Multidisciplinary life cycle assessment – a methodological outline for a systems approach to sustainability research

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Introduction – the need for multidisciplinary modelling

Understanding any field of sustainability requires a holistic systems approach, as sustainability is inherently multi-faceted. For example, to map out the economic implication of a technology without its environmental implications provides at best a short term understanding of its sustainability. Yet understanding the environmental implications of an industry or activity without considering how it relates to the wider social context is equally inadequate, because it is only through society that change can occur. As one part of a broad project, we [1] attempted to address this problem by modelling multiple sustainability criteria simultaneously for a complex agro-industry – rice – in India.

Life Cycle Assessment (LCA) is a useful approach to measuring the environmental impact of a product or service, yet it ignores social and economic dimensions. We used the LCA methodology as a framework, and added economic measures (based upon Supply/Value Chain Analysis (VCA)) and social indicators to generate a multifaceted understanding of sustainability.

[1] Barbara Harriss-White and Alfred Gathorne-Hardy (Oxford), D Narasimha Reddy (NIRD and IHD) M Venkatanarayana (NIRD), Gautam Mody, Mohan Mani and Meghna Sukumar (Centre for Workers' Management), Deepak Mishra (JNU), Aseem Prakash (TISS).

The drawing together of different methods and metrics into a single model identifies where and how different impact categories interact as trade-offs or synergies, as well as illuminating potentially unintended consequences of policy decisions.

This brief report offers an overview of LCA, of how we generated our multidisciplinary LCA (mLCA), as well as some key LCA terms and issues.

Multidisciplinary life cycle assessment

A multidisciplinary life cycle assessment is practically complex while essentially simple. It involves determining all the activities (processes/products) needed to produce the item of interest (in our case a kg of rice), and to measure the impacts associated with each activity, which can then all be summed.

In order for mLCAs to be useful however, the process of data gathering and analysis must be carefully controlled. For without an accepted method, meaningful comparisons between pieces of research are impossible.

LCA has four main stages: goal and scope definition, inventory analysis (this is an inventory of input/output data with regard to the system being studied. It involves collection of the data necessary to meet the goals of the defined study), impact assessment (which includes using other information to help assess impacts, for example weighting greenhouse gases or determining how to allocate between co-products) and interpretation (in which results are summarised and discussed as a basis for conclusions, recommendations and decision-making in accordance with the pre-defined goal and scope) (ISO, 2006).

mLCA can be used to look at almost any process or product. However, it is a quantitative method, so appropriate data must be available, and, as with all research, appropriate data collection methods are essential.

Below we lay out the basic 8 steps to generating a mLCA, followed by a little fleshing out of some key points/jargon. This document attempts to do no more than outline the methods; readers tempted to use this method should make full use of key LCA literature. The *European Commission, (2010) International*

Reference Life Cycle Data System (ILCD) Handbook, General Guide for Life Cycle Assessment, Joint Research Centre Institute for Environment and Sustainability is recommended. This is an in depth manual, and feely available from the web

A systems approach to sustainability research – how to do it (using examples from our and others' research).

1. Identify the functional unit, boundaries, 'impact categories' etc. (Our research had two functional units. I kg of white, parboiled rice as retailed in Chennai, and one hectare of land.)
2. Identify the impact categories (our research had greenhouse gas emissions, ground water, total energy, human/animal energy, the quantity, quality and gender of work, costs and profits)
3. Make a product map indicating the physical steps by means of which the function/functional unit is produced. Identify which impact categories affect each stage.
4. Establish the initial project boundaries.
5. Establish how to collect the data. Our research used questionnaire-based data collection, supplemented by secondary sources and expert questioning.
6. Pilot the data collection, testing the model to check that all the necessary data is collectable and collected.
7. Data Collection (->inventory analysis)
8. Inventory (data) analysis
    a. We use Excel for all analysis. A primary data sheet(s) is generated, directly transcribing the answers to question posed in the field into horizontal rows (one per individual). These are then used to populate specific worksheets that focus on certain specified impact categories/stages in the process (ie transport GHG emissions, manufacturing labour quality) as appropriate.
    b. A separate worksheet for constants and other key data inputs is valuable. It allows more transparent sensitivity analysis. For example the assumed methane emissions from a bullock yr^{-1}. All such assumptions that do not come from primary data collection should be clearly referenced.

KEY LCA TERMS AND CONCEPTS

Goal and scope definition.

What is to be studied and why. Key stages include identifying the functional unit, the impact categories, and the definition of the boundaries.

Function, Functional unit

It is important to have a clear definition of what is to be studied. This unit of interest is called the **functional unit**, and should be a meaningful product/function that is relevant to its final use/ consumption/disposal. It should also be appropriately defined so that comparisons can be clearly made. As the European commission put it "comparisons between different materials on a mass basis (e.g. "1 kg glass" vs. "1 kg PET") are meaningless and misleading. A comparison of materials can only be done in context of the products in which they are used. This is to consider their function by specifying and quantifying them in the functional unit (e.g. "1 l one-way glass bottle" vs. "1 l one-way PET bottle", and: "… both for still water delivery to final consumer")" (European Commission, 2010).

