Social Impact Assessment Across Manufacturing Facilities

A Thesis
Presented in Partial Fulfillment of the Requirements for the
Degree of Master of Science
with a
Major in Technology Management
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by
Justin R. Walters

Major Professor: Amin Mirkouei, Ph.D.
Committee Members: Aleksandar Vakanski, Ph.D.; Min Xian, Ph.D.
Department Administrator: Lee Ostrom, Ph.D.

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Authorization to Submit Thesis

This thesis of Justin R. Walters, submitted for the degree of Master of Science with a Major in Technology Management and titled "Social Impact Assessment Across Manufacturing Facilities," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

Major Professor: ____ Date: ____________
Amin Mirkouei, Ph.D.

Committee Members: ____ Date: ____________
Aleksandar Vakanski, Ph.D.

____ Date: ____________
Min Xian, Ph.D.

Department Administrator: ____ Date: ____________
Lee Ostrom, Ph.D.

Abstract

Social impact analysis urgently needs attention in various sectors (e.g., energy, agriculture, and healthcare) and manufacturing facilities (e.g., fuel and chemical production) due to the critical roles in enhancing sustainability benefits. Properly assessing social impacts requires a consistent set of guidelines and requirements to reduce practitioner bias. Life cycle assessment (LCA) is a widely recognized method that can be utilized to quantitatively assess three dimensions of sustainable development (i.e., social, economic, and environmental) in an integrated manner. Social life cycle assessment (SLCA) is a method following the LCA-defined principles, framework, requirements, and guidelines for assessing the social and sociological aspects of products, processes, and services and determining their potential positive and negative impacts along the life cycle. The social impacts of a process can be investigated in many industries, including design and manufacturing. This thesis aims to provide historical data and information on social impact assessment approaches and tools that have been previously developed. As of yet, a reliable and open-source tool has not been achieved to help decision makers in both academia and industry. Therefore, a web-based and open-source tool is proposed in this thesis for assessing social impacts in eight domains (e.g., education, health, connection to nature, cultural fulfillment, leisure time, living standards, and social cohesion) by allowing multiple metrics to be used and through the comparison of two processes. Additionally, a case study for the Idaho National Laboratory (INL) is conducted to compare the socio-environmental impacts of a design process. The results show that slight reductions in time consumption have dramatic impacts on mitigating emissions. The results also indicate that time consumption was the primary driver of social impacts. It is also found that pairing social analysis with environmental and economic analysis provides a more holistic outlook of how sustainable a process truly is.

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I would like to thank the staff and faculty of the University of Idaho. I would especially like to thank Alice Allen for her assistance in navigating the graduation requirements of my program. My advisor, Dr. Amin Mirkouei, was instrumental in providing support and guidance for both researching and writing this thesis. Finally, I should acknowledge Gerry Olsen, Drafting Manager at Idaho National Laboratory, for providing me the opportunities for real world experience and supporting my educational endeavors.

Dedication

I dedicate this work to my loving wife Reesa, and our children Brooks, Waylon, and Camryn. Thank you for being so understanding as I spent so much time working on this thesis, and my degree, to better both myself and our family.

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Statement of Contribution

I, Justin R. Walters, claim primary responsibility and first author ownership of the work presented herein. The co-authors listed in the articles within this thesis provided some guidance during method development and analysis, as well as assistance in editing prior to submission. The original draft was prepared by myself, Justin R. Walters, and initially edited by Dr. Amin Mirkouei. As the primary author of each publication, I claim responsibility for the ideas and published data that I produced to the best of my ability. Computer programming for the proposed tool presented in Chapters 2 and 4 were developed by Dr. Mirkouei and Mr. Georgios Makrakis.

Chapter 1. Introduction

1.1. Research Challenges and Motivation

Social issues such as human rights, child labor, education, and gender equality have gained more notice over the past decade throughout many industries that form modern life as we know it, including manufacturing, wastewater treatment, and shale gas production. To balance social responsibility with the demands of modern society, social life cycle assessment (SLCA) aims to reduce the negative impacts of these industries.

Previous studies exist for SLCA, most being from the past decade, but some early research can be found from the late 1990's. In many of these studies, the method used was a qualitative approach, mostly surveys, to gather data instead of developing and applying a quantitative approach. The following chapters outline methods and tools provided from previous studies, applying SLCA to an actual process to provide the areas needing improvement, and an SLCA tool developed to provide accurate and robust results.

1.1.1. Chapter 2 Challenge

Environmental and economic life cycle assessments have been studied since the 1970's and 1980's respectively while SLCA has seen an uptick in research over the past decade. For this reason, there are fewer studies to gather data from to create a holistic review of existing SLCA methods and tools. The challenge for researchers is that there is not one standardized method that has been agreed to be the best practice. The current methods that use a quantitative approach are summarized with advantages and disadvantages listed.

1.1.2. Chapter 3 Challenge

Employee morale plays a part in any industries successes or failures. SLCA can aid in identifying the most critical areas of concern for any industry and provide the tools to determine how changes in processes or procedures will affect the employees in that industry. Chapter 3 takes advantage of this type of scenario and presents a case study to improve employee morale and combine SLCA with environmental LCA.

1.1.3. Chapter 4 Challenge

Tools associated with LCA are plentiful, however, tools associated with SLCA specifically are more challenging to locate. Many of the tools that exist to perform SLCA cost thousands of dollars for a license or do not work properly without spending money to access specific databases, such as Social Hotspots Database. Chapter 4 introduces an open-source, web-based tool that will provide users with data from federal government agencies and a robust mathematical model to ensure results are scientifically proven.

1.2. Motivation of Thesis

All three chapters are motivated by the desire to understand the social impacts, specifically in the design and manufacturing industries. For a process to be sustainable, it must not only be economically and environmentally viable, but also offer minimal negative social impacts to workers, local community, and national and global society. The information proposed in this thesis can be applied to a myriad of processes in different industries.

Prior to starting this research, I was aware of sustainable practices as it relates to environmental impacts as that is a concept that is taught from a young age in society. Most adults learn the basic concept of economic sustainability pertaining to their personal lives, and not spending more than you have is by no means the same as operating a manufacturing line, but it illustrates the concept. Social impacts are less advertised than their better-known counterparts, but analyses on all three categories are necessary to achieve holistic sustainability. Chapter 3 illustrates how effective a socio-environmental analysis can be when analyzing a process document for inefficiencies and showing the results produced from revising that document.

LCA is a proven approach to being able to achieve more sustainable processes, but without the proper education and training, it can seem a daunting task. For this reason, LCA applications and software can bridge the gap between LCA experts and decision makers within companies. Currently, there are only a few programs that can be utilized to analyze all three categories of sustainability, which include OpenLCA, SimaPro, and Brightway2. Brightway2 requires a working knowledge of Python Programming Language. OpenLCA and SimaPro are more user-friendly, but require a license in order to fully utilize the software capability and access necessary databases. Chapter 4 introduces a tool that allows all users a fully functional program, as well as access to government data for social indicators.

1.3. Research Objectives and Tasks

This thesis is based on SLCA and socio-environmental LCA to analyze industrial processes. OpenLCA version 1.9, an open-source software for performing LCA, was used to assist in this analysis. Furthermore, MS Excel was used to assist with equation development.

Chapter 2 gathers information related to the approaches and tools that have been used by previous studies with relation to SLCA into one document. Previous studies apply a standard LCA structure to SLCA research, including four phases: Goal and Scope Definition, Life Cycle Inventory, Life Cycle Impact Assessment, and Interpretation. The main difference is in the inventory phase, where some studies refer to quantitative indicators, most reference qualitative indicators, which cannot easily be converted to a numeric value. As such, considerable time was spent learning about the quantitative equations that have been utilized in the past.

Chapter 3 required an elevated understanding of LCA analysis in order to properly apply the method to an active process document. Data was gathered from the affected organization so as to properly identify the areas of the document that could be improved. Equations were developed to account for time and energy usage. This data was used to calculate the socio-environmental impacts for both the current process and the proposed process. Ultimately, the relationship between the social and environmental impacts was key in understanding the issues with the document.

Chapter 4 required a working knowledge of JavaScript and HTML programming languages. To assist this, online courses were identified and completed. The original concept of the tool was developed in Python due to its ability to manage complex numeric applications. Ultimately, the user interface development of Python proved to be too time-consuming, and HTML and JavaScript were identified as the best alternative for finalizing the development of the proposed SLCA tool.

1.4. Research Scope

The socio-environmental assessment completed in Chapter 3 considers the social viability of the proposed document with respect to time consumption in terms of minutes and healthy population in terms of employee satisfaction. The environmental viability was considered for the proposed study with respect to emissions in terms of pounds of carbon dioxide. Percentage of change between the current and proposed approaches were used to present results.

This study primarily considered social impacts from the perspective of design and manufacturing organizations. Although the design and manufacturing organizations perform different tasks within the product development life cycle, they are interconnected processes because decisions made during the design process directly affect the manufacturing process. For example, if the stainless steel is what the designer of a particular part has called out on a drawing when aluminum would be sufficient. This seemingly simple change could save employee machining time, as well as minimize emissions of equipment to name two positive changes. The triple bottom line approach for sustainability assessment, or analyzing all three categories (environmental, economic, social) of impact, is a much more complex issue to solve and is beyond the scope of this thesis.

Coursework in Technology Management teaches that a good scope should state not only what is included, but also what is beyond the scope of work. The economic aspects of sustainability were not considered by any of the chapters in this thesis. While this area is worthy of consideration in further work, it exists beyond the scope of this thesis.

1.5. Thesis Outline

This thesis is presented in manuscript format and consists of five chapters.

Chapter 2 is a study of SLCA in previous studies in the context of a literature review. The paper identifies key areas still needing further research conducted and qualitative and quantitative analyses to assess the usefulness of identified approaches through narrative and systematic reviews. Mathematical modeling utilizing qualitative data can be an effective approach to identifying social impacts. This chapter has been submitted under the title “A quantitative approach for social impacts assessment: an overview and open-source tool” and is currently under review for publication in the International Journal of Life Cycle Assessment.

Chapter 3 considers a project in Eastern Idaho to produce a new procedure for a design organization, with relation to computer-aided design software, that improves social impacts, as well as environmental impacts. This chapter establishes the following social categories: communication, rework time, time for task completion, excessive working time, and social impacts of electricity usage. Publicly available data from both Idaho Power and the Union of Concerned Scientists were used to calculate accurate results for the socio-environmental impacts. This chapter is a conference paper published in the 2020 proceedings of the ASME IDETC/CIE: 25th Design for Manufacturing and the Life Cycle Conference, under the title “Social Life Cycle Assessment of Computer-Aided Design Tools.”

Chapter 4 provides information on properly performing analysis with the proposed SLCA tool in the form of a manual. Figures have been provided along with written direction to prepare the user of what functionality the tool offers, as well as what can be expected. A case study is presented with data gathered from actual government agency databases as an additional aid to users to showcase each phase and provide confirmation on what can be gained from using this tool.

Chapter 5 draws general conclusions for this thesis and offers suggestions for future work, and considerations of what has been accomplished.

Chapter 2. A Quantitative Approach for Social Impacts Assessment: An Overview and Open-Source Tool

This chapter was submitted for publication in the International Journal of Life Cycle Assessment, under the title "*A quantitative approach for social impacts assessment: an overview and open-source tool.*"

Justin R. Walters[1], and Amin Mirkouei[1,2]*

[1] Technology Management Program, University of Idaho, Idaho Falls, ID, 83402 USA

[2] Department of Nuclear Engineering and Industrial Management, University of Idaho, Idaho Falls, ID, 83402 USA

2.1. Abstract

Purpose Social impact analysis is in urgent need of attention in various sectors and manufacturing facilities due to the critical roles on enhancing sustainability benefits. Properly assessing social impacts requires a consistent set of guidelines and requirements to reduce practitioner bias. Life cycle assessment (LCA) is a widely recognized method that can be utilized to quantitatively assess three dimensions of sustainable development (i.e., social, economic, and environmental) in an integrated manner.

Methods 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. A comprehensive classification of social impact assessment techniques is presented through narrative and systematic literature review techniques, including qualitative and quantitative analyses to assess the usefulness of developed methodologies. Additionally, this study proposes an open-source tool for social impact analysis, particularly evaluating work environment health impacts, following the LCA-defined principles, framework, requirements, and guidelines for sustainability assessment. 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).

Results and Discussion 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. Both conducted narrative and systematic reviews aid in exploring

the standard social domains, indicators, metrics, methods, databases, and tools in different industries, as well as identifying the key parameters to guide future social impact analysis. 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 procedure and metrics. The proposed tool in this study can quantify the social impacts and determine the categories (e.g., occupational safety and health) that are being affected either negatively or positively.

