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LCSA Framework for Assessing Sustainability of Alternative Fuels for Transport Sector

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Consideration of alternative transport fuels, produced from feedstocks and renewable resources, is inevitable to enhance energy security and alleviate environmental burdens. Whilst these fuels are apparently considered to be clean, they may not be entirely sustainable from economic, environmental and social perspectives. A Life Cycle Sustainability Assessment (LCSA) framework that integrates all three components of the Triple Bottom Line (TBL) sustainability can potentially be used to evaluate the sustainability performance of fuels from well to wheel. This paper presents an LCSA framework consisting of Environmental Life Cycle Assessment (ELCA), Life Cycle Cost (LCC) and Social Life Cycle Assessment (SLCA) tools to assess the environmental, economic and social performance of alternative fuels. The framework is aimed at identifying the areas that require improvements for overall sustainability performance. The proposed framework provides a comprehensive basis that considers the region-specific variations in the life cycle data pertaining to alternative fuels. The added feature of the framework is its robustness to accommodate variations in natural resources, and other regional issues, such as socio-economic and demographic changes. The framework has been tested using a hypothetical example of canola-based biodiesel.

1. Introduction

Use of alternative transport fuels is emerging as one of the potential strategies to achieve energy security and alleviate environmental consequences. The selection of an alternative fuel depends on the ability to produce it from locally available feedstocks and renewable resources. The increased demand for fossil fuels will result in resource depletion, health impact and environmental issues (Kumar et al., 2018). Fuels for the transport sector thus need to be sourced in a manner that allows resource efficiency and conservation of fossil fuels for the future generation (Sebayang et al., 2017). Alternative fuels need to be analyzed and selected to address the environmental, social and economic challenges to ensure that the transportation industry becomes sustainable. The TBL sustainability assessment method that integrates the environmental, economic and social objectives could be used to select alternative fuels (Hall, 2011). The TBL sustainability analysis remains incomprehensive if it does not include the entire life cycle of a product or service. The LCSA incorporates all the three components of the TBL (ELCA, LCC and SLCA), and considers a cradle to grave approach (Ciroth et al., 2011) that generates more realistic as well comprehensive outcome. Research indicates that ELCA has been the most widely applied tool for assessing environmental impacts, while quite a few studies have employed LCC and SLCA along with ELCA. Like ELCA, SCLA follows the four steps, goal and scope, life cycle inventory, impact assessment and interpretation of results, to measure the social impacts caused to stakeholders during the product life cycle. The impacts of SLCA may not be discussed in the context of the functional unit as most of its data will be qualitative or semi quantitative (Ciroth et al., 2011). SLCA is a bit complicated as it is based on indicators and expert opinion that may vary across regions due to variations in the socio-economic and cultural issues (Mathe, 2014). Given the absence of region specific TBL assessment, utilizing all three Life Cycle Assessment (LCA) tools for alternative fuel selection, the current research endeavors to develop the sustainability assessment framework using a LCA approach.

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2. Review of literature on LCSA of alternative fuels

