The Use of LCA for the Development of Bioenergy Pathways

Marcelle C. McManus

Abstract Bioenergy and biofuels are key to meeting renewable energy and carbon reduction targets. Life Cycle Assessment (LCA) techniques are being used, with varying success and consistency, to help determine the sustainability of the current fuels and pathways selected. In order to meet our longer term targets and pursue long term sustainability emerging processes and systems need to be examined, as well as existing processes. Designers recognise that a large percentage of impacts and costs are pre-ordained within the design stage; so it makes sense to use LCA at the start of the research process in order to minimise these. Determining impacts at this stage could also help select the most promising options with maximum sustainability/GHG reduction potential. At the same time policy makers are beginning to use LCA as a tool to help inform policy choices for future energy pathways. Never the less, there are various uncertainties involved with its use at early stage research level, and also the expansion of LCA to look at wider consequences of the use of a particular product or system. LCA is changing from a traditional, retrospective tool to a more dynamic, forward thinking tool. Whilst this brings a multitude of benefits in terms of ability to predict impacts and minimise these in advance, this method of LCA use is not without uncertainties and difficulties. This paper explores why LCA is important within the bioenergy context and highlights some of the benefits, disadvantages, and changes that are seen through its use.

Keywords Emerging LCA · Anticipatory · Bioenergy

1 Introduction

Many countries and regions have targets to increase the amount of bioenergy and biofuels in order to help minimise greenhouse gas emissions and meet climate change targets. In order to ensure that their use helps meet these targets it is important that

M.C. McManus (✉)
Department of Mechanical Engineering, University of Bath, England BA2 7AY, UK
e-mail: M.McManus@bath.ac.uk

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their impact can be accurately, transparently and consistently measured. Life Cycle Assessment is an environmental management tool that is used to determine the impact towards a series of issues, such as climate change, resource use, acidification across a product or systems life; from production, and use, to disposal. It is increasingly used as a mechanism to help determine the sustainability of bioenergy systems and biofuel. The pathways from resource to fuel and use within bioenergy are many, and complex. The end users are focused on the availability of vehicle fuel, heat or electricity, but with bioenergy there are several methods available to produce these, see for example Fig. 1. Biomass resources vary from annual crops such as wheat, maize and sugar beet, to perennials such as miscanthus, switch grass, pine, spruce and residues and wastes, including forest residues, straw, municipal waste and waste oils. There are a similar number of conversion routes, including pyrolysis, gasification, esterification, digestion, etc., leading to a range of fuels such as biodiesel, bioethanol, bio-oil, bio-methane, methanol and hydrogen. LCA can be used to quantify the impact of these pathways with relatively high accuracy using attributional LCA. These impacts are commonly described in terms of energy and greenhouse balances, but other environmental impacts such as acidification, resource depletion and eutrophication can also be measured, and are often reported. Alongside the existing bioenergy pathways several more are under development. These can use novel feedstocks, such as algae, or new or rapidly developing conversion methods, such as the linocellulosic conversion to bioethanol. Many of these are at lab scale, meaning that LCAs are being performed at an earlier stage. This brings the associated benefits of being able to influence the process at an early process design stage, but with higher level of uncertainty due to the more experimental nature of the process. Despite, or perhaps because of, the increased uptake of bioenergy there has been a wide debate surrounding the sustainability of bioenergy, especially focusing around the food versus fuel debate (Royal Society [13]). For this reason second generation biofuels, which are made from biomass that doesnt directly compete with the food market (such as lignocellulosic bioethanol), are considered to be more beneficial.

2 Trends in Life Cycle Assessment

When LCA was initially developed in the 1970 to late 1990s it was a retrospective tool, predominantly used by industry in order to reduce resource use and waste production (Curran [3]; Hunt and Franklin [8]). The methodology was initially developed and published by the Society of Environmental Toxicology and Chemistry (SETAC) and these were then developed into a series of ISO standards in the 1990s. These standards were refined and amended in the 2000s. The method was developed to measure the impact of a product or system for which the data was currently or historically available (i.e. for a product in existence) for the purpose of decision making or reporting. Over the last years the way in which LCA is used has changed. This is primarily in two directions; wider towards a policy arena, and tightly focused around specific processes within early stage research. Over the last ten years a change in