Similarly if an mLCA were comparing organic compared to non-organic milk production, the functional unit should include an assessment of the quality of the milk (this could involve physical variables such as fat content, solids content, or instead could rely on an economic measure which takes these into account, so rupees/litre), to ensure that a fair comparison is being made.

Impact categories

What categories are measured? The wrong categories can give highly misleading results. The environmental impact of PVC is comparable to other plastics from the GHG perspective, but it is much worse when toxicity is measured(Wegner and Pascual, 2011). In our rice project we measured nine impact categories: greenhouse gas emissions, ground water, total energy, human/animal energy, quantity, quality and gender of labour, costs and profits. The restriction of environmental categories to energy, GHG emissions and water clearly limits the value of our results for environmental understanding (impacts on biodiversity, eutrophication, NOx, pm10 etc were outside the scope of this research), but also made the methodological objectives of the project feasible. See 'boundaries' below.

Checking boundaries and prioritisation

The stage of goal and scope definition also includes defining the project boundaries. The boundaries consist of what is and what is not included within the analysis, and involves both how long and how broad the analysis should be:

- The length of chain: while LCA is often portrayed as cradle to grave, it is both legitimate and quite common to study just one part of the chain (eg alternative technologies for spinning cloth yarn) if we can assume that after this stage, each product will be treated the in same way (i.e. that weavers buy equally from both spinning technologies).
- The breadth of the chain: how many different processes/factors should be included within the analysis, ie should we include the food that labourers eat? Should we include the veterinary medicine used on the ox that levelled the field? There is a trade-off between including everything for a perfect answer, and not wasting time – finding the right point along the curve of diminishing returns.

Defining the project boundaries is an iterative process because, during the development of the model, new activities will be discovered, and the importance of different stages of activity will become apparent.

The importance of what is and is not included within the project boundaries is further developed in Working Paper 3 – Baselines and Boundaries. [2] Two useful guidelines may be borrowed from PAS 2050 (a carbon footprinting methodology): i) include all sources of emissions responsible for greater than 1% of the total emissions[3], and ii) do not ignore more than 5% of total

[2] http://www.southasia.ox.ac.uk/working-papers-resources-greenhouse-gases-technology-and-jobs-indias-informal-economy-case-rice

[3] To determine if a category falls within the 1% rule, an initial calculation should be made using available data and appropriate assumptions. If the results suggest that it may be close to 1%, then further data collection should be made. If the analysis suggests the results will be substantially lower than 1% (ie <0.1%) then this category can be safely ignored, as long as there is not a risk that the 5% threshold is crossed.

emissions. Additionally by convention in LCA's, human inputs are ignored. [4] Clearly our analysis goes beyond carbon emissions, but a similar rule is useful for all metrics – no more than 5% of costs/labour/water etc should be ignored. For example in our research the transport of consumers to the retail outlets where they purchase rice is ignored[5][6].

Allocation processes

It is rare that only one product is produced along a supply chain. For example rice production produces rice, straw, husks and bran. What share of the GHG burden of rice production should be allocated to each co-product? There are a range of potential methods that can be used, see working paper 3 on baselines and boundaries.[7]

Collecting data

As a general rule primary data should be used, as if well carried out this gives more locally accurate estimates of actual emissions and thus a better chance of demonstrating where emissions can be reduced. There are exceptions though, when it is impractical or unnecessary to collect primary data, for example when there is already adequate data for that piece of research. In our research the emissions associated with fertiliser production are a good example: data sets already exist for the embodied GHG of different fertilisers, and it would be infeasible to collect raw data on fertiliser production in addition to the current research objectives. The common factors that prevent data collection on certain aspects of the mLC include lack of research resources, skills, time etc. In such cases secondary data must be used.

Secondary data is available from a range of LCA databases. The golden rule is to state why, where and how each data source was used so that readers can

[4] Human inputs are ignored because it is not possible to assume that these emissions would not take place without the production of the functional unit. While we can assume that the ploughing of an area of land uses additional diesel compared to not ploughing it, the displacement of labour by that tractor does not result in the extinction of humans and their environmental impact.

[5] This is excluded due to high variability and lack of control

[6] A fourth category is specifically not included by PAS 2050: Animals providing transport (e.g. farm animals used in agriculture or mining in developing countries). This category is clearly very important to different approaches to agriculture in India, so we are categorically including draught livestock within our analysis. Only PAS 2050 suggests the non-inclusion of draught livestock.

[7] http://www.southasia.ox.ac.uk/working-papers-resources-greenhouse-gases-technology-and-jobs-indias-informal-economy-case-rice

understand, compare and judge models and their results. Often good data is not available, in which case the available data must be used, but transparency and honesty about data sources and data quality raise the usefulness and comparability of LCA research.

