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Technical Paper | Consequential and Attributional Approaches to LCA: a Guide to Policy Makers with Specific Reference to Greenhouse Gas LCA of Biofuels

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1. Ecometrica 2. BP

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Abstract: Policies for supporting biofuels, such as the EU's Renewable Energy Directive RED), the Renewable Fuel Standard in the US, and the UK's Renewable Transport Fuel Obligation (RTFO), require life cycle carbon reporting to ensure that biofuels achieve greenhouse gas reductions relative to fossil fuels. These policies tend not to distinguish between two types of life cycle analysis (LCA); consequential LCA (CLCA) and attributional LCA (ALCA). Failure to distinguish between CLCA and ALCA can result in the wrong method being applied, a combination of the two approaches within a single analysis, a misinterpretation of the results, or an unfair comparison of results derived from different methods. This paper sets out the key differences between CLCA and ALCA and assesses which method is applied in the carbon reporting guidance for the RTFO and RED, or whether a mixture of the methods is used. We find that the RTFO guidance adopts a partial CLCA approach but that there are inconsistencies in the treatment of co-products and ALCA derived fossil fuel comparators are compared to partial-CLCA biofuel values. The LCA method used in the RED is largely consistent with ALCA, but this may not be the most suitable method for determining total greenhouse gas impacts, which is one of the main purposes of carbon reporting in relation to biofuels policy.

1. Introduction

Policies for climate change mitigation are increasingly being informed by the results of greenhouse gas life cycle assessments (GHG-LCAs) of alternative energy carriers and delivery pathways.

GHG-LCAs are of particular relevance to the biofuel sector because, within the EU, it is expected that incentives (in the form of obligation certificates) will be related to the life cycle GHG savings relative to conventional fossil fuels.

The current use of GHG-LCA for biofuel carbon reporting tends not to distinguish between two different LCA approaches: consequential LCA (CLCA) and attributional LCA (ALCA). These two approaches aim to answer different questions, and failure to distinguish them can result in the wrong method being applied, a mixture of the two approaches within a single assessment, or misinterpretation of results.

Attributional LCA (ALCA) provides information about the impacts of the processes used to produce (and consume and dispose of) a product, but does not consider indirect effects arising from changes in the output of a product. ALCA generally provides information on the average unit of product and is useful for consumption-based carbon accounting. Examples of ALCA methodologies include the PAS 2050 *Specification for the assessment of the life cycle greenhouse gas emissions of goods and services*, and to a large extent ISO 14044 *Environmental Management – Life Cycle Assessment – Requirements and Guidelines*. ALCA informs comparisons between the direct impacts of products , and is used to identify opportunities for reducing direct impacts in different parts of the life cycle.

Consequential LCA (CLCA) provides information about the consequences of changes in the level of output (and consumption and disposal) of a product, including effects both inside and outside the life cycle of the product. CLCA models the causal relationships originating from the decision to change the output of the product, and therefore seeks to inform policy makers on the broader impacts of policies which are intended to change levels of production.

Whereas ALCAs are generally based on stoichiometric relationships between inputs and outputs, and the results may be produced with known levels of accuracy and precision, CLCAs are highly dependent upon economic models representing relationships between demand for inputs, prices elasticities, supply, and markets effects of co-products. Such models rarely provide known levels of accuracy or precision and should therefore be interpreted with caution.

This paper describes the key differences between CLCA and ALCA. We then discuss the extent to which the Renewable Fuels Agency (RFA) and Renewable Energy Directive (RED) carbon reporting guidelines use an attributional or consequential approach, or a combination of the two.

It should be noted that the primary focus of this paper is GHG-LCA, and where the acronyms CLCA or ALCA are used they are intended to denote GHG-CLCA or GHG-ALCA (though the majority of the discussion in the paper will be applicable to CLCA and ALCA generally, and not only GHG-LCAs).