Conclusions 274 scientific articles were analyzed in the systematic review and 149 studies discussed in the narrative review to maintain an up-to-date knowledge of the state-of-the-science and recent breakthroughs. As of yet, a reliable and open-source tool has not been achieved to help decision makers in both academia and industry; thus, we proposed a web-based tool for assessing social impacts in eight domains by allowing multiple metrics to be used and through the comparison of two processes.

Keywords: Sustainability, Life Cycle Assessment, Social, Open-source Tool.

2.2. Introduction

Motivation 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 (Sutherland et al., 2020). Environmental and economic sustainability has received most research over recent decades, with the social aspects just gaining ground since the late 2000s (Venkatesh, 2019). 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.

Life cycle assessment (LCA) is a proven method that can be utilized to quantitatively assess three dimensions of sustainable development in an integrated manner (Zimdars et al., 2018). 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 Environment Program, and the Society for Environmental Toxicology and Chemistry (Siebert et al., 2018). 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.

Background. LCA method investigates the impacts on the environmental, economic, and social aspects (known as three pillars of sustainability) of a product, process, or service life cycle (Figure 2.1). There are four phases necessary to complete LCA, which are goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation (Lúcio, 2017). The starting point to LCA is defining the scope and system boundary in order to know which unit processes are being analyzed. Defining a functional unit is equally important at the beginning of 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 (Arzoumanidis et al., 2020).

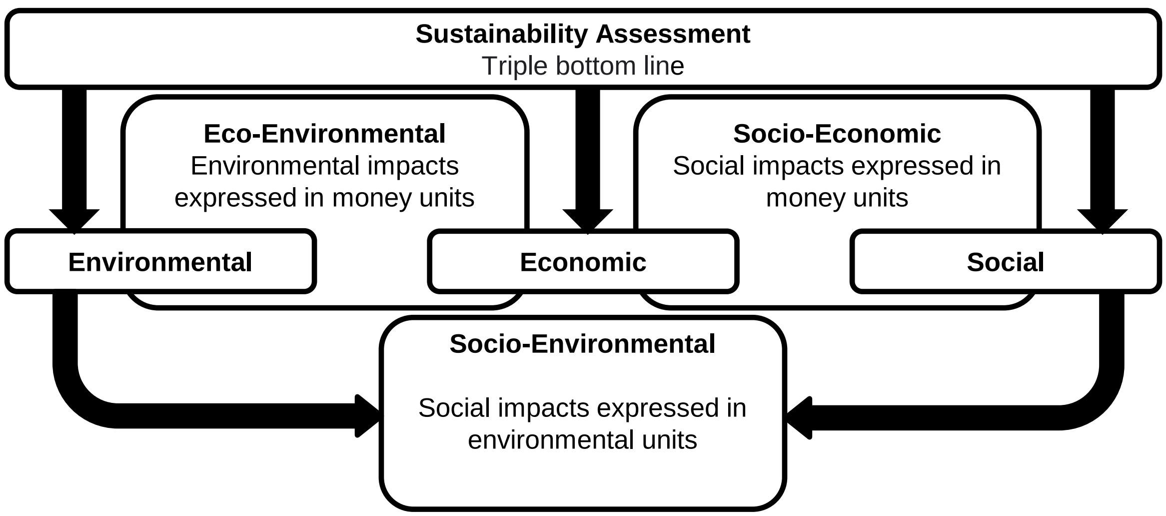

Figure 2.1. Sustainability assessment pillars and metrics

- *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 (Hanegraaf et al., 1998; Hendrickson et al., 1997; Hodowanec, 1998). Emerging technologies, such as wastewater treatment methods, have begun to utilize life cycle costing to meet the market needs and enhance sustainability benefits. Available tools that currently exist to aid with this analysis are OpenLCA software and International Reference Life Cycle Data System (Mehta et al., 2018; Rashidi et al., 2018). 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, as well as environmental impacts compared to the current design.

- *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 gain 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 (Finnveden, 1999; Miettinen and Hämäläinen, 1997; Sombekke et al., 1997). Recently, He et al. (2017) 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 10 times the environmental impacts as organic production methods. 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. 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.

- *Social impacts assessment (SIA).* There are several qualitative and quantitative methods for SIA, such as cultural impact analysis, stakeholder acceptance analysis. Earlier studies defined social indicators and metrics for different stakeholders (Ribeiro, 2017; Sutherland et al., 2016; van Haaster et al., 2017). Petti et al. (2018) conducted a systematic literature review on SIA, classified the existing methods, and highlighted the strengths and weaknesses. 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. 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.

2.3. Objective

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, particularly the developed methods, case studies, applications, and outcomes. The specific objectives of this study are (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.

2.4. Narrative Review

The narrative review conducted herein identifies the qualitative evidence of the need for the social life cycle assessment (SLCA). SLCA is a method that can be used to assess the social and sociological aspects of products, their actual and potential positive or negative impacts along the life cycle. There has not been as much research focused on SLCA as there has been on the economic and environmental assessment (Jørgensen et al., 2008). The most common tools used to conduct SLCA and gather data are surveys, the global reporting initiative framework, ISO 26000 standard, social hotspots database, and fair factories clearinghouse. Once the data has been collected, it has been common practice to categorize that data into groups of social issues to best determine what aspects of a process or product are being affected negatively and what aspects are being affected positively. Examples of such categories are user's safety, human health effects, employment, occupational safety and health, labor rights, human rights, housing and service infrastructure, education, and legislation and enforcement.

2.4.1. Quantitative Methods

2.4.1.1. Indicators and Metrics

Early studies have assessed the concepts and methods of SLCA, including the accurateness of typical indicators and metrics used. Their results have shown that the metrics studied were not found to be scientifically justified, but with further development, the information could provide insight for future SLCA studies (Arvidsson et al., 2015; Aschehoug et al., 2016; Haapala et al., 2013). Recent studies have completed further investigation into metrics, indicators, and system boundaries (Arzoumanidis et al., 2020). A wide variety of quantitative and qualitative indicators have been proposed and conducted for different purposes of improving local levels or regional boundaries (Dlouhá et al., 2013; Fawaz-Yissi and Vallejos-Cartes, 2011). Tirado et al. (2015) developed indicators to evaluate the social programs in Mexico City to identify the key parameters and promote better and faster changes toward those programs. Shiau and Chuen-Yu (2016) developed fourteen key indicators utilizing the social construction of technology for the SLCA of a Taiwanese offshore wind power farm, which was shown to be a socially sustainable project. Kuhnen and Hahn (2017) conducted a systematic review of trends, coherences, inconsistencies, and gaps in research on SLCA indicators across several industry sectors. Siebert et al. (2018) developed a set of social indicators to create a baseline for assessing and monitoring wood-based production systems in Germany. Fortier et al. (2019) developed and organized social indicators to evaluate energy justice by four categories of stakeholders for electrical energy systems: workers, electricity consumers, local communities, and society as a whole. Table 2.1 presents the applied domains, indicators, and metrics in prior published studies or reports for SIA or SLCA.

Table 2.1. An overview of domains, indicators, and metrics for social impact analysis

Domain	Indicator	Metric	Ref.
Education	Basic educational knowledge and skills of youth	Math skills	(McFarland et al., 2019)
		Reading skills	(McFarland et al., 2019)
		Science skills	(McFarland et al., 2019)
	Participation and attainment	Adult literacy	(U.S. Department of Education, 2019a)
		High school completion	(U.S. Department of Education, 2020)
		Participation	(U.S. Department of Education, 2018)
		Post-secondary attainment	(U.S. Department of Education, 2019b)
	Social, emotional, and developmental aspects	Bullying	(Han et al., 2019)
		Child physical health	(Köhler and Rigby, 2003)
		Social relationships and emotional wellbeing	(Centers for Disease Control and Prevention, 2019a)
		Preprimary education and care	(Gil et al., 2020)
Health	Healthcare	Satisfaction with healthcare	(U.S. Centers for Medicare & Medicaid Services, 2020)
		Population with regular family doctor	(Centers for Disease Control and Prevention, 2019b)
	Life expectancy and mortality	Asthma mortality	(Centers for Disease Control and Prevention, 2020a)
		Cancer mortality	(Centers for Disease Control and Prevention, 2020b)
		Diabetes mortality	(Centers for Disease Control and Prevention, 2020c)
		Heart disease mortality	(Centers for Disease Control and Prevention, 2021a)
		Infant mortality	(Centers for Disease Control and Prevention, 2020d)
		Life expectancy	(Centers for Disease Control and Prevention, 2021b)
		Suicide mortality	(Centers for Disease Control and Prevention, 2021c)
	Lifestyle and behavior	Alcohol consumption	(Centers for Disease Control and Prevention, 2021d)
		Healthy behaviors index	(Centers for Disease Control and Prevention, 2020e)
		Teen pregnancy	(Centers for Disease Control and Prevention, 2019c)
		Teen smoking rate	(Centers for Disease Control and Prevention, 2020f)
	Personal wellbeing	Happiness	(Blanchflower and Oswald, 2020)
		Life satisfaction	(Solé-Auró and Lozano, 2019)
		Perceived health	(Levine et al., 2017)
	Physical and mental health	Adult asthma prevalence	(Centers for Disease Control and

	conditions		Prevention, 2021e)
		Cancer prevalence	(National Cancer Institute, 2020)
		Childhood asthma prevalence	(Centers for Disease Control and Prevention, 2021e)
		Depression prevalence	(Centers for Disease Control and Prevention, 2021f)
		Diabetes prevalence	(Centers for Disease Control and Prevention, 2020c)
		Heart attack prevalence	(Centers for Disease Control and Prevention, 2021a)
		Coronary heart disease prevalence	(Diseases, 2011)
		Obesity prevalence	(Centers for Disease Control and Prevention, 2019d)
		Stroke prevalence	(Centers for Disease Control and Prevention, 2021g)
Connection to nature	Biophilia	Connection to life	(Chang et al., 2020)
		Spiritual fulfillment	(Skevington et al., 2019)
Cultural fulfillment	Activity participation	Performing arts attendance	(Suarez-Fernandez et al., 2020)
		Rate of congregational adherence	-
Leisure time	Activity participation	Physical activity	(Kekäläinen et al., 2020)
		Average nights on vacation	(U.S. Bureau of Labor Statistics, 2020)
	Time spent	Leisure activities	(U.S. Bureau of Labor Statistics, 2016)
	Working-age adults	Adults working long hours	(Angrave et al., 2015)
		Adults working standard hours	-
		Adults who provide care to seniors	(U.S. Bureau of Labor Statistics, 2020)
Living standards	Basic necessities	Food security	(U.S. Department of Agriculture, 2021)
		Housing affordability	(Board of Governors of the Federal Reserve System, 2019)
	Income	Median household income	(U.S. Census Bureau, 2020)
		Incidence of low income	(U.S. Census Bureau, 2020)
		Persistence of low income	(U.S. Department of Labor, 2021)
	Wealth	Median home value	(Federal Housing Finance Agency, 2021)
		Mortgage debt	(Federal Housing Finance Agency, 2011)
	Work	Job quality	(Howell and Kalleberg, 2019)
		Job satisfaction	(Chordiya et al., 2019)
Safety and security	Actual safety	Accidental morbidity and mortality	(Centers for Disease Control and Prevention, 2021h)
		Loss of human life	(Centers for Disease Control and Prevention, 2021i)
		Property crime	(Bureau of Justice Statistics, 2020)
		Violent crime	(Federal Bureau of Investigation, 2020)
	Perceived safety	Community safety	-
	Risk	Social vulnerability to environmental factors	(Thomas et al., 2019)
Social	Attitude toward others and	Trust	(Lee et al., 2020)

cohesion	the community	City satisfaction	(Hoogerbrugge and Burger, 2018)
		Belonging to community	(Tanaka et al., 2018)
		Discrimination	(Brondolo et al., 2012)
		Helping others	-
	Democratic engagement	Interest in politics	(Elliott, 2018)
		Registered voters	(U.S. Census Bureau, 2019)
		Satisfaction with democracy	(American Customer Satisfaction Index, 2020)
		Trust in government	(Esau et al., 2019)
		Voice in government decisions	(Rasmussen and Reher, 2019)
		Voter turnout	(U.S. Census Bureau, 2019)
	Family bonding	Parent-child reading activities	(Senechal, 2006)
		Frequency of meals at home	(Statista, 2019)
		Exceeded screen time guidelines	(National Institutes of Health, 2019)
	Social engagement	Participation in organized, extracurricular activities	(An and Western, 2019)
		Participation in group activities	(Kepper et al., 2019)
		Volunteering	(AmeriCorps, 2019)
	Social support	Close friends and family	(Hornstein and Eisenberger, 2018)

Early studies have focused on sustainable manufacturing technologies, value creation models, and indicator repositories for small-/medium-sized manufacturing enterprises (Sarkar et al., 2011; Ueda et al., 2009). Cooper et al. (2015) conducted a study to calculate the job creation and public perception of the shale gas production industry in the U.K. Recently, the social performance of the manufacturing industry has continued to be researched, with results showing a clear direction for future research and methods following ISO-26000 (Hasan, 2016; Sutherland et al., 2016). Margherita and Marcello (2016) proposed a predictive approach to estimate the global impacts on a manufacturing system and identify the key parameters for enhancing sustainability benefits across their proposed case study. More recently, several SLCA frameworks have developed, but the topics of these studies have become less broad and more focused, for instance, mitigating musculoskeletal disorders that have been occurring in the manufacturing industry; how society is impacted by emerging technologies; or creating a streamlined approach along with hotspot analysis to pinpoint where in the product system issues are likely to occur (Nguyen and Krüger, 2017; Ribeiro, 2017; Sousa-Zomer and Cauchick-Miguel, 2017, p.; van Haaster et al., 2017). Wilson (2017) conducted a sustainability study on China’s South-North Water Transfer Project, using a triple bottom line approach to answer the critical questions, such as the social impacts of relocating hundreds of thousands of people. More information on SLCA approaches and inadequacies can be found in Petti et al. (2018), Subramanian et al. (2018), Venkatesh (2019), and Zarte et al. (2019). Table 2.2 presents the conducted SIA studies in different industries.

