> we may observe, in every art or profession, even those which most concern life or action, that a spirit of accuracy, however acquired, carries all of them nearer their perfection, and renders them more subservient to the interests of society.

Introduction

The International Civil Aviation Organisation forecasts aviation demand to grow by 4% per year from 2015 to 2045. Currently, aviation accounts for 2% of global CO_2 emissions. This growth rate implies a doubling of current air travel demand in the next 20 years.

Aviation is unique in its ability to decarbonise. Unlike road vehicles, current battery technology is not feasible for electric commercial aircraft due to the substantial weight it would add. Aviation is a very highly regulated industry; any alternative fuels must undergo strict and extensive testing before they can be certified for use.

Sustainable Aviation Fuels (SAFs) are a form of aviation fuel that have lower lifecycle CO_2eq emissions than fossil fuel generated aviation fuel. SAFs are produced to meet the same physical and chemical requirements as fossil fuel generated fuels.

An Life-cycle Assessment (LCA) is a process to determine the environmental impacts and resource use of a product throughout its lifetime. The ISO 14040 specification guides an LCA through specifications of a template to be applied for the particular product scenario.

There is a growing interest from airline companies in SAF to be their fuel of choice in a portion of their flights. LCA's provide a ranking of options according to some criteria (CO2eq).

The TCD LCA is concerned with the lifecycle of SAF production through the HEFA conversion process. It aims to be comprehensive in its model development being aware of transparency of replicability which is currently lacking in the field. The following uncertainty analysis hopes to contribute toward that effort providing as high fidelity and output for the model as possible.

In an LCA context, uncertainty is an expression, in terms of probability of everything we do not know. This includes random and systematic errors in measurement as well as epistemic uncertainty (Hauschild, Rosenbaum, and Olsen (2018)).

In the following paper, an LCA is considered a deterministic decision support model Uusitalo et al. (2015). It's output should inform decisions by providing a realistic picture of outcomes.

LCA uncertainty has three broad categories parameter, model and scenario (Lloyd and Ries (2008)). Analysis of these often overlap (pic from hauschild maybe). Paramteric uncertainty is the most commonly performed uncertainty analysis (Lloyd and Ries (2008)). Parameter uncertainty concerns variability and uncertainty of definite values for the input paramters, Model uncertainty refers to the possible mismatch between the mathematical relationships defined and the real causal structure of a system (igos).

Literature Review

There is a wide range of literature on uncertainty in the Sciences. The standard defined by the Bureue… is centers its uncertainty analysis around experimental measurements and their deviations. Uncertainty in an LCA takes on a more qualitative form and identification of sources of uncertainty can become difficult without some method to classify the assumptions being made at all points in the assessment. Uncertainty analysis are rarely done in LCA's and a further point is made regarding the importance of uncertainty analysis in LCA's due to the nature of their use in decision making.

Uncertainty in LCA

the qualitative fuzzy notions and how they get narrowed down to what can be quantized which is parametric uncertainty

ISO 14044 requires an uncertainty analysis for public comparative studies. Despite this, a recent study by Bamber et al. (2020) shows that only 20% of LCA studies, for a period between 2014-2018 published an uncertainty analysis with their LCA. The number of LCA's published grew in that time period with a corresponding decline in uncertainty analysis.

An LCA is considered a deterministic decision support tool, the impact assessment generated by an LCA is dependent on model calculations that can have uncertainties along with the initial uncertainties of input data assumptions and sources. There is more qualitative uncertainty in the impact assessment stage as value judgements may play a larger role (Lloyd and Ries (2008)).

Any LCA has a large amount of assumptions that need to be made at all stages, from goal and scope to impact assessment. All these assumptions have some element of uncertainty attached to them. The first task in an uncertainty analysis is to evaluate the sources of uncertainty in an LCA.

There is no generally agreed upon classification of uncertainty in an LCA. Hujibergs 98 formed the intial set of uncertainties affecting the product system to be modelled commonly used: * Temporal variability (seasons). * Spatial variability (geography, population density). * Parameter uncertainty (inputs to representation calculations) * Model uncertainty (algorithmic representation of process). * Uncertainty due to choices (in goal and scope, functional unit, system boundaries).

Bjork added

- Epistemological uncertainty (relating to lack of knowledge of physical phenomena).

- Mistakes.

Hauschild, Rosenbaum, and Olsen (2018) added a further relevance uncertainty relating to whether the associated impact actually maps the area of concern.

These categories are generalised to three broad categories: parametric, model and scenario. Parametric uncertainty relates to variability and uncertainty of the inputs to the model. Model uncertainty relates to lack of knowledge about accuracy of the equations used and codified to the 'real world' causal mechanism. Scenario uncertainty concerns variability in the state of the world for different use cases of the model results.

Parametric uncertainty analysis is the most common form of analysis done in LCA's. It's inconclusive if this is where the most uncertainty in an LCA is found or if its due to the availability of tools or some other ease of performing such an analysis over the others. Lloyd and Ries (2008) that more assumptions and value judgements are present in scenario uncertainty compared to inventory analysis related uncertainty, which could be from the model or parameters. The uncertainty and variability associated with the model and parameters is completely concerned with deviation from a model result. It says nothing about the uncertainty attached to how these results are used or interpreted in decision making.

Looking at sources of uncertainty in the LCA, then defining which ones can be quantified. Parameter uncertainty and variability is the most directly quantifiable source of uncertainty. A starting point for its quantification is determining the effect different inputs have on the output result of the LCA model. This is direct uncertainty of singular quantities. To aggregate this uncertainty and view its affect on the whole model uncertainty propogation methods are needed.

Uncertainty in Representation/Modelling

because it fits the modelling decision support template

An LCA aims to model a natural system. In an LCI an algorithm is developed to calculate the elemental flows for the LCA. Figure shows a schematic of these layers of abstraction from the natural system. The initial LCA was done in Excel. This research implemented Python code that replicated the algorithmic implementation with more flexibility that the Excel form for random sampling simulations.

The phase of the LCA analysed of particular concern is the Lifecycle Inventory phase. This is an accounting all inputs and output resources in the product system. Due to the general computational nature of this phase, it can be considered a model. The following paper takes a decision support tool modelling approach to uncertainty analysis and quantification Walker et al. (2003).

Models are by definition a description of reality in some language. Computer models are algorithmic representations of reality. While there is great power in the reach of algorithmic representations some element of abstraction of the natural system is always present. This is known as the complexity at the heart of software (Evans) in the Software Engineering domain and is a well studied property of environmental models. (Warmink et al. (2010)) provides a framework based on Walker for evaluating uncertainty in models that form the based of decision making.

The broad categories defined above of parametric, model and scenario have parallels in decision support tool modelling.

Walker et al. (2003) identifies the three dimensions of uncertainty as

- Location: where the uncertainty manifests itself within the model
- Level: where the uncertainty manifests along a spectrum from determined knowledge to total ignorance.
- Nature: uncertainty due to the variability of nature or our lack of knowledge of the 'mechanisms' of nature.

Warmink et al. (2010) provides a decision tree for categorisation of identified model uncertainty.

Approaches

Current LCA software has sampling capabilities with all providing Monte Carlo sampling methods. Igos contains a comparison functionalities in terms of uncertainty representations.

Parameter Uncertainty vs variability

Methodology

Abstraction and assumptions made increases the closer the modelling comes to software.

Results

Analysis of one unit process should give us a template of the rest.

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