2. Differences Between Attributional LCA and Consequential LCA

Table 1 provides an overview of the key differences between ALCA and CLCA. A more detailed discussion of the differences is given below.

Table 1. Key differences between ALCA and CLCA

	Attributional LCA	Consequential LCA
Question the method aims to answer	What are the total emissions from the processes and material flows directly used in the life cycle of a product?	What is the change in total emissions as a result of a marginal change in the production (and consumption and disposal) of a product?
Application	ALCA is applicable for understanding the emissions directly associated with the life cycle of a product. ALCA is also appropriate for consumption-based emissions	CLCA is applicable for informing consumers and policy-makers on the change in total emissions from a purchasing or policy decision.

	accounting. ALCA is not an appropriate approach for quantifying the change in total emissions resulting from policies that change the output of certain products.	CLCA is not appropriate for consumption-based emissions accounting.
System boundary	The processes and material flows directly used in the production, consumption and disposal of the product.	All processes and material flows which are directly or indirectly affected by a marginal change in the output of a product (e.g. through market effects, substitution, use of constrained resources etc).
Double-counting and accounting for absolute emissions	No double-counting of emissions. The emissions allocated to one product in an ALCA will not to allocated to other products in other ALCAs. In theory, if ALCAs were conducted for all products the sum of the results would equal total emissions from consumption[1].	Double-counting of emissions. The scope of different CLCAs may overlap and the same emissions may be counted in multiple CLCAs. If CLCAs were conducted for all products the sum of the results may be multiple times higher (or lower) than total emissions from consumption.
Marginal or average data	ALCA tends to use average data, e.g. the average carbon intensity of the electricity grid.	CLCA tends to use marginal data e.g. the marginal carbon intensity of the electricity grid.
Market effects	ALCA does not consider the market effects of the production and consumption of the product.	CLCA considers the market effects of the production and consumption of the product.
Allocation methods	ALCA allocates emissions to co-products based on either economic value, energy content, or mass.	CLCA uses system expansion to quantify the effect of co-products on emissions.
Non-market indirect effects	ALCA does not include other indirect effects.	CLCA should include all other indirect effects, such as the interactions with existing policies or the impact of R&D on the efficiency of the production of other products.
Time-scales, means by which change is promoted, and magnitude of the change	ALCA aims to quantify the emissions attributable to a product at a given level of production at a given time.	CLCA aims to quantify the change in emissions which result from a change in production. It is necessary to specify the time-scale of the change, the means by which the change is promoted, and the magnitude of the change.
Uncertainty	ALCA has low uncertainty because the relationships between inputs and outputs are generally stoichiometric	CLCA is nearly always highly uncertain because it relies on models that seek to represent complex socio-economic systems that include feedback loops and random elements.

1 The results of each ALCA would have to be multiplied by the number of functional units produced and then summed.

2.1 The questions the methods aim to answer

Consequential and attributional LCAs seek to answer different questions:

ALCA answers the question "What are the total emissions from the processes and material flows used during during the life cycle (production, consumption and disposal) of a product, at the current level of output?".

In contrast CLCA seeks to answer the question "What is the change (either positive or negative) in total emissions which results from a marginal change in the level of output (and consumption and disposal) of a product?".

2.2 Application

ALCA is useful for comparing the emissions from the processes used to produce (and use and dispose of) different products. It is also valuable for identifying opportunities for reducing emissions within the life cycle or supply chain, through improvements in processing efficiency or new technologies.

ALCA is also useful for consumption-based carbon accounting which aims to quantify actual emissions from the consumption of goods and services. Consumption-based carbon accounting is an alternative to production-based accounting, which quantifies total emissions from production. A country's consumption-related emissions may be higher than its production-related emissions if the embodied emissions of the products it imports are greater than the embodied emissions of exported products. However, both approaches should give similar totals for global emissions.

However ALCA is not suitable for quantifying the total change in emissions which result from changes to the output (and other life cycle stages) of a product. This is because there may be indirect impacts which are outside the scope of an ALCA.