Table 2.2. Prior social impact studies in different industries

Industry	Indicator	Metric	Method/Resource	Location	Ref.
Shale gas production	Work and social support	Employment and public perception	External databases and surveys	United Kingdom	(Cooper et al., 2016)
Manufacturing	Democratic engagement	Government support	ISO-26000	Bangladesh	(Hasan, 2016)
	Social performance	Social needs of stakeholder groups	United Nations Global Compact U.N. Environment Programme and the Society of Environmental Toxicology and Chemistry Social Hotspots Database Sustainable Manufacturing Indicator Repository ISO 26000 Global Reporting Initiative	United States	(Sutherland et al., 2016)
Water transfer	Social support	People resettlement	Review of previous individual studies	China	(Wilson et al., 2017)

2.4.1.2. Mathematical Programming

Early studies started to see the need to move from a qualitative approach to a quantitative approach in order to provide scientific results to aid decision makers. Fawaz-Yissi and Vallejos-Cartes (2011) developed a methodology that combined qualitative and quantitative approaches utilizing five indicators with simple metrics for each. Other studies took this concept a step further in developing a mathematical programming model for all three sustainability pillars to investigate tradeoffs during the decision making process (Table 3) (Eastwood and Haapala, 2015; Mota, 2015). Recent studies show that this concept is still being researched and developed, for example, Cao, et al. (2016) applied Mamdani's fuzzy inference system to calculate a social sustainability score from an ergonomics perspective (Cao et al., 2016). Popovic and Kraslawski (2017) formulated a quantitative analysis similar to SLCA, which required less data in comparison to other similar equations. Grubert (2018) performed a literature review on SIA and SLCA studies. Their results demonstrated that standardization of data gathering and adopting social science methods and techniques are needed for the continued growth of SLCA. There has been continued development of analytical equations, assessing productivity and corporate social responsibility, recommending better medications to protect society, and managing products with high chemical impacts (Arvidsson et al., 2018; Gbededo and Liyanage, 2018). Traverso et al. (2018) utilized a quantitative method to analyze the social impacts of run-on flat tires in which thirteen companies partnered to develop the study and choose the most accurate indicators and metrics. This study identified reference values for ideal and worst-case scenarios. For example, zero hours of child labor per product or zero training hours per product, a calculation could then be performed. The result could be compared to the reference values for an accurate comparison of the level of sustainability. More detailed information on fuzzy logic analysis can be found from Padilla-Rivera and Guereca (2019). More information on developing equations as well as how the results can be used to aid decision makers can be found from Subramanian and Yung (2018) and Souza et al. (2018). Table 2.3 presents different mathematical modeling approaches utilized by previous studies.

Table 2.3. Prior studies that applied mathematical programming method for social impact analysis

Method	Indicator	Metric	Advantages	Disadvantages	Ref.
Qualitative and mathematical models	Rural development, quality of life, social participation, and gender	-	Mathematically aid decision makers	Data uses assumptions and is specific to rural central chile	(Fawaz-Yissi and Vallejos-Cartes, 2011)
Multi-objective mathematical models	Work	Job creation	Used for a wide range of products	No weighting included in mathematical models, thus not a good tool for deciding between similar processes	(Eastwood and Haapala, 2015; Mota, 2015)
Mamdani's fuzzy inference system	Work	Job quality and satisfaction	Well-suited to human input and widespread acceptance	Relies on the knowledge of experts	(Cao et al., 2016)
Fuzzy logic analysis	Community, work, and education	public participation, employment, living condition, work hours, salary, and training	Standardization and weighting used to provide robust mathematical results	Needs applied to other scenarios to prove its efficiency and accuracy	(Padilla-Rivera and Güereca, 2019, p.)

2.4.2. Qualitative Methods

2.4.2.1. Surveys

Early studies have utilized data from the International Manufacturing Strategy Survey to determine social priorities and compare new or modified operations strategies with traditional approaches (Longoni and Cagliano, 2015; Wiengarten and Longoni, 2015). Tamura et al. (2016) proposed a method of knowledge for supporting local-oriented manufacturing by comparing vacuums and refrigerators manufactured for Malaysia versus products manufactured for Japan, allowing designers to better understand the target area and what functionality and features are important for domestic consumers. Recently, customized surveys have been developed to model the system and integrate available data from the manufacturing processes (Peruzzini et al., 2017). Additionally, stakeholder surveys have been developed for suppliers, employees, customers, and community members to identify improvement areas, such as training, skills, infrastructure, and workplace safety for workers (Singh and Gupta, 2018).

Manufacturing companies have been the main focus of green supply chain management research recently. Petljak et al. (2018) conducted a study to assess the sustainability performance between green in-store activities and supply chain management. They utilized empirical evidence from 190 responses by Croatian food retailers from a self-administered survey. The data collected and the results presented in this study are based on one country and should be extended to assess similar situations in other locations. The automotive industry has also used survey data collection methods to provide evidence about whether project risk management and green supply chain management are positively related by receiving inputs from 145 project managers in the Malaysian automobile manufacturing industry (Fernando et al., 2018). Survey data collection has been used to investigate the role of the government in clean technology adoption in developing countries. Satapathy et al. (2017) collected data from a survey of Indian firms and compared the empirical outcomes with the current government policies to summarize the research findings and determine the key areas for improvement.

2.4.2.2. Interviews

Early studies show examples of both stakeholder participation methods and little stakeholder participation. Floros-Phelps et al. (2007) conducted a review of building-centered community development process to provide a sustainable community. Dlouha et al. (2013) developed questionnaires for quick data collection, simple to understand, and analysis, but the proposed method does not allow for full stakeholder participation because of the impersonal nature of the procedure. Jasinski et al. (2016) developed a framework for automotive sustainability assessment. They selected the criteria from previous studies and refined them by interviewing 24 automotive experts to serve as a design structure for automotive development. Maia et al. (2017) utilized the Q-sort method to validate the scale and indicators drawn from the analysis of judges regarding the safe and healthy work of a manufacturing organization. Their results show that it was possible to achieve positive impacts through social practices as long as the needs are clearly defined and have actions to ensure compliance. More information on stakeholder participation can be found in Pelletier (2018), where a study was conducted to research the social risks and benefits of Canadian egg production facilities. It was shown that local communities, value chain partners, and society stakeholders were at low risk, however, the workers were at high risk for working hours, equal opportunity, and fair salary. Table 2.4 presents industries that have utilized qualitative approaches to SLCA.

Table 2.4. Prior studies that applied qualitative methods for social impact analysis

Industry	**Indicator**	**Metric**	**Method/Approach**	**Location**	**Ref.**
Manufacturing	Short-term performance and long-term performance	-	Survey	-	(Longoni and Cagliano, 2015)
Manufacturing	Product life cycle	-	Survey and case Studies	Malaysia and Japan	(Tamura et al., 2016)
Manufacturing	Public engagement,	-	Survey	Europe	(Peruzzini et

	human rights, economic development, technological development, social development, health, and safety				al., 2017)
Steel	Human rights, working conditions, health, safety, cultural heritage, and governance	-	Survey	India	(Singh and Gupta, 2018)
Clean technology	Government and society	-	Survey	India	(Satapathy et al., 2017)
Construction	Society	-	Interview	USA	(Floros Phelps et al., 2007)
Automotive	Society, safety, labor rights, human rights, and work	Accidents, congestion, collision avoidance, intelligent vehicle, job creation, job satisfaction, and mobility capability	Interview	-	(Jasiński et al., 2016)
Manufacturing	Performance	-	Q-Sort	-	(Caixeta de Castro Maia et al., 2018)
Egg production	Work	Working hours, equal opportunity, and fair salary	Survey and interview	Canada	(Pelletier, 2018)

2.5. Systematic Review

Scholars have limited time to maintain an up-to-date knowledge of the state-of-the-science and recent breakthroughs. Therefore, literature reviews play an essential role in helping the investigators identify the key variables and bridge the research gaps. The conducted systematic review study herein covers developed SIA or SLCA methods and tools to enhance sustainability benefits across many sectors. A systematic review aims to reduce bias from the author instead of narrative and comparative reviews that often reinforce partialities and the author's research interest. In addition, systematic review studies aid in identifying the major parameters of previous works to guide future studies by exploring the indicators, methods, and tools. Two databases are generated in Web of Science, using the title search (TI) between 2010 and 2020 with a total of 274 papers. On average, a consistent increase in publications per year is an indicator of growing interest in SLCA (Figure 2.2).

- Keyword Set 1: TI: (Social AND Life Cycle Assessment)
- Keyword Set 2: TI: ((Sustainability OR Sustainable) AND Social AND Impact)

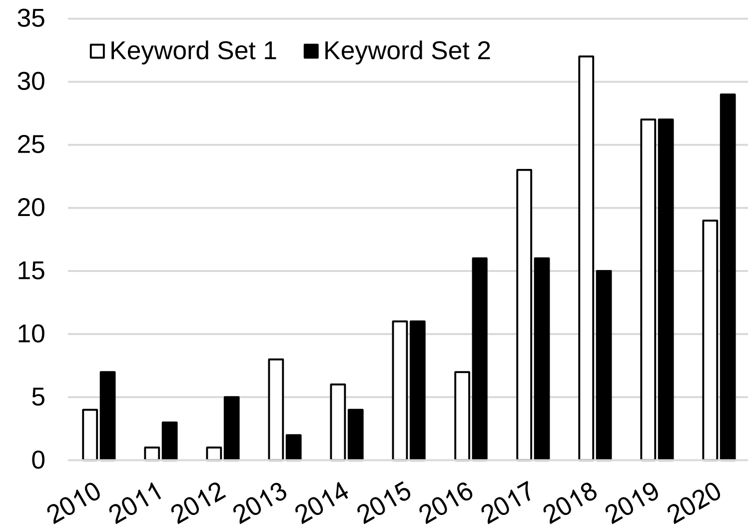

Figure 2.2. Comparison of published articles for each keyword set between 2010 and 2020

The research and development for a more holistic sustainability program is the primary reason, influencing the increased interest in SLCA. More quantitative studies have been developed over the years about economic and environmental impacts assessment, but very few quantitative studies have been conducted on the social aspects. All most-cited articles in both keyword sets are published prior to 2019, with most being published prior to 2016; since then, new SLCA methods have been developed. Thus, an up-to-date review study is necessary. Keyword set 1 had more citations than keyword set 2 since it was less defined and searched for SLCA only.

Table 2.5 presents the top five productive organizations with the highest level of authorship in each keyword set. Table 2.6 reports the top ten countries with the most publication records for both keyword sets.

Table 2.5. Top 5 productive organizations by publication records

Keyword Set 1	Records	Keyword Set 2	Records
Technical University of Berlin	8	Hong Kong Polytech University	3
Rhein Westfal Th Aachen	5	Politecn Milan	3
University G Dannunzio	5	Aristotle University of Thessaloniki	2
Chalmers University of Technology	4	Arizona State University	2
Mediterranean University Reggio Calabria	4	Columbia University	2

Table 2.6. Top 10 countries by publication record

Keyword Set 1	Records	%	Keyword Set 2	Records	%
Germany	25	18%	USA	15	11%
Italy	21	15%	China	14	10%
Brazil	13	9.3%	England	13	9.6%
USA	13	9.3%	Italy	11	8.1%
Spain	12	8.6%	Germany	10	7.4%
Sweden	10	7.2%	Spain	10	7.4%

Canada	9	6.5%	Romania	7	5.2%
France	8	5.7%	Brazil	6	4.4%
Netherlands	8	5.7%	Greece	5	3.7%
China	7	5.0%	Iran	5	3.7%

2.6. Proposed SCLA Tool and 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 developing free databases, and improve its effectiveness. The proposed tool herein follows the standard LCA structure by allowing the user to complete all LCA phases: Phase 1 (goal and scope definition), Phase 2 (life cycle inventory) by either inputting their own metric data or importing a predetermined database, Phase 3 (life cycle impact assessment) by running the data through a predetermined equation, and Phase 4 (results interpretation) 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. Table 2.1 outlines many United States 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. The U.S. Environmental Protection Agency developed a human wellbeing index that assesses the wellbeing of a given population (Summers et al., 2017). As part of this index, a formula was developed in order 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, which provides a quantitative value and a visual representation of that same data to complete Phase 4. The final step includes generating a PDF report that will present information from all phases in one document. Figure 2.3 presents the proposed tools functionality as it relates to the standard LCA method framework. The developed tool with a case study are provided in Supplementary Materials.

