Combining Ex-ante LCA with Scenario-Discovery and conditional probabilities to assist decision-making under distinct degrees of Incertitude

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1. Introduction

In times of ecological emergency, it is necessary to prioritize the allocation of limited time and resources to the exploration of solutions that are more likely to substantially limit the ecological and social crisis. In this context, ex-ante LCA should assess new technological directions before their exploration is initiated. For instance, "Should time and resource be allocated to researching how seaweed could enhance bovine digestion?" or even broader; "Should we look for new microalgae to enhance fish health in European aquaculture?". Ideally, policy-makers would be interested in the likelihood of such research directions eventually generating market scale technologies that environmentally outperform alternatives, i.e. the likelihood of a successful development. However, providing estimates for such broad technological directions whose exploration is inherently chaotic generally comes with substantial levels of incertitude.

As already pointed out by van der Giesen et al.[1], the ex-ante LCA community generally employs "uncertainty" to qualify all forms of "incertitude", but theoretical advances[2–4] within Post-normal Science[5] have emphasized the need to differentiate distinct levels of knowledge characterizing incertitude for sound science-advised decision-making. Stirling[3] and Wynne[4] propose that "uncertainty" should be reserved to incertitude when the level of knowledge on likelihoods, typically on probability distributions assigned to parameters of an ex-ante LCA model, is "problematic"[3]. When the level of knowledge is deep enough, well supported by data and experts, and probability distributions can reasonably be assigned to parameters values, incertitude is instead treated as belonging to "risk"[3,4]. As LCA is a quantitative assessment, practitioners need to assign values to parameters. Even when the level of knowledge is very superficial, there is a tendency to apply wide uniform distributions to parameters and propagate these distributions together with the other parameters' ones. According to Stirling, this corresponds to treating incertitude as "risk", while this incertitude should be treated as "uncertainty". This can deceive decision-makers by providing over-confident estimates and artificially reducing the genuine level of incertitude. Another approach is to assign values to these uncertain parameters within explorative and easily interpretable scenarios without assigned probabilities. However, developing relevant scenarios for complicated systems can be challenging and the risk of overlooking important potential configurations can be high[6]. Scenario-discovery[6] has therefore been proposed to palliate these issues and aims at computationally discovering scenarios of interest within a large parameter space, thus allowing stakeholders to reflect on the likelihood of these scenarios only.

With this work, we present a new case study on the likelihood of success for microalgae-based fish health enhancement in European aquaculture within which we acknowledge the different levels of incertitude. We then use a Scenario-Discovery algorithm[6] on the uncertain parameters to discover interpretable scenarios within which the conditional probability of success is higher than a certain decision threshold. With this work, we promote the use of ex-ante LCA for policy-making regarding broad technological directions, acknowledging the chaotic nature of technological developments, and build a bridge between concepts and methodologies from Post-normal Science and LCA modelling.

2. Materials and Methods

For the case study, the decision-making problem is summarized as "Should we invest time and resources in looking for new microalgal compounds to enhance fish health and growth performance in aquaculture?" . To assist such decision-making, we assess the probability of a successful technogical development, i.e. trout production using microalgal compounds environmentally outperforming the production of trout not using microalgal compounds.The associated LCA model and product system combine previous work on the production and environmental impacts of undiscovered bioactive microalgal compounds in Europe with a new paramereterised trout farm model.

The incertitude applying to the parameters ruling the production of the undiscovered microalgal compound (nature of the strain, location and techno-operational setup etc.) and the background system belongs to “risk” as the chosen probabilities distributions are supported by knowledge, even miminal in certain cases. On the contrary, the incertitude applying to the compound effect on the fish, and to the potential for enhancement in the farm when the microalgal compounds are brought to market (e.g mortality levels) belongs to “uncertainty” as the level of knowledge about the probabilities is too limited to provide non-deceveing estimates a priori. We thus apply arbitrarily large uniform ranges to the latter uncertain parameters and propagate this incertitude via Monte Carlo sampling together with the other parameters for which incertitude belongs to risk.

While both forms of incertitude are propagated together, we then delimitate regions in the input space which are defined by the values of parameters subect to uncertainty values only. This yields a table of dimension Δ (number of uncertain parameters) with cells/regions of size *[dA, dB,...,dΔ]* with *dx* the chosen resolution for parameter x (cf. figure 1). Within a region {[A_0,A_0+dA],[…],[$Δ_0$,$Δ_0$+dΔ]}, the proportion of simulations for which the trout production enhanced with microalgal compounds environmentally outperforms the production without compounds can be interpreted as the probability of success for the technological pathway conditional to A ϵ [A_0,A_0+dA],…, *Δ* ϵ [*Δ* $_0$, *Δ* $_0$+d*Δ*].

The PRIM algorithm is finally applied on this segmented input and output spaces to discover Scenarios of success, i.e. boxes of regions for which the conditional probability of success is superior to a threshold for decision-making fixed at 70% (cf. figure 1). To do so, the algorithm iteratively selects increasingly smaller boxes within the input space by maximizing an objective function which concentrates cases of interest.

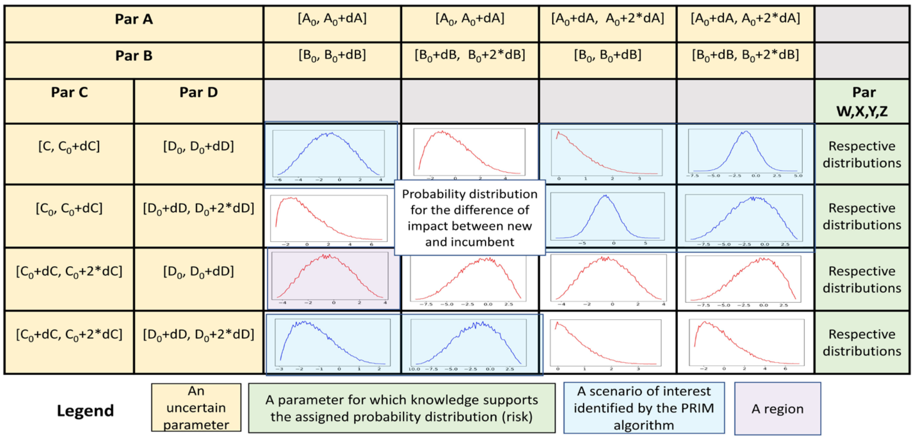

Figure 1: Illustration of the uncertainty and risk propagation and Scenario-Discovery process. The illustration is provided in a case where only four parameters (A, B, C, D) are subject to uncertainty in Stirling's definition. Blue probability distributions correspond to regions in which the conditional probability of success is higher than 70%. dx is the resolution with which the space of parameter x is divided.

3. Results and Discussion

The results are currently being processed and will identify under which conditions of compound effect and fish farm enhancement potential (uncertainty) would the probability of successful technological development be over 70%, taking into account all possible production pathways for the compound (risk). This will help the decision-makers to decide on the likelihood of the identified scenarios only and then take a decsion of investing of not. We will demonstrate the feasibility of the approach together with its limitations, may they be technical, computational or theoretical. Following Stirling's call to “keep it complex”[3], our work proposes and illustrates and approach for ex-ante LCA to comply to the needs of sound science-based advice to policy-making in a Post-normal age[5].

4. References

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