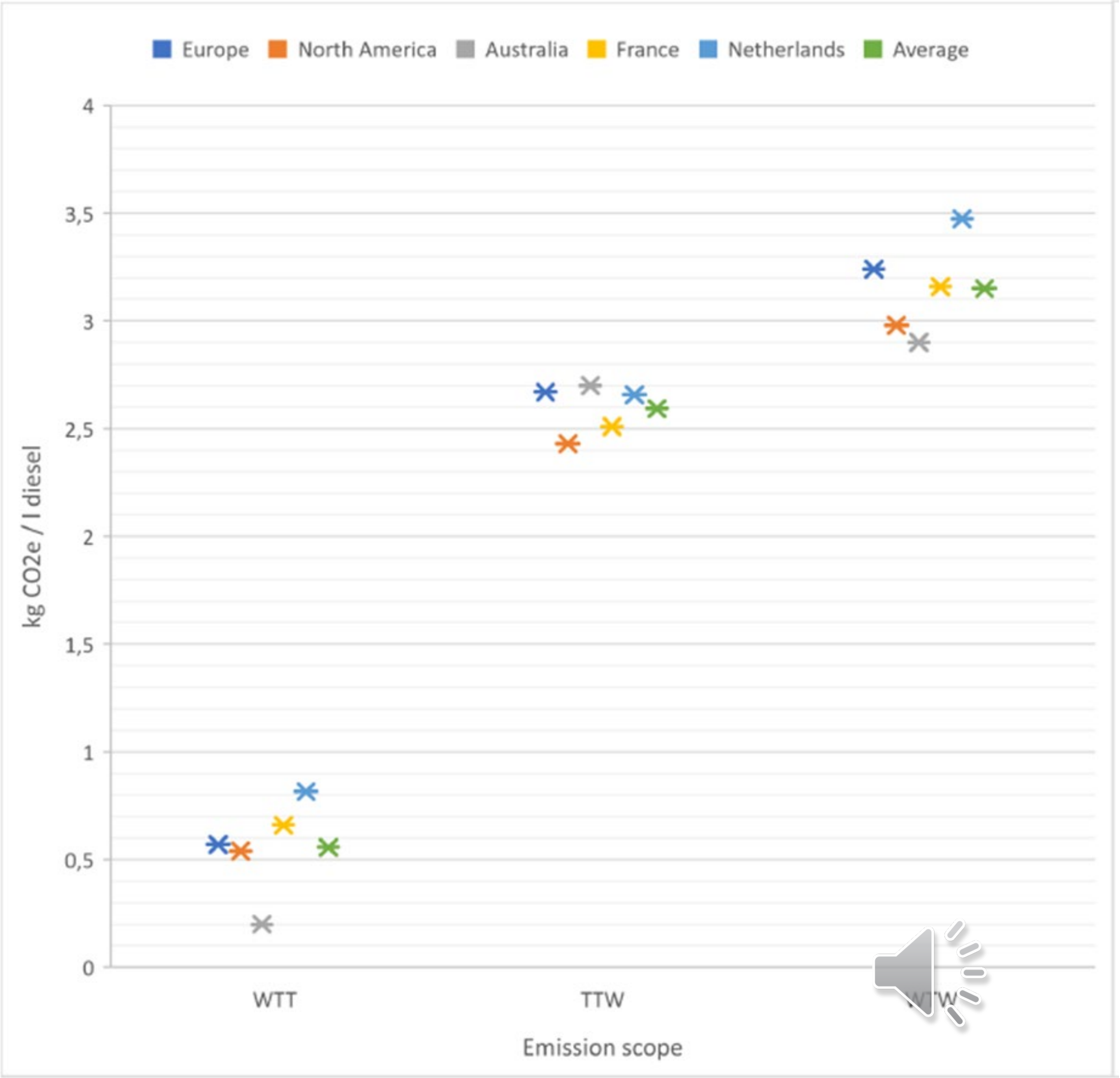
TU Delft, [1]Districon

Presenter: Lóri Tavasszy, TU Delft

Background

- Topic: Emission reporting & calculation standards
- Simple principle: *distance * volume * unit energy consumption factor * unit emissions factor*
- Data requirements rarely satisfied
- Problem for standards: trade-off between simplicity and accuracy
- Uncertainties may confound understanding of true variation