The UNEP-SETAC has developed a guideline to integrate the ELCA, SLCA and LCC into the LCSA that evaluates positive and negative environmental, economic and social impacts of a product throughout its life cycle under an identical system boundary (UNEP/SETAC Life Cycle Initiative, 2011). Guinee et al. (2011) describes the LCSA through a conceptual framework combining ELCA, LCC and SLCA by emphasizing the need for LCSA for encompassing people, planet and prosperity. Zamagni et al. (2013) states that LCSA is still in a conceptual level and so there is a need for frameworks with practical case studies to make the LCSA usable. By summarizing all the challenges in LCSA, Guinée (2016) points out that there is a need for practical case studies with efficient ways of communicating the LCSA results and method. There are not many studies that have considered the LCSA approach for investigating the alternative fuels. Onat et al. (2014), for instance, conducted a LCSA study of alternative fuels using an EIOLCA (Economic Input Output LCA) model for different alternative fuel vehicle types in the USA. The main concerns about using EIOLCA is that it evaluates a lower number of environmental effects, calculation is based on the transactions of a particular economy, and it is not very suitable for a product level analysis (EIOLCA, 2018). Due to the scope of the study, the social indicators have been limited to the US population. Onat et al. (2016) employed a dynamic model that was only applicable to the US based economy. In another study, Osorio-Tejada et al. (2017) employed the Analytical Hierarchy Process (AHP) for Multi Criteria Decision Making (MCDM) to evaluate the TBL aspects of biodiesel and LNG use as a transport fuel in Spain, but only the GHG emission out of the nine TBL indicators was found, calculated based on the LCA approach. The SLCA requires that both upstream and downstream processes and people are involved in the analysis to carry out a holistic and realistic assessment. The LCSA application in the sectors other than fuels also lacks a uniform and consistent approach when it comes to defining the parameters such as goal and scope definition, impact assessment and interpretation of results. Akber et al. (2017), for instance, conducted a comprehensive study regarding the Pakistan electricity sector by considering the cradle to grave approach but faced a constraint regarding social data and methodology which necessitated the selection of social indicators only related to employment and energy security. The equal weighting method was also employed in the study to produce single score results for all three sustainability dimensions rather than using other appropriate weighting methods. Santoyo-Castelazo and Azapagic (2014), on the other hand, overcame the weighting issues by applying stakeholders' opinion and scenario analysis based on different weighting approaches though it was focused only on the electricity generation phase. Though these studies used MCDM techniques to combine TBL indicators based on different weightings, the scenario analysis related to interdependencies among the three pillars of sustainability was missing.

In conclusion, the reviewed sustainability assessment frameworks demonstrate no uniform or consistent approach to define the system boundary when they conduct the LCA, LCC and SLCA in the context of the LCSA. The other challenges include difficulties in interpreting and communicating the results, and scenario analysis incorporating interdependencies among the three pillars of sustainability as well as data quality that needs to account for regional perspectives and methods for SLCA (Guinée, 2016). Most importantly, alternative fuels have not been found to be rigorously assessed in the context of the TBL indicators where their impacts conform to the LCA guidelines (Onat et al., 2016) and there is a need for a robust framework for the sustainability assessment of various fuel options.

3. The proposed framework for LCSA

A sustainability assessment framework that employs the LCA, LCC and SLCA tools to measure the TBL performance of alternative fuels is shown in Figure 1 and has been discussed in the following sections.

3.1 Fuel selection

The first step involves alternative fuel selection for a particular region or country (Figure 1). Accordingly, the relevant literature has to be reviewed to develop the criterion for fuel selection, e.g. feedstock availability; types of vehicles; performance of alternative fuels; transport infrastructures and cutting-edge technology; long-term availability and government policies for a particular region.

3.2 Selection of TBL indicators and the determination of threshold values

The next phase of the framework is intended to review the literature to list the relevant TBL indicators that are used to reflective of the social, economic and environmental performance of the transport fuels using an LCA approach (Figure 1). Once the list of indicators has been prepared, a census is conducted to ascertain the views of the stakeholders who are directly related to the production, use, business, technology, policies and maintenance associated with the transport fuels. For example, the stakeholders are grouped into five categories namely academia, business, manufacturer, users and legislative authority with each respondent category consisting of equal number of respondents to avoid any bias. The survey helps in selecting the appropriate TBL indicators and assigns weightings on the basis of their relative importance. Once the TBL indicators have been selected, it is required to find the threshold values for comparing them with the real data obtained from the field/case studies. The threshold values are chosen realistically so that they are achievable in the fuel sectors in a particular region while maintaining standard fuel supply. For the framework, the standard fuels are defined on the assumptions; locally available feedstock, reasonable socio-economic obligations, and follow all environmental requirements during fuel production and combustion. A thorough literature search and consultation with the local experts are required to discern these threshold values for comparison with calculated values obtained from the field data.

