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CONFERENCE REPORT: 62ND DISCUSSION FORUM ON LCA

LCA and decision making: when and how to use consequential LCA; 62nd LCA forum, Swiss Federal Institute of Technology, Zürich, 9 September 2016

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Abstract The 62nd life cycle assessment (LCA) forum was held on 9 September 2016 to discuss the state of research and application with regard to consequential life cycle assessment. This conference report presents the highlights of the LCA forum. The state of the art of consequential LCA was presented from different viewpoints. It was pointed out that consequential LCA is more than marginal mixes and avoided burdens and involves causal modelling. It was also said that social responsibility calls for consequential LCA. Currently, different models are used to support decision making. It was suggested to make use of the variety of models to check the conclusiveness of their results and thus the reliability of the LCAs. Current and future implementations of consequential LCI models in background databases and linking algorithms were presented. Several speakers presented consequential LCA case studies covering the sectors energy, transport, housing and mining. Some of the LCA models used in the case studies are complemented with general and partial computable equilibrium models and agent-based models and use environmentally extended input-output data or process-based LCA data. Some of the presentations focused on elements such as constrained production, marginal market mixes and technologies or recycling and system expansion. In three parallel workshops, the needs, contents and methodology, and implementation of consequential LCA approaches were discussed. The participants seemed to generally agree on the basic goal that LCA should be able to reflect the consequences of decisions. The inquiry among the participants showed that the demand for consequential LCA studies is hardly existent. The appropriate implementation of consequential modelling in LCA databases and on the appropriate model to be used in consequential LCA case studies was debated. It revealed a need for further and extensive discussions to be able to reach (minimum) consensus.

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1 Introduction and overview

The 62nd life cycle assessment (LCA) forum was opened with a welcome address given by Rolf Frischknecht (treeze Ltd., Switzerland). He introduced a quote which illustrates the need for more than attributional LCAs in one sentence: “From a purely statistical viewpoint’, the poet said,’ being a non-smoker, I could smoke for about seven years longer than a smoker” (Augustin 1997). Using a purely attributional life cycle assessment model to assess the environmental impacts of large-scale policy measures may result in similarly contradicting

situations like the smoker who would like to enjoy smoking several years longer, but only as long as he or she does not smoke! In a first session, the state of the art of and tools for consequential LCA were presented (Section 2). The speakers of the second and third sessions presented examples of consequential LCAs covering different economic sectors and using different approaches (Section 3). Finally, the questions on needs, contents and methodology, and implementation of consequential LCA approaches were discussed in three parallel workshops (Section 4) and preliminary conclusions were drawn in the final plenary discussion (Section 5).

2 State of the art of and tools for consequential LCA

Reinout Heijungs (Vrije Universiteit Amsterdam, The Netherlands) started with analysing the consequences for LCA practice of doing consequential LCA (CLCA). He argued that it is not just about inserting marginal process data instead of average process data in the existing formulas and neither just about solving multi-functionality by substitution instead of partitioning. Rather, a renewed exercise into the methodological foundations of LCA is required. He argued that CLCA will be based on causal models which are, in principle, verifiable (Heijungs and Guinée 2015), while attributional LCA (ALCA) lacks, for example, a causal basis and is necessarily based on axioms (Heijungs 1998).

Bo Weidema (Life Cycle Academy, Barcelona) talked about system boundary issues related to consequential LCA, focusing on social responsibility, rebound effects and aggregation errors. With respect to social responsibility, Bo Weidema explained three different approaches: a company's value chain (for which he proposed economic allocation), a company's physical supply chain (for which he proposed mass allocation) and the consequences of a company's action (for which he proposed the consequential model). He argues that social responsibility must always include the consequential product life cycle and may additionally include consequences of other activities in a company's value or supply chain. He stated that first-order rebound effects (caused by price differences of the products or services compared) should always be taken into account in consequential LCA. He finally points to some challenges faced in consequential LCA background data such as missing LCI data on different technology levels and on marginal suppliers.

