NOTE ON UNCERTAINTY MANAGEMENT

IN A GREENHOUSE GAS EMISSIONS ASSESSMENT

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SUMMARY

- The uncertainty of the data is determined qualitatively according to its reliability.

- Emission factor uncertainty is derived from recognized emission factor databases.

- The uncertainty of an emission is the quadratic sum of the relative uncertainties of the factor and the data: $U(E) = \sqrt{U(D)^2 + U(F)^2}$

- To calculate the total uncertainty of a sum of emissions, we need to group emissions using similar and dependent emission factors into subsets. $\delta\alpha_j = \sum \delta E_i$ $\delta E = U(E) * E$The uncertain sums of the emissions in each of these groups are then added together: with . $U(\Gamma) = \frac{\sqrt{\sum \delta\alpha_j{}^2}}{\Gamma}$ $\Gamma = \sum E_i$Finally, the uncertainty of the sum of these subsets is derived from the square root of the sum of the squares of the uncertainties of the quantities added (non-correlation assumption): with , sum of emissions.

Introduction

Uncertainty is a physical and statistical notion that materializes the imprecision associated with a measurement or quantity. It corresponds to the notion of standard deviation and variance in mathematics.

In practical terms, the uncertainty gives a confidence interval, commonly 95%, within which the actual value lies. So a weight of 10 kg with an uncertainty of 3 kg indicates that the real mass of this weight is, with a 95% chance, contained in the interval [7 ;13] kg.

This notion can be expressed in several ways. As a percentage: 10 kg ± 30%, as an absolute value, as above, 10 kg ± 3, or as an interval, so as not to bias the reader by the average: [7 ;13] kg.

Uncertainty arises as soon as a measurement is made. When filling a fuel tank, for example, it's not possible to measure exactly how many molecules of fuel have actually been in the tank. A sensor of this precision doesn't exist, nor does anyone need one. The information retained is the useful information.

1Figure 1 : Illustration of fuel volume measurement at a service station

In a way, uncertainty expresses the degree of simplification of the useful value in relation to the real value.

Carbon measurement is largely subject to uncertainties and their handling. Whether physical, statistical or compound, it is important to know how to quantify these uncertainties in order to interpret the results and analyses associated with the measurements as accurately as possible.

METHOD

1. Emission factor uncertainty

Whenever possible, carbon footprint measurements should be based on reliable and recognized emission factor databases. For each emission factor, these bases indicate the year and time period of validity, the geographical perimeter where this emission factor is valid, and the uncertainty associated with this factor.

The uncertainty of the emission factor reflects variations in the carbon intensity of an activity over time, or the variability of the carbon intensity of a process, depending on the conditions in which it is carried out.

Example: Figure 2 below shows the non-constant carbon intensity of Swiss electricity. For example, the emission factor associated with Swiss electricity in 2022 is 100 gCO2e/kWh, with an uncertainty of 10%. This factor is intended to provide an average value over a period. It therefore takes account of these variations in the form of a percentage uncertainty. It should be read as follows: A kWh of electricity in Switzerland will emit an average of 100 g of CO2e in 2022, plus or minus 10%, because sometimes, over this period, electricity emitted more carbon per kWh, and sometimes less. This percentage reflects the variability of the phenomenon under study.

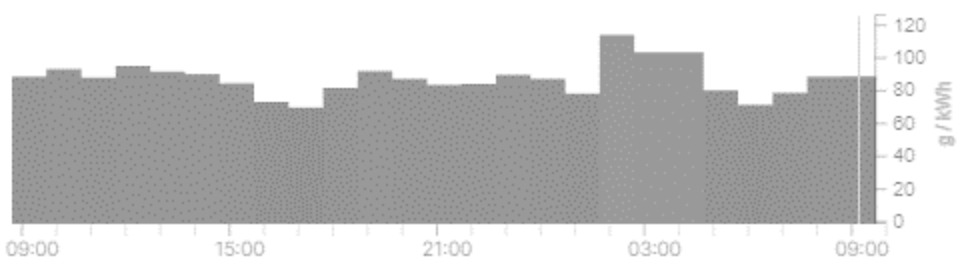

Figure 2 : Estimated carbon intensity of Swiss electricity over a 24-hour period[1]

In another sense, the uncertainty of the emission factor can reflect the variability of a process or product. Let's take the emission factor :

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Laptop, France, 156 kgCO2e/unit, 50% uncertainty
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This emission factor covers all the laptops that can be bought in France. Uncertainty takes into account the different products and manufacturing processes possible. A powerful laptop

[1] Source: electricitymaps.com

with the latest technology does not logically have the same carbon intensity as a cheap computer at the end of its production run.