Evolution of standards (EN16528 ➔ GLEC ➔ ISO14083) and tooling

Standards & Methods	Legal basis	GeographicScope	Modes of Transport	Trans-shipping	Remarks
EN16258	Official	Europe	All	–	
SmartWay	Program	North America	All	–	
CE Delft	Research	Global	Partly	–	
GHG Protocols	Method	Global	–	–	Several specific areas
ISO	NGO	Global	–	–	
GLEC	Framework	Global	All	–	Based and further developed on existing methods
EcoTransIT	Commercial	Global	All	–	Based on EN16258, GLEC
BigMile	Commercial	Global	All	✓	
IMO	Official	Global	SEA	–	United Nation
CCWG	Initiative	Global	SEA	–	
ICAO	Official	Global	AIR	–	
IATA	Association	Global	AIR	–	
Green Logistics	Research	Europe	–	✓	
Green Efforts	Research	Europe	–	✓	
Green Freight Europe/ Asia	Program				
ITEC	Initiative	Europe	–	✓	ECOHubs
CarbonCare	Commercial	Global	All	✓	

After Wild (2021)

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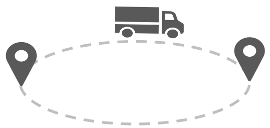
A typical case complicating data needs and requiring additional analysis, assumptions, or guesswork

A



Dedicated trip: one customer

Carbon footprint shipment construction site = Energy consumption × Emission factor

B

Shared trip: multiple customers

Carbon footprint shipment construction site = Energy consumption × Emission factor × Allocation factor

weight and distance ⇩ Allocation factor

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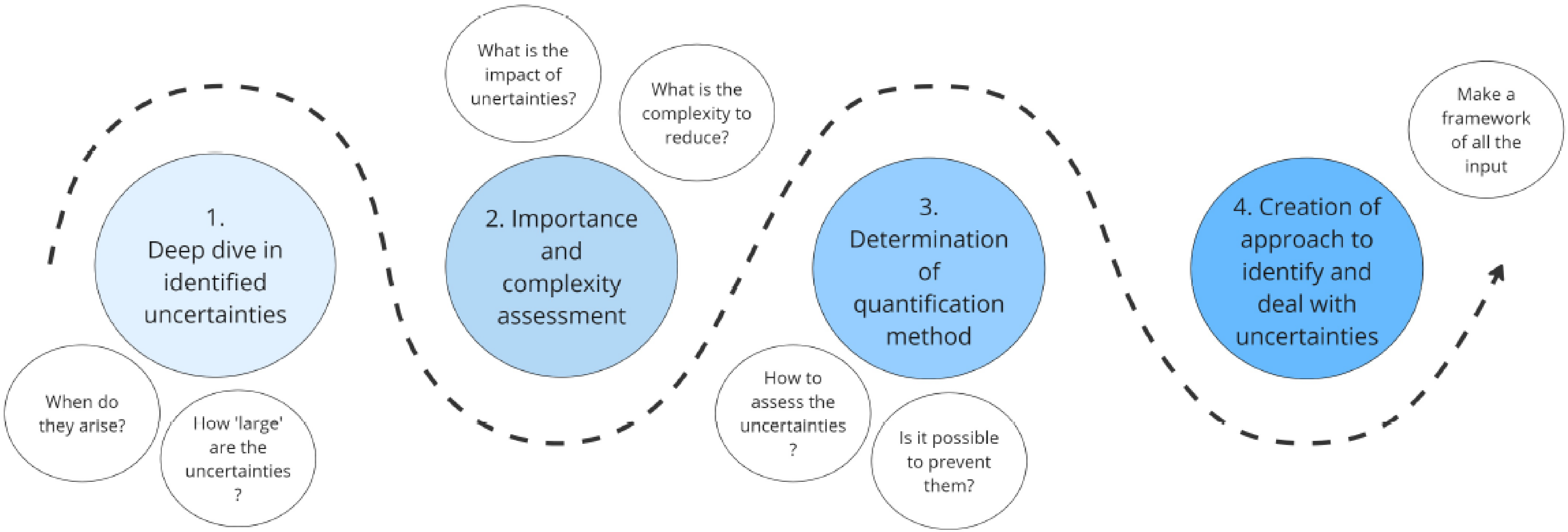
How to deal with uncertainty in emissions reporting: a design study for supporting tooling