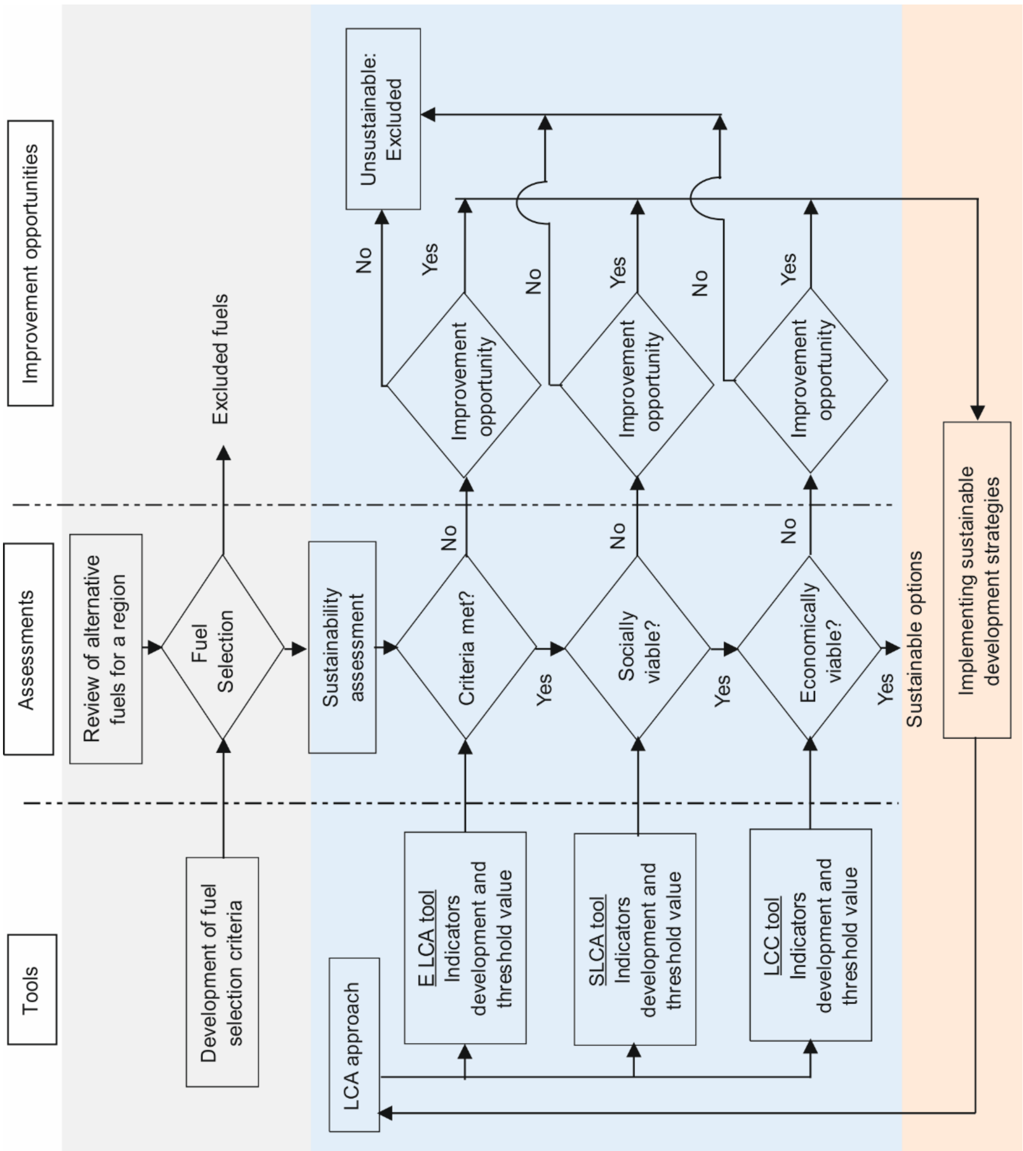

Figure 1: Holistic sustainability framework for LCSA to assess the alternative transport fuel

3.3 Data collection

Once the indicators have been developed, a questionnaire is designed to enable the collection of information from key stakeholders and literature/government reports and policies.