In the absence of a tailor-made emission factor for every product on the market, these emission factors, the scale of a type of product or a type of process, logically present high uncertainties, as the sets they cover are highly variable.

When the emission factor used is not derived from a database, and is not associated with an uncertainty, the latter must be estimated and documented.

In the case of an emission factor calculated from a life cycle assessment (LCA), the uncertainty must be calculated using a sensitivity analysis when the analysis is drawn up.[2]

In the case of an emission factor calculated by the supplier of the product or service, the supplier must be able to present the associated uncertainty, together with documentation concerning the assumptions made.

In the case of an emission factor derived from specialized, recognized scientific literature, for a generic product or process, the uncertainty to be considered is the equivalent uncertainty for similar products and processes at the same scale of detail, as determined on recognized bases.

Example: If an organization uses Isoflurane as an anaesthetic gas, and the emission factor associated with the use of this product does not exist in existing databases, a search of scientific publications will reveal a paper[3] cited more than 200 times (i.e. recognized), which estimates an emission factor for the use of this product.

At the same time, for all fugitive emissions, ADEME's Base Carbone® indicates an uncertainty of 30%. This uncertainty can then be used in conjunction with the emission factor derived from the scientific literature.

[2] See specialized documentation on life cycle assessment

[3] Sulbaek Andersen, M. P. (2012). Assessing the impact on global climate from general anesthetic gases.

