LCA OF EMERGING TECHS

- FROM AN UNCERTAINTY PERSPECTIVE

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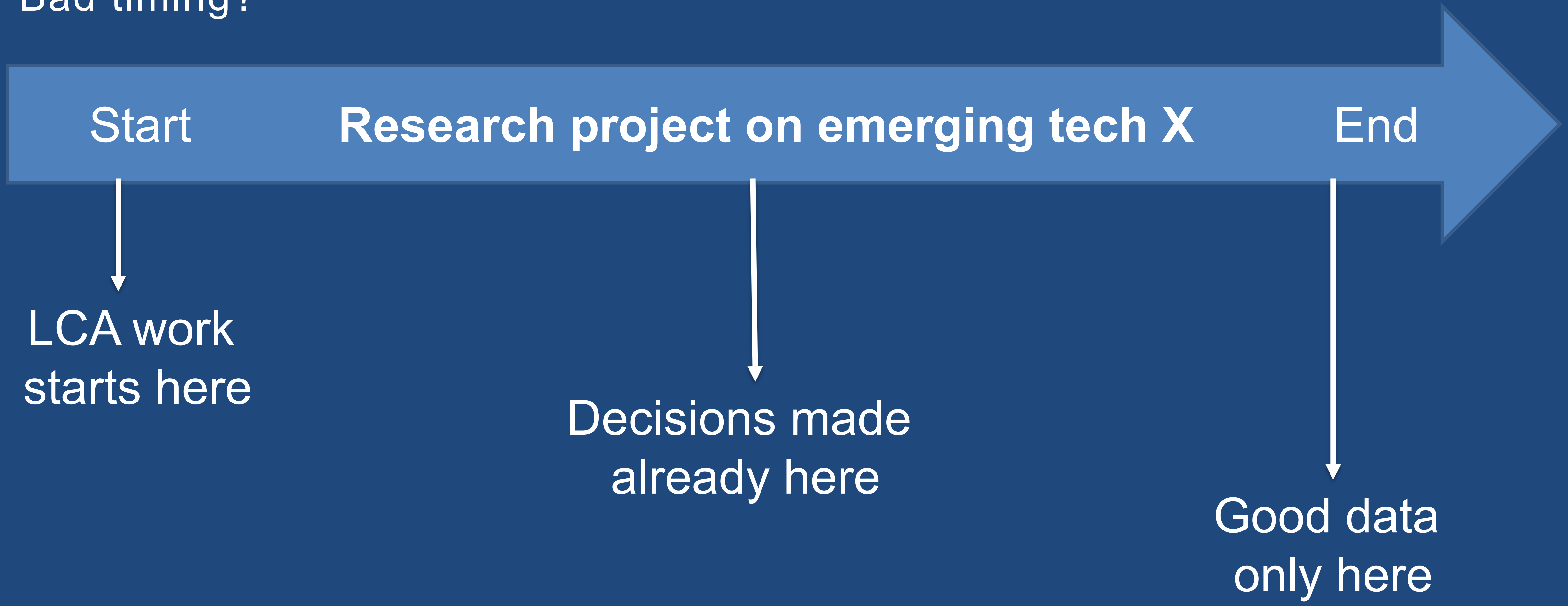
Today on LCA of emerging tech

- Why it is about uncertainty
- Cases from own (consequential) research
- General conclusions & way forward

Authors:

Bad timing?



Start **Research project on emerging tech X** End

LCA work starts here

Decisions made already here

Good data only here

LCA of emerging tech
= predict the future (which is uncertain)
= dealing with uncertainty

Uncertainty, theory

- **nature:** epistemic, aleatory
- **location:** quantity, model, context

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UNCERTAINTIES IN LCA

CrossMark

How to treat uncertainties in life cycle assessment studies?

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Abstract

Purpose The use of life cycle assessment (LCA) as a decision support tool can be hampered by the numerous uncertainties embedded in the calculation. The treatment of uncertainty is necessary to increase the reliability and credibility of LCA results. The objective is to provide an overview of the methods to identify, characterize, propagate (uncertainty analysis), understand the effects (sensitivity analysis), and communicate uncertainty in order to propose recommendations to a broad public of LCA practitioners.

Methods This work was carried out via a literature review and an analysis of LCA tool functionalities. In order to facilitate the identification of uncertainty, its location within an LCA model was distinguished between quantity (any numerical data), model structure (relationships structure), and context (criteria chosen within the goal and scope of the study). The methods for uncertainty characterization, uncertainty analysis, and sensitivity analysis were classified according to the information provided, their implementation in LCA software, the time and effort required to apply them, and their reliability and validity. This review led to the definition of recommendations on three levels: basic (low efforts with LCA software), intermediate (significant efforts with LCA software), and advanced (significant efforts with non-LCA software).

