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# A QUANTITATIVE APPROACH AND AN OPEN-SOURCE TOOL FOR SOCIAL IMPACTS ASSESSMENT

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## ABSTRACT

*Social impact analysis urgently needs attention in various sectors due to its critical roles in enhancing sustainability benefits. Properly assessing social impacts requires a consistent set of guidelines and requirements to reduce the practitioners' bias. Life cycle assessment (LCA) is a widely recognized method that can be utilized to quantitatively assess three dimensions of sustainable development in an integrated manner. This study proposes an open-source tool for social impact analysis, that particularly evaluates work environment health impacts, following the LCA-defined principles, framework, requirements, and guidelines for sustainability assessment. The proposed tool in this study can quantify the social impacts and determine the categories that are being affected either negatively or positively. In addition, this study provides an overview of the existing social impact assessment approaches, identifies the critical challenges of the current techniques, and highlights opportunities for continued research to achieve more effective solutions. As of yet, a reliable and open-source tool has not been achieved to help decision-makers in both academia and industry. Thus, we developed a web-based tool for assessing social impacts in eight domains by allowing the use of multiple metrics and comparing two processes.*

**Keywords:** Sustainability, Life Cycle Assessment, Social Impacts Assessment, Design, Manufacturing, Open-source Tool.

## 1. INTRODUCTION

### 1.1. Motivations and Challenges

Over the last century, the global population has grown 400 percent, the standard of living has increased 10-fold, and the desire to efficiently utilize natural resources for future generations usage has stimulated research efforts in sustainable developments. Due to the nature of these facts, the planet cannot sustain society's collective lifestyle mostly because of a failure to properly manage industrial activities over recent decades [1]. Environmental and economic sustainability has received the most research over the recent decades, with the social aspects just gaining ground since the late 2000s [2]. Properly assessing the three dimensions of sustainability (i.e., social, economic, and environmental) for various technologies, products, and services can reduce an excessive weight on the earth, its natural resources, and livable areas [3–5].

LCA is a proven method that can be utilized to quantitatively assess three dimensions of sustainable development in an integrated manner [6]. LCA is a widely recognized method that provides principles, framework, requirements, and guidelines for sustainability assessment. Many organizations worldwide have applied the LCA method, such as International Organization for Standardization, United Nations (UN) Environment Program, and the Society for Environmental Toxicology and Chemistry [7]. Therefore, sustainability assessment using the LCA method as a standard procedure is essential to reduce practitioner bias and be consistent with the set of guidelines and requirements.

### 1.2. Background

LCA method investigates the impacts on the environmental, economic, and social aspects (known as three pillars of sustainability) of technology, product, or service life cycle. **Figure 1** presents dimensions of sustainable development in an integrated manner, including 1-dimensional aspects (i.e., environmental, economic, and social) and 2-dimensional aspects (i.e., eco-environmental, socio-economic, and socio-environmental). There are four phases necessary to complete LCA, which are goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation [8]. The starting point to LCA is defining the scope and system boundary

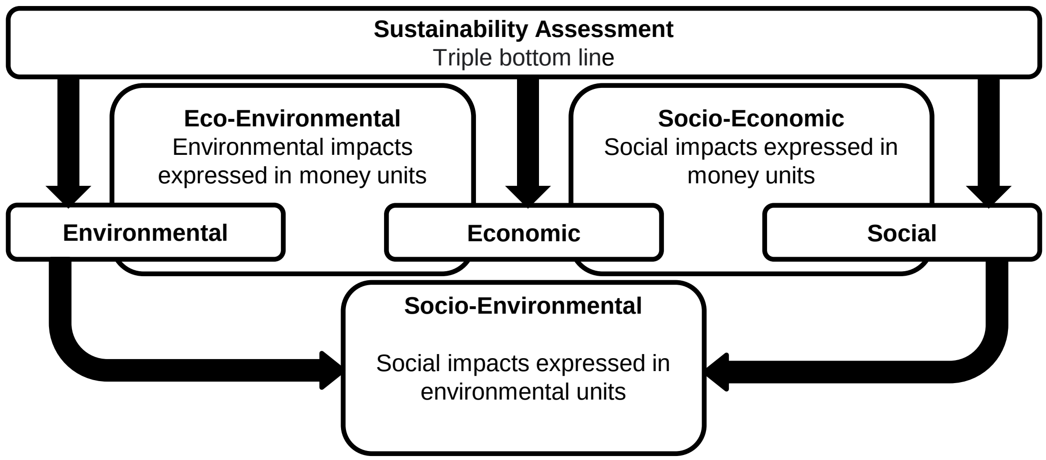


**Figure 1. Sustainability assessment pillars and metrics**

in order to realize which unit processes are being analyzed. Defining a functional unit is equally important at the beginning of the analysis to provide a quantified description of the function of a product that serves as a reference point for all calculations during the impact assessment phase [9].