The difference in the application of ALCA and CLCA was illustrated by Searchinger *et al* (2008). Searchinger *et al* found that on the basis of a conventional ALCA US corn-based ethanol gave a 20% emissions saving compared to gasoline. However, on the basis of a CLCA of the increase in output demanded by the US Energy Independence and Security Act, they predicted a 47% increase in emissions compared to gasoline. The expected increase in GHG emissions was attributed to land use changes induced by higher prices of corn, soybeans and other grains, predicted as a consequence of the additional demand for corn starch for ethanol production.

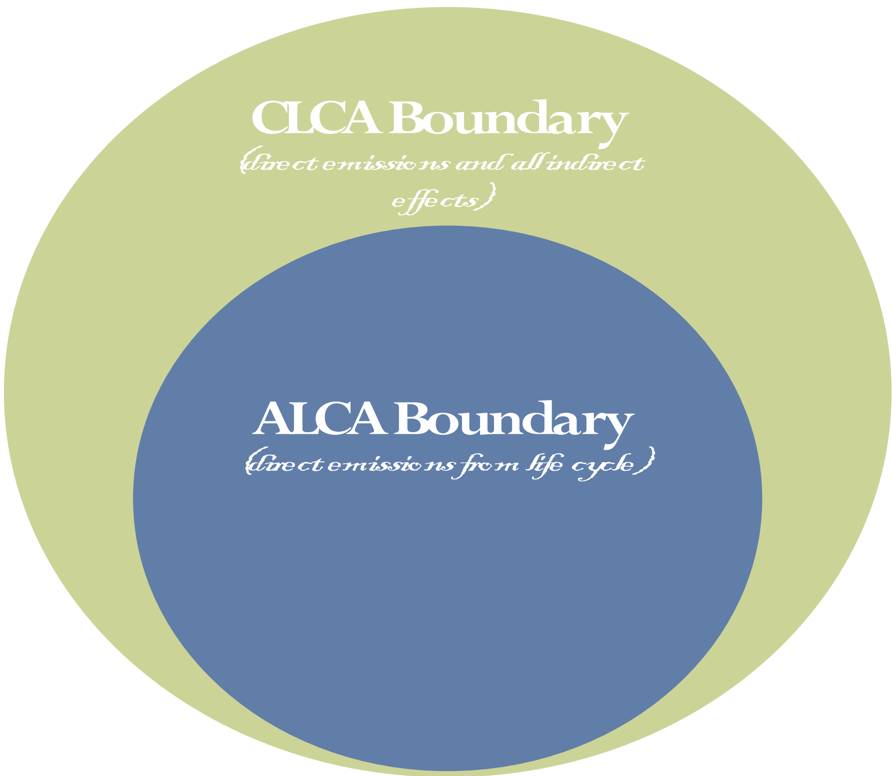
CLCA is the appropriate method for quantifying the total change emissions from a change in the level of output of a product as it takes into account both direct and indirect effects, and may therefore be of greater relevance to policy makers than ALCA.

However, policy makers should also be aware that CLCA results are dependent on descriptions of economic relationships embedded in models. CLCA models generally attempt to reflect economic relationships by extrapolating historical trends in prices, consumption and outputs, however, as discussed in Section 4, caution with the interpretation of such models is necessary.

2.3 System boundary

A key difference between the two approaches is their system boundary. Both approaches consider the same life cycle stages, but ALCA considers only the processes used at each life cycle stage, and, as noted above, does not consider indirect effects[2]. The system boundary for CLCA includes all changes in emissions which are caused, directly or indirectly, by a change in the level of production. Figure 1 illustrates the systems studied by ALCA and CLCA.