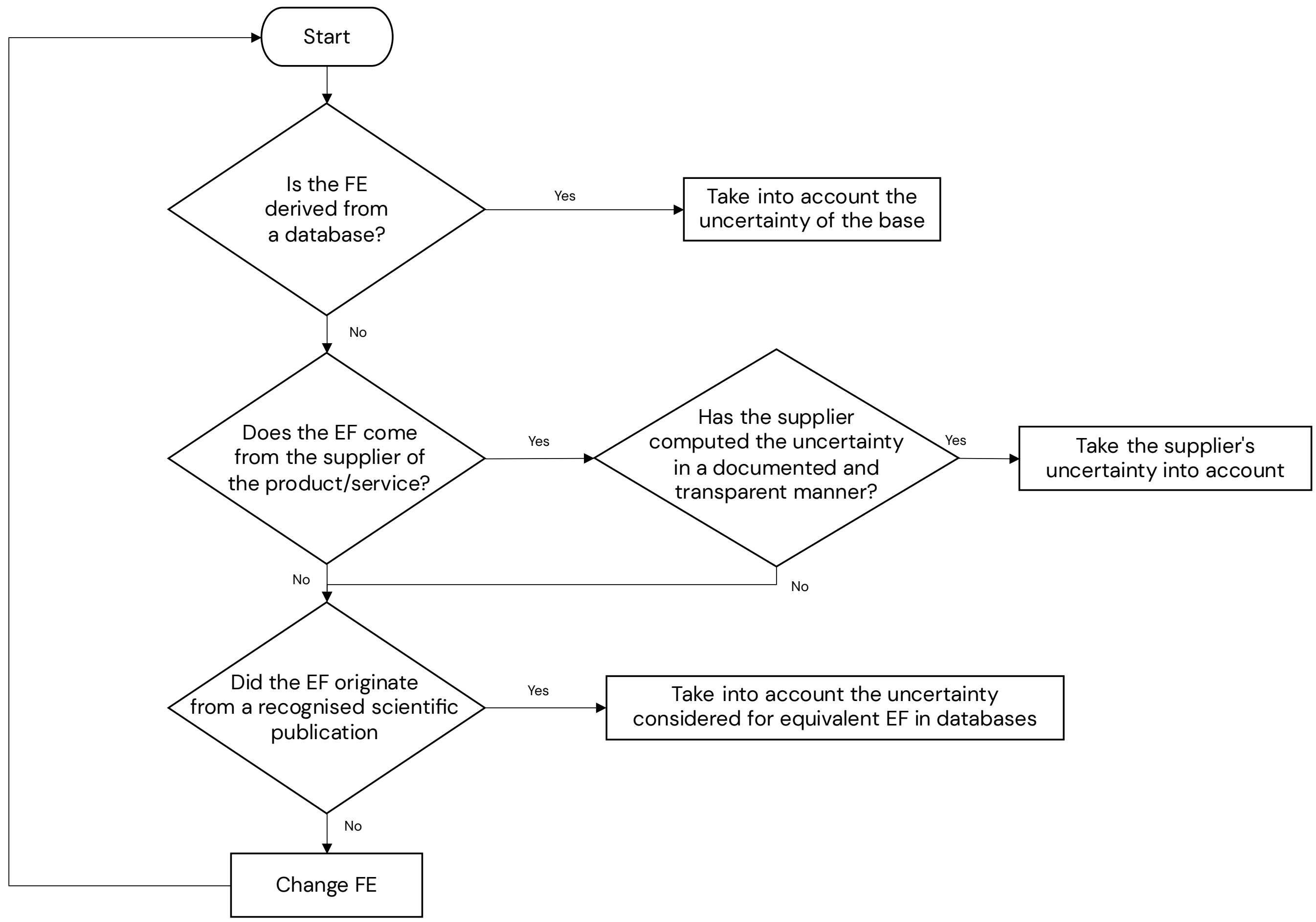

Figure 2 : Decision algorithm for emission factor uncertainty

2. Data uncertainty

Once the emission factor has been selected, activity data must be linked to calculate the associated climate impact.

This activity data can take many forms and be determined in many ways. The uncertainty associated with these data is generally determined qualitatively by the person handling the data.

If the data is in the same unit and form as the emission factor, then the uncertainty is generally quite low. An inventory indicates that 10 vehicles have been purchased over a period, so there's very little chance that there are 9 or 11. So if the emission factor has to be associated with a number of vehicles, then the uncertainty is very low, if not zero.

If the data is in the same unit and form as the emission factor, but comes from a source of inferior quality (such as an accounting ledger of several tens of thousands of lines, in which the representativeness of the data is not guaranteed), it is reasonable to consider an uncertainty that reflects the average quality of the data. The reasonable range varies between 1% and 10%, depending on what is being considered.

If the data is derived from intermediate calculations and/or assumptions, a greater uncertainty must be considered.

Example 1: We have at our disposal the emission factor "Electricity Angola, kWh". The data available are the financial volumes spent on electricity in Angola over the period under consideration. However, it is impossible to obtain directly the volumes of electricity consumed in kWh. Analysis of several Angolan bills shows an average cost per kWh of 0.30$. Using this indicator, we transform the total $ into kWh. This conversion required several manipulations of the primary data and the use of external sources. A larger uncertainty, commensurate with the assumptions made, must be taken into account, generally in the range of 10% to 40%.

Example 2: Suppose we have no data directly related to our layout, but we know that around 20 people occupy offices in Angola. We'll assume that the surface area of the space must be around 300 m^2 (to have 15 m^2 of space per person). Office consumption should be around 50 $kWh/m^2/year$, excluding heating and air-conditioning. Total consumption is estimated at around 15,000 kWh. For assumptions of this order, the uncertainty to be considered should be in the range 40% to 80%.

