Accounting for uncertainty in the assessment of material requirements and related climate change impacts of the energy transition

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1. Introduction

The current French electricity production mix is dominated by nuclear source (76.3% of the French grid mix in 2015), whereas renewables comparatively represent a minor share (17.5%) [1]. Yet, the recent French "Energy transition act" has set stringent targets to increase the share of renewables in the French electricity mix: respectively 23% targeted by 2020 (i.e. thus adopting the target set by the European directive 2009/28/EC), and 32% by 2030.

Renewable electricity generation systems require various raw materials and metals for which global demand is increasing [2]. In particular, renewable electricity generation systems require steel, aluminium and copper, the global production of which generates significant impacts on climate change, due to their relatively large production volumes compared to other metals [3].

In this context, this study aims at quantifying the requirements for three base metals (iron in steel, aluminium and copper) and for concrete, that would result from the French electricity transition by 2050. The consequences of these requirements in terms of climate change impacts are estimated. Given the significant uncertainties regarding material intensities of electricity generation systems, the study adopts a possibilistic approach to uncertainty representation and propagation.

2. Materials and methods

Three steps are distinguished in the calculation approach. The first step aims at setting the material intensity in terms of direct requirements for steel, aluminium, copper and concrete with respect to several electricity generation systems (in tonnes of materials / MW installed): on-shore wind, off-shore wind, rooftop photovoltaic (PV), ground-mounted PV, hydraulic, nuclear and natural gas. Only electricity generation systems are adressed, therefore disregarding electricity distribution and storage. The data is compiled based on an extensive litterature review that illustrates the imprecision of available data. In such cases, LCA studies of products and systems most often arbitrarily select probability distributions to account for data uncertainty. Because probability distributions reflect random variability, it is preferred here to address uncertainty using so-called possibility distributions [4], as they are better suited to address incomplete/imprecise information. An example of a possibility distribution (also referred to as a fuzzy set) is illustrated in Figure 1.

In the second calculation step, the cradle-to-gate climate change impacts of steel, copper, aluminium and concrete productions are calculated considering a consequential modelling approach. Finally, in the third step, the potential future capacities installed from 2012 to 2050 are drawn from the so-called « Decarbonization through electricity » scenario of energy transition in France by 2050, as defined by the French National Alliance for the Coordination of Research for Energy (ANCRE). This scenario is characterized by a significant increase in electricity consumption, particularly in the transport sector, and includes both reducing fourfold French emissions of greenhouse gases between 2012 and 2050, and decreasing the proportion of nuclear in the electricity mix down to 50% in 2025 [5].

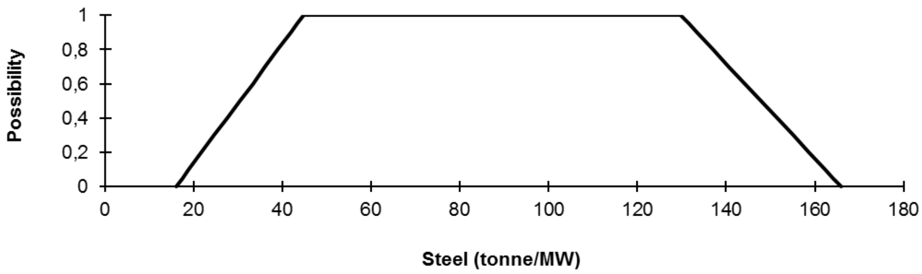

Figure 1: Direct requirement for steel for ground-mounted PV systems: possibility distribution derived from literature data

3. Results and discussion

The results of material requirements and corresponding climate change impacts, as a consequence of the French electricity transition from 2012 to 2050, are expressed as a family of cumulative probability distributions for the proposals: *i)* “requirement for materials (steel, copper, aluminium or concrete) is lower than a certain value” and *ii)* “climate change impact induced by the production of these materials is lower than a certain value” (Figure 2). The upper (plausibility) and lower (belief) bounds of the resulting family of probability distributions are distinguished. The distance between these two bounds results from the incomplete and imprecise nature of the information available on material intensity of electricity generation systems.

In a decision-making framework, working with such imprecise risk indicators is not convenient. Accordingly, considering previous works by Dubois and Guyonnet [6], this study additionnally computes a single indicator (so-called “confidence index”), as a weighted average of upper and lower bounds. This indicator allows considering a trade-off between optimistic and pessimistic estimates. In particular, considering this confidence index as the sole indicator of likelihood, there is a 20% risk that the production of steel, copper, aluminium and concrete, as a response to the French electricity transition from 2012 to 2050, induce more than 444 million tonnes of CO_2-eq.

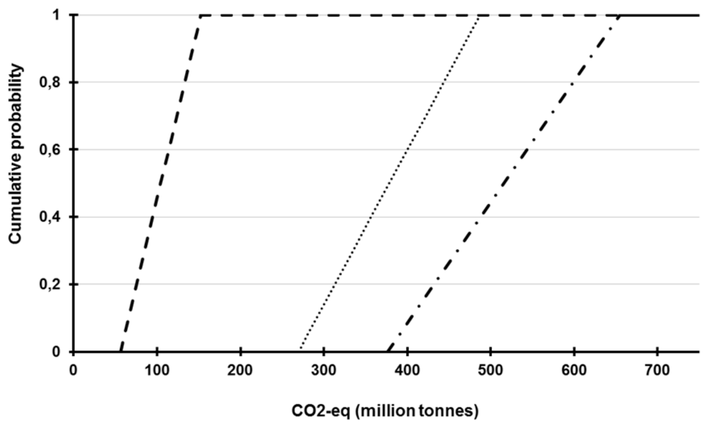

Figure 2: Results of uncertainty propagation, as a family of cumulative probability distributions

4. Conclusions

Results of this study are expressed as upper and lower bounds on the probability that requirement for steel, copper, aluminium and concrete, and their subsequent cradle-to-gate climate change impacts, should be lower than a certain value. Moreover, results with a confidence index value of 80% are derived, and further put in perspective with current requirements for materials and generated greenhouse gas emissions of specific French economic activities. These results are intended to inform decision-makers in the most transparent way, for them to eventually decide whether the calculated risks (that material use and corresponding climate change impacts be larger than given values) are acceptable or not. In the latter case, options to divert the energy transition towards lower requirements for materials, and subsequently lower climate change impacts, should be considered.

5. References

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