Figure 1. Systems boundaries for ALCA and CLCA

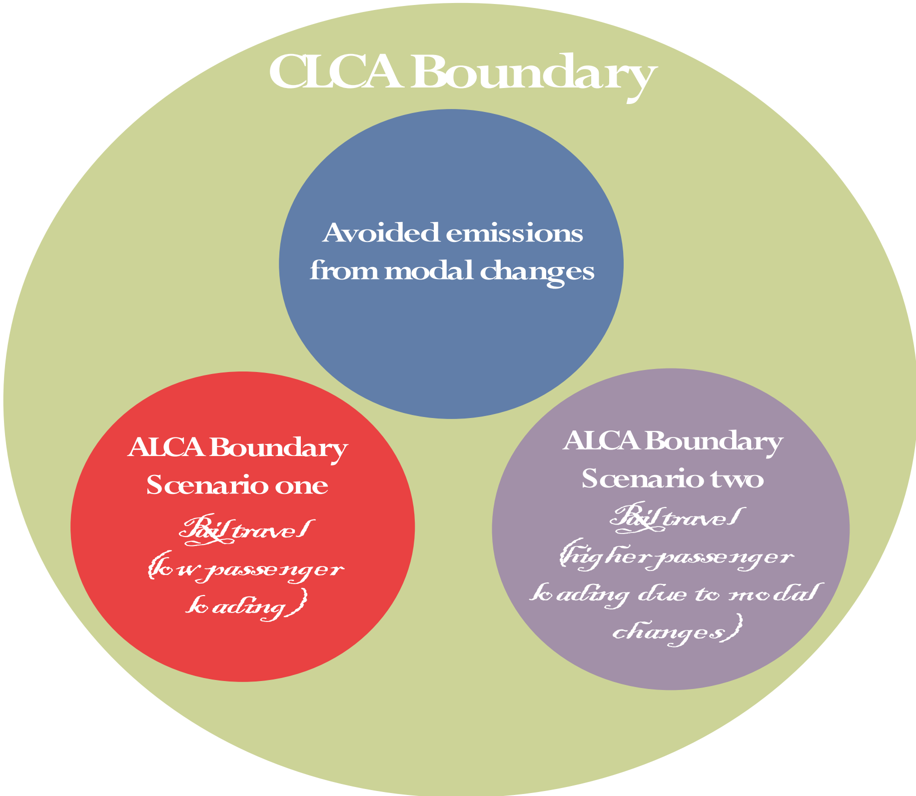


It should be noted that although the system boundary for CLCA is greater than that for ALCA this does not entail that the emissions figures from a CLCA will be greater than from an ALCA (e.g. where the product investigated is credited with an emissions reduction due to its co-products substituting other carbon-intensive products. See sections 2.4 and 2.7 for further discussion of this issue).

An additional point to note is that sequential ALCAs will only provide a partial picture of a change. The figure below illustrates two sequential ALCAs for passenger rail travel, with a change to passenger loading over time. ALCA 2 will show a reduction in GHG emissions per passenger-km compared with ALCA 1 as loading increases, but it will not capture the changes in emissions from reduced air and car journeys or the possible impacts of new travellers. By contrast a CLCA would seek to estimate the total effects of the change.

2 ALCA includes direct land use change but does not include indirect land use change.

Figure 2. Sequential ALCAs and CLCA



2.4 Double-counting and accounting for absolute emissions

For ALCA, the system boundary for one product should not overlap with the system boundary for any other product, i.e. there will be no double counting of emissions. In theory, if ALCAs are conducted for all products and services, and the findings of each ALCA are multiplied by the quantity of each product produced, the sum of the results should equal total emissions. For this reason ALCA is appropriate for consumption-based carbon accounting.

In contrast CLCA is not intended as an accounting method, and is inappropriate as a method for consumption-based carbon accounting for two separate reasons:

1. For CLCA, the system boundary for one product may overlap with the system boundaries for other products, and the same emissions will be counted more than once. For example, the emissions from land use change may be counted once as direct emissions for the crop grown on land converted to agricultural use, and again as indirect emissions for the crop that displaced the first crop. This characteristic of CLCA defies the 100% rule in carbon accounting (which requires that the sum of individual analyses should not be greater than total emissions).