**Economic assessment.** Earlier studies employed various techniques (e.g., cost-benefit analysis, input-output analysis, and cash flow analysis) to better understand whether a process or system is sustainable and cost-effective before political or business policies are created [10–14]. Emerging technologies, such as wastewater treatment methods and rare earth elements recovery, have begun to utilize life cycle costing to meet the market needs and enhance sustainability benefits [15,16]. Available tools that currently exist to aid with this analysis are the OpenLCA software and the International Reference Life Cycle Data System [17,18]. Recently, this type of analysis has been paired with both of the other aspects of LCA in which to form a more holistic approach to gaining accurate data. For example, Bait (2019) conducted an eco-environmental impact assessment of a tubular solar water heater. Their results show that the proposed system can reduce the costs and payback period, and environmental impacts compared to the current design [19].

**Environmental impacts assessment.** Earlier studies employed different environmental impacts assessment methods (e.g., system analysis, scenario analysis, substance flow analysis, and root-cause analysis) to acquire information on the effects associated with all stages of a product, process, or system life cycle. This information is calculated by utilizing material and energy requirements and emissions to air, water, and soil [20–22]. He et al. (2017) recently conducted a study and assessed the long-term environmental effects of organic rice production in subtropical China. Their results show that conventional rice production had ten times the environmental impacts as organic production methods [23]. Tassielli et al. (2017) investigated the environmental impacts of cherry production in the Apulian Region of Italy, and they recommended changes to the current methods to become more sustainable [24]. More recently, Moretti et al. (2020) assessed the environmental impacts in the process of converting used cooking oil to renewable fuels and other bio-based materials [25].

**Social impacts assessment (SIA).** There are several qualitative and quantitative methods for SIA, such as cultural impact analysis, stakeholder acceptance analysis [26]. Earlier studies defined social indicators and metrics for different stakeholders [27–29]. Petti et al. (2018) conducted a systematic literature review on SIA, classified the existing methods, and highlighted the strengths and weaknesses [30]. Siebert et al. (2018) conducted an SIA study on wood-based products in Germany. They were able to establish a set of social indicators to use as a starting point by screening global wood-related sustainability standards, analyzing SLCA case studies, conducting stakeholder interviews [7]. Recently, Padilla-Rivera and Guereca (2019) conducted a study in which four wastewater treatment plants were ranked utilizing fuzzy logic analysis with respect to all three pillars of sustainability [31].

## 1.3. Objective and Scope

LCA is a highly useful tool that was created in the 1960s and has been further developed in some fashion in the following decades. However, environmental and economic studies have been the driving factors, and have therefore received the majority of development over the decades. The primary focus of this study is to review the conducted socio-environmental impacts assessment studies and more particularly, the developed methods, case studies, applications, and outcomes. The specific objectives of this study are to (1) investigate the current state-of-the-science and gain an in-depth understanding of intricacies, (2) highlight the potential paths for future directions, and (3) propose an open-source, web-based tool for SIA, using LCA phases. A case study is used to demonstrate the application of the proposed tool and verify the method for assessing various social domains (e.g., education, health, connection to nature, cultural fulfillment, leisure time, living standards, and social cohesion). This study provides the most up-to-date review of social impact assessment methods, databases, and tools that have been developed during the past two decades. Qualitative methods, including surveys and interviews, have been used extensively in previous studies; however, more recent studies have explored the use of quantitative methods due to consistency and reliability in impacts assessment procedures and metrics.

## 2. MATERIALS AND METHODS

The presented tool in this study utilizes the standard LCA structure defined in ISO 14040. **Figure 2** presents the proposed tool functionality as it relates to the standard LCA method framework. The structure is partnered with a unique mathematical model that is used to calculate an indicator score, as well as a domain score to provide easy-to-understand results of the largest improvement areas.