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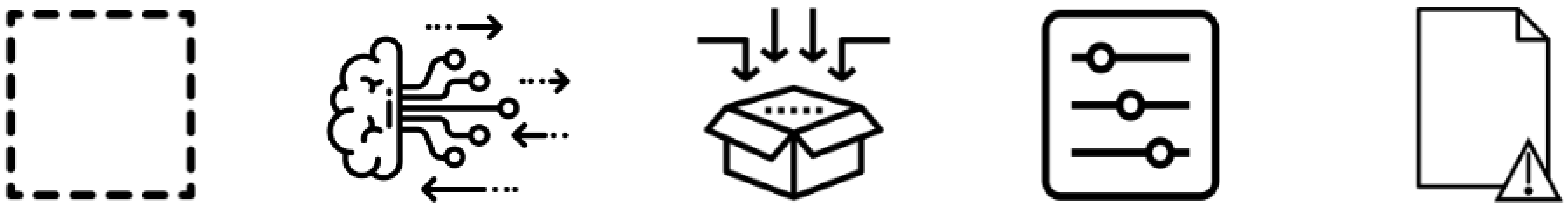
Causes of uncertainty

Variability : Randomness originating from external input data
Ambiguity: Because people have different interpretations
Epistemic: Occurs due to lack of knowledge

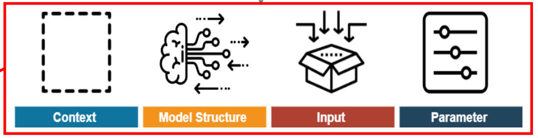


Context	Model Structure	Input	Parameter	Model Technical
Uncertainties can occur in setting the system boundaries of the model, as well as the framing and formulations of problems in these boundaries.	Uncertainties can occur by the representation of the reality to the model. This can be due to uncertainty in relationships between inputs or outputs and variables, among variables and definitions or assumptions.	Uncertainties can occur in the data input for the model or due to external factors. The data input can exists out of data that is needed as input for the estimation.	Uncertainties can occur when there are a priori or calibrated parameters. A priori parameters, hard to calibrate and fixed, require approximation based on experience. Unknown calibrated parameters need determination through calibration.	Uncertainty caused by software or hardware faults, errors in algorithms, errors in model source code and bugs.

Appearance of uncertainties (detail)

Nature of uncertainty:

1. Stochastic: Randomness originating from external input data
2. Ambiguity: Because people have different interpretations, uncertainty arises in the actual definition chosen
3. Epistemic: Occurs due to lack of knowledge



Context Uncertainty, Classification

Source of Uncertainty	Explanation	Nature
Definition of Carbon Footprint	There are different interpretations of a 'carbon footprint', other interpretations can lead to another scope and leads to including or excluding emissions in the measurement.	Ambiguity
Boundary Carbon Footprint of Transportation	There are different system boundaries that can be defined for a carbon footprint of freight, for example: taking all the transport elements in the chain or only between two segments. Or including empty trips or not. When these boundaries are not clear, different interpretations can arise.	Ambiguity

Model Structure

Source of Uncertainty	Explanation	Nature
Different Allocation Methods	There are multiple options to allocate emissions, the method that is used has a big influence on the carbon footprint of a shipment of the customer. In literature the ton-great circle distance is recommended. However, other papers suggest to use the most limiting factor and great circle distance. Other suggest only great circle distance or use another 'distance' type.	Ambiguity
Linear Approach Calculating Emissions	In literature it was found that the emissions N2O and CH4 have not exactly a linear relationship with energy use as CO2. This is a simplification of the model.	Epistemic
Assumptions of trip data	When the trip details are partially available, assumptions can be made to still make an estimate with all available information.	Epistemic