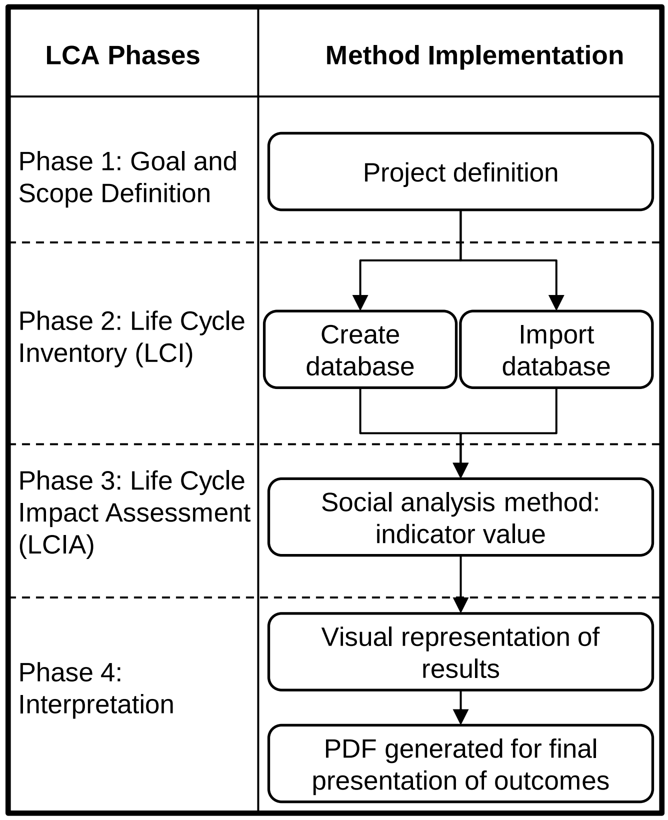

Figure 2.3. Structure of proposed SLCA tool embedded in LCA framework

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.

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

According to the U.N. 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 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), which will allow for a better 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 2.7 presents information on how the proposed tool developed as part of this study compares to the most common LCA tools currently available.

Table 2.7. Prior developed LCA tools

Tool	Open-Source	Databases Included	User-Friendly	LCA Structure	Mathematical Model	Report Generated	Objectives 1	2	3	Ref.
Brightway2	☑	×	×	☑	☑	☑	☑	☑	☑	(Mutel, 2019)
BEES 4.0	×	☑	☑	☑	☑	☑	☑	☑	×	(plavappa, 2009)
GaBi	×	☑	☑	☑	☑	☑	☑	☑	×	(Sphera, 2021)
Greet LCA	×	☑	☑	☑	☑	☑	×	☑	×	(Argonne National Laboratory, 2015)
LCAPIX	×	☑	☑	☑	☑	☑	×	☑	×	(KM Limited, 2007)
OpenLCA	☑	☑	☑	☑	☑	☑	☑	☑	☑	(GreenDelta, 2021)
SimaPro	×	☑	☑	☑	☑	☑	☑	☑	☑	(SimaPro, 2021)
SLCA Tool	×	×	×	×	☑	×	×	×	☑	(Zimdars et al., 2018)
TEAM	×	☑	☑	☑	☑	-	☑	☑	×	(PricewaterhouseCoopers, 2021)
Umberto	×	×	☑	☑	☑	☑	☑	☑	×	(ifu hamburg, 2021)
This Tool	☑	☑	☑	☑	☑	☑	☑	☑	☑	-

Up to the current 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. 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. Fuzzy logic analysis utilizes a standardized and weighted approach to provide reliable results, but this approach has not been applied to multiple alternate scenarios in order to prove its legitimacy.

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 (Dlouhá et al., 2013; Zhang and Haapala, 2015). Recent studies have continued to build upon the existing frameworks developed previously and investigate other impacts utilizing the modified frameworks (Gregori et al., 2017; Tsalis et al., 2017; Tseng, 2017). For example, Alsaffar et al. (2016) conducted research 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. More recent studies have expanded upon the singular framework designs and started developing tools, such as computer applications (Alessandra et al., 2018; Weidema, 2018). Siebert et al. (2018) developed a framework known as regional specific contextualized social life cycle assessment in which a set of social indices and indicators is established, and a product's social effects can be calculated (Siebert et al., 2018). 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: (i) downloading the option with access to the social hotspot database and exiobase, and (ii) downloading the option without access to those databases and inputting a users' own data into the program (Zimdars et al., 2018).

2.7. Conclusions and Future Directions

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. This review provides a comprehensive overview of existing quantitative and qualitative methods, databases, and tools related to SIA through narrative and systematic literature review techniques. The narrative review examines the current studies and identifies the potential pathways to bridge existing gaps and future perspectives across LCA analysis. 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. The systematic review shows that SIA research has been a rapidly growing field over the last ten years. From both narrative and systematic reviews, 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. At present, 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 industry or process.

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Chapter 3. Social Life Cycle Assessment of Computer-Aided Design Tools

This chapter was published in the 2020 proceedings of the ASME IDETC/CIE: 25th Design for Manufacturing and the Life Cycle Conference, under the title "*Social Life Cycle Assessment of Computer-Aided Design Tools*."

Justin R. Walters[1] and Amin Mirkouei[1,2]*

[1] Technology Management Program, University of Idaho, Idaho Falls, ID, 83402 USA

[2] Department of Nuclear Engineering and Industrial Management, University of Idaho, Idaho Falls, ID, 83402 USA

3.1. Abstract

Social life cycle assessment (SLCA) is a newly developed concept that is used to assess the potential positive and negative social impacts of products and services. However, the existing approaches have not focused on improving social aspects in the execution of computer-aided design (CAD) software. The Idaho National Laboratory's Materials and Fuels Complex is currently using Creo Parametric CAD software to design all experimental equipment. The purpose of this study is to conduct a socio-environmental life cycle assessment on the existing design procedures and present the findings and possible solutions to upper management. A comparison was performed to highlight the differences between the procedures. To determine the social effects, the Social Hotspots Database in OpenLCA was used in connection with a low, medium, high, and very high scale, which was used to quantify specific social categories. The social categories developed for this study include communication, rework time, time spent investigating non-normal methods of task completion, excessive working time, and social impacts of electricity usage. The environmental aspects were calculated by gathering data on carbon dioxide emissions per computer, utilizing the Creo software. The results produced through the calculations show that in all three areas of interest, the proposed approach decreased time and carbon dioxide emissions as well as an increase in employee satisfaction. Due to the virtually nonexistent SLCA studies in relation to the use of CAD software, it is anticipated that this study will provide a starting point for a more in-depth analysis of engineering departments.

Keywords: Social Aspects, Life Cycle Assessment, Computer-Aided Design, Sustainability.

NOMENCLATURE

Parameters

C	Emissions (lb CO2 per kWh)
Ei	Energy used for project i (kWh)
ES	Saved energy (kWh)
K	Energy used (kW per minute)
Li	Emission from project i (lb CO2)
LS	Saved emissions (lb CO2)
n	Number of projects
Pi	Project i duration (minutes)
T	Time (minutes)
TS	Saved time from project i (minutes)

Decision Variables

CIW	Canadian Index of Wellbeing total score
L	Percentage of CO2 emissions
P	Percentage of time saved
S	Percentage of employee satisfaction

3.2. Introduction

Motivation and Challenges. Employee morale is the primary social motivation behind this study because certain sections of the original drafting guidelines are creating friction among most of the drafting groups. Much of the employees' time was being taken to discuss those specific sections rather than completing work. Particularly, the current method of utilizing computer-aided design (i.e., Creo) software is not ensuring their time and resources are being used to the best of their ability. Thus, this study aims to assess the social and environmental aspects through the life cycle assessment (LCA) method, and consequently improve the current standards for completing models and drawings.

The challenges for conducting this research started with the limited database access for SLCA. This study utilized a simplified version of the Social Hotspots Database (SHDB). Due to the lack of social data available, a socio-environmental approach was taken instead of a purely social study. When all affected work groups gathered to discuss best practices and methods forward, it was difficult to get a consensus on what the best practices were for this particular engineering software and not letting the dominant personalities run the meetings.

Background. Web of Science and Google Scholar were utilized to search for similar studies conducted in SLCA with relation to CAD. Through the literature review, it was discovered that there are nearly no other studies that specifically conduct SLCA with respect to CAD. The earlier SLCA studies utilized CAD as a tool to design products more effectively to reduce social effects from a given process. A case study conducted by Luthe et al. (2013) utilized CAD capability to virtually simulate a new design concept for skis. They were able to eliminate high energy-intensive materials and reduce carbon emissions of materials used in comparable skis. The result was a more holistic sustainability approach than had been previously conducted. Weidema (2018) performed a study in the practicality of social foot-printing for socio-economic assessments. The author develops a method that overcomes the need for an excessive amount of data, which is currently required for SLCA. The results indicate that income inequality is the key driver between productivity and human well-being.

A study conducted by Laurenti et al. (2015) analyzed some challenges to sustainability assessment through the design of electronic products. The result was identifying specific areas in which design practice can prevent unintended consequences for addressing sustainability concerns. The study also recommends that CAD tools be refined to assist product designers in designing for end-of-waste of resources in the use phase (Laurenti et al., 2015). Tsalis et al. (2017) proposed an SLCA framework to aid management in assessing social impacts from a company daily activity. They also developed a case study to evaluate the effectiveness of their framework. Subramanian and Yung (2018) conducted an SLCA study on an integrated desktop computer, using quantitative indicators that were applied and normalized based on a three-level scale, and a weighting factor. The study concluded that there is a potentially negative social impact on workers, the local community and society, however, low effects were recorded for value chain actors and consumers.

In the engineering sector, manufacturing processes are highly dependent on the accurate design, documentation, and fabrication of products in a variety of industries. Currently, the Materials and Fuels Complex (MFC) at the Idaho National Laboratory (INL) has several documents that layout different processes for conducting business, specifically for the drafting department within the Engineering Organization. The company approved methods for utilizing the Creo CAD software have been captured in a standard practice document (Supplemental Requirements for the Creation and Use of 3-D Models). This document was written to attempt to improve the communication of requirements for using Creo. For example, ‘Standard 10011’ is the Drawing Requirements Manual that lays out the company requirements for creating, revising, and checking drawings. A section within Standard 10011 has been created for listing the requirements of Creo CAD software for the creation of three-dimensional (3D) models, as well as two-dimensional drawings. The standard is currently being reviewed and rewritten to remove outdated information, as well as to create a more holistic document.

The proposed method of communicating requirements for CAD software is compared to the original document in the categories previously mentioned. The SHDB is utilized within OpenLCA to quantify the scores from each category to analyze the chance of each happening. The amount of carbon dioxide (CO_2) emitted to the atmosphere from the computer usage is calculated by multiplying the kilowatt-hours (kWh) consumed by the computer in a day by the amount of CO_2 emitted from hydroelectric production, which is the largest producing source of electricity for the state of Idaho.

Table 3.1 presents the recent published studies that applied social assessment. Only a few studies have developed a multi-criteria decision making to evaluate either environmental or social aspects in design and manufacturing processes, using qualitative or quantitative approaches. A methodology developed by Souza et al. (2018) utilized SLCA framework as well as input-output analysis to evaluate different social effects of ethanol biorefinery systems in Brazil. In a study conducted by Traverso et al. (2018), the entire life cycle of a specific tire was considered. The similarities conducted between the two studies are taking into account a quantitative approach to SLCA. The main differences are utilizing information from 13 different companies and running calculations for ideal, as well as worst-case scenarios. Fontes et al. (2018) worked with a group of companies as well to develop a group of indicators along with positive and negative impacts, all of which fit into one of three categories: workers, consumers, and local communities. The main similarity between the two studies is looking at the worker category. Zimdars et al. (2018) developed a new SLCA approach by combining biophysical pressure and added value by utilizing Exiobase and SHDB, respectively. This is one of the few studies reviewed that combined social and environmental impacts. Song et al. (2018) conducted a study on greenhouse gas (GHG) emissions due to vehicle use in Macau. Although this study did not consider social impacts, it did aid in the understanding of the environmental impacts of GHGs. Singh et al. (2018) conducted a study on the social impacts of a steel manufacturer in India. This particular study utilizes a scoring scale of 0 to 1 for each of five categories, which is then totaled to compare categories. Pelletier (2018) conducted a study in which SLCA was utilized to rank social impacts of egg farms in Canada. Much similar to this study, worker hours were considered a higher risk category.