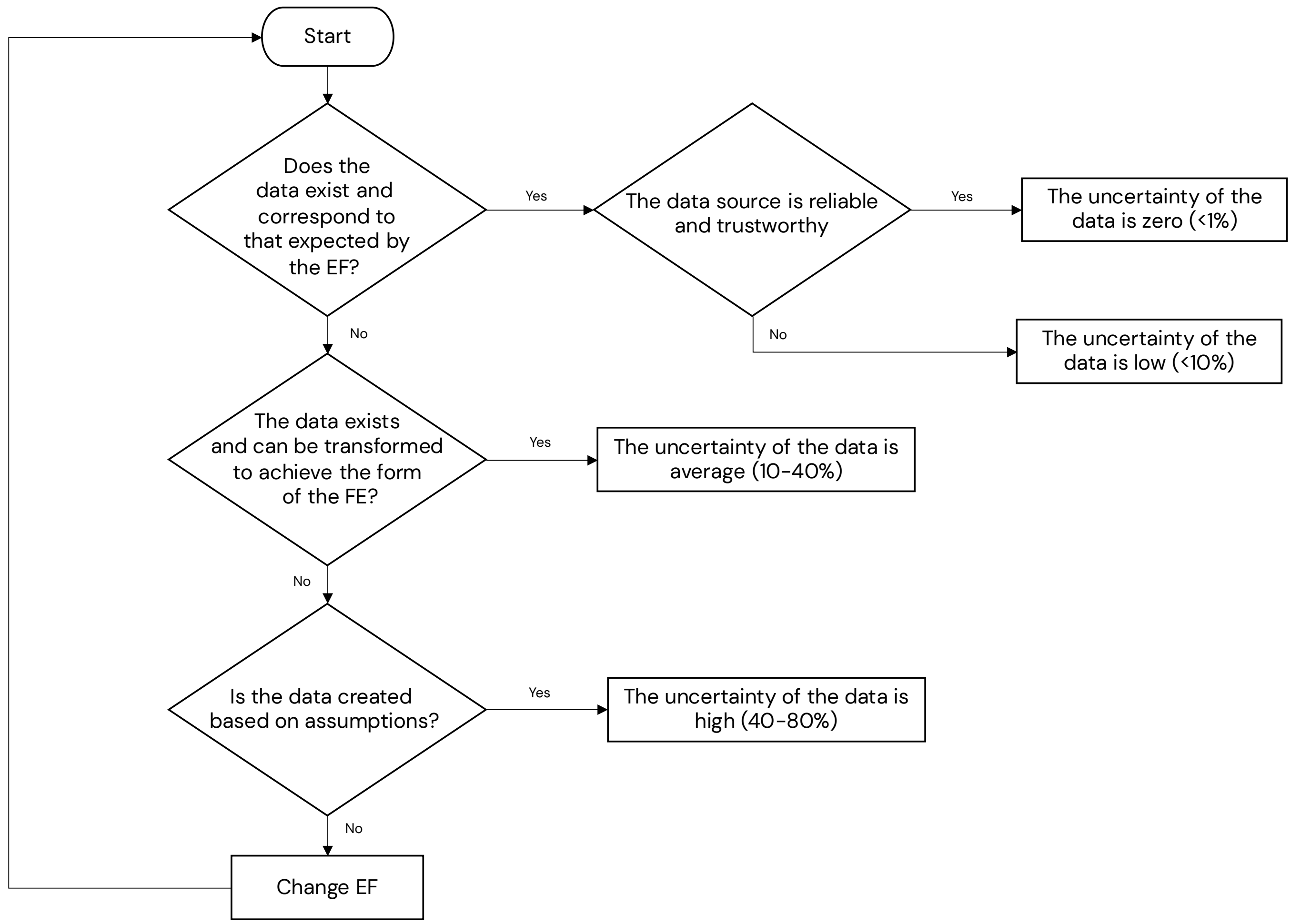

Figure 3 : Decision algorithm for data uncertainty

3. Issue uncertainty

Once the emission factor and the activity data have been identified and the respective uncertainties determined, the calculation of emissions E in mass of CO_2e is the composition of data D and emission factor F.

Equation 1

$$E = D * F$$

Several conceptual approaches to uncertainty define different methods for combining uncertainties. The approach adopted in this document will be the simplest one, allowing us to demonstrate the overall quality of the measurement without seeking absolute precision, in line with qualitative estimates of the uncertainties of the elements concerned.

We therefore assume independence and non-correlation between the two variables to be combined. These realistic assumptions lead to the combination equation as the quadratic sum of the uncertain quantities (where $U(x)$ represents the uncertainty of the variable in %) :

Equation 2

$$U(E) = \sqrt{U(D)^2 + U(F)^2}$$

The uncertain emission quantity is therefore given by the combination of the uncertainty of the variable with the volume of the variable:

Equation 3

$$\delta E = U(E) * E$$

Example: Given a fuel consumption of 100 L, uncertain at 10%, and an emission factor of 3 kgCO2e/L, uncertain at 5%.