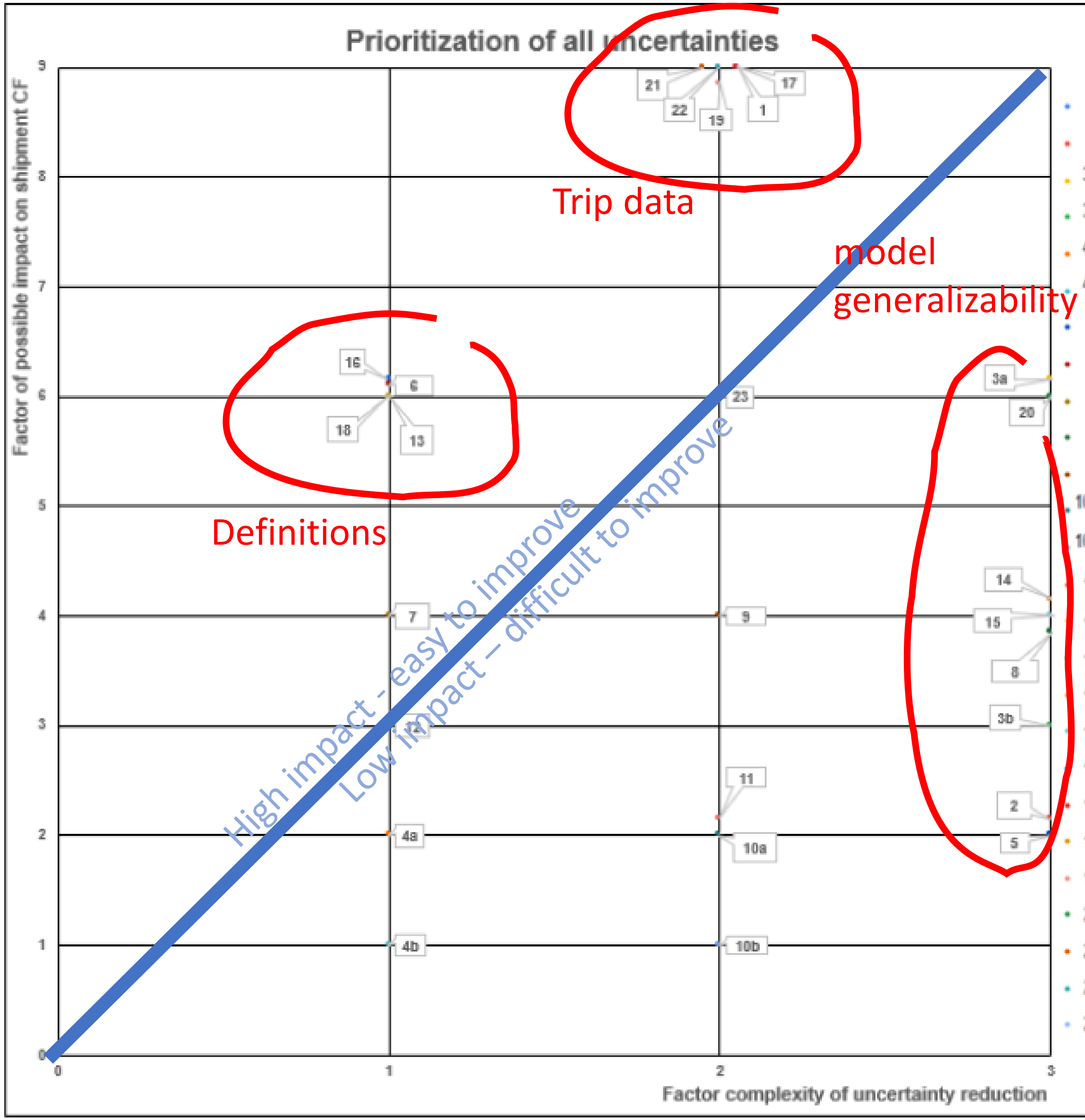
Parameter

Cause of uncertainty	Explanation	Nature
Measurement error emission factor TTW	Due to multiple measurements of the tank-to-wheel emission factors there will be a measurement error.	Epistemic
Measurement error emission factor WTT	Due to multiple measurements of the well-to-tank emission factors there will be a measurement error.	Epistemic
Different emission (intensity) factor databases	Due to the different databases there are multiple emission factors that can be used for specific situations.	Ambiguity
Default emission intensity factors	The default emission intensity factor are the amount of CO2-equivalent per ton-km this is a general factor which makes it very generic and often deviates from reality.	Epistemic
Conversion factor	When the payload is measured in different metrics than the preferred allocation method a conversion factor is needed. This factor has measurement errors.	Epistemic