Yi Yang (CSRA Inc., USA) presented a path forward for consequential LCA and decision making. Yang emphasised that LCA is a decision-making tool and therefore is consequential in nature. He pointed out that different classes of models can be and have been used to estimate the environmental consequences of a decision. There are, for example, linear models such as process-based and IO-based LCA (Yang 2016) and non-linear optimisation models such as computable general equilibrium. Considering that each class of models has strengths and limitations, he proposed relying on different models collectively and the idea of preponderance of evidence for decision making (see, e.g., Yang and Heijungs 2016). Specifically, each model estimate or prediction is seen as a point of evidence; the more estimates point to the same direction or the same magnitude of impact, the stronger evidence the results would be considered of what would occur as a result of the decision in question. By contrast, if most model estimates are scattered and widely inconsistent between one another, the results would be considered as providing little evidence of what would occur as a result of the decision in question. In this case, more research is needed, and it is more scientific to acknowledge partial or no knowledge than to give false certitude based on any single model estimate (Manski 2013). This practice is especially relevant for policy making for that it has potentially large economic and environmental impacts. Yang further elaborated that the reason behind this proposal is that LCA studies a complex system and model estimates/predictions are empirically unverifiable; thus, the use of different classes of models altogether has a better chance of predicting the future than relying on any single class of models alone (Yang and Heijungs 2016). Meanwhile, Yang urges a modeller to improve the predicative capability of a model by relaxing some of the major restrictive assumptions and making them more reflective of reality (Yang and Heijungs 2016).

Gregor Wernet (ecoinvent, Switzerland) presented the current implementation of the consequential system model in ecoinvent version 3 (Wernet et al. 2016). The implementation uses substitution of by-products and is restricted to the use of unconstrained suppliers in a small-scale, long-term perspective. Products are largely constrained if they are by-products (which are always constrained by the demand for the reference product) or if there are technological constraints. By-products can still be modelled as inputs. In these cases, constrained markets lead to a decreased availability for a marginal consumption, where substitution takes place. Examples of used refrigerants and sodium hydroxide production were presented. The approach is practical for a large database but has its limitations, and it is recommended to check important background data when carrying out studies. When needed, more detailed data, e.g. on specific future electricity mixes, can be added to the system model.

Gregor Wernet (ecoinvent, Switzerland) also presented the OCELOT project on behalf of Chris Mutel. OCELOT is a joint project of the Paul Scherrer Institute and ecoinvent with the goal to create an open-source implementation of a database-linking algorithm on the example of the ecoinvent version 3 cut-off and consequential models. A clear code structure and thorough documentation are foreseen to allow independent users to apply the algorithm to any suitable unit process-based database. Having some established

implementations of system models available as examples will allow users to make smaller modifications with relative ease while also providing guidance for larger changes. The results are expected for Fall 2016.

3 Case studies: lessons learned

Enrico Benetto (LIST, Luxembourg) presented the return of experience from two research projects where computationally based consequential LCA was used for policy decision making support at Luxembourg's scale. In the first one, partial and general computable equilibrium models were combined with an environmentally extended input-output database to assess the consequences of greenhouse gas emission reduction scenarios (Igos et al. 2015). In the second one, an agent-based model is used to simulate the evolution (and calculate the corresponding environmental impacts and benefits) of the car fleet following the introduction of policy measures (e.g. deployment of charging infrastructures, subsidies) aiming at fostering electro-mobility (Querini and Benetto 2015). The results have shown that simulation and modelling approaches can effectively provide a more accurate picture of the foreground consequential life cycle inventories (LCIs), in particular by identifying the main improvement levers (e.g. specific policy actions and time frame of implementation) and by involving the (public) stakeholders in the loop.

Charlotte Roux (Mines ParisTech, France) presented a consequential approach for LCA adapted and applied to urban projects ecodesign. Building LCA tools addresses a wide range of construction or retrofitting projects, from individual houses to multifunctional neighbourhoods. Energy consumption is a crucial parameter, linked to the long life time of such projects. In the suggested approach, marginal technologies and system expansion are used as main inventory modelling hypotheses. Macro-economic effects on commodity prices (elasticity, rebound effects) are disregarded, considering the small economic scale of an urban project compared to the national economy. Several illustrating examples were presented: primary or secondary steel as construction material, determination of marginal electricity mix using several approaches (short/long term, static/dynamic), local constraints on district heating networks and use of transport simulation model evaluating change in local traffic conditions. Integration of existing constraints (production capacities, resources availability, local urban environment, etc.) adds valuable information to LCA of buildings and districts. It reinforces the importance of improvement of energy performance of buildings, of onsite renewable energy production and of resource efficiency (e.g. design for dismantling).