The CO2e emissions associated with fuel consumption are therefore :

$$E = D * F = 100 * 3 = 300\ kgCO2e$$

The uncertainty, in percent, results from equation 2 :

$$U(E) = \sqrt{U(D)^2 + U(F)^2} = \sqrt{10\%^2 + 5\%^2} = \frac{1}{4\sqrt{5}} \approx 11{,}2\%$$

The uncertain emission quantity is therefore :

$$\delta E = U(E) * E \approx 11{,}2\% * 300 \approx 33{,}6\ kgCO2e$$

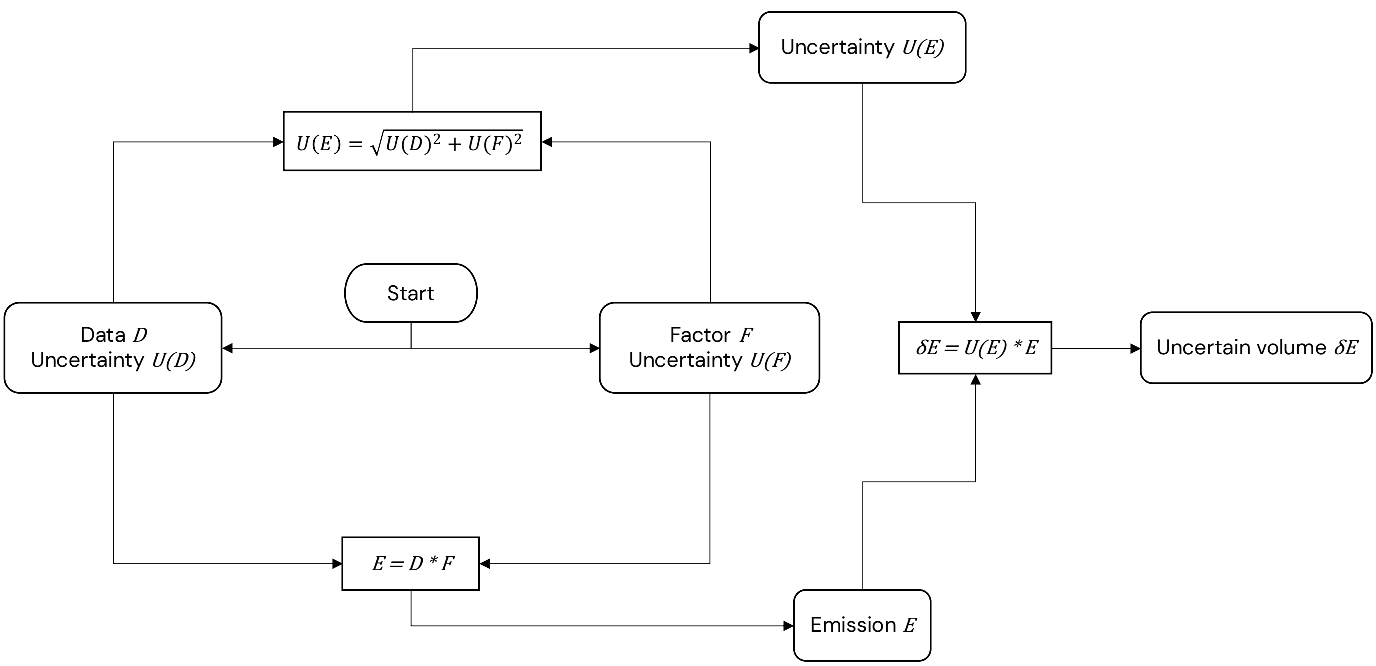

Figure 4 : Flow chart for calculating emission uncertainty

4. Sum of uncertainties

A carbon footprint is the sum of multiple emissions from each activity, at each location. Thus, the total footprint Γ results from the addition of each elementary footprint E_i.

Equation 4

$$\Gamma = \sum E_i$$

When summing independent and uncorrelated variables, the uncertainties are calculated as follows:

Equation 5

$$U(\Gamma) = \frac{\sqrt{\sum((E_i * U(E_i)^2)}}{\Gamma} = \frac{\sqrt{\sum \delta E_i{}^2}}{\Gamma}$$

However, in this case there is a significant notion of correlation and dependency between the variables. If the same emission factor has been used for both vehicle and generator fuel, then the uncertainties of these two emissions are both dependent on the uncertainty of the same emission factor. The independence of the variables cannot therefore be neglected in this case.