Input Data

Data input	Cause of uncertainty	Explanation	Nature
Average energy consumption/unit-km during a certain time	Average value	Specific route characteristics, driving behaviour, environmental influences and when multiple vehicles are used; also the vehicle characteristics are less reflected in the output.	Stochastic
	Unknown how average energy consumption/unit-km is calculated	When it is unknown how the average energy consumption/unit-km is calculated there is a possibility that wrong calculations are made.	Epistemic
Average energy consumption/km during a certain time	Average value	Specific route characteristics, loading characteristics, driving behavior, environmental influences and when multiple vehicles are used; also the vehicle characteristics are less reflected in the output.	Stochastic
	Unknown how average energy consumption/km is calculated	When it is unknown how the average energy consumption/km is calculated there is a possibility that wrong calculations are made.	Epistemic
Amount of energy	Measurement error amount of energy	When the fuel consumption is based on data from fuel cards there exists a measurement error, when someone tanked on the 31st of the month the data is included in the past month but is used in the next month.	Epistemic
Default energy consumption/km	Approximation of fuel consumption	No specific route characteristics, driving behavior, environmental influences and vehicle characteristics of trip reflected in the output. Due to approximation effect of load included (default factors fuel consumption empty, full and capacity).	Stochastic
	Industry average	No specific route characteristics, loading characteristics, driving behaviour, environmental influences and vehicle characteristics of trip reflected in the output.	Stochastic
Energy type	Specifications or the energy type is unknown	It might be the case that for example the fuel type is defined as "(bio-)diesel" while there are multiple types of (bio-)diesel.	Epistemic
Origin, stops and destination shipment	Different interpretations of origin	Often the destination of a shipment is known, the origin of the transport of a shipment can have ambiguity when this is not defined clearly.	Ambiguity
	Aggregated level 'origin' and 'destinations' due to lack of knowledge or privacy reason	It might be that organizations only know the origin as 'city' and have no specifications in 'postal code' level.	Epistemic
	Information stops are unknown, or only a part is known.	When only a part of the trip data is known, or the trip data is unknown. Assumptions have to be made.	Epistemic
Payload	Multiple definitions of "weight" payload	There could be different interpretations of tonne (packaging included or not).	Ambiguity
	Information payloads are unknown, or only a part is known.	When only a part of the payload known, or the payload is unknown. Assumptions have to be made for the allocation of emissions.	Epistemic
Shipment type	Different interpretation shipment type	When the shipment type is different interpreted the wrong emission intensity factor can be applied.	Ambiguity
Distance	Multiple Definitions of Distance	Uncertainty can arise when these distances are assumed to be equal. For example, if the average fuel consumption is calculated using the number of liters and the total planned distance, and then multiplied by the number of kilometers actually driven, an incorrect calculation is made. In addition, it is questionable whether the carbon footprint can be compared when different distances are used.	Ambiguity
	Distance Unknown	When distance is unknown, an estimation must also be made, for which Google Maps can be used, which requires input of address data. When done in this way, the shortest feasible distance is calculated. This means that there is a deviation from the real driven distance.	Epistemic
Vehicle Type	Different Interpretations of Vehicle Types	There are multiple ways and interpretations to describe a vehicle type. Due to this, the input for fuel consumption estimation can be wrong, or the wrong emission factor will be applied.	Ambiguity
	Vehicle Type Unknown	When the vehicle type is unknown, there will be a broad range of possible vehicle types. Due to this, the input for fuel consumption estimation can be wrong, or the wrong emission factor will be applied.	Epistemic
Amount of Trips	The Amount of Trips are Unknown or Only a Part of the Trips is Known	When only a part of the total trips is known or the trip data is unknown, assumptions have to be made, for example, based on the total demand and capacity of a vehicle. This brings uncertainty in the amount of trips as input data.	Epistemic