Rolf Frischknecht (treeze Ltd., Switzerland) presented a simplified consequential case study of a Swiss municipality, which committed itself in the municipal code to lower the primary energy consumption to 2000 W and the annual greenhouse gas emissions to 1 ton CO_2-eq per person. As one of the measures, the administration purchases renewable electricity. The carbon footprint of operating its existing buildings is low even if they have a comparatively highly specific electricity demand. The real estate department faces a situation where refurbishment projects which would help increase the energy efficiency of existing buildings are declined because of low carbon electricity used to operate these buildings. He presented two consequential thinking models that focus on electricity. The thinking models are used to derive (1) a national consequential electricity mix and (2) a residual European electricity mix. (1) Inefficient buildings contradict the strategy of the municipality as well as the policy measures underlying the ambitious scenarios of the national energy strategy 2050. If efficiency measures are not implemented on the majority of the building stock, the electricity demand is likely to surpass the annual available amount of electricity from renewable sources and new gas-combined cycle power plants need to be installed to cover the additional demand. (2) If renewable electricity generated by the municipality's utility is used efficiently, surplus production is available for export to Europe. The export of renewable electricity may help the European Union and its member countries to accelerate the phaseout of nuclear and coal power plants. Thus, the current European non-renewable electricity mix is determined and used as an alternative consequential electricity mix. The case study of a building with retirement apartments shows that replacing the existing heating system with an electric heat pump and renewable electricity shows lower greenhouse gas emissions than any alternative which involves refurbishments. However, applying the consequential electricity mixes (Swiss or residual European mix) reveals that energy efficiency measures plus a replacement of the heating system helps to reduce greenhouse gas emissions on the long run and independent of the fact whether renewable electricity will be purchased during the entire lifetime of the refurbished building.

Dieuwertje Schrijvers (Bordeaux University) discussed the application of consequential LCA to the primary production and recycling of rare-earth elements (REEs). These materials require some extra reflection as there is no primary production route that produces only one individual REE. For each mine, one REE can be identified that puts a constraint on the production volume: the determining co-product. The other elements are co-products. Some co-products might lead to the substitution of another material with the same function. However, several REEs are supplied in excess and will be stockpiled (Binnemans et al. 2013). Therefore, she introduced the concept of demand constraints, which determine whether a co-product will be absorbed by the market or whether anthropogenic stocks (i.e. stockpiling or waste treatment) should be modelled. This approach can give us a qualitative indication whether the recycling of REEs can avoid primary mining,

substitute other materials with a similar function or will just lead to increased stockpiling.

Thomas Dandres (CIRAIG, Polytechnique Montréal, Canada) presented the macro-LCA (M-LCA) approach, an extension of the consequential LCA that implements prospective elements to model future environmental impacts related to global economic perturbations caused by major changes in the society. In the M-LCA approach, economic impacts are based on the GTAP model, an economic general equilibrium model, which provides the production variations for each economic sector in each region of the world in response to a given economic change. The environmental impacts of each regional economic sector are then computed according to the LCA methodology. In this presentation, the M-LCA approach was used to compare two European Union (EU) energy policies (business as usual vs. bioenergy from 2005 to 2025). The results show that economic and environmental consequences of the bioenergy policy are not limited to the EU, but they can also affect the rest of the world. Indeed, the M-LCA approach provides sufficient information to track side effects of perturbations through time. It is found that the bioenergy policy would decrease the coal price and thus enhance the consumption of coal on the short term. Nevertheless, on the long term, the bioenergy policy would have fewer impacts than the business as a usual policy on human health, resources and climate change but more on ecosystems.

Table 1 shows the country/region, the economic sector, the research objective as well as the additional information of the consequential LCA case studies presented at the LCA forum.

4 Workshops

After the presentations, the following three topics and questions were discussed in workshop groups:

- A. *Needs*: Experiences with commissioners (enterprises and administrations) asking for consequential LCAs? What were the questions to be answered by consequential LCA? What was the motivation to commission the study? Which parts of the product system were changed compared to an attributional LCA? Where did the information for establishing scenarios come from? How consequential should daily LCAs be? In which sectors would you expect CLCAs to be performed?
- B. *Contents*: Experiences with commissioners (enterprises and administrations) asking for consequential LCAs? What were the questions to be answered by

Table 1 Country/region, economic sector, research objectives and additional information of the consequential LCA case studies presented at the LCA forum

Country/region	Economic sector	Research objective	Additional information	Publications
LU	Energy	What are the environmental consequences of a GHG emissions policy implementation in the energy mix as compared to BAU?	Cut-off of 2.5% of GHG emissions each year following energy policy	Igos et al. (2015)
LU	Transport	What are the environmental consequences of policy actions (subsidies, infrastructure deployment, multi-modal scenarios) implementation on the mobility system, with special focus on commuters' mobility?	150,000 commuters per day (resident population 537,000) Objective 2020: 40,000 electric vehicles, multimodality interconnections (tramway, trains)	Querini and Benetto (2015)
LU	Agriculture	What are the environmental consequences of an additional production of 145 GWh of biogas from an additional demand of 80 kt of maize as compared to BAU?	20/20/20 EU targets Luxembourg, 11% biofuels in the final energy consumption Limited land use potential, high energy consumption rate, increasing energy imports from neighbouring nations	Vázquez-Rowe et al. (2013)
FR	Housing	What are the environmental consequences of a new urban district, including commuting?	From individual houses to multifunctional neighbourhoods New construction or retrofitting Early design phase	Roux et al. (2016)
CH	Housing	What are the environmental consequences of electricity saving policy applied on a municipality owned building stock?	Focus on the model representing an appropriate consequential electricity mix	Unpublished
GLO	Mining	What are the environmental consequences of an increased recycling of rare earth metals?	Identification of long-term marginal suppliers	Paper in preparation
EU	Energy	What are the environmental consequences of a significant development of wood-bioenergy in Europe (heat and electricity sectors)?	Comparing a bioenergy policy to a baseline policy scenario Timeframe: 2005 to 2025 Including uncertainty assessments	Dandres et al. (2011); Dandres et al. (2012); Dandres et al. (2014)