The way to maintain results close to reality without complicating the calculation by adding the notions of covariances, correlation coefficients, and so on, is to create sets of elements that are sufficiently distinct to be able to assume the independence of these sets and thus to be able to apply the *Equation 5*.[4]

These sets synthesize distinct emission categories that are not supposed to be correlated, or at least have negligible correlation

To be independent, elementary groupings must include all emissions associated with the same emission factor. Thus, if several locations are taken into account in the measurement for each emission, the elementary grouping level for calculating uncertainties will erase the geographical notion. Similarly, if two distinct emissions use the same emission factor (diesel for car and diesel for generator), then these emissions must be included in the same set to avoid any correlation between them.

[4] (Intergovernmental Panel on Climate Change, 2001)

Thus, to perform an uncertainty calculation along these lines, we first calculate the uncertain quantity of each elementary set $\delta\alpha_j$, by simply summing the uncertain quantities δEi:

Equation 6

$$\delta\alpha_j = \sum \delta E_i$$

The relative percentage uncertainty of this level is therefore :

Equation 7

$$U(\alpha_j) = \frac{\delta\alpha_j}{\alpha_j}$$

We can then determine the uncertainty as a percentage of the total or of each subtotal by re-applying *Equation Equation* **5** to the previously calculated sets:

Equation 8

$$U(\Gamma) = \frac{\sqrt{\sum \delta{\alpha_j}^2}}{\Gamma}$$

Example: Consider the following emissions:

Show name	kgCO2eq	Uncertainty
Diesel - Vehicles - France	75	9%
Diesel - Vehicles - Switzerland	40	14%
Diesel - Generator - Switzerland	74	13%
Electricity - Switzerland	81	39%
Plane - Short-haul - Switzerland	20	9%
Plane - Short-haul - France	24	33%
Plane - Long-haul - France	56	48%
Buy - IT - France	38	4%
Purchase - Services - Switzerland	13	28%

The first step is to create independent elementary sets:

- Diesel-related emissions are summarized as follows
- The electricity can remain as it is.
- Aircraft emissions are summarized as follows
- Purchases can remain as they are.

This leads us to consider the following sets:

Set	kgCO2e	Quantity uncertain
Diesel	189	21,97
Electricity	81	31,59
Plane	100	36,6
Buy - IT	38	1,52
Purchasing - Services	13	3,64

The uncertain quantity is taken from *Equation Equation* **6**.

So we finally apply *Equation Equation* **8** to obtain the total uncertainty:

$$U(\Gamma) = \frac{\sqrt{\sum \delta\alpha_j{}^2}}{\Gamma} = \frac{\sqrt{21{,}97^2 + 31{,}59^2 + 36{,}6^2 + 1{,}52^2 + 3{,}64^2}}{189 + 81 + 100 + 38 + 13} \approx 12{,}6\%$$

If we wish to have the uncertainty only of purchases, we can compose only purchases:

$$U(\alpha_{Achats}) = \frac{\sqrt{\sum \delta\alpha_j{}^2}}{\alpha_{Achats}} = \frac{\sqrt{1{,}52^2 + 3{,}64^2}}{38 + 13} \approx 7{,}7\%$$