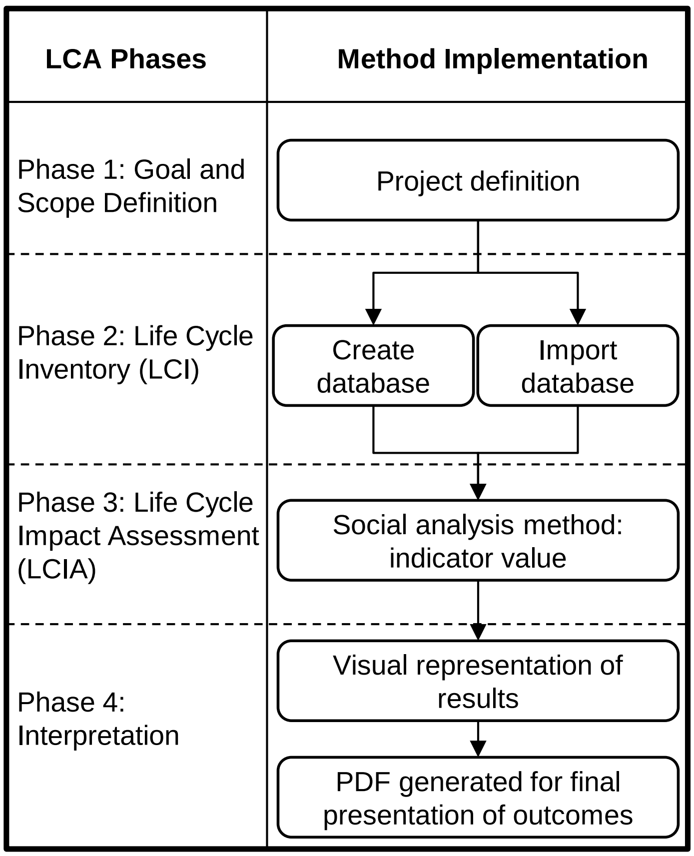


**Figure 2. Structure of proposed SLCA tool embedded in LCA framework**

Access to databases is a base functionality of this tool to aid decision makers in locating necessary information quickly. This tool comes as open-source software for LCA and sustainability assessment. It has been developed by the University of Idaho's Renewable and Sustainable Manufacturing Lab (RSML) Research Group (https://webpages.uidaho.edu/rsml/lca.html) [32]. As open-source software, it is freely available, without license costs. The source code can be viewed and modified by anyone. Furthermore, the open-source nature of the software makes it very suitable for use with sensitive data. The software and any models created can be shared freely. In addition, the simplicity compared to other exhaustive tools (e.g., SimaPro, GaBi, and OpenLCA) makes it also suitable for educational purposes, especially for those tools that are not open source.

**Phase 1 (Define the goal and scope of the LCA).** The purpose of the LCA and the goal of each study should be defined within Phase 1. The scope of the study should be defined, which can include: function, functional unit, reference flow, system boundaries, data categories, inputs and outputs, and data quality.

**Phase 2 (Life Cycle Inventory).** Phase 2 collects data for inputs, either by utilizing the provided databases or creating a custom database with values determined by the proper organization and/or department. The developed tool allows users to create a database using pre-programmed indicators or importing their own database as a CSV file. This option enables users to either apply the developing team's expertise or customize what type of information is most useful for their research. The access to existing databases is out of the scope of this work. The authors leave it to the discretion of each user to either create a database or acquire one.

If the user prefers to move forward with the predefined database option, the simple act of creating a database is all that is needed. The data that has been selected for each indicator is as follows: Metric Name, Location where research is taking place, Score assigned to the metric, and Total Score possible for that metric. When entering information into the specific fields, it is important to note that adding a new process will not eliminate the data that has been entered into the fields, but will roll the processes number up a digit with a maximum of two processes. Therefore, once the "Add new process" option has been selected the data will need to be updated for the next process and the option will need to be selected again to save the data. Utilizing different processes will allow users to compare current with proposed processes. Such comparison is valuable as it can demonstrate the advantages of newer processes and data over already established ones. This tool also provides the feature of adding a new record, enabling the user to input various metrics for each indicator. Once the information has been included in the table, it can also be exported as a CSV file, which allows the user to manipulate data and then import it back into the tool or keep records of what information has been utilized at any point in the project. This tool offers users the option to import their database in the form of a CSV file. Similar to the previous database option, the functionality is available to add a CSV file for up to two processes.