Results and discussion For the basic recommendations, minimum and maximum values (quantity uncertainty) and alternative scenarios (model structure/context uncertainty) are defined for critical elements in order to estimate the range of results. Result sensitivity is analyzed via one-at-a-time variations (with realistic ranges of quantities) and scenario analyses. Uncertainty should be discussed at least qualitatively in a dedicated paragraph. For the intermediate level, the characterization can be refined with probability distributions and an expert review for scenario definition. Uncertainty analysis can then be performed with the Monte Carlo method for the different scenarios. Quantitative information should appear in inventory tables and result figures. Finally, advanced practitioners can screen uncertainty sources more exhaustively, include correlations, estimate model error with validation data, and perform Latin hypercube sampling and global sensitivity analysis.

Conclusions Through this pedagogic review of the methods and practical recommendations, the authors aim to increase the knowledge of LCA practitioners related to uncertainty and facilitate the application of treatment techniques. To continue in this direction, further research questions should be investigated (e.g., on the implementation of fuzzy logic and model uncertainty characterization) and the developers of databases, LCIA methods, and software tools should invest efforts in better implementing and treating uncertainty in LCA.

Keywords Communication · LCA software · Life cycle assessment · Sensitivity analysis · Uncertainty analysis · Uncertainty characterization

1 Introduction

Life cycle assessment (LCA) methodology is now a recognized and widespread approach for evaluating the environmental impacts of products, technologies, and policies. The use of LCA as a decision support tool can, however, be hampered by the numerous uncertainties embedded in the calculation, as well as the fact that the results cannot be verified, validated, or confirmed due to many constraints (technical, conceptual, legal,

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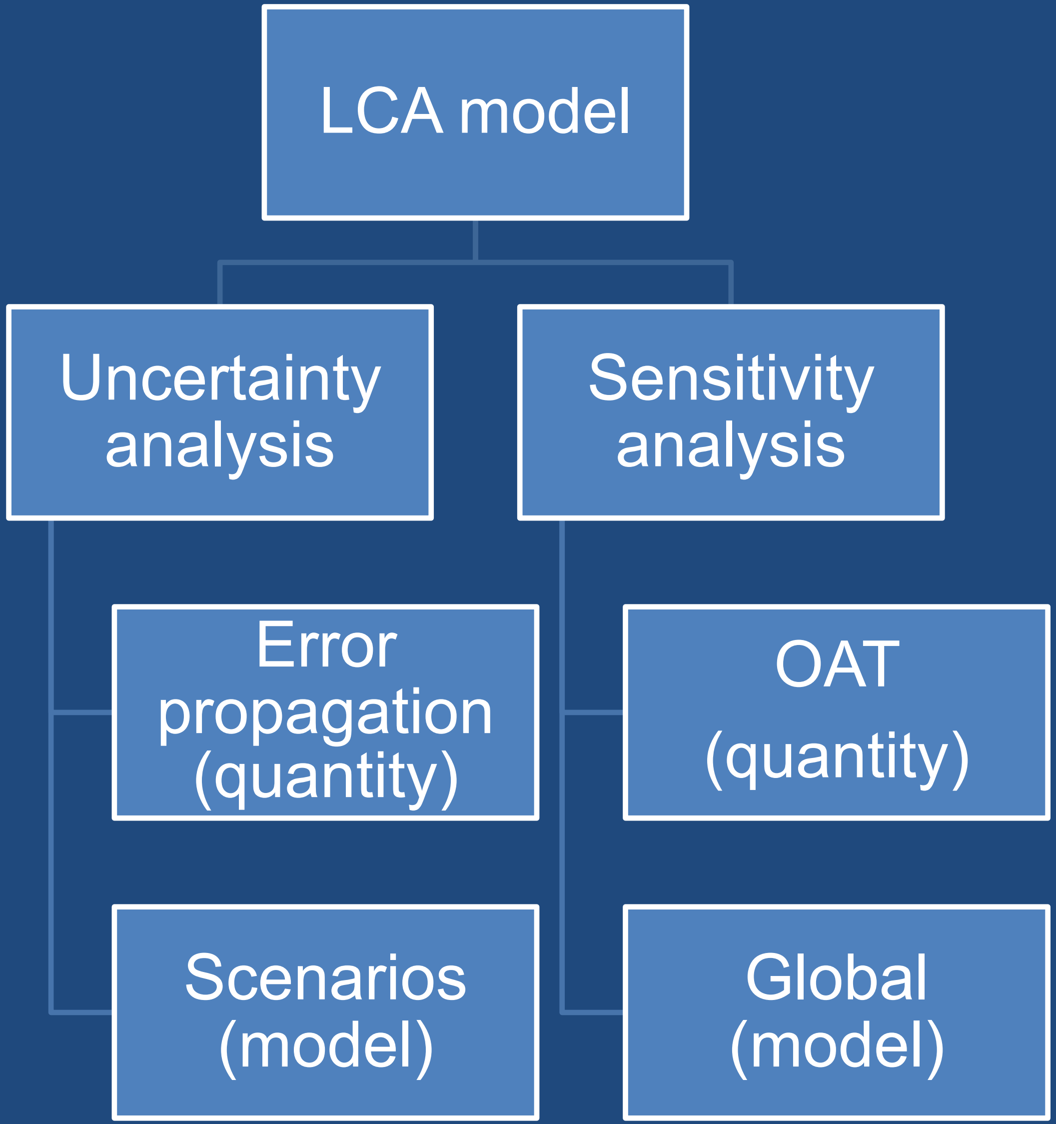
Uncertainty, practice