3.4 Life cycle assessment tools

Once the raw data has been gathered, the environmental, economic and social indicators of sustainability are calculated using the ELCA, LCC and SLCA tools, as indicated in the left column in Figure 1. ELCA follows the

ISO-14044 guidelines to estimate the environmental indicators (ISO, 2006). Accordingly, a functional unit, which is Vehicle Kilometers Travelled (VKT) is chosen to calculate the inputs and outputs for well to wheel stages, including feedstock production, fuel production and usage stage of the fuel life cycle for developing a life cycle inventory prior to calculating the environmental indicators. In the next stage, the relevant impact assessment method(s) are selected for the analysis. The Australian indicator method, for example, can be used for converting inventory data to environmental indicators if the evaluation is done in Australia. LCC analysis, on the other hand, follows the same inventory and functional unit as ELCA to calculate the economic indicators following the AS/NZS 4536:1999 (Australian and New Zealand standard, 1999) guidelines in terms of $/VKT. Life cycle cost and cost/VKT are some examples of economic indicators. A scenario analysis needs to be accomplished by varying the variables like cost of fuel, inflation, and discount rates etc. Government subsides, if any, also need to be included in the analysis to make it more realistic.

Social LCA can be carried out based on the UNEP-SETAC guideline. Social impact categories are selected depending on the interaction between the life cycle activities and people involved. There can be several indicators for the social performance of an alternative fuel at each stage of its life cycle. These indicators can be selected from the literature and the globally accepted guidelines published by UNEP-SETAC, IPCC, SDG, IEA, OECD and various government and semi government reports relevant to the selected region. Getting the expert opinion is the next logical step to establish the relevance and weighting of the selected indicators. This facilitates the process of assessing and addressing the social implications associated with various fuel types. The respondents in the census can be categorized and selected from various segments, such as academia, industry experts and consultants from the relevant stakeholders.

3.5 Application of the proposed sustainability assessment framework using a hypothetical case study

Following Figure 1, the first step is to determine the environmental indicators of the selected fuel using an ELCA tool. Examples of environmental indicators that are relevant to this research are Energy Consumption (EC), Energy Ratio (ER), Global Warming Potential (GWP), Eutrophication (EP), and Ozone Layer Depletion (ODP), etc. Once these indicators have been determined for a fuel type, they are compared to their threshold values to examine if the required level of environmental performance has been achieved. A fuel type is declared as “not qualified” for social assessment if it fails to meet its threshold value. The hotspots that are identified in the ELCA analysis would be treated using improvement strategies until all environmental indicators have met the threshold values (Figure 1). Once environmental criterion has been met, SLCA would be conducted to determine social indicators. Some examples of social indicators are employment generation, working environment, public health, and social acceptability, etc. Similar processes as discussed before would be carried out by developing social strategies, and institutional arrangements that enable the selected fuel type to meet the social objectives of the sustainability. LCC of the fuel type is carried out to ascertain the economic indicators like life cycle cost, cost/VKT etc. If economic indicators have not met the threshold values, policy instruments like environmental tax, rebates, and soft loans, etc. can be considered to achieve the required economic objectives.

A hypothetical example of canola-based biofuel has been used to test the sustainability assessment framework. The indicators that were chosen for this example are assumed. The purpose is to demonstrate the functioning of the proposed framework. The following discussions are thus fictitious, and they have been described in way that they were based on a real-world data which is actually not the case. The system boundary for this LCA analysis to estimate social, economic and environmental indicators started from the farming stage of the feedstock through to combustion in the vehicle and the functional unit is VKT. As shown in Table 1, EC, ER and GWP are three environmental indicators that the authors intend to collect through surveys. When these indicator values were compared with the threshold values none of them was found to meet the environmental objectives. The threshold values are chosen for this study by reviewing the works of Biswas et al. (2011) and Rustandi and Wu (2010).Through an LCA analysis, a hotspot has been identified to determine the environmental improvement of mitigation strategies. The hotspot analysis shows that the fertilizers, herbicide and pesticide production during pre-farm and biodiesel production during post-farm stages are the two main energy intensive processes. Unlike energy consumption and energy ratio, the on-farm stage was responsible for the highest global warming potential mainly due to the soil emission from fertilizers. Three improvement strategies as shown in Table 1, thus, have been selected to treat the energy and GHG hotspots. These are; i) by product utilization, ii) both by product and straw utilization and, iii) crop rotation with by product and straw utilization in order to reduce energy consumption and GHG emission associated with the production and application of urea fertilizer. Here, canola meal and glycerol are considered as a by-product which reduce both energy and environmental burden on overall biodiesel production. Straws considered as a replacement for diesel for process heating during ethanol production. The second and third environmental improvement strategies helped all environmental indicators to meet the threshold values.