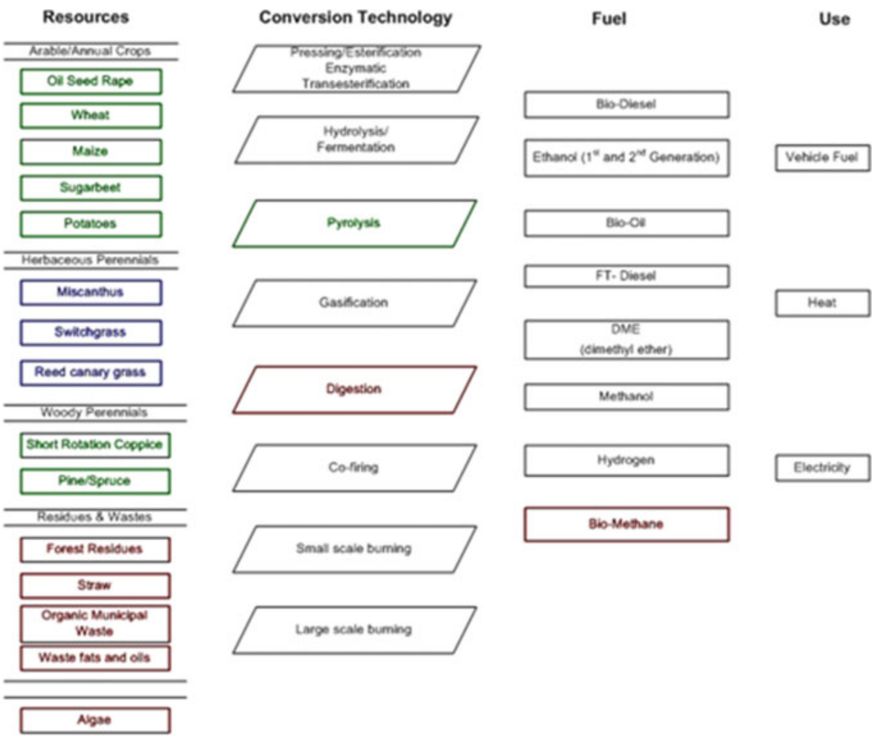

Fig. 1 Resources, Conversion technologies, fuels and uses for bioenergy

the way in which LCA has been described has also been seen. The more traditional type LCA is now often called attributional LCA (aLCA). That which looks wider, for example towards the implications of the use or expansion of a system, is called consequential LCA (cLCA). This move is reflected in the academic literature and the uptake of the tool (McManus and Taylor [11]). It is often presented in literature that 80% of all environmental effects associated with a product are determined during the design stage (Tischner et al. [19]), so the trend to increasingly use LCA at the early stages of research and design is relatively unsurprising (Fig. 2). Use at this stage enables the practitioner to explore options for minimising impact from the earliest stage of a product or systems life. LCA practitioners and researchers can work together to select the most environmentally benign materials and processes; hence reducing impact from the outset (e.g. Griffiths et al. [6]).

Whilst this can enable the reduction in negative impact, there are a number of methodological and practical difficulties that arise from using LCA in the determination of environmental load within the research stage of process development (Hetherington et al. [7]). One of the most significant issues when conducting early stage research based LCA is scalability. Lab based processes do not necessarily use the same processing stages as they would when commercialised, and efficien-

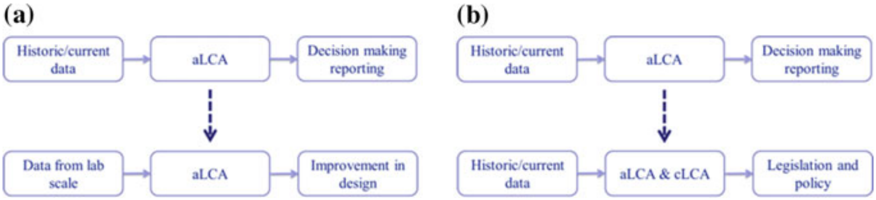

Fig. 2 Trends in LCA

cies are likely to be better at commercial scale. The resultant early stage LCA may have significantly more variables, complexities and scenarios than a "traditional" LCA (Hetherington, et al. [7]). Another issue commonly encountered in this type of research is the use of materials, enzymes etc. that have not previously been used; therefore the potential impact is particularly hard to predict for use within and LCA. In a field that is developing as rapidly as bioenergy this can be a significant issue. As an example, despite extensive research on both lab and small scale lignocellosic ethanol production, no large scale commercial lignocelluloses-to-ethanol facility has yet been brought into production. Therefore, technology uncertainty and potential commercial scale operation parameters also contribute to the knowledge gap when undertaking an LCA in this area (Spatari et al. [16]).