LCA model

Uncertainty analysis

Error propagation (quantity)

Scenarios (model)

Sensitivity analysis

OAT

(quantity)

Global (model)

A toolbox…

UHP Homogenisation, milk

- Electricity consumption (quantity, epistemic) → power laws
- Estimated avoided fresh cheese production (model, aleatory)→ scenarios using literature & models (WRAP)

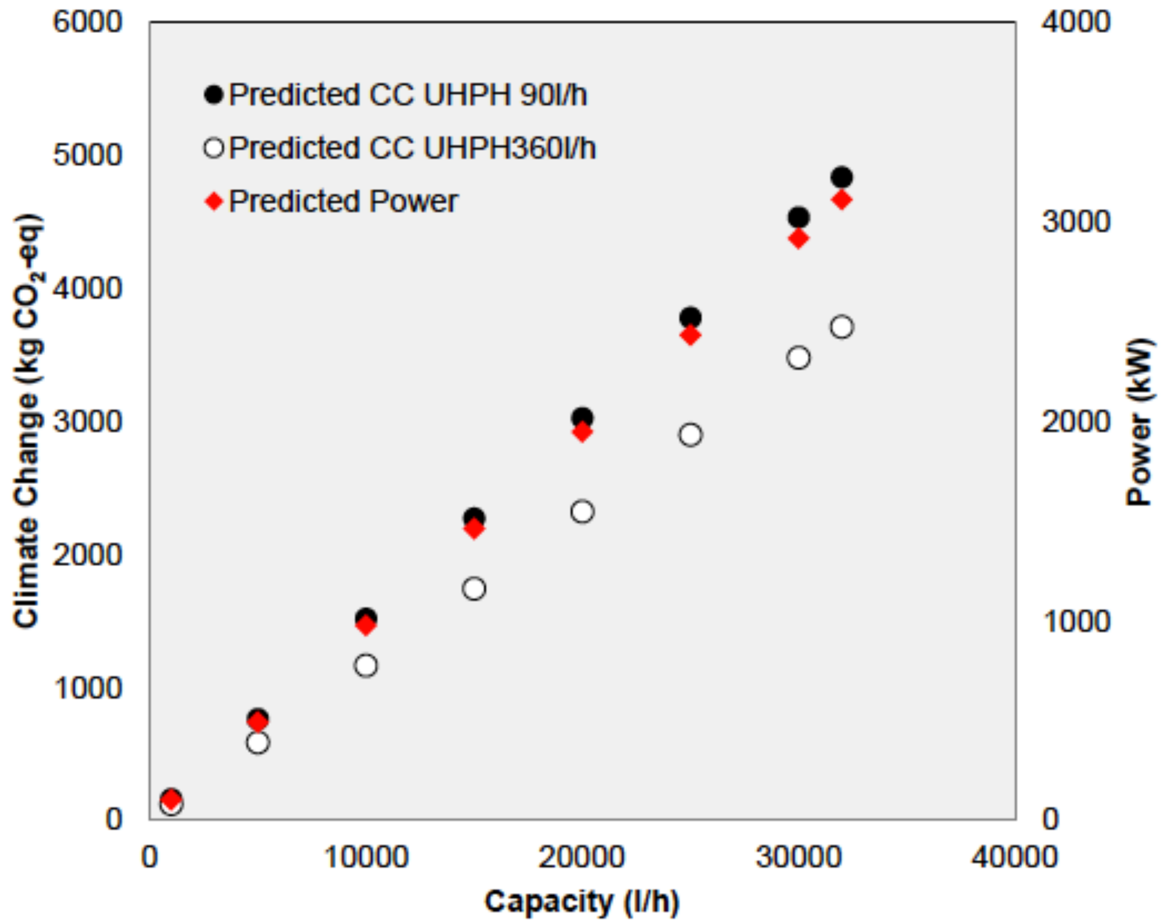
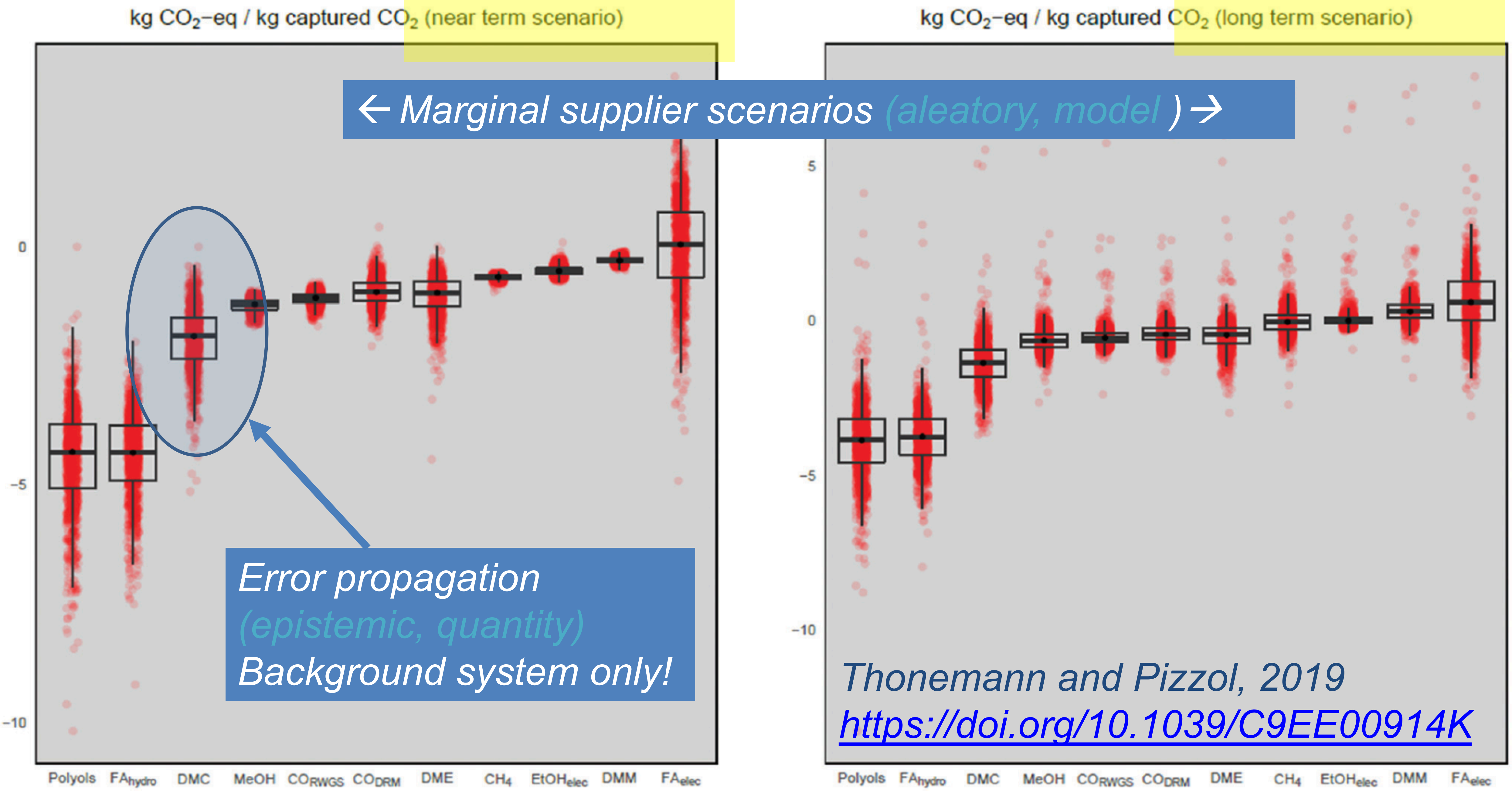