Table 3.1. A summary of recent SLCA studies, focusing on social and environmental aspects

Year	Type of data		Method		Assessment aspects		Case study	Ref.
	1	2	Data collection	Analysis	3	4		
2018	×	☑	Questionnaire	Statistical & criteria scoring	×	☑	Sugarcane ethanol production	(Souza et al., 2018)
2018	☑	☑	Questionnaire & statistical databases	Performance value	×	☑	Life cycle of a tire	(Traverso et al., 2018)
2018	×	☑	Survey & company data	Scoring criteria & turnover rate	×	☑	×	(Fontes et al., 2018)
2018	☑	☑	SHDB Exiobase	Total social score	☑	☑	×	(Zimdars et al., 2018)
2018	×	☑	Field Test	Calculate total emissions	☑	×	GHG emission four different types of fuel source passenger vehicles	(Song et al., 2018)
2018	☑	×	Survey	Scoring scale	×	☑	Steel manufacturer	(Singh and Gupta, 2018)
2018	☑	×	Survey	Average values presented	×	☑	Egg production	(Pelletier, 2018)
2019	×	☑	VSB simulation	Average values presented	☑	☑	Sugarcane production	(Cardoso et al., 2019)
2019	×	☑	PSILCA	Contribution analysis	×	☑	Raw material sourcing	(Di Noi et al., 2020)
2019	×	☑	Sustainability Global Index SEWATS	Fuzzy logic analysis	☑	☑	Wastewater treatment systems	(Padilla-Rivera and Güereca, 2019)
2019	☑	×	Questionnaire	Scoring criteria	×	☑	Municipal solid waste management	(Ibáñez-Forés et al., 2019)
This study	☑	☑	Statistical databases & field test	Statistical & criteria scoring	☑	☑	Design and manufacturing	

1: Qualitative; 2: Quantitative; 3: Environmental; 4: Social

Cardoso et al. (2019) evaluated and compared social impacts between manual and automated sugarcane production. Di Noi et al. (2019) conducted a study by assessing social and economic impacts for the sourcing of raw materials in the EU. Padilla-Rivera et al. (2019) utilized LCA, fuzzy logic analysis, and sustainability global index to compare four different wastewater treatment plant processes to identify the best method. Ibanez-Fores et al. (2019) conducted a study utilizing SLCA to find areas of improvement in the municipal solid waste industry for developing countries.

Objectives. This study utilizes a socio-environmental approach to creating a sustainable design process. The proposed approach can integrate social impacts with economic or environmental impacts since both of those categories impact society. The goal of this study is to provide enough information that employees can complete a drawing assignment, following the company standards. For example, employees utilize the correct parameters within a model to save time and effort by relating parameters to the drawing. The SLCA study conducted herein assesses the social impacts of the new guide compared to the relevant information from the previous standard and applies a cradle-to-grave system boundary of the design process. The functional unit selected in this study is time saved (minutes) per employee over a one-day period. The SLCA is performed using data and information from prior published studies, field study, and OpenLCA databases (e.g., SHDB).

3.3. Materials and Methodology

At INL, in order for a project to be initiated, the design engineer or project manager must submit a request to the drafting manager. Once the request has been received, it will be placed in the queue of new works that need to be assigned. Most work is assigned on a first-come, first-served basis unless there are Department of Energy milestones attached to the project schedule. The work is assigned to a drafter based on whoever is able to complete the work on schedule and ensure that the workload is spread around amongst drafters. It is expected once a drafter receives a new project that they will contact the customer (engineer) within two business days to let them know their project has been assigned and to go through the project to ensure the drafter knows what is expected of them. By keeping the lines of communication open between drafters and customers, this action mitigates the idea of high conflict scenarios that could arise.

3.3.1. Communications Process

Current Approach. Once starting a project in CAD software, there are several requirements and national standards to meet the project goals. Particularly, a specific section of the company drawing standard was developed to relay the correct information to employees who are working on these particular tasks. The current drawing standards include the default layers and font styles, along with what software products are included with our specific licenses. Some general requirements are also listed, such as saving every 15 minutes to avoid redoing the work due to technical issues or power surges. All other technical information and information on best practices was dispersed by mentor and mentee relationship practices or by word of mouth amongst coworkers.

Proposed Approach. The same standards need to be followed, but with the proposed process, they will be more clearly defined and more information will be available for employees. The drafting manager has required that the drafting group writes a guide that will explain all of the requirements and expectations for the use of Creo software. The guide will include a general requirements section that covers saving and uploading files to the data management software, Windchill, every 15-30 minutes, as well as making sure to check in all files on a regular basis, e.g., daily or weekly at the latest. Besides, ensuring all files are checked in prior to any extended absences from work. The default layers of Creo will be listed to ensure all employees are working on the same data. This data needs to be available to aid employees in being able to investigate issues and make decisions based on company standards. Making this data available also aids management to better make decisions on what aspects employees could use more training or what aspects of the document need to be revised to increase productivity. The tasks associated with the previously mentioned data are performed daily and can be time-consuming for employees if not performed as efficiently as possible. Time saved on every project equals more projects being kept in-house and worked through an efficient process. Additionally, transferring information from a model to a drawing is critical in finishing projects accurately and efficiently. This task is completed by inputting all pertinent information (i.e., part name, material, description, and number) into preset parameters.

The parameters allow for inputting the previously mentioned information in one location. Predefined parameters are located in what are called start models or templates for all modeling scenarios. These scenarios include purchased items, parts, and assemblies that all parameters needed for the drawings are included. Fonts would be the next section and essentially requires only Creo fonts are used, and no third party fonts are to be used. Model environment requirements are to be the next section where the following information is stated: (a) all models will utilize the start models, (b) models shall be created in such a way that driver dimensions can be used in the drawing and not added driven dimensions, (c) relations shall be adequately explained with comments, and (d) 3D notes shall be added to models to identify uncommon features and placed on a unique layer that can be hidden prior to printing.

Depending upon complexity, there are two approved methods for creating weldments in CAD. The first method is by modeling each part in a separate file and creating an assembly model to bring all of the individual components together. The second method is to model all of the components in one part file so that it appears as the finished product without isolating individual components. The assembly method is the preferred method within this particular organization. When library parts are used, it is preferred to save a copy of that part and name it according to the agreed-upon naming convention. Drawings will be created from the appropriate template, local and leader notes will be attached to the views they are found, a trimetric or isometric view at a reduced scale is to be shown on the drawing, and all parts will have materials assigned to them. Upon revising a drawing, every part removed from an assembly needs a null part file that will be placed into the assembly and act as a placeholder for the removed part. The completion of this task allows future employees to work on a particular file to know the design of the assembly has changed in relation to its original intent. File naming conventions are an essential aspect of this standard practice and will be formatted as follows:

the original number shall be placed in the file name parameter for legacy drawings, the number parameter will be the new six-digit number, and the name parameter may be either the six-digit number, a description of the part, or the alternate identifier. For new parts and assemblies, the six-digit number will be inserted into the file name, number parameter, and the name parameter will be a descriptive identifier of the part or assembly. Drawings shall have identical file names as the parent file they were created from. Standard drawing symbols and drawing notes will be located in Windchill under the INL Drawing Tool Library folder.

Once a project has been completed, and the files are ready for release into Windchill, step files are to be made of all fabricated items for using by the machine shop. Life cycle states are also to be used to ensure model integrity. The life cycles include design, detailing, in check, released, and obsolete. Design plan is to be used when sharing model files back and forth between drafting and engineering. Detailing is to be used when the design is complete, and drawings are being created. In check is the state the file will be in a while awaiting approval for release. Released is to be used when a drawing has gone through the approval process. Obsolete is to be used when a part has been removed from an assembly, or a drawing has been canceled. Figure 3.1 shows the design process from initial tasks to the releasing of files into an electronic document management system. Equations (2-4) analyze the amount of time that can be saved per project by comparing the current approach with the proposed approach. The result either verifies or disproves that the proposed requirements show an improvement in relation to the current requirements.

$$P_1 = n \times T_1 \quad (2)$$

$$P_2 = n \times T_2 \quad (3)$$

$$TS = P_1 - P_2$$

4)

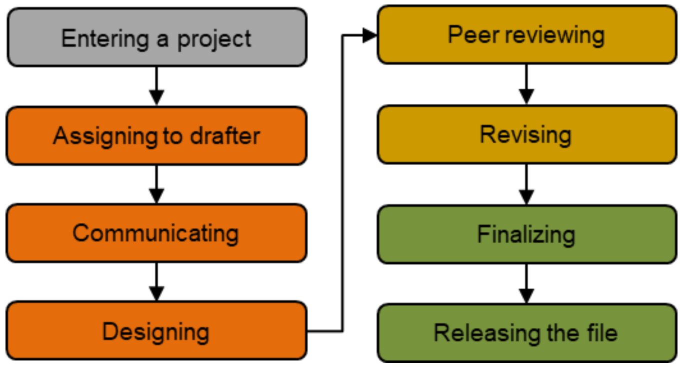

Figure 3.1. Design Process Flow Diagram

3.3.2. Energy Usage

In the drafting department, computers and software are the two main requirements to be able to complete designing and drafting tasks. The computers that are purchased for this department are more advanced than that of an employee who only needs to conduct regular office work tasks. Not all computers in this department are precisely the same, so for this study, some average assumptions will be used. There are currently 12 employees in the drafting department at MFC whom all have similar computers. Running under the assumption that each computer consumes approximately 150 watts of electricity, this calculates to 1.5 kWh per day based on a 10-hour day. If the price of electricity per kWh is 13 cents, the minimum daily cost to run each computer is 19.5 cents. Equations (5-8) calculate the energy usage and amount of CO2 emitted for the current approach and the proposed approach. Equations (9) and (10) calculate the amount of energy saved and CO2 emission reduced between the current and proposed approaches.

$$E_1 = P_1 \times K \tag{5}$$

$$L_1 = E_1 \times C \tag{6}$$

$$E_2 = P_2 \times K \tag{7}$$

$$L_2 = E_2 \times C \tag{8}$$

$$ES = (E_1 - E_2) \tag{9}$$

$$LS = (L_1 - L_2) \tag{10}$$

Based on the Idaho Power, various approaches are applied for electricity production in the state of Idaho (Figure 3.2). According to the Union of Concerned Scientists, the amount of CO2 emitted from hydroelectric power plants is approximately 0.02 pounds per kWh (“Environmental Impacts of Hydroelectric Power | Union of Concerned Scientists,” n.d.). As presented in Figure 3.2 hydroelectric power makes up nearly half of the total electrical production for the state, therefore, in this study, CO2 output will be measured against hydroelectric production only. Taking 1.5 kWh per computer per day and CO2 output of 0.02 pounds per kWh calculates to a minimum of 0.03 pounds of CO2 output per computer per day for the department (Table 3.2).

Table 3.2. Department CO_2 emission production

Computer users	Energy use (kWh/day)	CO_2 (lb./kWh)	Total CO_2 (lb./day)
1	1.5	0.02	0.03
12	1.5	0.02	0.36

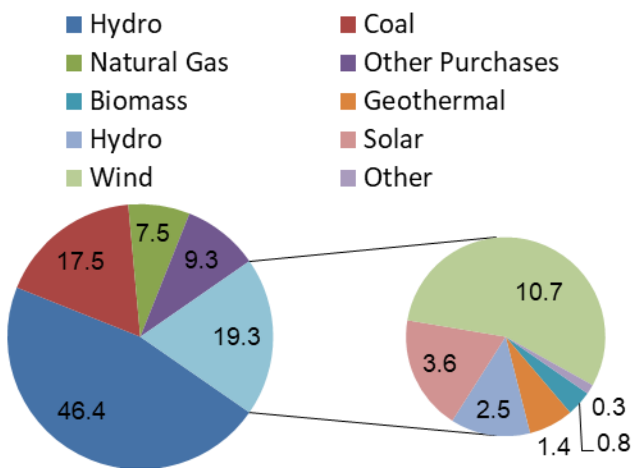

Figure 3.2. Information about energy sources in Idaho, collected from Idaho Power website

3.4. Socio-Environmental Impacts

In the environmental assessment, the primary scale used to quantify environmental impact results is through ratio scales. The dominant scale for SLCA has been classified as ordinal scales. Ordinal scales are seen in many research fields as a measure of scoring when there are potential underlying variables that cannot be accounted for. One such example is in a psychology study on happiness, which could have an underlying variable such as a person's true happiness that could not be measured with any certainty. According to a study conducted by Arvidsson (2019), ordinal scales in SLCA (i.e., low, medium, high, and very high) can be used to score social topics in each life cycle phase based on qualitative data from a company's behavior. The results of the scores can then be multiplied to weight categories differently and then summed up to be incorporated into a social hotspot index. For this study, the low, medium, high, very high classification has been used to quantify results in a clear and concise manner.

