Risk Measures in monetary valuation of LCA results

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ABSTRACT

A recurring issue in LCA is the impact assessment of inventory items that are associated with a probability lower than one. In many production life cycles, smaller or larger calamities may occur that are quite clearly not part of day-to-day operations. Taking the impacts of such calamities into account requires the use of risk measures that allow comparison with the impacts of standard operation. Typically, 'technical' or 'neutral' risk measures are used, if risks are taken into account. We argue that for risks with very low probability but very large consequences this practice leads to wrong interpretation of results and undervaluation of the impacts (external effects) of calamities. An illustrative example is the risk of core melt and subsequent containment failure in nuclear reactors. Similar issues are being discussed in the field of damage assessment of greenhouse-gas emissions.

Risk in LCA

At several stages of a life-cycle analysis, an LCA practitioner may encounter risks. It is interesting to distinguish two types : risks at the inventory stage, i.e. emissions or other interactions between system and environment that occur with probability less than one[1], and risks at the impact assessment stage, i.e. impacts that occur with probability less than one as a result of 'every day' emissions.

At the inventory stage, typical risk case studies concern e.g. transports of hazardous chemicals, mining accidents, containment failures of waste storage facilities, hydropower dam breaks or (other) calamities in power generation plants. At the impact assessment stage, typical risk studies would concern e.g. increased health risks due to pollutant emissions, extinction of certain species due to land use or climate change or the increased incidence of extreme weather events with global warming.

Incorporating these risks in LCA is not trivial. The effects of calamities are typically highly local, as well as temporary and non marginal. For many of the examples listed above, the effects of the one-off event cannot be considered steady-state or small with respect to the surrounding 'background'. This is all in contradiction with general requirements of LCA, especially with the use of standard characterization factors. It should therefore be clear that a very specific impact assessment is needed when taking calamities into account, in order to calculate the exact consequences (impacts) of that calamity.

Even then, the question remains how to scale those consequences to compare them to the certain impacts of the production life cycle under consideration. Given that LCA is often a decision-support tool, it may be very useful to quantify the effects of calamities along with those of standard operations or the uncertain impacts along with the certain impacts. When doing this, it is essential to consider what effect the use of different risk measures will

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[1] We use 'probability less than one' rather loosely in this paper, covering both single-event risks and risks with continuous probability-density functions.

have on the results. In the following paragraph, types of risk measures are discussed briefly.

Risk measures

In risk assessment, standard practice is to use as a risk measure either the expectation value of societal risk (e.g. ExternE [1]) and/or the exceedance of individual risk standards (planning of transports of hazardous materials). The societal risk approach is probably more appropriate for LCA type assessments, but the question is whether the expectation value is the appropriate measure to obtain results that may be compared – added – to the other LCA results.

Alternative risk measures exist that take into account the level of risk aversion in actors' utility functions (see e.g. Jonkman et al. [2]). These risk measures tend to look like higher-order moments of the probability distribution function. Where expectation value is the first-order moment of the PDF, the second-order moment involves also the variance. Risk aversion is indeed reflected by judging a risk to be less acceptable when the outcome is less predictable (higher variance). A tiny probability to lose everything one possesses is less acceptable than a chance of 50% to lose €50.

Risk aversion is reflected, amongst others, in insurance premiums for low probability, high consequence events. Such risks may have the same expectation value as more 'common' risks, but insurers will typically demand higher premiums. As the actual level of relevant risk aversion is hard (impossible) to determine for many cases, the risk measures apply a factor to allow for different levels or even a risk-aversion function (as a function of damage).

In our theoretical exercise below, we will use a fairly simple measure of risk, that is expressed as :

$$\text{Risk} = [\text{Expectation value}] + \alpha\,[\text{standard deviation}] \quad (1)$$

This measure is taken from [2], with α a factor indicating the 'level' of risk aversion.

A theoretical exercise

One area where risks may play an important role in LCA is comparisons of different methods of power generation. In almost all production chains of large-scale power plants, major calamities may occur. The largest accident to date in terms of immediate fatalities was the collapse of a hydro-power dam in China. In coal mining, some 800 people die yearly in accidents around the world. Nevertheless, most attention probably goes to risks in the nuclear power chain, most notably to the risk of core melt and containment failure in the plant itself.