Fig. 2. Upscaling of the climate change (CC) impact (kg CO_2-eq) using power laws of power (kW) related to capacity (l/h).

Valsasina et al. (2016)
https://doi.org/10.1016/j.jclepro.2016.11.059



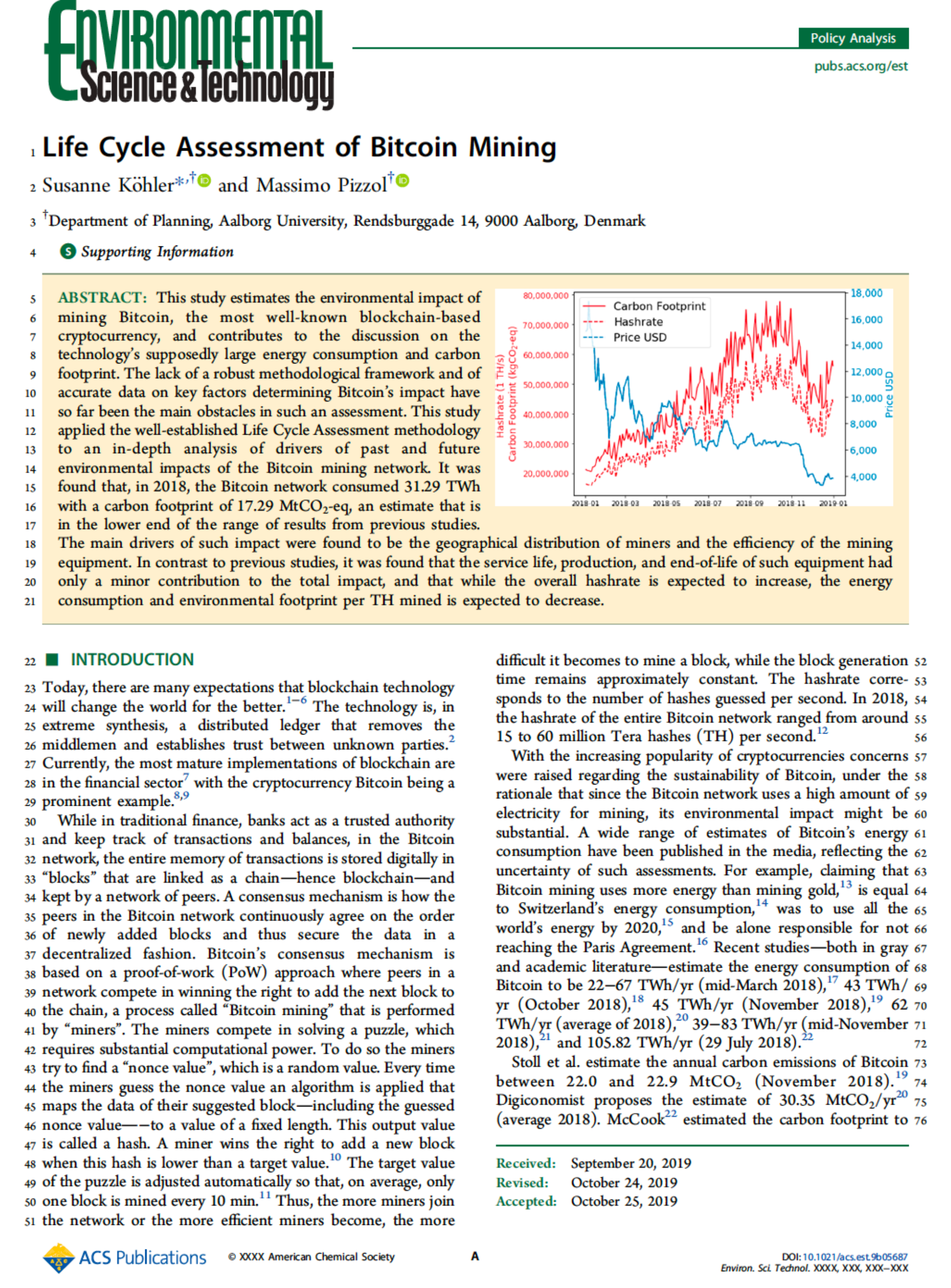
← *Marginal supplier scenarios (aleatory, model)* →

Error propagation
(epistemic, quantity)
Background system only!

Thonemann and Pizzol, 2019
https://doi.org/10.1039/C9EE00914K

g. 3 Global warming impact of CO_2-conversion technologies (results for FT are excluded here for readability reasons and can be accessed in the ESI†)

Bitcoin Mining



Environmental Science & Technology
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Life Cycle Assessment of Bitcoin Mining

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Supporting Information

ABSTRACT: This study estimates the environmental impact of mining Bitcoin, the most well-known blockchain-based cryptocurrency, and contributes to the discussion on the technology's supposedly large energy consumption and carbon footprint. The lack of a robust methodological framework and of accurate data on key factors determining Bitcoin's impact have so far been the main obstacles in such an assessment. This study applied the well-established Life Cycle Assessment methodology to an in-depth analysis of drivers of past and future environmental impacts of the Bitcoin mining network. It was found that, in 2018, the Bitcoin network consumed 31.29 TWh with a carbon footprint of 17.29 $MtCO_2$-eq, an estimate that is in the lower end of the range of results from previous studies. The main drivers of such impact were found to be the geographical distribution of miners and the efficiency of the mining equipment. In contrast to previous studies, it was found that the service life, production, and end-of-life of such equipment had only a minor contribution to the total impact, and that while the overall hashrate is expected to increase, the energy consumption and environmental footprint per TH mined is expected to decrease.

INTRODUCTION

Today, there are many expectations that blockchain technology will change the world for the better.[1−6] The technology is, in extreme synthesis, a distributed ledger that removes the middlemen and establishes trust between unknown parties.[2] Currently, the most mature implementations of blockchain are in the financial sector[7] with the cryptocurrency Bitcoin being a prominent example.[8,9]