To quantitatively measure the socio-environmental impact between these two specific approaches, the Canadian Index of Wellbeing (CIW) was applied. This index combines eight domains, which are community vitality, democratic engagement, education, environment, healthy population, leisure and culture, living standards, and time use to quantitatively report how well the country is performing in these particular sectors. In this study, healthy population, environment, and time use have been considered from the list of domains. For the index, it is common to have an ordinal scale of 0 to 5 to rank aspects, such as employee satisfaction (Figure 3.3). This method also takes a resulting percentage of each subcategory in each domain to be able to measure the CIW score.

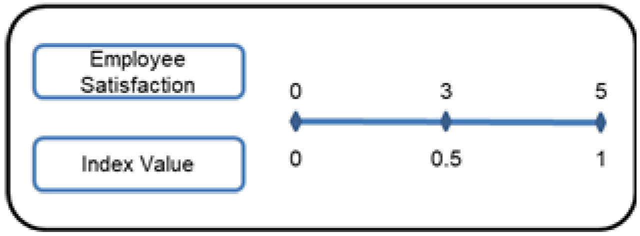

Figure 3.3. Ordinal scale for ranking employee satisfaction aspect

Equations (11-14) calculate the percentage of time and CO2 emitted, as well as healthy population to assess both environmental and social aspects of the aforementioned design approaches.

$$P = (P_1 - P_2)/P_1 \tag{11}$$

$$L = (L_1 - L_2)/L_1 \tag{12}$$

$$S = (S_1 - S_2)/S_1$$

13)

$$CIW = (P + L + S)/3$$

14)

Using the demo version of SHDB database was very limited, and most of the existing flows were not of any use to this particular study. The available data in the demo database was as follows: community infrastructure, governance, health and safety, human rights, and labor rights and decent work. Under each of these main categories were several subcategories. For example, community infrastructure has three subcategories: access to hospital beds, improved drinking water, and improved sanitation. Governance has two subcategories: corruption and the legal system. Health and safety have two subcategories: occupational injuries and deaths and occupational toxics and hazards. Human rights have three subcategories: gender equity, high conflict zones, and indigenous rights. Labor rights and decent work have seven subcategories, which are child labor, forced labor, freedom of association, migrant workers, poverty, wage assessment, and working time. Arvidsson et al. (2018) conducted a case study in which human health impacts were assessed for three different industries. The disability-adjusted life years were used as the indicator for all three cases. This study finds that it is important to report both positive and negative health impacts for different categories in order to know how best to help the population affected.

3.5. Results and Discussion

After completion of calculations (Eqs. 2-4), the proposed approach was shown to have a decrease in time per project (Figure 3.4). The energy usage per day and amount of CO2 emitted per day had no change due to the work schedule remaining the same for both approaches. However, the results from Eqs. (5-10) show that because less time was spent per project, the amount of CO2 emitted per project was decreased slightly (Figure 3.4). The result of the healthy population was measured by ordinal scale with respect to employee satisfaction. The main purpose of this study was to measure employee job satisfaction, which increases or decreases work productivity depending upon the results. The final equations showed that employees had an increase in job satisfaction under the proposed method. By decreasing the amount of time spent per project, employees can be more productive and be challenged with their work tasks. There is also a correlation between CO2 emissions and physical health, even though the numbers per day are the same the fact that more work is being produced in that one-day results in a better percentage of emission per project.

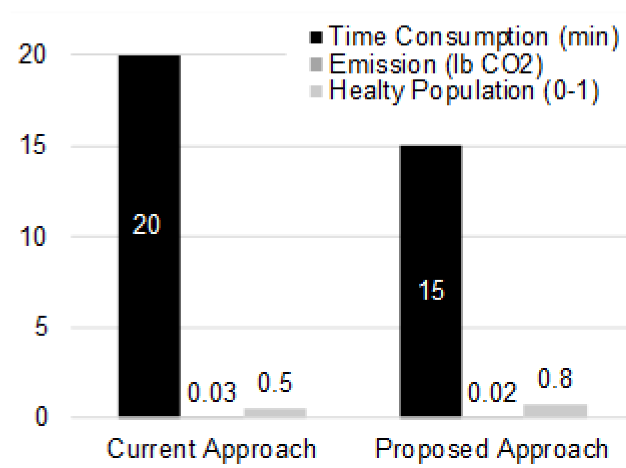

Figure 3.4. Results of time consumption, CO_2 emission, and healthy population for each approach

Figure 3.5 presents the percentages of change between the current and proposed approaches. The categories created by this particular comparison are as follows: communication, rework time, time spent investigating non-normal methods of task completion, excessive working time, and social impacts created by electricity usage. In both approaches, letting a customer know within two business days of receiving a project opens the lines of communication between the drafter and the customer. This enables the customer to ensure that the drafter is aware of any specific design requirements that may not be evident from the supplied information. It also enables the customer to ensure that the drafter knows exactly what deliverables are needed and what schedule those deliverables need to adhere to. The drafter then has had the chance to review the supplied information, if any has been supplied, and is then given the opportunity to ask any questions or ask for further information that may be needed to complete the design for the customer.

The utilization of life cycle states within Windchill is relatively new to the department and is broadened in the proposed method. These states have been utilized minimally since the adoption of Windchill with only the use of design and release states. By broadening the life cycle states used within Windchill, the users have more control over iterations of files. It is understood between customer and drafter that if a file is in the design state, either person is able to modify and check in their changes to collaborate with each other. This utilizes the primary purpose of Windchill as a data management tool, which is for multiple people in different locations to be able to collaborate, make modifications to files as necessary, and share those modifications quickly with the design team or stakeholders. When a file is promoted to the detailing state, this locks the file down to a specific group, which in this case, is the drafting group. This state signifies to anyone outside of drafting that drawings are being created from the existing 3D models and that any modifications from that point on will be altering the drawings, as well as the models. By utilizing this function, the customer or stakeholder who wants to make changes must communicate with the drafter and discuss what changes

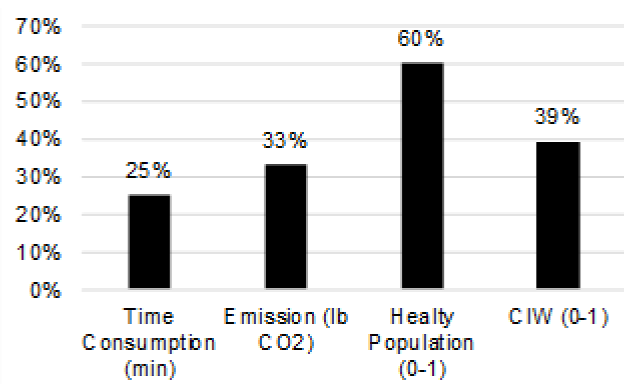

Figure 3.5. Percentage of change between the current and proposed approaches

need to be made. The previous method of keeping files locked was for the drafter to check in their files regularly, but to keep them checked out. This method allowed customers to be able to look at the files, but kept them from modifying them just like the detailing state does. The only caveat to this method is that nobody except for that drafter could make any modifications or even check in the files. This has proven to be an issue of great concern in recent years when an employee would be absent unexpectedly, and nobody else had access to the files or knew if the files that could be seen were up to date. With the proposed approach herein, all of the drafting group would have access to the files in the event of an emergency, and project schedules can continue to be met. If the changes are minor, the drafter should be able to incorporate them into the model in such a way that the drawing would remain accurate and precise. If the change were more of a major redesign, then the drafter could demote the files back into the design state where the customer and drafter could collaborate as necessary. Either way, communication is forced between customer and drafter to ensure the project needs are being met in an efficient manner.

The original Creo section in the drawing requirements manual does not layout any specifics to minimize the amount of time spent reworking tasks for any reason except for saving files regularly. The proposed guide is aiming to standardize methods of completing some common tasks in order to keep the amount of time to rework data to a minimum. Having to complete tasks, again and again, could develop for many reasons ranging from power outages to revising a coworkers' project. By standardizing aspects of the business, such as naming conventions, bill of materials, the use of library parts in an assembly, parameters, and drawing templates, all employees are on equal footing no matter their experience level.

Revising files can be positively affected by standardization as well. The simple task of locating files within Windchill could take several times longer if random names were attributed to the files instead of the six-digit drawing number. The use of library parts saves time when initially installing, as well as revising to a different size or length and is far easier to replace than deleting and installing new parts. Standard parameters and drawing templates complement each other and work together to adhere to national standards for drawing formats and also company standards that require specific types of information to be included on the face of a drawing. Another aspect that can lead to rework is if a coworker develops their own approach of completing a certain task and is not forthcoming with that information or is no longer with the company to inform others of what had been done. One example of this happening is writing relations to get a string of text to pull information from a model and relay that onto the face of the drawing. Relationships are written using a computer code language and can be challenging to interpret without the proper training. If this were to happen, there would be two options to revise the relation, either the drafter would delete the text and type in the necessary information or the drafter would be forced to research using the internet or coworkers to try and learn how to correctly modify the relation so that it would appear as needed. The best method to keep this from happening is to standardize any shortcuts and add them to the document to ensure all employees have access to the information when necessary.

Taking surveys and having discussions with the MFC Drafting Group proved to be challenging to reveal the most popular best practices. In a team environment, the more dominant personalities seem to be heard over the more subdued personalities of other employees. To keep the discussions and topics on track, much effort was given to make sure that all employees' suggestions were heard and addressed. The naming convention for legacy drawings was one such discussion where the act had to be walked through to ensure the correct information ends up in the correct location. In this case, one of the stronger personalities did not understand how the Windchill software was categorizing the data and had the information in contradicting locations. Once the steps had been walked through, the employee was able to see how these actions made more sense than their initial suggestion. After conducting tests with the step files and conducting meetings with the machine shop as to the best method for machining purposes. Once the question was proposed and some investigating had been done, it was discovered that there is a translator that can take the native Creo geometry and import that information directly into MasterCAM (a famous Computer-Aided Manufacturing software). According to the data received, the company could solve this issue by purchasing the translator and stop drafting from creating the step files. This action reduces cost and time per project, as well as creates a better work environment for employees due to the fact they are no longer required to complete non-value added tasks in their daily routines.

None of the previously mentioned SLCA categories apply to the tasks being analyzed in this study. The only exception that could be argued as applicable was the risk of excessive working time. Through research, it did appear that with access to the full database, there would be some useful indicators that information could be drawn from for a complete assessment. The company is extremely diligent in informing all hourly employees to track all the time spent on work activities. There is always a risk, however, that some employees would feel pressured by customers or even managers to work more to meet the needs of the project without being compensated for that time.

With project managers, customers, line managers, and the employees themselves in place, it would appear that there are enough checks and balances to keep this event from occurring. Line management in this particular organization has made it clear and makes a point to know what their employees' work schedules are to be able to account for their reported time. The company does not take part in any activity that would jeopardize their ability to continue to operate one of the nation's national laboratories.

During the research phase of this study, there were many articles that had the same opinion that more research and data needs to be available to conduct more comprehensive sustainability assessments. The most often quoted method for sustainability assessments is the triple bottom line approach, which includes environmental, social, and economic aspects (Hersh and Mirkouei, 2019; Mirkouei, 2016; Mirkouei et al., 2017, 2016; Mirkouei and Kardel, 2017). This approach has been strongly criticized because it balances and makes trade-offs, which in some cases may be necessary, but which should be done as a last resort and not a common practice. Sustainability as a whole is considered an integrative concept at the theoretical level, but in practice, evaluations mainly consist of merging or comparing final results from separate assessments based on different logics. The use of the typical elements of the LCA methodologies, such as functional unit, system boundaries, and the consideration of all life cycle phases is very elusive in SLCA literature, and the choice of indicators and data is not always scientifically justified. SLCA has not been developed to the extent as its counterparts, environmental LCA, and has plenty of room for further development in data and methods.

Iofrida et al. (2018) investigated the reason why SLCA is lacking in development compared to environmental and economic LCA. This paper shows that from the beginning of SLCA in the 1990s that it has been a struggle to fully develop and that there still is not a standardized assessment procedure, as is found in the other two LCA methods. Subramanian et al. (2018) conducted a review of 90 published works in relation to SLCA. This review investigated the methodology framework, boundary scoping, data inventories, and practices. The review concluded that many of the studies' interpretation of sustainability differed from the actual definition of sustainability. D'Eusanio et al. (2018) conducted a study utilizing SLCA for the production of a jar of honey. The assessment was performed using the subcategory assessment method. Positive social aspects were highlighted, but the study also concluded that further developments were required in order to improve the assessment, as well as to reinforce the awareness of social sustainability.