**Phase 3 (Life Cycle Impact Assessment).** Phase 3 determines if the predefined mathematical model will provide the desired results or if a custom mathematical model is required to provide the appropriate result. The custom mathematical model is a feature that will be coming in the future. The current mathematical model utilizes a weighted approach to normalize the calculation. Values for each metric are combined to create an indicator ($k$) score for a given process or product using Eq. (1), where $n_m$ represents the number of metrics, $n_i$ represents the number of locations, $w_i$ represents the population weight for location $i$, and $x_{mi}$ represents the metric value for location $i$ and metric $m$ combination.

$$\overline{X_k} = \frac{\sum_{m=1}^{n} \sum_{i=1}^{n} w_i x_{mi}}{n_m} \quad (1)$$

The weight value is calculated for each metric by dividing the Total Score possible by the Score given for that metric in a particular location. That weight is then multiplied by the Score to calculate the metric value. The sum of the metric values is calculated and divided by the total number of metrics to provide the indicator value. Once the method has been selected, the results for the calculation will appear in the results section next to the appropriate process.

The US Environmental Protection Agency developed a human wellbeing index that assesses the wellbeing of a given population [33]. As part of this index, a formula was developed to provide a weighted quantitative result to present indicator and domain scores, as shown in Equation (1). The proposed tool adapted these equations to provide an easy-to-understand mathematical model to complete Phase 3. The output of this model provides a quantitative value and a visual representation of that same data to complete Phase 4.

**Phase 4 (Result Interpretation).** The results calculated in Phase 3 will be numerically and graphically represented in order to compare processes or products. A report can also be generated to combine all phases of the LCA into a single PDF document for easy and quick dispersion of documentation study. The graphically represented data is dynamic and will allow the user to gather numerical values by hovering over the desired indicator. The user also has the option to manipulate, which indicators are shown in the graph and may be useful if numerical values span an extensive range and some may appear as nonexistent until shown alone.

The final step in the process is to generate a PDF report of the information input into the tool. The PDF will include various information, namely Name of the project, Name and email of performer, Phase 1 (Goal and Scope Definition), Phase 3 (LCIA) Method Chosen and indicator results, and Phase 4 (Graphical Display of Indicator Results).

## 3. CASE STUDY AND RESULTS

This section includes a case study for demonstrating the application of the developed SLCA tool. It is important to ensure all of the components listed in the bullet point have been addressed in the statement for a clear representation of the study. This information will also be provided in the final report, as shown in **Figure S1** in *Supplementary Materials.*

A set of metrics, locations, scores, and total scores are presented in **Figure 3**. These are retrieved from actual federal government agency databases for the following indicators: Health, Education, and Safety. **Table S1** (in *Supplementary*

