Harvesting Precision: Developing an Uncertainty Strategy for an Agricultural Carbon Footprint Calculator

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1. INTRODUCTION

The Embrapa-designed Footprint Pro Carbon calculator, integrated into the Bayer Pro Carbon Connect platform, plays a pivotal role in quantifying carbon emissions across agricultural processes. It encompasses both foreground (agricultural processes) and background (agricultural input production) aspects within the Life Cycle Assessment (LCA) framework.

Quantifying carbon emissions within a calculator is challenging due to uncertainties and varied accountability methods. Nonetheless, addressing these uncertainties enhances the reliability, comparability, and precision of results (GHG Protocol, 2022).

While LCA identifies four uncertainty types (Rosenbaum et al., 2018 - parameter, model, scenario, and relevance), we prioritize parameter uncertainty in this study. This choice is driven by the wealth of accountability methods (like GHG Protocol, 2022) and the more practical implementation within a calculator's scope.

This study aims to develop a strategy for implementing uncertainty calculations specifically focusing on parameter uncertainty within the Footprint Pro Carbon calculator for agriculture.

2. METHODS

In essence, parameter uncertainty involves characterizing input parameters and employing an error propagation method to extend this uncertainty through calculations to the final aggregated carbon footprint results. Within the agricultural sector, this involved conducting a comprehensive study to harness uncertainty information pertaining to all agricultural input data and associated emission methodologies. The latter encompasses nitrogen emissions (both direct and indirect), fuel emissions, emissions associated with input production, and land-use change (carbon sequestration was not included in the calculator). The process necessitates methodological decisions on how to characterize uncertainty and choose an error propagation method, with these choices mutually influencing each other.

Table 1 shows the considerations for the choice of error propagation method. Among the considered ones - Taylor Series, Analytical, and Monte Carlo - the Monte Carlo method was primarily selected for the calculator due to its scalability and rich output information.

Table 2 outlines key questions and challenges related to the uncertainty of the parameters. Notably, the uncertainty information was available in plenty of references, allowing for comprehensive consideration for all parameters (making sensitivity or contribution analyses not required) even with harder requirements due to the Monte Carlo error propagation method. Additionally, the Pedigree Matrix (Weidema et al. 2013) was incorporated to account for uncertainty related to representativeness and quality.

3. RESULTS AND DISCUSSION

The final uncertainty strategy was as follow:

- Uncertainty information was gathered for all inputs and parameters using available data from references, databases and data collection processes of the agricultural inputs. No sensibility or contribution analysis was made;
- Pedigree Matrix coefficients used as additional uncertainty;
- Monte Carlo simulation will be used to propagate the uncertainty to the final results. Additional tests shall be done to assess independence among parameters;
- Final aggregated result will have rich uncertainty information, making it possible to perform further analysis such as uncertainty contribution and key point analysis.

4. CONCLUSIONS

Navigating uncertainty provides crucial insights for decision-making and agricultural development, especially in carbon emission accountability. This work reveals the decisions and methodologies in addressing uncertainty within the Footprint Pro Carbon calculation, presenting a comprehensive overview of the applied strategy.

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6. REFERENCES

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Table 1. Error propagation methods and further characteristics (Igos et al., 2018).

Method	Information requirement	Output	Chosen?
Taylor Series (1st order linear assumption)	Variance	Variance	Not chosen as the calculator has enough complexity to require not only first degree series. Only variance as result.
Analytical (variance formulas)	Variance	Variance	Not chosen as it does not scale well with further demands of the calculator. Only variance as result.
Monte Carlo (random sampling)	Distribution	Distribution	Chosen. Has rich information output and is scalable. Tests are required for the independence of data.

Table 2. Questions, challenges and decisions on uncertainty distribution of parameters.

To which data should I apply uncertainty?	After an initial examination of the uncertainty data within the method references, databases, and data collection, the decision was made to assign uncertainty to all parameters because there was sufficient available data well described. In cases where this proves challenging, one could perform a sensitivity or contribution analysis to identify and prioritize the most crucial variables for which uncertainty information should be obtained as we perceived this step to be the most time and resource intensive.
What types of uncertainty will be considered for each parameter?	We opted for the ecoinvent methodology (Weidema et al., 2013) because it aligns with the utilization of the ecoinvent database as background information for the calculator. This methodology incorporates both measurement uncertainty and variability-induced uncertainty as 'base uncertainty.' Subsequently, this 'base uncertainty' is augmented with the uncertainty arising from insufficient quality and representativeness, a factor accounted for through the application of Pedigree Matrix coefficients.
What metrics will be used to characterize uncertainty for the parameters?	The Monte Carlo method requires a comprehensive parameter description in the form of a distribution. Consequently, each parameter must have a parameterization of its uncertainty distribution, with the required information collected from the corresponding data references.
What will be the output for uncertainty?	The Monte Carlo method allows for the uncertainty to be given by means of a standard deviation or a confidence interval, as the uncertainty result is in the form of a distribution.
Is there any requirement for the data?	To execute a Monte Carlo simulation, it is crucial for the data to exhibit independence (lack of correlations among parameters). To evaluate this independence, statistical correlation tests will be applied. In the event of high correlation among parameters, the Monte Carlo sampling method will be adjusted by incorporating copulas to account for the variable correlations.