Table 1: Evaluation of the environmental sustainability

Indicators	Calculated value/VKT	Threshold value	Values after Improvement Strategies		
			1	2	3
EC(MJ)	2.33	1.52	1.71	1.49	1.20
ER	1.13	1.72	1.53	1.76	2.20
GWP ($KgCO_{2-eq}$)	0.27	0.19	0.191	0.164	0.105

SLCA of canola-based biodiesel that has incorporated the aforementioned second and third environmental strategies into its supply chain have been conducted to determine social indicators using the same system boundary. As mentioned during the ELCA analysis, this hypothetical example was provided to test the framework. The actual survey will be required to collect the sample data from the respondents. Three social indicators including employment generation, public health and social acceptability need to be measured on a 1 to 5-point Likert scale on the basis of the respondents' level of satisfaction. The score 5 represents the maximum level of satisfaction and the respondents not giving a score of 5 have been asked to provide suggestions/improvement strategies that would have completely satisfied the respondent. Table 2 shows that out of the three indicators, only public health had met the highest level of satisfaction (i.e.5). In the case of employment generation, 40 % of the respondents did not score 5 as they would like more local people to be employed which is not possible immediately and requires long term planning. The remaining 20 % who did not score this indicator 5 had expressed that it is difficult for a new fuel industry to generate employment quickly. More than 70 % of the respondents scored 5 for the public health indicator in this example by assuming the fact that biodiesel significantly reduced all the tail pipe emissions and could enhance the public health condition. In the case of social acceptability, 45 % of respondents did not score 5 as there was no significant promotional campaign for public awareness of the benefits of biodiesel and also there was not enough incentive to encourage users. The remaining 25 % believed that biodiesel would not be socially acceptable due to its higher price and availability issues. Based on respondents' suggestions, possible improvement strategies for social indicators have been considered. In the case of employment generation, employment of local people appears to be achievable, and also the awareness campaign to popularize biodiesel could easily be performed to improve the social acceptance. Table 2 shows that the incorporation of these strategies could achieve the social objectives of sustainability.

Table 2: Example of evaluation of the social sustainability

Indicators	Surveyed value (%)	Threshold value (% of the respondent provides maximum score)	Values after improvement Strategies (%)
Employment generation	40		80
Public health	71	50	-
Social acceptability	30		75

Using the same boundary as ELCA and SLCA, LCC per VKT has been calculated, as shown in Table 3 with the hypothetical values. The costs and benefits associated with the newly incorporated environmental and social strategies have been incorporated into the cost of inputs of the existing life cycle inventory for LCC analysis. Threshold values have been chosen based on the current diesel price of Western Australia. Still, the life cycle cost of biodiesel did not meet the threshold values. On this basis, another strategy has been deployed to make the fuel economically viable, which is the removal of excise duty on biodiesel. Prior to 2011 in Australia, full excise on biodiesel was refunded to the biodiesel producers by the biofuel production grant mechanism. According to the revised policy of the Australian government, the current excise rate is 0.027 AUD/L of biodiesel and this rate will also increase to 50 % of the diesel excise by 2030 (Farrell, 2017). After incorporating this economic strategy, the fuel was able to meet the economic objective of sustainability. Further reduction of LCC can be possible if external costs, including the carbon cost, are implemented by the government.

Table 3: Evaluation of the life cycle cost

Indicators	Calculated value	Threshold value	Values after improvement strategies	
			by product and straw utilization	After providing rebate
life cycle cost (AUD/VKT)	0.189	0.115	0.116	0.114

4. Conclusions

A holistic LCSA framework has been developed to identify and select improvement strategies to enable alternative fuels to meet the environmental, social and economic objectives. It involves the development of the TBL indicators and their threshold values using literature and surveys. Once the indicators have been selected, raw data from the supply chain of alternative fuels would be gathered to calculate the TBL indicators for assessing the sustainability and suggesting the improvement strategies. A hypothetical example has been used to test the framework. LCA approach has been applied to calculate the indicators. The proposed framework has been shown to be robust and has been demonstrated to accommodate various scenarios more comprehensively.

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