2. The second reason that CLCA is not appropriate for carbon accounting is that the approach estimates *changes* in emissions relative to the next most likely production scenario, and does not quantify absolute existing emissions. For example, the co-products from a production process may

replace other carbon-intensive products (which would have been produced otherwise, i.e. they are next most likely production scenario).

Thomassen et al (2008) provides an illustration of this feature of CLCA. They report the findings from an ALCA and CLCA for milk production in the Netherlands. The results are shown in Table 2 below:

Table 2. Results from ALCA and CLCA for Dutch milk production (Thomassen et al (2008))

ALCA - mass allocation (gCO_2e/1 kg milk)	ALCA - economic allocation (gCO_2e/1 kg milk)	CLCA (gCO_2e/1 kg milk)
1,560	1,610	901

The results from the CLCA for milk production were significantly lower than the results from the ALCA as the consequential method took into account emissions that would be avoided by meat from dairy cows substituting beef and pork production (which is highly carbon intensive).

In some cases it is possible that the results for a CLCA will be negative, if the change in the level of production causes a reduction in emissions greater than the emissions from the production of the product. This does not mean that the absolute emissions from the production of the product are negative, but that the production of the product will cause a reduction in emissions elsewhere in the system. Box 1 provides an example of a simplified system in order to illustrate the difference between quantifying absolute emissions and relative changes in emissions.

Box 1 – An example of absolute emissions and relative changes in emissions

Assume a simple system which is described by the following information:

1. The direct emissions from producing Product A = 3 $kgCO_2e$
2. The direct emissions from producing Product B and its co-product C = 2 $kgCO_2e$
3. There are no other products in the system
4. Product A and C are substitute goods
5. If Product C is not produced then Product A will be produced

If a CLCA is undertaken for product B, system expansion will be used to account for co-product C's effect on emissions. Because co-product C substitutes product A, product B receives a “credit” of -3 $kgCO_2e$. The direct emissions for the production process for products B and C are 2 $kgCO_2e$. The results of the CLCA for product B are -1 $kgCO_2e$.

Clearly the actual emissions in the atmosphere from the production of product B are not -1 $kgCO_2e$. The result of the CLCA shows the relative change in emissions compared to the “next most likely scenario”, which is the production of product A.

The fact that CLCA is not appropriate as a carbon accounting method does not entail that CLCA is flawed, but rather that its purpose is not to account for absolute emissions. Policy makers and researchers should be aware of this, and should not use CLCA as an accounting method[3].

3 A further reason that CLCA is not appropriate for carbon accounting is that the results from different CLCAs cannot be aggregated. Each CLCA must use a specific starting-point from which the marginal change is measured. CLCA

2.5 Marginal or average data

CLCA aims to quantify the consequences of a change in the level of production. This means that the data used should reflect the technologies and inputs which are affected by the change. For example, if the change which is studied is an increase in the production of a product, the relevant electricity emissions factor should be for the grid margin (the carbon intensity of the additional electricity which is generated to manufacture the product, not the grid average). Ekvall and Weidema (2004) describe the methods for identifying the appropriate marginal data.

In some cases average data can be used as a proxy for marginal data in a CLCA if the average and marginal values are thought to be similar.

Typically average data is used for ALCA, although if an ALCA is conducted for an marginal unit of production (rather than to find the emissions for an average unit of production) marginal data should be used for the ALCA.

2.6 Market effects

CLCA considers the market effects of a change in the level of production of a product, whereas ALCA does not.

A change in the level of output of a product will affect the market price of the inputs used to make the product, and also the price of substitute goods for the product itself, and the substitutes for its co-products. These price signals cause changes in the output of other goods, which in turn may increase or reduce emissions.