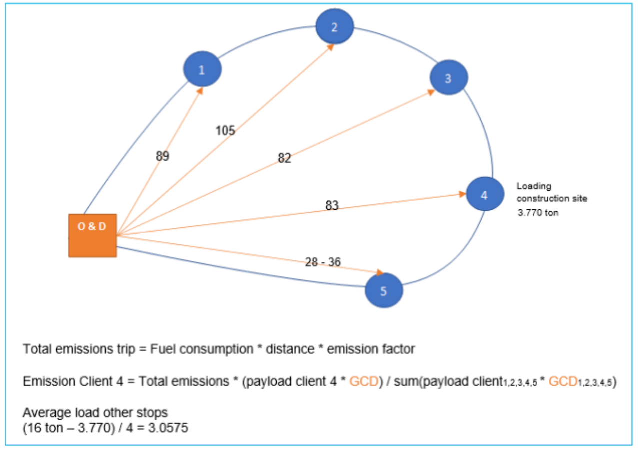
CONTEXTUAL	
Definition	e.g. what is carbon, what is a footprint?
Logistics System boundary	scope, number of clients, trip, tour etc.
MODEL STRUCTURE	
Allocation Methods	when co-loading, how to distribute
Functional forms	linear/non-linear
Activity assumptions	trip modelling constructs
VARIABLES	
Fuel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