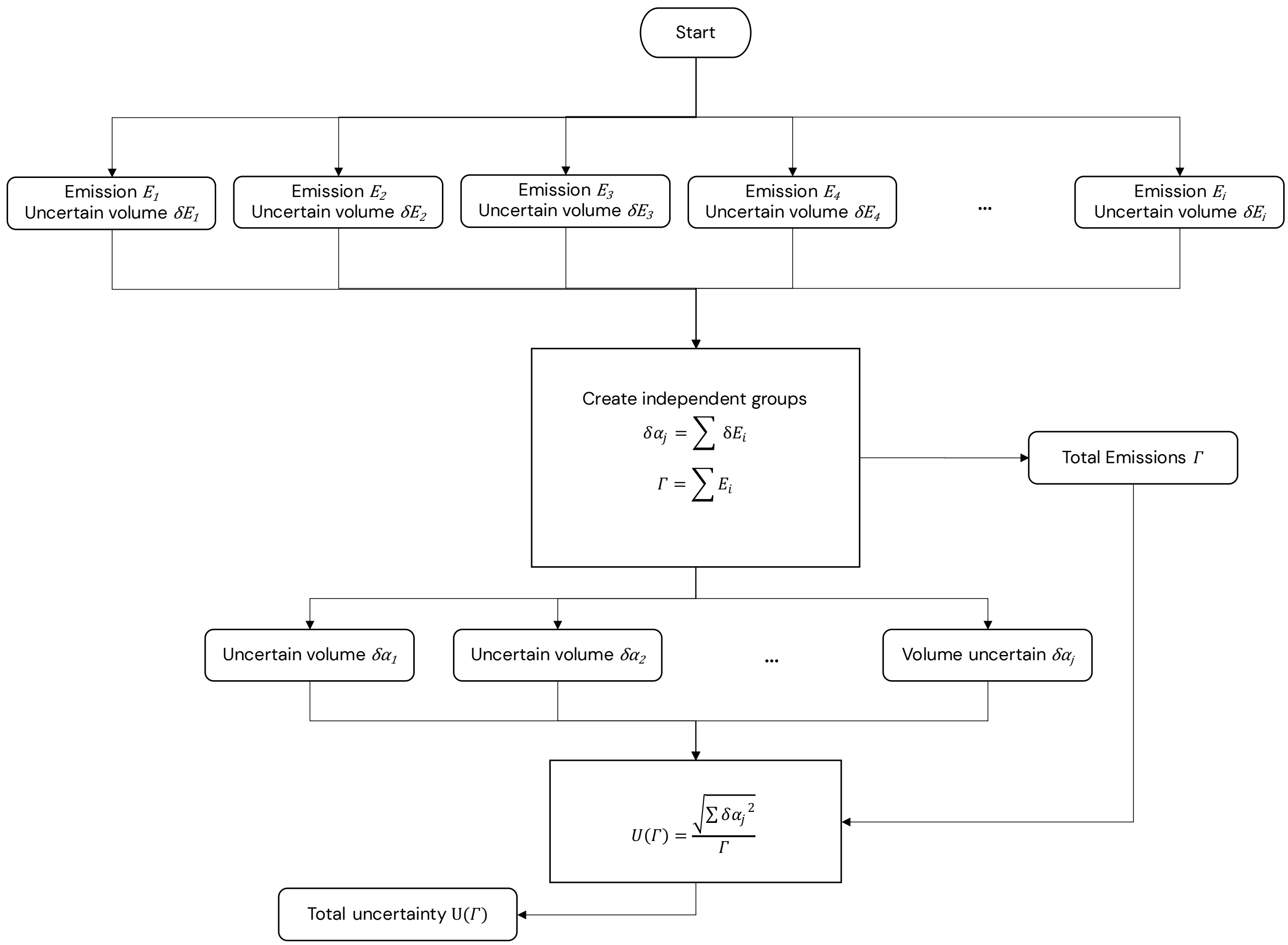

Figure 5 : Flow chart for calculating the uncertainty of an emission sum

CONCLUSION

Measuring uncertainty in carbon footprint calculations is not absolute. Phenomena such as correlation and dependency of quantities force us to simplify our approach, to keep our calculations as accessible as possible.

Thus, the approach developed in this document moderately overestimates total uncertainty, but is generally sufficient to provide a clear picture of the confidence to be placed in the figures.

This method can be implemented quite simply on a spreadsheet. If a line corresponds to an elementary emission, the uncertainty of the emission factor in percentage and the uncertainty of the data must be indicated for each line. Equation **2**In a column, apply the Equation to determine the total uncertainty of the elementary emission, then multiply it by the emission volume to obtain the uncertain quantity. Each row is then tagged according to its elemental set. For example, we can tag all energy-related rows together with the keyword "Energy". Finally, we can create a pivot table that includes each elementary set and the sum of the uncertain quantities. Finally, we square each of these uncertain quantities, add them up, take the square root, and divide it by the emission total to obtain the total uncertainty.

A total uncertainty of less than 10% indicates very good measurement quality. If it is between 10% and 25%, the quality of the measurement is satisfactory. Between 25% and 50%, the measurement suffers from certain assumptions on the data or from regular use of financial emission factors. Finally, if the uncertainty exceeds 50%, the results should be treated with caution.

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