An example of market effects was provided by Searchinger *et al's* (2008) study of US corn ethanol: the increase in demand for corn was predicted to increase its market price; farmers were then predicted to respond to this price change by growing more corn rather than other crops (e.g. soy); the predicted contraction in the supply of soy in the US was then predicted to cause an increase in the global market price of soy; which was then predicted to send a signal to farmers in other countries to produce more soy; it was finally predicted that a proportion of the new supply of soy would come from the conversion of high carbon stock land creating additional emissions. These emissions were then attributed to the additional volume of bioethanol in the CLCA.

Market effects can decrease emissions as well as increase them (e.g. if a change in production increases the price of other goods this may reduce demand and decrease total emissions). As demonstrated by the Searchinger *et al* study, CLCA models may contain numerous steps and interactions. In economic systems many interactions include feedbacks and side-effects that may be overlooked or underestimated (for example, Searchinger *et al* did not consider the effect of soy pricing on cattle ranching – where cattle ranching is itself a causal factor in land use change).

2.7 Allocation methods

results could only be aggregated if the starting point of successive CLCAs is based on the outcome scenario of previous CLCAs, in a specific order of dispatch.

Allocation methods are required where a single process produces two or more products, and the emissions from the process need to be allocated between the outputs. ALCA allocates emissions by economic value, energy content or mass, whereas CLCA avoids allocation by using system expansion[4]. System expansion involves identifying the products which are substituted by the co-products of the product studied; then quantifying the emissions associated with the substituted products; and deducting the results from the total for the multifunctional process[5].

Identifying the correct products that are substituted by co-products can have a large impact on the results of consequential LCA. A recent CLCA for soybean meal reported 721gCO_2e/kg of soybean meal if palm oil is the marginal oil, or 344gCO_2e/kg of soybean meal if rape seed oil is the marginal oil (Dalgaard *et al* 2008). Identifying the correct marginal product is often dependent on the judgement of the LCA practitioner, and therefore reduces the certainty of the results.

2.7 Non-market indirect effects

The production of a product may have other consequences such as effecting broader behavioural change; R&D benefits which are applicable to systems not directly associated with the product (e.g. R&D for biofuel feedstocks may also improve the yield of other crops, and consequently reduce land conversion and its associated emissions); or the physical displacement of activities may cause additional emissions (e.g. the displacement of subsistence agriculture may lead to indirect land use change).

2.8 Time-scales, method by which change is promoted, and magnitude of the change

ALCA seeks to describe emissions attributable to each unit of product at a given time and level of output. For CLCA it is necessary to define the change which is being assessed in terms of: the time-scale for the change; the methods by which the change is promoted; and the magnitude of the change. Each of these factors will influence the total change in emissions resulting from the decision or policy under review, and are relevant for identifying the appropriate marginal data to use, the market effects of the change, the substitution effects of co-products, and the non-market indirect effects of the change.

3. RFA and RED Carbon Reporting Methodologies

The Renewable Fuels Agency[6] (RFA), which administers the RTFO, and the Renewable Energy Directive both set out guidance for quantifying the emissions from biofuel production (RFA 2008, and EU 2008), however, neither the RFA or RED state the type of LCA approach they take. We screened each set of guidance for the characteristic methods which distinguish CLCA from ALCA (i.e. use of marginal data; inclusion of market effects; system expansion; and inclusion of non-market indirect effects). Table 3 shows this review.

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4 ISO 14044 and the PAS 2050 recommend system expansion wherever possible to avoid the need for allocation. This can lead to an undesirable combination of ALCA and CLCA methods within a single analysis.

5 System expansion could be characterised as a market effect, i.e. co-products impact on the market for the products they substitute.