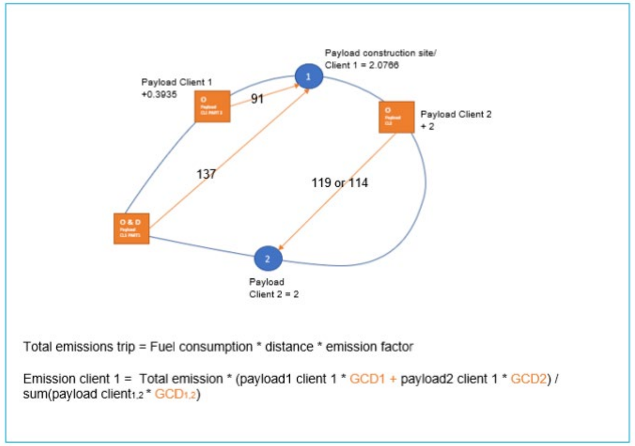


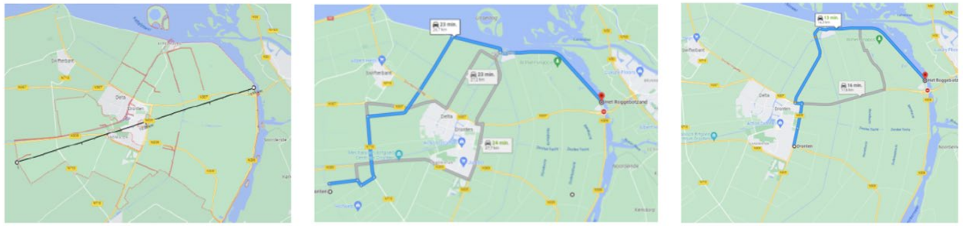
Uncertainty	DURP
1 Unknown Energy Type (S1 t/m S7)	18
2 Uncertainty in Emission Factors (S1 t/m S6)	6
3a Uncertainty When Conversion Factor Needs to Be Applied (S2, S7)	18
3b Uncertainty When Conversion Factor Needs to Be Applied (S1, S3, S4, S5, S6)	9
4a Uncertainty in Definition: Payload (S2, S7)	2
4b Uncertainty in Definition: Payload (S1, S3, S4, S5, S6)	1
5 Uncertainty Due to Variability of Average Value (S2, S3)	6
6 Uncertainty About Calculation (S2, S3)	7
7 Uncertainty in Definition: Distance (S2 t/m S7)	4
8 Uncertainty Due to Other Distance Type Than Used for Average: Distance (S3 t/m S7)	12
9 Uncertainty Due to Unknown Distance (S2 t/m S7)	8
10a Uncertainty in Specification Level: Address Origin, Stops, and Destinations on GCD (S2)	4
10b Uncertainty in Specification Level: Address Origin, Stops, and Destinations on GCD (S1, S3, S4, S5, S6)	2
11 Uncertainty in Specification Level: Address Origin, Stops, and Destinations on Unknown Distance (S3, S4, S5, S6, S7)	4
12 Uncertainty in Definitions: Address Origin, Stops, and Destinations on GCD (S1, S3, S4, S5, S6)	3
13 Uncertainty in Definitions: Address Origin, Stops, and Destinations on Unknown Distance (S3, S4, S5, S6)	6
14 Uncertainty Due to Variability of Default Value (S4, S6)	12
15 Uncertainty Due to Variability of Average Modeled Value (S4, S6)	12
16 Uncertainty in Definition: Vehicle (S4, S6, S7)	6
17 Uncertainty in Unknown Vehicle Type (S4, S6, S7)	18
18 Definition: Shipment Type (S7)	9
19 Unknown Shipment Type (S7)	18
20 Emission Intensity Factors (S7)	18
21 Payload Other Stops Unknown: Assumption Average Value Payload with Help of Vehicle Capacity (S5, S6)	18
22 Adres Other Stops Unknown: Assumption Trip is Dedicated; Replace Allocation Factor * 2 (S5, S6)	18
23 Unknown Amount of Trips: Assumption Total Demand/Capacity Vehicle (S6)	12

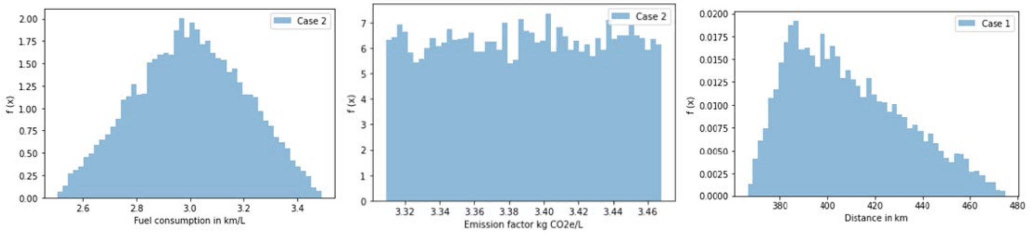
Case study

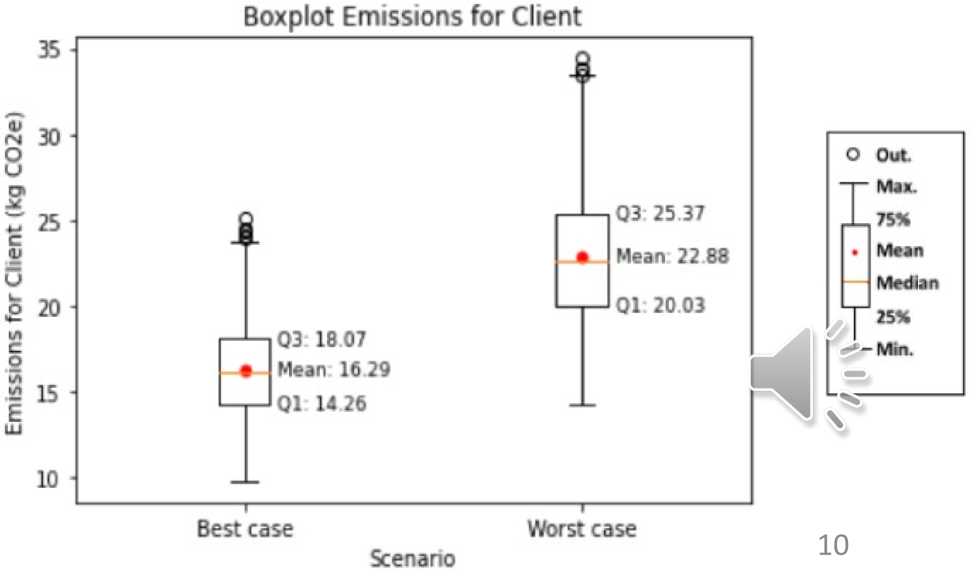
- Construction logistics
- Partial data provided by companies
- Key unknowns: fuel consumption, trip patterns (case 1)











How to cope with uncertainty

Current scope

- Uncertainty measurement: tools
- Uncertainty reduction: guidelines
- Regulation? Trust in data?
- ISO alignment (aggregate!)