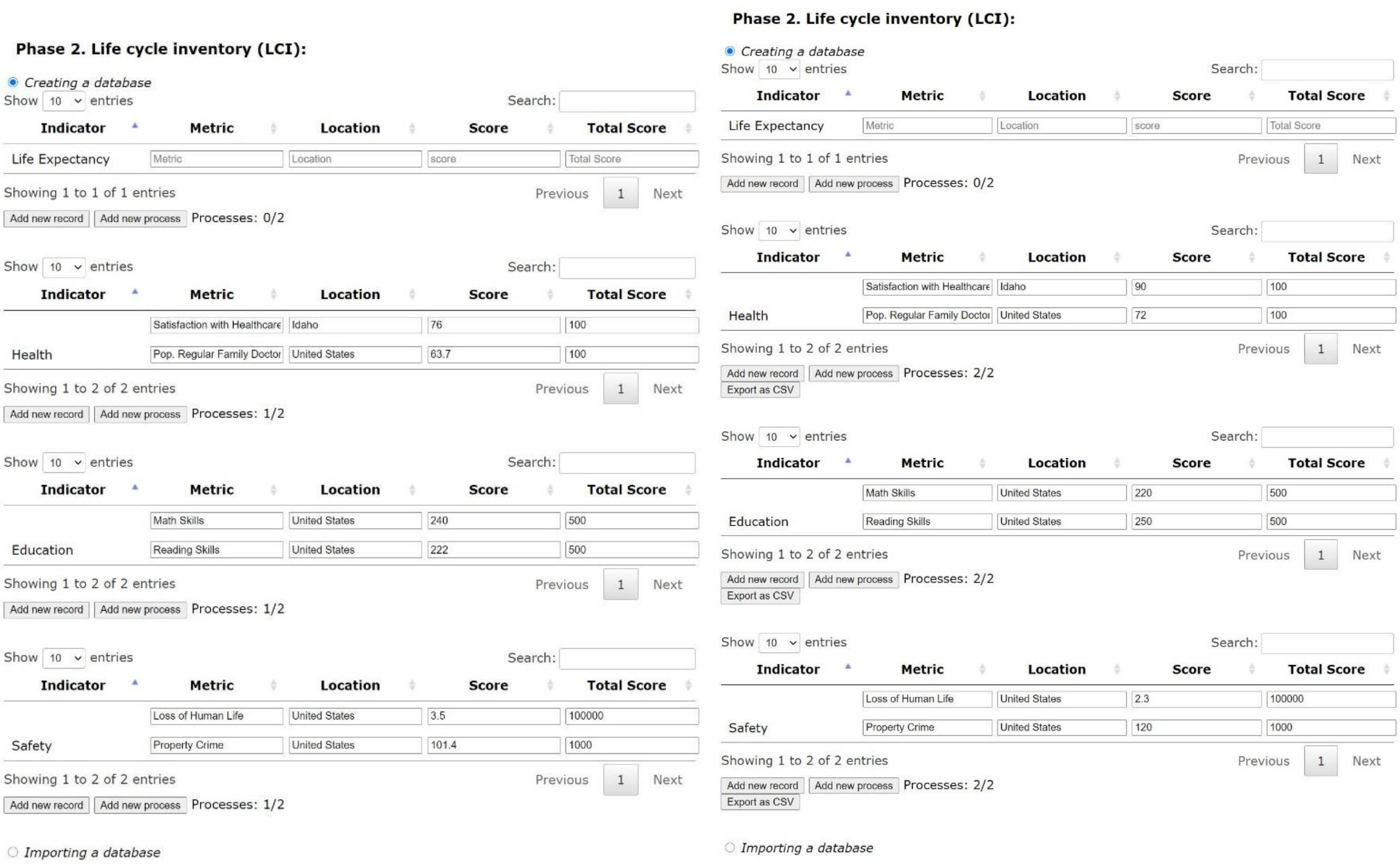


**Figure 3. Case Study Phase 2 (LCI) for process 1 (left) and process 2 (right)**

*Materials*) outlines many US government agencies that can provide data for various indicators and metrics, as well as research articles when government agencies did not provide information in a specific area. Links to these databases are available to aid user-friendliness. To input multiple metrics, the “Add new record" button needs to be selected. Once this information is entered into the table, the add new process button can be selected to save that data into memory for use in the calculation phase.

With the addition of a new process, the process’s quantity value will increase, and the data will be saved to memory for use in the Phase 3 calculation. At this point, it should also be noticed that a new button appears with the name "Export as CSV." This can be used to export the data that has been added, into a CSV file that can be opened and manipulated as necessary by the study.

**Figure 4** shows what to expect in Phase 4 after the calculation has been completed in Phase 3. The indicator scores are represented graphically and are color-coded to aid in identifying indicators quickly. This representation is dynamic and will provide numerical data simply when hovering over one of the data sets. Another feature of the dynamic representation is that indicators can be hidden and shown by clicking on their name in the legend. In order to provide this information to a team, the “Generate” button was created that once selected, will print all of the information, except the values from Phase 2 into a PDF document that can be saved and shared throughout a project team, as shown in *Supplementary Materials.*

## 4. DISCUSSION

The proposed SLCA tool in this study can address some of the discussed issues earlier. The main focus has been on SLCA and providing accurate and reliable quantitative results when analyzing multiple products, processes, or systems. An open-source tool helps scholars in both academia and industry to use it frequently, find the issues, help develop free databases, and improve its effectiveness due to its simplicity. The proposed tool herein follows the standard LCA structure by allowing the user to complete all LCA phases by automatically providing results in a predetermined format. In order to complete Phase 2, it is important to have access to accurate data to provide robust results for the use of decision making.

According to the UN Environment Programme, the limitations that exist with SLCA are (a) collecting data because there are not many databases in existence to gather background data from, (b) social effects are not always quantifiable, and little experience exists to aggregate social effects along a life cycle, (c) limited experience in LCA and social science is needed to interpret results, and (d) stakeholder participation is critical with SLCA compared to other forms of LCA. The organization’s report concludes that although there are several issues, SLCA is an area that is in urgent need of attention in many industries, including the chemical facilities where the socio-economic effects of a given chemical could be assessed over the life cycle. Proposed methods of continued development of SLCA are as follows: conduct case studies, involving SLCA, environmental LCA (ELCA), life cycle costing (LCC). These will allow for a more comprehensive understanding of how the methodologies can be combined into an integrated approach, produce educational materials, develop tools, assess social acceptability of products, detail the stakeholders’ approach, and create models to present findings. **Table 1** presents information on how the proposed tool developed as part of this study compares to the most common LCA tools currently available.