When comparing nuclear power to fossil-fuel based power, the probability of accidents is much larger in the latter case, but the scale (of damages) of the largest possible accident is largest in the former. Besides, the damages of accidents in the fossil fuel chains are largely internalized through insurances, as victims are mostly employees. Nevertheless, in the traditional risk-neutral approach (expectation value), nuclear power comes out with lower risk per kWh generated than fossil-based power. When expressing damages (fatalities) in financial terms, the accident risks in all chains are negligible compared to the monetized LCA results (climate change impacts, air pollution impacts, et cetera) as was shown in [1] and NewExt [3]. The former calculates external costs of 0.01 €cent/kWh, based on a probability of containment failure of 1:100,000.

When using a risk-averse measure, this changes the result significantly. With $\alpha=1$ in equation (1), the risk-averse measure would yield a result that is over 300 times higher : 3.2 €cent/kWh. This is approximately a factor 10 higher than the calculated external costs of normal operation (see [1]).

A different approach is to start from the reported damages of the Chernobyl accident. In Belarus and Ukraine, a total of US$436 billion in damages are expected over 30 years after the accident. With a rough estimate of 9000 GW-year of nuclear power produced world wide until the year 2000, the average damage would be roughly 0.5 €cent/kWh. An estimate of the 'probability' of Chernobyl is in fact approximately 1:5000 GW-year (Hirschberg et al. [4]). Using this, the average damage (risk neutral) would be about 0.9 €cent/kWh. A risk-averse result for external costs, using the same risk measure as before, could be of the order of 35 to 65 €cent/kWh.

These figures for Chernobyl are still a factor of 10 higher than the risk-averse results derived from ExternE [1]. This is not surprising, as the Chernobyl reactor was of a notoriously unsafe type. Safer reactor types, such as the PWR used in [1] or the even safer EPR, that is currently being built in Finland, are typically assigned a probability of containment failure of a factor 20 to 1000 (or more) lower and the release may also be much smaller than was the case in Chernobyl. On the other hand, economic damages might be more severe if the accident concerned a reactor in a highly-developed and densely populated area.

In practice

It should be noted that obviously the risk measure used here is not necessarily realistic. What we want to demonstrate is that the use of neutral risk measures for this type of low probability, high consequence risks is not appropriate when results are to be compared to damage calculations of standard day-to-day operation in life-cycle assessments. If external costs are being calculated with a view to internalization, insurance premiums for such major accidents would – if feasible at all – most certainly be at least similar in size in terms of €cent/kWh to e.g. the external costs of greenhouse-gas and pollutant emissions of coal-powered electricity (see e.g. [5]). Again in terms of €cent/kWh, this effectively means that these power chains might be benefiting from 'hidden' subsidies that are relatively large with respect to other means of power generation.

Clearly, increasing insurance premiums to extend coverage to the full size of a major accident would raise the price of nuclear power. This is in line with the 'polluter pays principle' but not necessarily feasible in terms of public opinion, especially in countries with a high percentage of nuclear power. Based on willingness-to-pay assessments, a Swiss study [6] concluded that internalization through increased liability insurance might be economically efficient up to a level of coverage 5 or 6 times higher than the current level of mandatory coverage.

Other low probability, high consequence risks in environmental (life-cycle) assessments may be encountered in damage assessments of greenhouse-gas emissions. The way in which e.g. costs of increased probability of large-scale natural disasters (flooding, cyclones) are incorporated, has a significant influence on the total damage costs per unit of GHG emission. A related application is discussed in [2], where different risk measures are applied in a cost-benefit study of improved protection against flooding of a Dutch polder area. In finding the economically optimal protection level, the risk measure is again of great influence.

Conclusions

In assessments where the need arises to compare risks to e.g. continuous impacts (LCA) or financial investments (CBA), risk should first be classified by the size of the consequences, not by expectation value. When the consequences are high, but expectation value (probability) is low, the effect of averse risk measures on the results should be assessed. Even if the exact functional form of the risk-averse measure is not known, a sensitivity analysis based on a variety of risk measures could still be made. Especially when the results are input for policy making, as is the case for both power generation and climate change issues, this would shed better light on the relevance of (low-probability) risks.

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