As previously stated, one of the main components for performing a design project is to have a computer with the appropriate software installed. To be able to utilize this equipment, electricity needs to be generated and transferred to the appropriate location. In the state of Idaho, nearly half of all electricity produced is produced by hydroelectric power plants. Because one type of power plant is so prevalent in the creation of electricity, this was the only type taken into consideration when calculating CO2 emissions. The calculations show that a minimum amount of approximately 0.03

pounds of CO_2 would be emitted from the generation of enough electricity to power one computer for one day under the current method of communicating requirements. Under the proposed approach, this number would stay the same because there are a set number of minimum hours that employees are expected to work each week. The change that would be expected is the number of projects completed during those work hours would be expected to increase. Therefore, the CO_2 emitted from electricity production per project would be expected to decrease.

The intention of the proposed guide is to be a fluid document that updates as software versions update or new methods are developed for completing tasks in that software. The results of implementing the new guide will not be apparent until the guide has been in place and is being utilized by employees who are expected to find any faults that lie within so they can be corrected, which will make the document valuable. One of the main projected results of this implementation is to lower the risk that any employee feels they are wasting their time with the work they are completing. It can feel frustrating and even depressing if an employee cannot make what they deem a simple modification to a drawing because it was completed in a non-familiar way previously. If an employee is continually frustrated with their work, there is the potential that they will quit and move on to a different job, which can be detrimental to the department to lose talented employees.

By taking surveys and hearing all users' inputs to what information is essential and also what methods are best practices for the software. If the proposed document addresses the previously mentioned concerns, then the risks are lower than the new guide will not outperform the previous document. Keeping the employees who are subject matter experts in their given fields involved in process development can only lower the risk that companies have processes that do not work or have tasks that add no value and just waste time and resources. Cutting costs and time off of projects are reasonable goals and results that companies like to see, but it is just as important to take care of the employees that are creating that bottom dollar for the company and make sure they have a voice in the process they work in daily, as well as making sure that they know the tasks they are completing have value to the company.

Upon review of this document, it was decided that because MFC is the only location at INL that utilizes Creo, the information pertaining strictly to Creo should be removed from the standard, and a guide should be written to aid employees in completing assigned tasks in a company approved fashion.

3.6. Conclusion

SLCA studies will continue to grow in popularity as companies' worldwide advance to an enhanced holistic sustainability outlook. This is especially exciting due to the limited amount of studies that have been conducted in SLCA up to this point. This study focuses on the socio-environmental impact assessment of communicating best CAD practices and methods to employees. In order to accomplish this specific assessment, the following categories were developed: communication, rework time, time spent investigating non-normal methods of task completion, excessive working time, and social impacts of energy usage from computers, utilizing CAD software. The previously mentioned categories were ranked using a low, medium, high, and very high scale. This information was input into the free version of SHDB in OpenLCA, which calculated the risk of that particular category occurring. The study showed enhanced positive effects in all categories when looking at the proposed process in comparison to the current process. Social impacts of energy usage were calculated in the form of CO2 emissions per computer used in the department. According to the calculations of this study concluded that the proposed design process improves on all of the social categories indicated. The non-value added tasks removed from the design procedure increased the productivity and employee satisfaction, however, this action did not have any effect on the amount of CO2 emitted per computer per day. This study shows that CO2 emissions decreased per project, which can also contribute to a physically healthier population. The potential paths for future work include (a) improving SHDB by adding more data and information from different projects, (b) conducting similar studies for other engineering departments, and (c) developing a more holistic SLCA decision-making framework in relation to CAD software utilization.

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Chapter 4. Proposed SLCA Tool User Manual

4.1. Abstract

There is no free, open-source tool that is capable of performing social life cycle assessment of a process or product. In the future, this web-based tool will not only provide a social life cycle assessment, but also be able to calculate environmental as well as economic life cycle assessment.

4.2. Introduction

This tool utilizes the standard LCA structure defined in ISO 14040. The structure is partnered with a unique mathematical model that is used to calculate an indicator score as well as domain score to provide easy to understand results of largest improvement areas. Access to databases will be a base functionality of this tool so as to aid decision makers in locating necessary information quickly. This tool is an open-source software for Life Cycle Assessment (LCA) and sustainability assessment. It has been developed by University of Idaho's Innovative Design and Manufacturing Laboratory (IDEAL) Research Group (https://webpages.uidaho.edu/ideal/lca.html). As an open-source software, it is freely available, without license costs. The source code can be viewed and changed by anyone. Furthermore, the open-source nature of the software makes it very suitable for use with sensitive data. The software as well as any models created can be shared freely.

This chapter focuses on the original version of the tool. It explains how to carry out the first steps in working with the tool such as importing databases and creating a mathematical model. This document then provides an overview of operations and features including descriptions of how to use them. The website provides links to databases, the source code, a case study, among other things. A link to this document, case studies, and databases is illustrated in Figure 4.1 as the first bullet point under Getting started.

To get started the user is asked to provide the name of their project, their name, and their email address. This information will be input in the final report that is generated in phase 4 of the tool. See Figure 4.1 for an example of what the user can expect to find when using the tool.

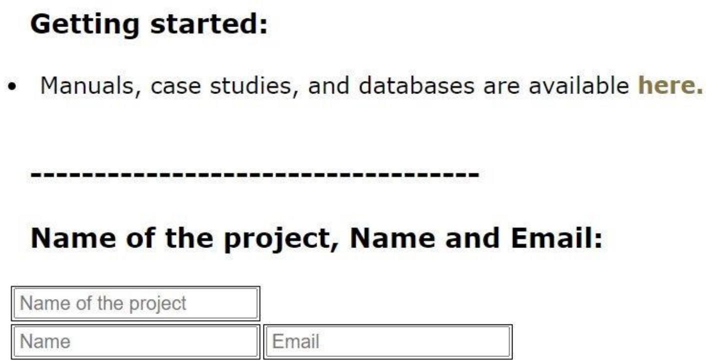


Figure 4.1. Getting started

4.3. SLCA Tool

4.3.1. Phase 1

Define the goal and scope of the LCA. Within this definition the purpose of the LCA should be defined as well as the goal of the study. 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. Figure 4.2 shows a text box, which can be altered in size to fit the user's need, as well as unlimited character number to ensure that the full goal and scope information can be accurately captured for the project. Underneath the text box is an example of what a common goal and scope definition statement might look like and also includes the key components in bold text to allow the user easy identification for areas of most usefulness to their application needs.

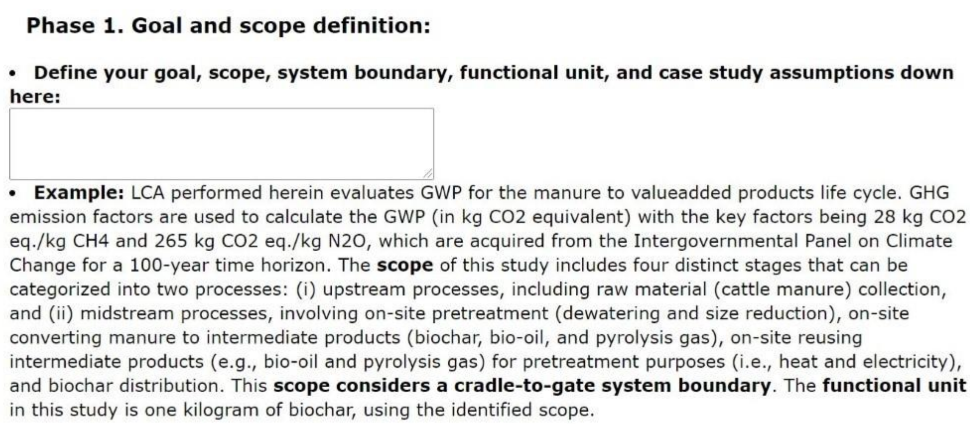


Figure 4.2. Phase 1 Definition Statement

4.3.2. Phase 2

Add data for inputs either utilizing the provided databases or creating a custom database with values determined by the proper organization/department. This tool allows users to create a database utilizing preprogrammed indicators or importing their own database as a CSV File. This option allows users the flexibility of either applying the developing team's expertise or to customize what information is most useful for their research. Figure 4.3 shows what a user can expect to find upon entry to the website prior to any options being chosen.

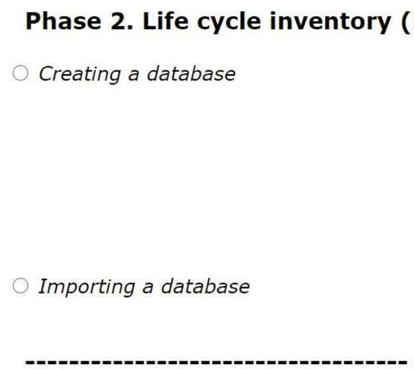


Figure 4.3. Phase 2 (LCI)

If the user prefers to move forward with the predefined database option a click of creating a database is all that is needed. Figure 4.4 shows what the user can expect once this option has been chosen. The data that has been selected for each indicator is as follows: Metric Name, Location where research is taking place, Score given to the metric, and Total Score possible for that metric. When inputting information into the specific fields it is important to note that adding a new process will not eliminate the data that has been input 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 processes with proposed processes. Figure 4.5 shows an example of what the user can expect to see when multiple processes have been input into the tool. This tool also allows the feature of adding a new record which will allow the user to input multiple metrics for each indicator as shown in Figure 4.6. Once the information has been input into the table all of it can be exported as a CSV File, shown in Figure 4.5, which allows the user to manipulate data and then import back into the tool or the ability to keep records of what information has been utilized at any point in the project.

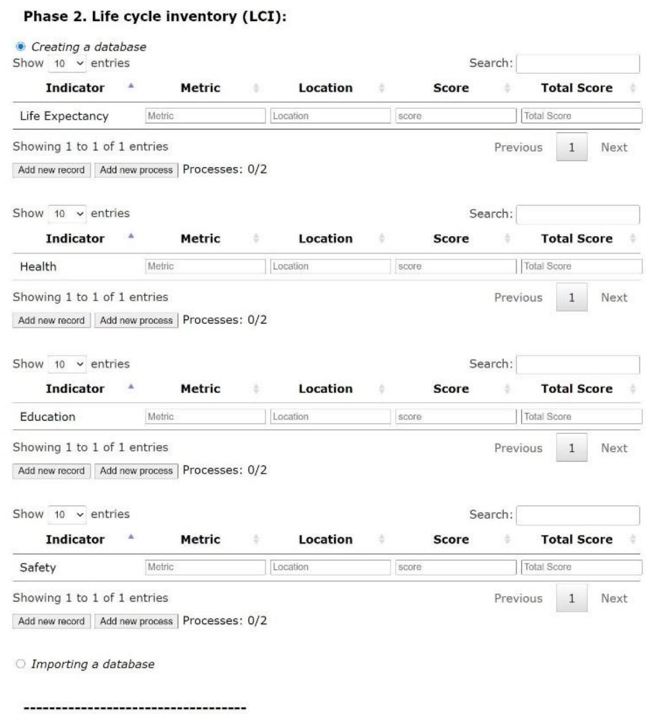


Figure 4.4. Phase 2 Create Database

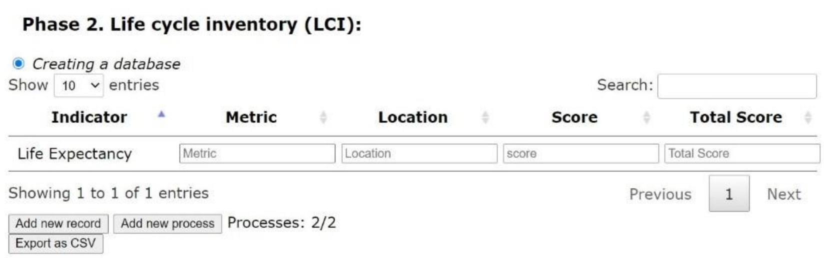


Figure 4.5. Phase 2 Multiple Processes

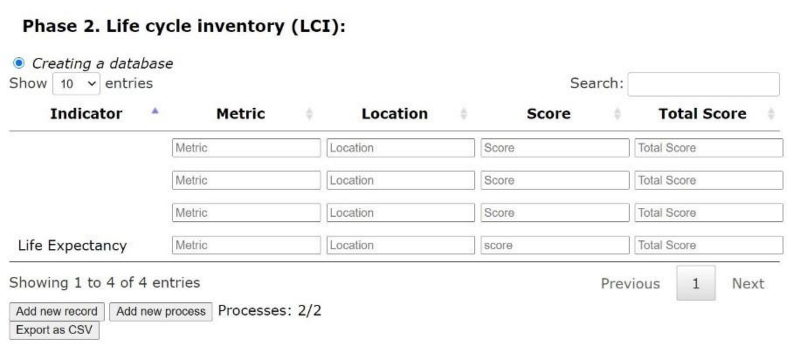


Figure 4.6. Phase 2 Multiple Metrics

As stated previously, this tool offers the option for users to import their own database as well in the form of a CSV File. Figure 4.7 shows the layout once this option has been selected. Just as in the previous database option, the functionality is available to add a CSV file for up to two processes.