Up to the time period, some efforts have been put into developing a quantitative approach to calculate SLCA from qualitative data. The earliest approaches are to assign the qualitative data a value that would produce a result to aid decision makers in creating policies. Some approaches that have shown promise are Mamdani’s fuzzy inference system and fuzzy logic analysis [34]. Mamdani’s approach is well-suited for human inputs and has gained widespread acceptance in many areas over the years since its creation, but it requires data input from subject matter experts, which may not be readily available in many industries. The fuzzy logic analysis utilizes a standardized and weighted approach to provide reliable results, but this approach has not been applied to multiple alternate scenarios to prove its legitimacy.

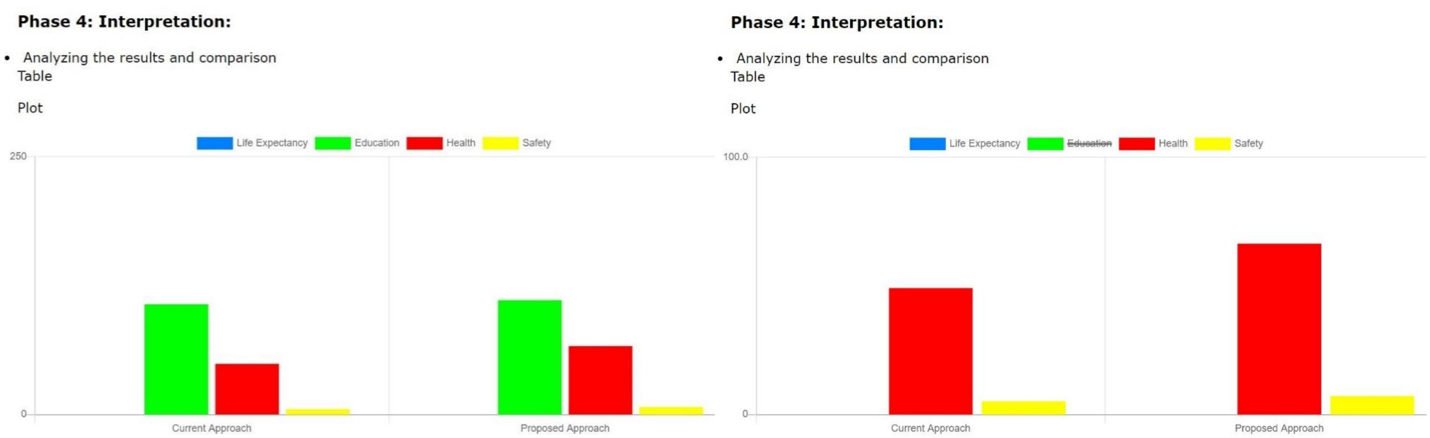


**Figure 4. Case Study Phase 4 for process 1 (left) and process 2 (Right)**

**Table 1. Prior developed LCA tools**

| Tool | Open-Source | Databases Included | User-Friendly | LCA Structure | Mathematical Model | Report Generated | Objectives 1 | 2 | 3 | Ref. |
|---|---|---|---|---|---|---|---|---|---|---|
| Brightway2 | ☑ | × | × | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | [25] |
| BEES 4.0 | × | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | × | [26] |
| GaBi | × | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | × | [27] |
| Greet LCA | × | ☑ | ☑ | ☑ | ☑ | ☑ | × | ☑ | × | [28] |
| LCAPIX | × | ☑ | ☑ | ☑ | ☑ | ☑ | × | ☑ | × | [29] |
| OpenLCA | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | [30] |
| SimaPro | × | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | [31] |
| SLCA Tool | × | × | × | × | ☑ | × | × | × | ☑ | [3] |
| TEAM | × | ☑ | ☑ | ☑ | ☑ | - | ☑ | ☑ | × | [32] |
| Umberto | × | × | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | × | [33] |
| This Tool | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | ☑ | - |

1: economic; 2: environmental; 3: social.