While in traditional finance, banks act as a trusted authority and keep track of transactions and balances, in the Bitcoin network, the entire memory of transactions is stored digitally in "blocks" that are linked as a chain—hence blockchain—and kept by a network of peers. A consensus mechanism is how the peers in the Bitcoin network continuously agree on the order of newly added blocks and thus secure the data in a decentralized fashion. Bitcoin's consensus mechanism is based on a proof-of-work (PoW) approach where peers in a network compete in winning the right to add the next block to the chain, a process called "Bitcoin mining" that is performed by "miners". The miners compete in solving a puzzle, which requires substantial computational power. To do so the miners try to find a "nonce value", which is a random value. Every time the miners guess the nonce value an algorithm is applied that maps the data of their suggested block—including the guessed nonce value−−to a value of a fixed length. This output value is called a hash. A miner wins the right to add a new block when this hash is lower than a target value.[10] The target value of the puzzle is adjusted automatically so that, on average, only one block is mined every 10 min.[11] Thus, the more miners join the network or the more efficient miners become, the more difficult it becomes to mine a block, while the block generation time remains approximately constant. The hashrate corresponds to the number of hashes guessed per second. In 2018, the hashrate of the entire Bitcoin network ranged from around 15 to 60 million Tera hashes (TH) per second.[12]

With the increasing popularity of cryptocurrencies concerns were raised regarding the sustainability of Bitcoin, under the rationale that since the Bitcoin network uses a high amount of electricity for mining, its environmental impact might be substantial. A wide range of estimates of Bitcoin's energy consumption have been published in the media, reflecting the uncertainty of such assessments. For example, claiming that Bitcoin mining uses more energy than mining gold,[13] is equal to Switzerland's energy consumption,[14] was to use all the world's energy by 2020,[15] and be alone responsible for not reaching the Paris Agreement.[16] Recent studies—both in gray and academic literature—estimate the energy consumption of Bitcoin to be 22−67 TWh/yr (mid-March 2018),[17] 43 TWh/yr (October 2018),[18] 45 TWh/yr (November 2018),[19] 62 TWh/yr (average of 2018),[20] 39−83 TWh/yr (mid-November 2018),[21] and 105.82 TWh/yr (29 July 2018).[22]

Stoll et al. estimate the annual carbon emissions of Bitcoin between 22.0 and 22.9 $MtCO_2$ (November 2018).[19] Digiconomist proposes the estimate of 30.35 $MtCO_2/yr$[20] (average 2018). McCook[22] estimated the carbon footprint to

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Environ. Sci. Technol. XXXX, XXX, XXX−XXX

Changes all the time!

- Energy efficiency of equipment (quantity, epistemic) → OAT
- Location of miners (model, aleatory) → literature/expert-based scenarios
- Background system (quantity, epistemic) → Monte Carlo

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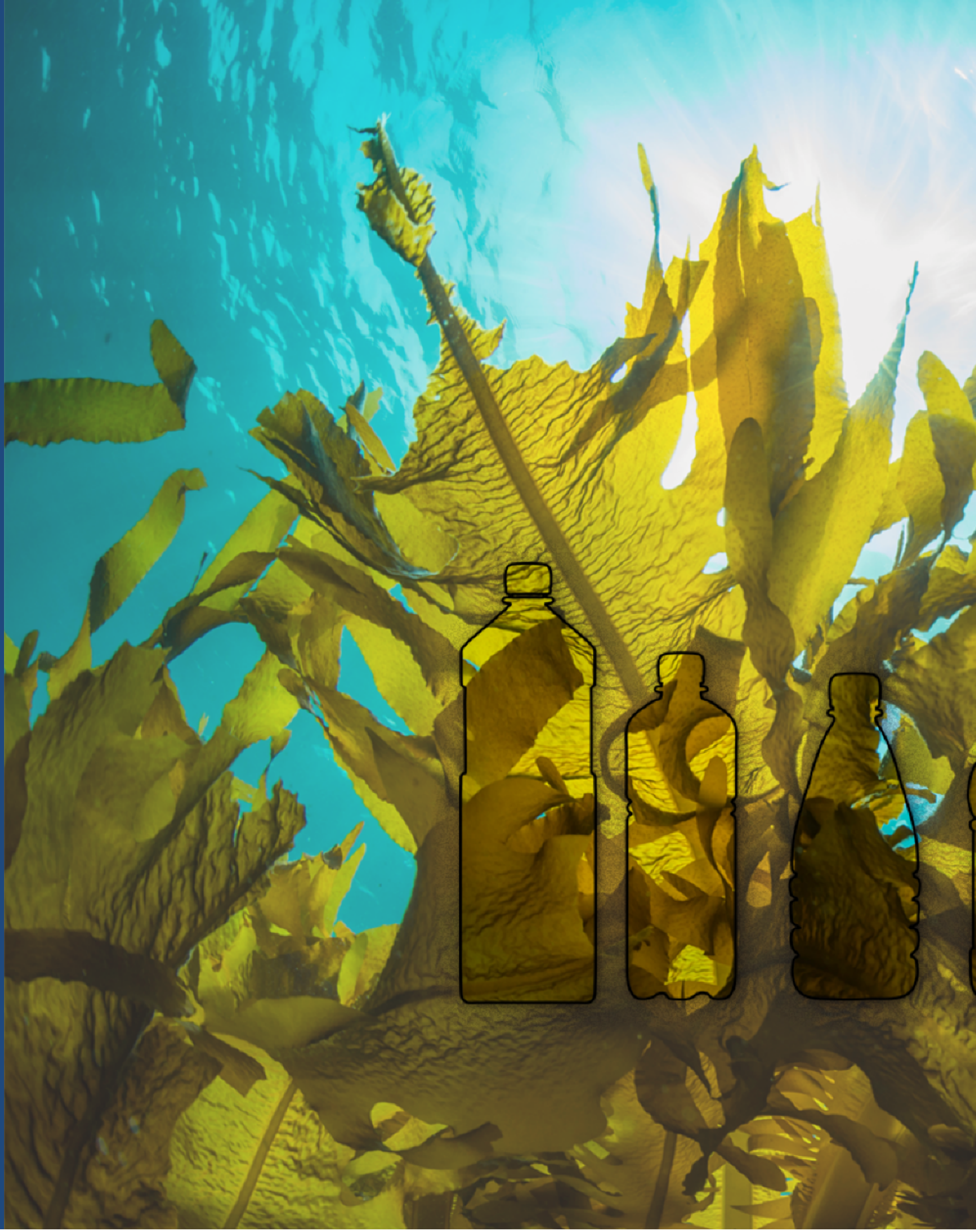
Bioplastic from seaweed