On the other side of the scale LCA is being used more outwardly, in a consequential approach, to help formulate policy. Consequential LCA is broader and explores the potential wider changes to the system that may arise from using the product in question (Sanchez et al. [14]). For example a consequential analysis of a biomass plant would examine the impacts of the production, use and disposal of the plant (and associated feestocks etc.), but could also include the impact of offsetting the energy that would have been alternatively used. As it takes into consideration a range of broader factors it is often used as a policy tool rather than a technology assessment (Plevin et al. [12]). It has been used most widely in the bioenergy arena (Taylor and McManus [18]).

As with the development of LCA into early stage research, the development of consequential LCA is not without problems. Many consequential LCAs have been developed from a number of attributional LCAs, with a number of smaller system studies being linked together to either add or offset each other, but some of these studies have been shown to produce misleading results (Bento and Klotz [2]). The systems that are under analysis, such as global biomass/land/energy systems, are complex; sometimes the only pragmatic option is to build the analysis from a series of smaller sub systems. Never the less, these dont necessarily reflect the complexity of the systems in question.

3 Developing Bioenergy Pathways: LCA Uncertainties

As bioenergy is promoted as a mechanism to provide low carbon energy it is clear that the impact of the bioenergy pathway selected is understood and that different options can be reliably compared. Bioenergy systems are complex. As is shown in Fig. 1 there are numerous feedstocks and conversion technologies. Many of the feedstocks have the potential to be grown for a multi purspose; i.e. after harvest they could be used for either bioenergy or another commodity, such as food, animal feed or the building industry. Such decisions will primarily be made on an economic basis, potentially bringing further uncertainties to any wide reaching LCA study in the area. The ISO standards oversee the general life cycle thinking approach to life cycle assessment, but there are also a number of tools that can be used and adopted to calculate the greenhouse gas emissions from numerous bioenergy systems, for example those developed to be used under the EU Renewable Energy Directive (RED) and the US based ones such as GREET and GHGenuis. Undertaking a full LCA requires expert knowledge, but the online tools can be used with a more cursory understanding of the underlying methodology. Whittaker et al [20] show that between the ISO standards, the GHG accounting methodologies such as PAS2015 and RED, and the online GHG tools there lies a significant decrease in consistency and transparency. This indicates the trade-off between the requirement of expert knowledge, and the use of quick GHG tools. Results from such tools (using the same inventory input data) range from just over 500 kg CO2 eq/ha to over 3000500 kg CO2 eq/ha. Some of the differences in approach result from differing allocation methods or the development of the counterfactual (what is displaced/not used) (Whittaker et al. [21]). Clearly, a consistent approach is required. A mechanism for understanding how the impacts from lab scale research is translated into impacts in commercial production; and a wider system for looking at global consequences is also required.

There is little research covering the implications in terms of consistency or predictability of moving between early and later product and system stages on environmental impact. Never the less, there are many disciplines from which LCA can learn. Business and technology development work in terms of technology readiness levels; from these funding and commercial predictions can be determined. It is certainly the case that as the technology matures there would be increased certainty of cost and impact, Fig. 3. However the manner of linkage is not yet established. Nor is it known whether there would or could be a repeatable mechanism for predicting impacts from lab scale research up to commercial scale research. More work is required in this area. Beyond the commercial processing impacts also lie the uncertainties associated with the use of the product in question. The development of LCA has been widely discussed over recent years. The expansion of LCA from an attributional approach only, to those that look at the wider consequences (cLCA) and all the studies, tools and methods that lie between the two have been widely discussed (see for example Whittaker et al. ([20],[21]). While there are problems and issues with the simplification of any system into a model, the use of such models is perhaps the only way in which we can determine likely impacts of our activities. Although aLCA and