Inventory analysis

This step involves multiplying data activity and emission factors for each stage. It is useful to combine this activity with a mass balance analysis, to check that all material has been accounted for. A mass balance is simply a sum of all material entering the process map, and all material exiting. A closed mass balance analysisis not always possible, for example in agricultural stages of production, where material is essentially created from unmeasured streams (sunlight, carbon dioxide etc).

Checking uncertainty

As in all models, the adage 'garbage in garbage out' is true for mLCA models. On top of creating a good model and using the best data, it is useful to carry out uncertainty analysis, so that the importance of each assumption can be tested. The most critical assumptions can then be analysed further. In addition the whole model can be run through a monte-carlo simulation, to give a guide to the certainty of the final answer. As it is not always possible to apply traditional uncertainty measures such as standard errors, such demonstrations of uncertainty are extremely useful.

Figure 1. A selection of additional factors to consider. A wider range is available from the PAS guidelines

Some additional complicating factors for GHG calculations:

'**Delayed emissions'** How should the creation, end use and disposal of a light bulb be calculated ? PAS 2050 suggests using the weighted average over the product's life time.

Fixed carbon If a product is made from organic material, then the carbon within that project can be counted as removed from the atmosphere as long as i) it is not food, ii) at least 50% is expect to last longer than a year and iii) it comes from sustainable sources (ie a certified sustainable forest rather than a wood from recent tropical deforestation). To use these factors, an understanding of the likely lifetime of the products and likely final fate of the products is essential.

Land use change: This must be included if the land was converted to agricultural land on /after 01/01/1990, GHGs from LUC are then assumed to be released over 20 yrs, but this convention does not include changes to soil carbon in existing systems

Energy – all the embodied emissions associated with energy production should be included, such as those involved in mining, distribution and disposal of waste

Capital Goods. PAS 2050 suggests that these should be ignored.

Allocation. PAS 2050 likes to firstly expand the system boundary, but when this is impractical to use a range of allocation methods.

Problems with LCA

Life cycle assessment is not a perfect method. Its limitations are split between common/unavoidable methodological errors such as poor choice of boundaries, discussed in the Working Paper on Baselines and Boundaries, and fundamental problems some of which will be discussed here.

While the production and use of products/processes are extended for both time and space, in LCA emissions tend to be aggregated across time horizons and summed across space (see Finnveden et al (2009)and Hauschild (2005) for further reading). Additionally LCA divides the total emissions into a functional unit, often giving emissions that are near infinitesimally small compared to the whole; and there are no links between production and emissions pathways.

But in real life the time, location and scale of environmental impacts are critical to the impact of many pollutants. For example the same emission will be far worse if exacerbated by weather/other high emissions, in vulnerable environments, and if the level is above the absorptive capacity of the sink environment. GHGs are an exception as far as location goes, as the only GHGs measured are long lived enough to mix evenly in the atmosphere. The same applies to many gases listed under the Montreal Protocol.

In addition:

- The most important problem with LCA and mLCA is when the guidelines prescribe ignoring certain factors. An obvious example in our research is the emissions from livestock in transport. Others include ignoring changes in biomass stocks including soil carbon. The solution adopted in our research is both to work with the standard methodology, then transparently include additional factors that are important, and present both results.
- Poor metric analysis. PAS 2050 reduces all units to GWPs, for example 1kg methane is equivalent to 25kg of carbon dioxide, and 1kg nitrous oxide is equivalent to 198kg carbon dioxide. This is called taking a 'basket approach' and derives from the Montreal Protocol methodology. It is very useful as it allows GHGs to be tackled as a group, but the metric is far from perfect.
- Similarly when wider factors are looked at, they too are reduced to a single metric, for example eutrophication is reduced to phosphate equivalents, acid rain is reduced to sulphur dioxide equivalents; and in the value chain the social relations of labour which in our research include class and caste relations and for which the ILO has generated a family of 125 indicators are reduced to the quantity and gender of labour and its incomes and wage rates.
- The method is 'top down', not 'bottom up'. How to approach environmental agricultural sustainability is an issue of long debate since before Malthus, but the method, results and interpretation of LCA clearly fall into a top down as opposed to systems based, consultative or participatory approach to understanding sustainability.
- LCA is sometimes used to ask the wrong question. ie when different methods of producing chicken are compared – which misses the point that the impact of chicken production on the environment would be reduced by eating less chicken. This problem of framing is well covered by Garnett (2013).

- Finally, from the policy perspective, there is a danger in LCA, as there is in all complex models, that the apparently simple numbers that may result are misleadingly incomplete. LCA will provide answers to the questions that are asked of it, but these answers should not be mistaken for judgments on the relative sustainability of each functional unit as a whole. Just because a product is better from the GHG perspective does not automatically make it more sustainable when a wider range of factors (such as on biodiversity, immediate chemical pollution etc) are introduced.

Further reading:

European Commission, (2010) International Reference Life Cycle Data System (ILCD) Handbook, General Guide for Life Cycle Assessment,, Joint Research Centre Institute for Environment and Sustainability,.

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