Necessary extensions

- Analyse impact on carrier selection
- Improve data storage systems
- Investigate uncertainties for other modes of transport

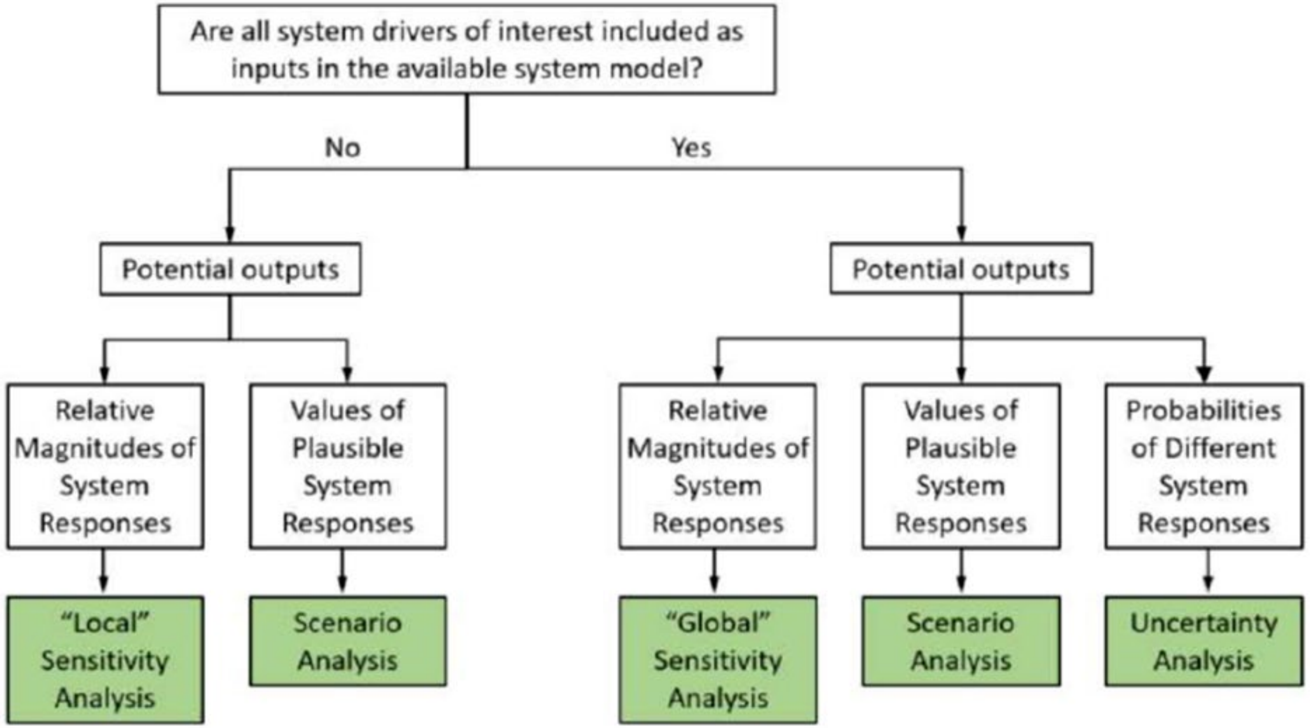


Figure from Maier et al. (2021)

Main Results

- Uncertainty is not negligible
- Impact = (1) financial and (2) emissions

- Fundamental sources of uncertainty: definitions, data quality, model generalizability
- Prone to manipulation – a factor 2 is possible

- Managing uncertainty is not trivial, given its complexity
- Incentives for uncertainty reduction?