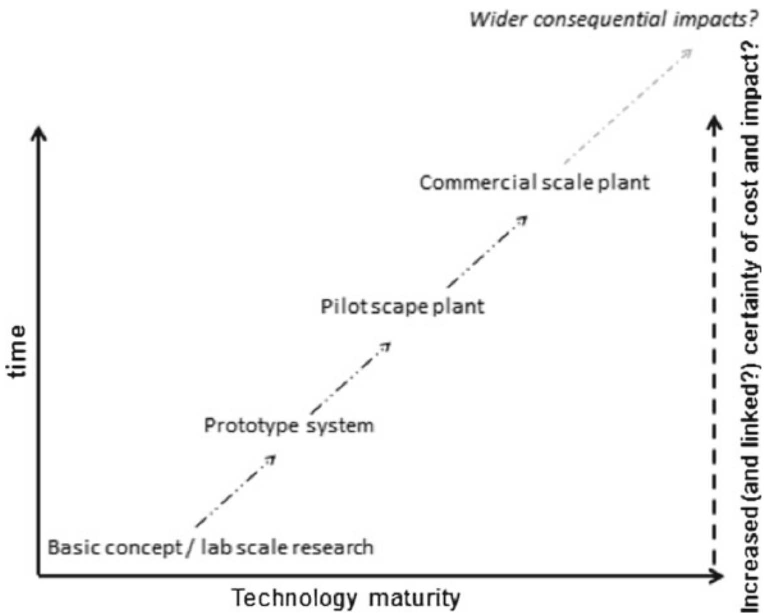

Fig. 3 Technology maturity and potential certainty in LCA impacts

cLCA have been criticised for lack of consistency and transparency at times (see for example McManus et al. and Plevin et al. [12]) there really is currently no better way to model the complexities associated with the production and use of, for example, biofuel. Recognition of the weaknesses of the current system and tools does exist, and the opportunity that currently exists to improve is crucial. As the systems expand in the more consequential LCAs the adaptation of knowledge from other disciplines is required and how we need to examine how a model, or combination of models, can used in order to answer complex and dynamic questions whilst recognising both strengths and weaknesses of the modelling frameworks and available data (Suh and Yang [17]).

As bioenergy markets expand it is likely that the global systems will maintain complexity that is difficult to model. It is also likely that the research into novel ways of extracting energy from biomass will continue at a rapid pace. Expanding on Figs. 2 and 4 explores the option of moving from a tight attributional type LCA to a wider consequential one based primarily on the type of data coming from lab scale research. This is beginning to be seen in the public discourse surrounding bioenergy as speculation of future scenarios and how new types of biofuels and bioenergy might help our future demand increases. Strategic policy making that encompasses thoughts of potential impacts is to be highly commended. However, it is clear that LCA is at a point where lessons from other sectors could possibly be incorporated and that a clear indication of the level of speculation and uncertainty associated with any such study should be highlighted.

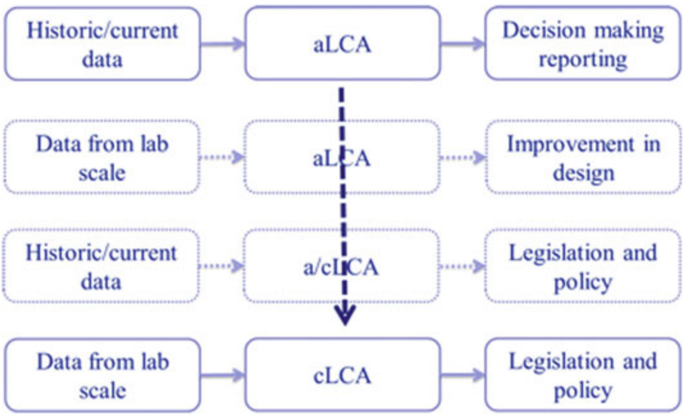

Fig. 4 Current and potential trends in LCA development

4 Conclusions

Life Cycle Assessment is a tool that can be extremely helpful to determine impacts across a wide sector. It is of particular use in the bioenergy area; where many policies and legislative mechanisms are developing that require the use of LCA. There is a requirement that any replacement for our current fossil fuel system has a beneficial comparative impact in terms of greenhouse gas emissions. LCA is an excellent tool to measure this. The use of LCA is changing rapidly; and at this time of transition there is an opportunity to reflect and learn from other sectors. No model can accurately map the complexities of potential positive or negative impacts associated with the production and use of bioenergy. Life Cycle Assessment is the closest we have to a tool that can predict impacts and enable us to minimise and reduce them. It has been a very successful tool, with use in policy making and legislation increasing exponentially over a short period of time. Never the less, the way in which it is used is being stretched. Recognition of this may mean that the fragility of the model can be overcome and LCA will emerge a stronger and ever increasingly used tool. But if these issues and problems are ignored it is possible that the tool will become increasingly mis-used and the results mis-interpreted with regrettable effects on both bioenergy and the LCA tool itself.

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