consequential LCA? How to practically identify marginal technologies? Establishing consequential LCA models: Trade-off between completeness and materiality? What are current research topics?

– C. *Implementation*: Do we need IT solutions to foster CLCAs? Or do we need better sectoral information? Can software routines substitute market and economic knowledge? Scenario: generic implementation or case by case? Use of uncertainty in CLCA compared by ALCA? Easy applicable and understandable platform for LCA tool? Does one single platform suffice?

A. Needs The conclusion of the workshop group discussing the needs from the users' point of view was that in reality, customers rarely ask for consequential LCA but neither for attributional LCA. Most customers do not know the difference, and they might appreciate the use of consequential LCA. But, also consultants often rather use attributional LCA as an approximation for consequential LCA as they are usually more familiar with attributional LCA. However, to achieve a better picture of the supply chain of a certain product or for a better understanding of issues such as indirect effects, the boundaries of attributional LCA are often expanded. In such cases, consequential thinking is included in the analysis even though no consequential LCA is used. In the end, the workshop members concluded that good consulting should include more thinking of possible evolutions outside of the system analysed. These evolutions may affect the system independent of the use of attributional or consequential LCA.

B. Contents For practical projects, it was noted that the choice of either attributional or consequential LCA is mostly taken by the LCA practitioner, with clients usually not having a clear opinion on the issue. The discussion of consequential LCA from a scientific point of view started off with how marginal technologies are defined: Identifying the marginal flows was not seen as too difficult, since the marginal flow can be selected from the ecoinvent database. However, different scenarios have different marginal flows, which may cause some difficulty in identifying them. The term 'marginal' caused some confusion in the group, since the term has different meanings for economists (where marginal means the incremental change induced by "one unit more"). The group recommends collaborating with economists and specialists to make use of their knowledge and existing models when defining and modelling future scenarios. At the same time, it was mentioned that economic general equilibrium models introduce assumptions that demand too much information for process-based LCA. Another area of discussion was the appropriate system level for consequential LCA: While the currently available consequential model is proposed for small-scale and short- to mid-term 'marginal' changes induced by a single product, some participants see the most reasonable application of a marginal approach in the assessment of large-scale and mid- to long-term changes, induced, e.g., by a change in infrastructure or in technology. Using small-scale models for large-scale decision requires adaptations of the database since large-scale changes affect the background data. In conclusion, the general views about the usefulness of the currently available consequential model(s) varied widely. The group did not attempt to establish a common definition of consequential LCA.

C. Implementation During the discussion, it was stated that it is difficult to duplicate the results of a consequential LCA and that assumptions made in the foreground system are easier to follow. Doubts were raised whether time is ripe for a consequential LCA database. It was agreed that this would be a rather ambitious task. The group could not agree on a clear definition of consequential LCA. The linearity assumption used (also) in consequential LCA was challenged. Some participants argued that LCA tools to be used for consequential LCA are (or should be) different from the ones used for attributional LCA. It was agreed that consequential LCA requires information beyond the information needs of an attributional LCA. Some preferred to use additional models and their results separate from the LCA tool to establish consequential product systems and to establish guidelines and clear and standardised interfaces. Others favoured a one-stop solution, where all necessary models and data are included and where the software system is able to recognise and decide whether or not a consequential LCA model is suited or required, e.g. by the size of the reference flow (1 kWh or 1 TWh of electricity). Some participants explicitly expressed their preference of using basic LCI data on a unit process level and adjust key datasets selectively and tailored to the (consequential) goal and scope at issue.

5 Plenary discussion and conclusions

In his closing statement, Rolf Frischknecht shared his impression that the participants seemed to generally agree on the basic goal that LCA should be able to reflect the consequences of decisions. However, the lively discussions on the appropriate implementation of consequential modelling in LCA databases and on the appropriate model to be used in consequential LCA case studies revealed a need for further and extensive consensus and harmo nisation discussions.

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