- Unconstrained seaweed suppliers? (model, aleatory) → supply stats, interviews
- Scalability pilot to industrial? (quantity and model, epistemic) → LCA iterations, assumptions & scenarios discussed with domain experts



https://vbn.aau.dk/en/projects/novel-enhanced-bioplastics-from-sustainable-processing-of-seaweed

Microalgae-based veterinary products for aquaculture

All technological scenarios are open

Which microalgae and which cultivation system?
(epistemic, model)

Archetypes, sensitivity analysis


MDPI


Schott

Which type of bioactivity for the molecule?
(aleatory, model)

Archetypes, health issues categorization

Type A disease : Viral infection with no known treatment and low mortality, chronic

Type B disease : Bacterial infection currently treated with oxytetracycline, high mortality, outbreaks

Prophylactic : improve FCR and increase disease resistance

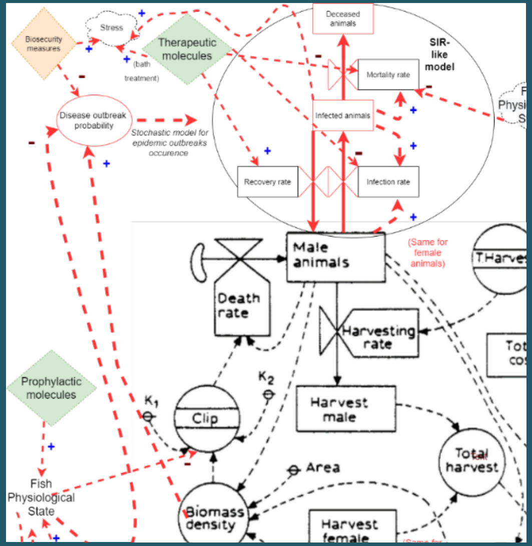

Intrafish

Wikiwand

FOSAF

What changes for fish farming?
(epistemic, model)