6 The agency that administers the RTFO.

Table 3. Assessment of RTFO and RED carbon reporting approaches

	RTFO	RED – Annex V
Marginal/average data	The average carbon intensity for the grid is used for imported electricity. Marginal data is required when undertaking system expansion for co-products.	Average data is used for the electricity grid emissions factor. Average data is used for the fossil fuel comparator. No other guidance on the use of average or marginal data is given.
Market effects	The reporting guidance states that there are wider environmental impacts, including ILUC, which are not within the control of the supply chain, and thus not quantified within the methodology. The RFA will monitor these wider effects and report on them separately. The methodology requires reporting on the use of idle land (as this may reduce ILUC effects).	There is no quantification of market effects. However, the European Commission will report on the inclusion of indirect effects in 2010.
Allocation methods	System expansion is the preferred method. If sufficient data is not available then allocation by market value is used[7].	Allocation is by energy content (with some exclusions for wastes or residues). system expansion (though using a restricted method) is used for excess electricity from co-generation.
Non-market indirect effects	As with indirect market effects, the reporting guidance states that there are wider environmental impacts which are not within the control of the supply chain, and so not quantified within the methodology. RFA will monitor these wider effects and report on them separately.	There is no quantification of non-market indirect impacts. The European Commission will report on the inclusion of indirect effects in 2010, however the current focus is on market-related indirect land use change and not other non-market indirect impacts.

The RFA approach can be characterised as a partial consequential LCA methodology. The direct causal impacts of the supply chain are quantified using largely CLCA methods, and indirect effects are acknowledged (but are not quantified within the method – with this assessment taking place separately).

The RTFO method allows allocation by market value (if system expansion is not possible). This may be problematic as it allows a mixture of both consequential and attributional methods within a single analysis. It is not clear how the results from such an analysis should be interpreted – being neither the attribution of absolute emissions nor the relative change in emissions resulting from a decision. In addition, reporting companies may be able to significantly alter their reported emissions by selecting the approach which gives the most favourable results. There are also issues with the validity of the fossil fuel comparator (i.e. the comparison is not valid if the fossil fuel comparator value is calculated using allocation by market value and the biofuel value is calculated using system expansion).

7 The guidance states that allocation by market value is compatible with the substitution approach and both can be used simultaneously to assess the impact of different co-products. From the considerations presented in this paper we suggest that this is not the case; system expansion is appropriate for CLCA and allocation by market value is appropriate for ALCA.

The RED approach is largely consistent with an ALCA methodology, with the exception of the treatment of excess electricity from co-generation. Inconsistencies will be created in the future if the European Commission develops a method for indirect effects. The results for indirect effects (effectively a partial CLCA) should not be added to the results from the existing RED approach (ALCA) as the aggregate figure will be neither the absolute emissions from the production of the biofuel, nor the relative change in emissions caused by a change in the level of production.

Additional problems may arise for a hybrid approach if co-products are dealt with by allocation methods (e.g. in an ALCA for direct emissions), but are also included in the calculation of indirect effects (e.g. substitution effects of co-products). A form of double counting arises if co-products are accounted for twice within a single analysis.

The confusion between ALCA and CLCA within current policy applications may, in part, be due to the way the debate has been framed in terms of direct and indirect effects. It may appear that direct effects can be quantified using ALCA methods, and that indirect effects can be quantified using CLCA methods, and that the results of the two analyses can be summed to give a total carbon intensity figure. This is incorrect for two reasons:

1. The sum of absolute emissions figures (from ALCA) and the relative change in emissions figures (from CLCA) gives results which are neither absolute emissions or the relative change in emissions caused by the production of the product.

2. If co-products are dealt with in the calculation of direct emissions (using allocation methods) they should not be dealt with again in the calculation of indirect emissions (co-product substitution).

The problem with combining ALCA and CLCA methods is that the output is not suitable for either the normal purposes of ALCA (product comparison, supply chain improvements, and consumption-based carbon accounting) or for accurate policy impact analysis.

4. Interpretation

CLCAs seek to describe the total impact of a change. CLCAs are therefore meaningless without a framing description of the nature of the overall change expected taking account of the magnitude, timescales and methods to be used to promote the change. Given that CLCA models often seek to simplify complex economic systems, close scrutiny is required of the following:

1. the boundaries and relationships covered by the model (and a consideration of what is not covered);
2. the underlying assumptions about relationships within the model;
3. the starting conditions and baseline scenario;
4. tests or reality checks against which the model results may be compared.