Early studies have utilized existing databases, such as 3-LENSUS, to assign values to specified indicators and applied that information to either the existing framework or a framework developed within that study to calculate impact values [35,36]. Recent studies have continued to build upon the existing frameworks developed previously and investigate other impacts utilizing the modified frameworks [37–39]. For example, Alsaffar et al. (2016) conducted research on how to improve social performance through a manufacturing process in a bicycle pedal manufacturing plant in which the worker health impact with relation to air freight used was calculated [40]. More recent studies have expanded upon the singular framework designs and started developing tools, such as computer applications [41,42]. Siebert et al. (2018) developed a framework known as regional-specific contextualized SLCA in which a set of social indices and indicators is established, and a product's social effects can be calculated [7]. Zimdars et al. (2018) developed a computer application that expands from using working hours as a single metric and adding biophysical pressure, reflects the negative influence of the degraded natural environment, and added value, representing the potential benefits for stakeholders due to financial investments. This tool is available in two options: (a) downloading the option with access to the social hotspot database and exiobase and (b) downloading the option without access to those databases and inputting a users' data into the program [6].

## 5. CONCLUSION

Over the past decade, initial research has been conducted on SIA in many different industries (e.g., manufacturing, construction, and energy) and has gained popularity due to researchers seeing the need for a more holistic analysis than previously addressed. These concepts have accelerated research and development in finding new or integrated approaches, as well as identifying other sources to support widely applied methods, e.g., LCA. However, there is a dearth of literature, including a detailed assessment of each approach for SIA from various resources, such as case studies and literature reviews. It is evident that the developed SIA methods can be broken down into eight domains for impact analysis, which are education, health, connection to nature, cultural fulfillment, leisure time, living standards, safety and security, and social cohesion. SIA research has been a rapidly growing field over the last ten years. It is clear that continued development of mathematical modeling to provide accurate and robust results is necessary to make SLCA a more useful method for enhancing sustainability benefits.

As of yet, a reliable and open-source tool has not been achieved, therefore, the opportunities remain for exploring either new or mixed techniques to enhance the benefits of SIA. Nowadays, the need to integrate all pillars of sustainability is essential to reveal the gaps between the methodologies of each pillar. This study directs future research towards the development of mathematical modeling with relation to not only SLCA, but also ELCA and LCC to address the stated sustainability challenges. The improved calculation methods will enable researchers and decision makers to make calculated decisions based on complex data. A fully integrated approach can be designed to include all sustainability pillars, which would allow decision makers a full picture of how well a process or system is being performed overall and areas that may need attention. Further investigation to advance SLCA techniques are as follows:

- Exploration of mathematical modeling concepts for social impact analysis across various manufacturing facilities.
- Exploration of the social metrics, indicators, and domains that may provide information from specific industries or processes.


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**Supplementary Materials**

Name of the project, Name and Email:

Case Study

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Phase 1. Goal and scope definition:

SLCA performed herein evaluates basic education skills, actual safety, and healthcare indicators within the United States. All indicators are based off of average scoring gathered from data provided by federal government agencies. The scope of this study is to provide a case of how this tool performs while utilizing real data as values. The scope considers a cradle-to-gate system boundary. The functional unit in this study is a numerical value, using the identified scope.

Phase 3. Life cycle impact assessment (LCIA):

$$\bar{X}_k = \frac{\sum_{m=1}^{n_m} \sum_{i=1}^{n_c} w_i X_{mi}}{n_m}$$

Results:

Social Result of Process 1:  LifeExpectancy: 0 Education: 106.88  Health: 49.17 Safety: 5.14

Social Result of Process 1:  LifeExpectancy: 0 Education: 110.9  Health: 66.42 Safety: 7.2

Phase 4: Interpretation:

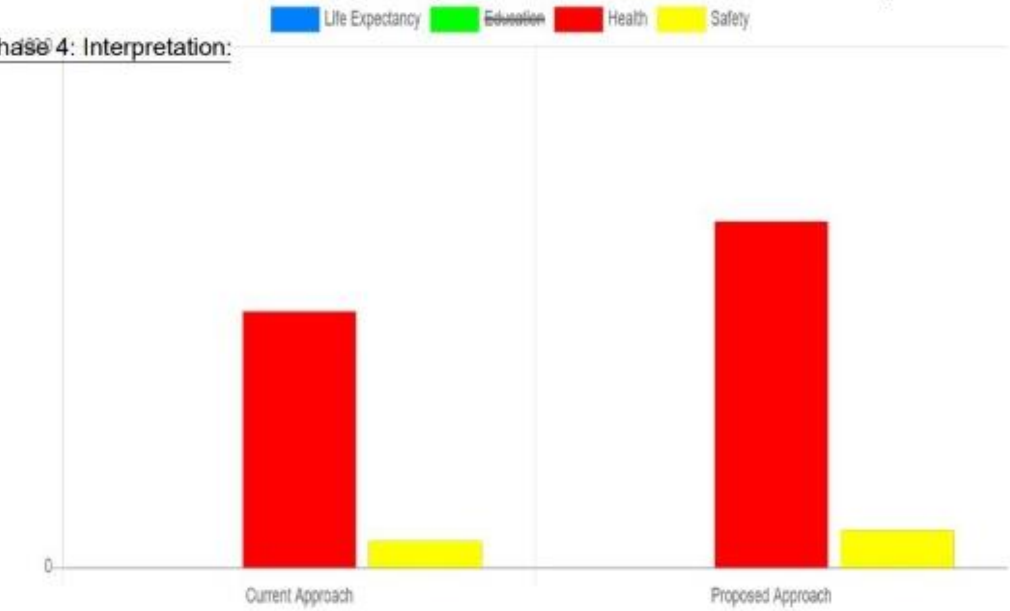


**Figure S1. Case study final report**

**Table S1. An overview of domains, indicators, and metrics for social impact analysis**

| Domain | Indicator | Metric | Ref. |
|---|---|---|---|
| Education | Educational skills | Math, reading, and science skills | [43] |
| | Participation and attainment | Adult literacy and participation | [44] |
| | | High school completion | [45] |
| | | Post-secondary attainment | [46] |
| | Social, emotional, and developmental aspects | Bullying and child physical health | [47] [48] |
| | | Social relationships and wellbeing | [49] |
| | | Preprimary education and care | [50] |
| Health | Healthcare | Satisfaction with healthcare | [51] |
| | | Population with a regular family doctor | [52] |
| | Life expectancy and mortality | Asthma, cancer, and diabetes mortality | [53] |
| | | Heart disease mortality | [54] |
| | | Life expectancy | [55] |
| | | Suicide mortality | [56] |
| | Lifestyle and behavior | Alcohol consumption | [57] |
| | | Healthy behaviors index | [58] |
| | | Teen pregnancy | [59] |
| | | Teen smoking rate | [60] |
| | Personal wellbeing | Happiness and perceived health | [61] [62] |
| | | Life satisfaction | [63] |
| | Physical and mental health conditions | Adult asthma prevalence | [64] |
| | | Cancer prevalence | [65] |
| | | Childhood asthma prevalence | [64] |
| | | Depression prevalence | [66] |
| | | Diabetes prevalence | [67] |
| | | Heart attack prevalence | [54] |
| | | Obesity prevalence | [68] |
| | | Stroke prevalence | [69] |
| Connection to nature | Biophilia | Connection to life | [70] |
| | | Spiritual fulfillment | [71] |
| Cultural | Participation | Performing arts attendance | [72] |
| Leisure time | Activity participation | Physical activity | [73] |
| | | Average nights on vacation | [74] |
| | Time spent | Leisure activities | [75] |
| | Working-age adults | Adults working long hours | [76] |
| | | Adults who provide care to seniors | [74] |
| Living standards | Basic necessities | Food security | [77] |
| | | Housing affordability | (Board of Governors of the Federal Reserve, 2019) |
| | Income | Median household income | [79] |
| | | Incidence of low income | [79] |
| | | Persistence of low income | [80] |
| | Wealth | Median home value | [81] |
| | | Mortgage debt | [82] |
| | Work | Job quality | [83] |
| | | Job satisfaction | [84] |
| Safety and security | Actual safety | Accidental morbidity and mortality | [85] |
| | | Loss of human life | [86] |
| | | Property and violent crime | [87] |
| | Risk | Social vulnerability to the environment | [88] |
| Social cohesion | Attitude toward others and the community | Trust and city satisfaction | [89] [90] |
| | | Belonging to community | [91] |
| | | Discrimination | [92] |
| | Democratic engagement | Interest in politics and registered voters | [93] [94] |
| | | Satisfaction with democracy | [95] |
| | | Trust in government and voter turnout | [96] [94] |
| | | Voice in government decisions | [97] |
| | Family bonding | Parent-child activities and meals | [98] [99] |
| | | Exceeded screen time guidelines | [100] |
| | Social engagement and support | Participation in organized activities | [101] [102] |
| | | Volunteering and close friends/family | [103] [104] |