Fish farm archetypes +
System Dynamics model

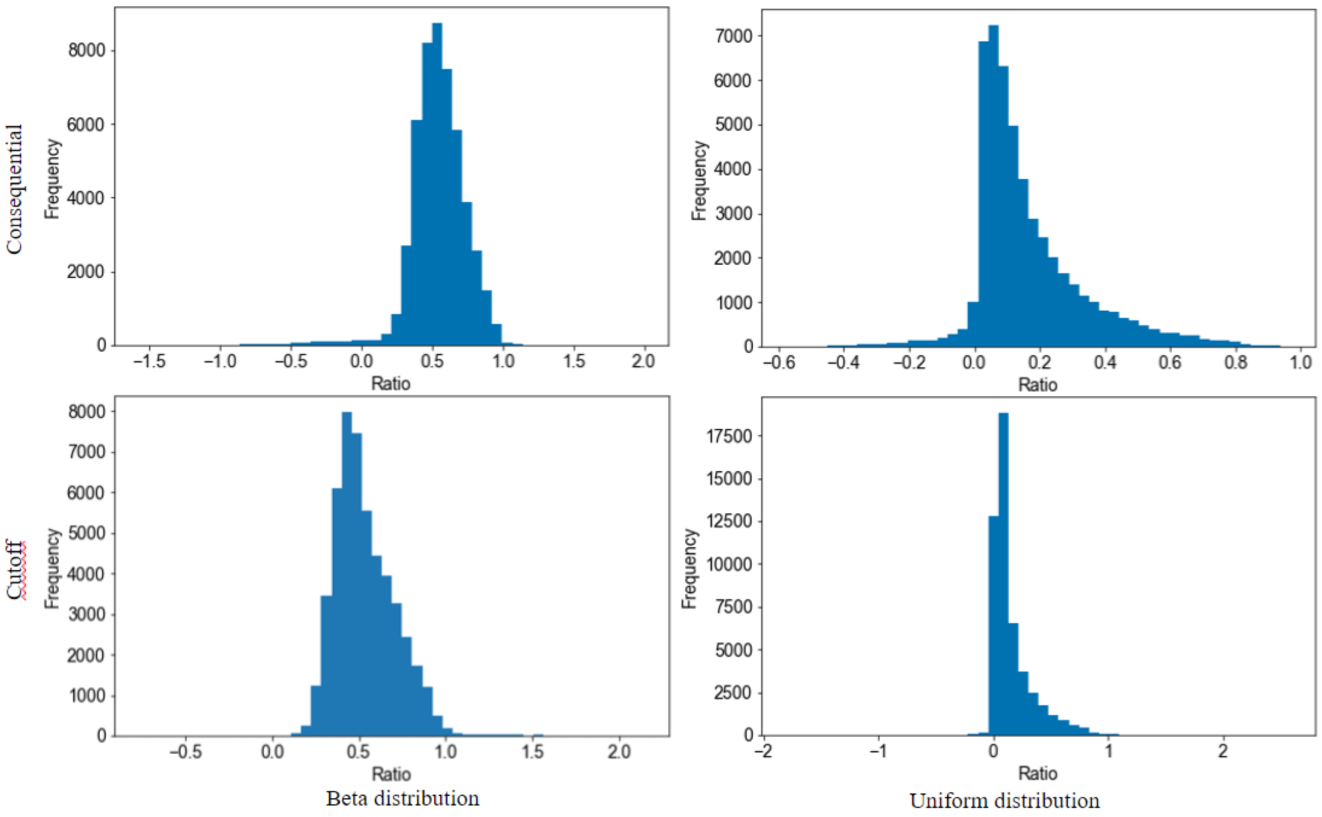


Consequential LCA

https://vbn.aau.dk/en/projects/microalgae-microbiomes-a-natural-source-for-the-prevention-and-tr

Foreground vs background

- Database might not reflect technical maturity
- What is the uncertainty introduced? (epistemic, aleatory, quantity…and model)
- Simulation improving efficiency (quantity) shows nonlinearity



Pizzol, Sacchi, Köhler, Andersen, submitted 2020 (Frontiers in Sustainability)

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Wrapping up

- LCA of emerging tech is about uncertainty
- So you can use the entire uncertainty-toolbox!
- Experience shows that model and aleatory most critical
- Stakeholders-supported models / scenarios is **way forward**

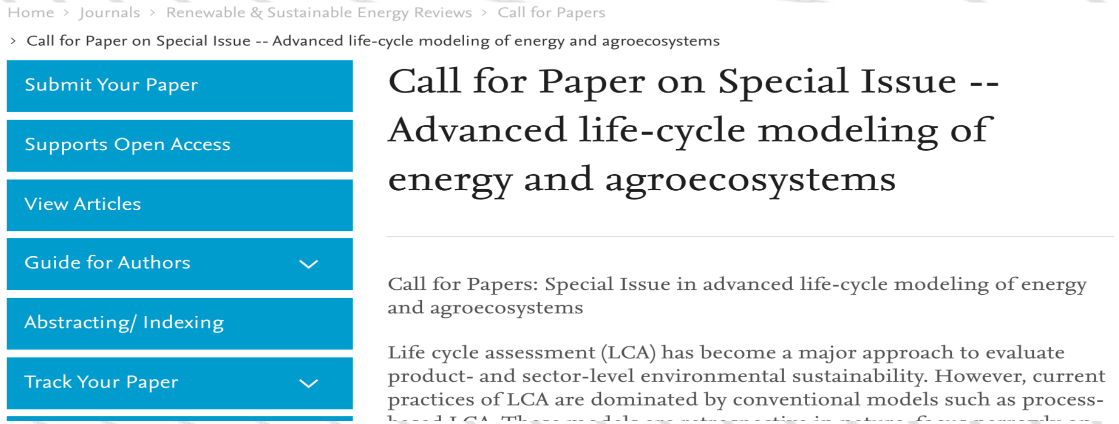
👉Open! Special Issue Uncertainty in Prospective Sustainability Assessment (*Sustainability*)

Uncertainty in Prospective Sustainability Assessment

Guest Editor
Assoc. Prof. Massimo Pizzol

Deadline
15 December 2020

👉Open! Special Issue Advanced life-cycle modeling of energy and agroecosystems (R&SER)



Call for Paper on Special Issue -- Advanced life-cycle modeling of energy and agroecosystems

Call for Papers: Special Issue in advanced life-cycle modeling of energy and agroecosystems

Life cycle assessment (LCA) has become a major approach to evaluate product- and sector-level environmental sustainability. However, current practices of LCA are dominated by conventional models such as process-

THANK YOU

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