Policy makers should be aware that proponents/detractors of given technologies often approach CLCA with a particular modelling framework that supports their *weltunschaung* (world view). For example proponents of bioenergy see a logical fit between greater use of bioenergy and biofuels within a more carefully stewarded and more technically advanced use of ecosystems. They can point to the large areas of land that have low levels of production which offer great prospects for improvement. Their models will tend to emphasise the potential for yield increases and protection of ecosystems through active management.

On the other hand the detractors of bioenergy tend to have a “fragile earth” view with the emphasis on how a rising population and per capita consumption is putting pressure on the earth's resources. Their model might show how rates of yield increases have slowed since the 1980's while land degradation and deforestation have increased. Their models will tend to show that any increase in investment in bioenergy or other production will have a negative effect on natural resources.

CLCA is less well defined than ALCA, and therefore allows a much greater degree of interpretation which can be used to support different viewpoints.

5. Conclusions

ALCA and CLCA use different methods and systems boundaries in order to answer distinct questions. The results from CLCA and ALCA are correspondingly different and have different applications, and it is therefore essential that practitioners and policy makers understand the difference between CLCA and ALCA; that the different methodological approaches are not combined within a single analysis; and that the correct analysis is applied for the policy issue at hand.

There are a number of areas of confusion in the current application of LCA to biofuel policy making:

1. No clear distinction is made between ALCA and CLCA

2. ALCA is used for carbon reporting (in the case of the Renewable Energy Directive, Annex V), but it does not capture all the effects resulting from the production of a biofuel. CLCA may be better suited for use within policies which seek to reward biofuels which reduce total emissions, and discourage biofuels which do not.

3. Reporting methodologies may use a combination of CLCA and ALCA methods – resulting in a hybrid which is neither ALCA or CLCA (in the case of RTFO reporting).

4. The results of semi-CLCA methods are compared to the results of ALCA methods (also in the case of RTFO reporting).

We suggest three alternative routes for improving the use of LCA for biofuel policies:

1. Reporting companies should undertake ALCAs for individual supply chains. Policy makers should be aware that ALCA results do not show the total effects from biofuel production, and a policy level impact assessment should be undertaken to look at the total impacts of a biofuel policy.

   An advantage of this approach is that ALCA is more straightforward for reporting companies and a higher level of certainty is achieved compared to CLCA. However the policy level impact assessment may still involve a number of uncertainties, and there may be issues to resolve in how ALCA results are incorporated within a policy level impact assessment.

2. Reporting companies should undertake a partial CLCA for individual supply chains (similar to RTFO reporting but with marginal data and only using system expansion for co-products). In addition an “indirect effects adder” should be developed by a qualified agency which can be added to the partial CLCA results.

An advantage of this method is that it allows the total impacts of a biofuel to be expressed in a single number, however there may be considerable uncertainty associated with the results due to the use of economic modelling, marginal data, and co-product substitution.

3. A third option is to stop using LCA carbon reporting for individual supply chains. In its place an initial policy level impact assessment should be conducted which identifies the key “hot spots” or indicators for the success or failure of the policy, e.g. increased conversion of high carbon stock land, or failure to increase agricultural productivity in line with expectations. These indicators should be monitored and if the evidence suggests that the policy is creating negative impacts it should be revised.

A final point to note is that current biofuel policies place considerable emphasis on supply chain carbon reporting as a mechanism for delivering “good” biofuels and avoiding “bad” biofuels. Given the uncertainties with CLCA and the limited scope of ALCA it is important for policy makers to explore additional policy measures to ensure biofuels deliver greenhouse gas reductions, e.g. investment in agricultural productivity, protect high carbon stock lands, and identify and monitor potential negative impacts.

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