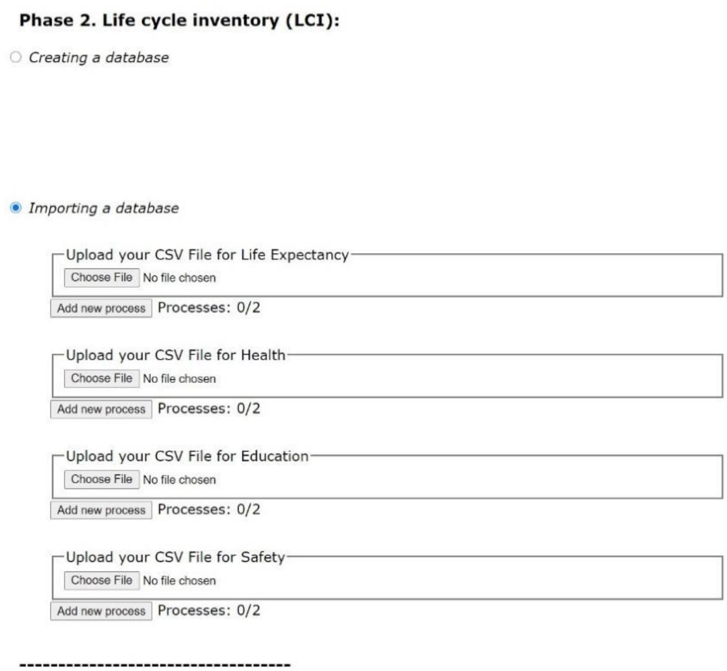


Figure 4.7. Phase 2 Import Database

4.3.3. Phase 3

Determine if the predetermined mathematical model will provide the desired results or if a custom mathematical model is required to provide the required result. The custom mathematical model is a feature that will be coming in the future. The current mathematical model shown in Figure 4.8 utilizes a weighted approach to normalizing the calculation. 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.

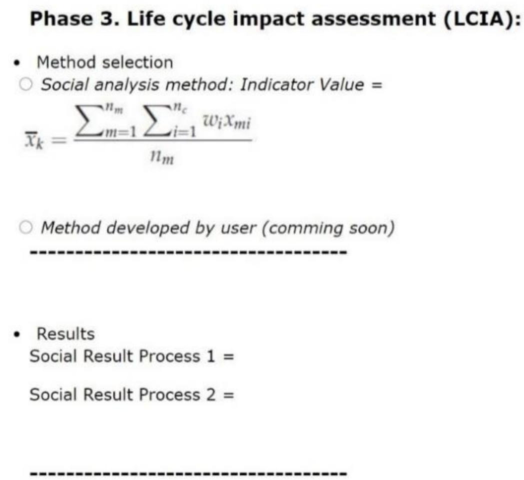


Figure 4.8. Phase 3 (LCIA)

4.3.4. Phase 4

The results calculated in Phase 3 will be numerically and graphically represented in order to compare processes or products as shown in Figure 4.9. A report can also be generated at this point so as to combine all phases of the LCA into one PDF document to allow for dispersion of study documentation easily and quickly. 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, which may provide useful if numerical values span a large 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 gather the following information: 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).

Figure 4.9. Phase 4 (Interpretation)

4.4. Case Study and Results

This section includes a case study for demonstrating the application of the developed SLCA tool. Figure 4.10 shows an example of what would be appropriate to input into the table cells in order to get started. The information listed in these cells is important as it will be provided in the final report generated at the end of the study.

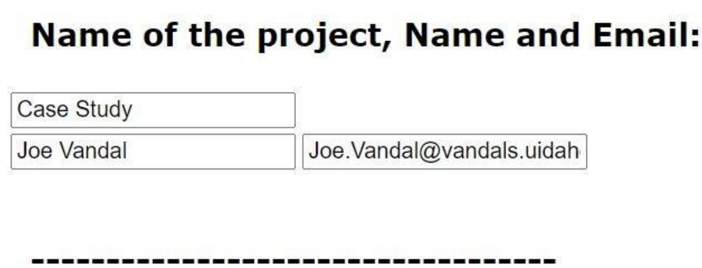


Figure 4.10. Case Study Getting Started

4.4.1. Phase 1

Figure 4.11 shows an example of what would be appropriate to list for goal and scope definition. It is important to ensure all of the components listed in the bullet point have been addressed in this statement for a clear representation of the study. This information will also be provided in the final report.

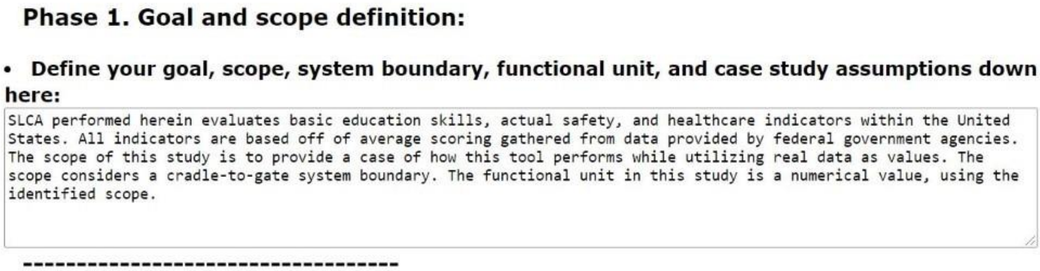


Figure 4.11. Case Study Phase 1

4.4.2. Phase 2

Figure 4.12 shows an example of metrics, locations, scores, and total scores retrieved from actual federal government agency databases for the following indicators: Health, Education, and Safety. In order to input multiple metrics, the Add new record button needs to be selected. Once this information was input into the table add new process was selected to save that data into memory for use in the calculation phase.

Figure 4.12. Case Study Phase 2 (LCI) Process 1

Figure 4.13 shows an example of how to input a second process. Simply alter the scores as required by the data being utilized and select add new process, once this option is selected the processes 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 will export the data that has been input into a CSV file that can be opened and manipulated as necessary by the study.

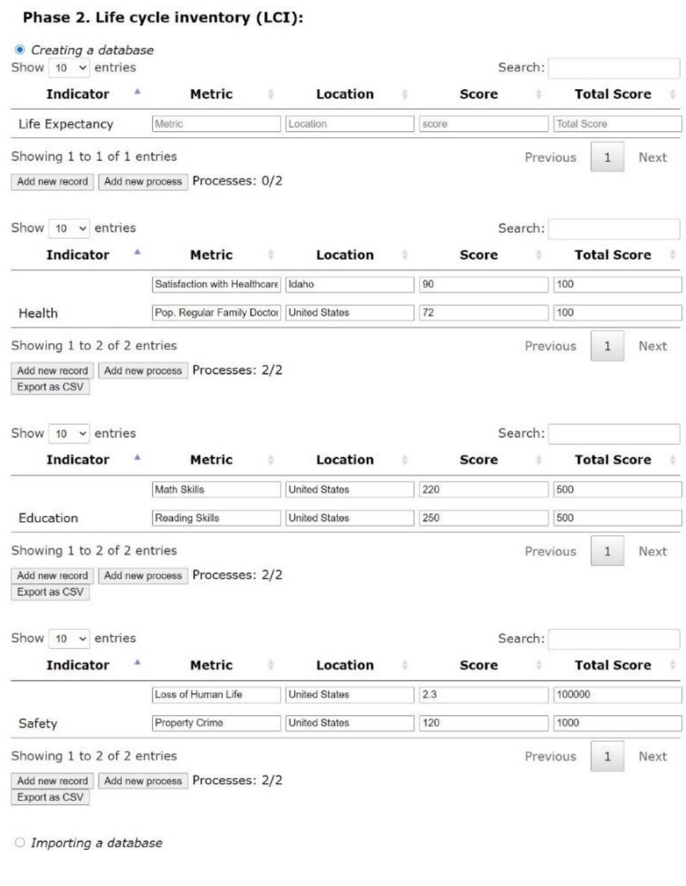


Figure 4.13. Case Study Phase 2 (LCI) Process 2

4.4.3. Phase 3

Figure 4.14 shows an example of what to expect after selecting the pre-programmed calculation. The indicator scores appear below and are separated by Process 1 and Process 2 designations for clarity.

Phase 3. Life cycle impact assessment (LCIA):

- Method selection

◉ *Social analysis method: Indicator Value =*

$$\overline{x}_k = \frac{\sum_{m=1}^{n_m} \sum_{i=1}^{n_c} w_i x_{mi}}{n_m}$$

○ *Method developed by user (comming soon)*

- Results

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

Social Result of Process 2:
LifeExpectancy: *0*
Education: *110.9*
Health: *66.42*
Safety: *7.2*

Figure 4.14. Case Study Phase 3 (LCIA)

4.4.4. Phase 4

Figure 4.15 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 the name in the legend as shown in Figure 4.16. In order to provide this information to a team the generate button was created that will print all of the information, except the values in phase 2, into a PDF document that can be saved and shared throughout a project team as shown in Figure 4.17.

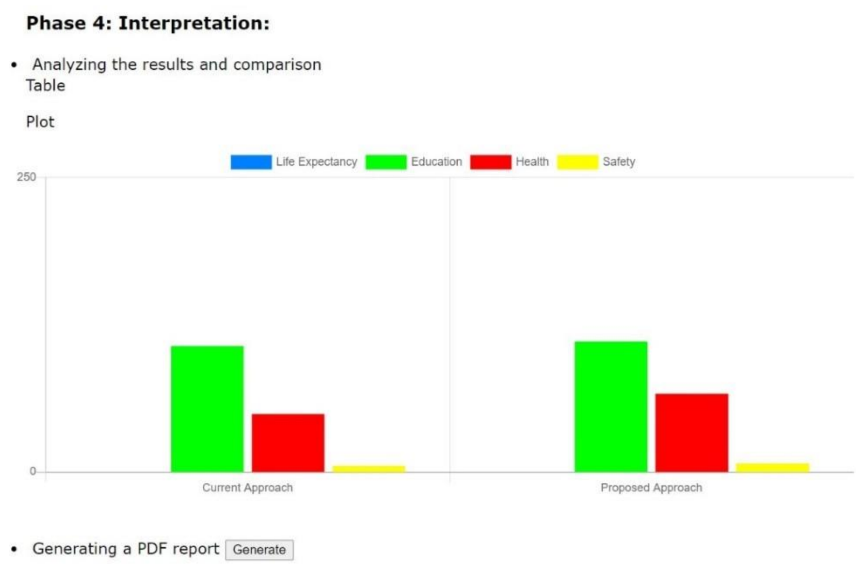


Figure 4.15. Case Study Phase 4

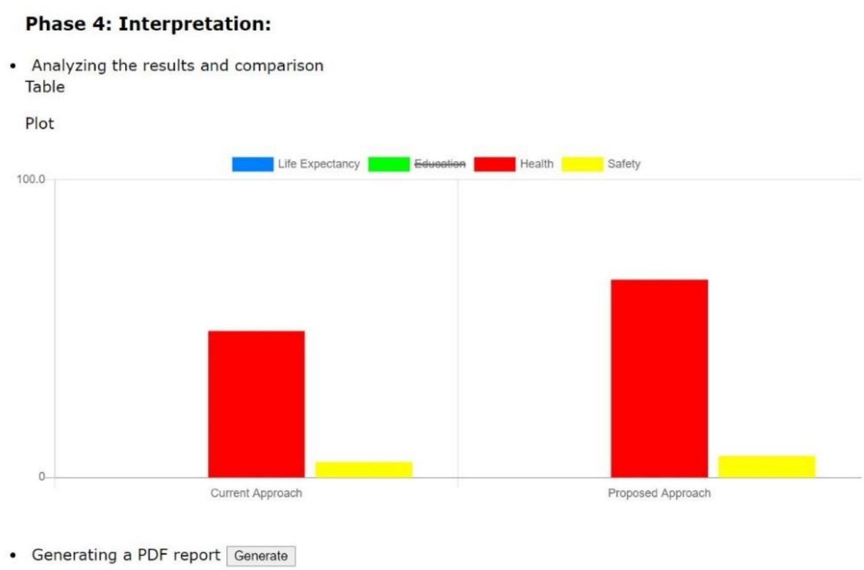


Figure 4.16. Case Study Phase 4 Alternate

Name of the project, Name and Email:

Case Study

Joe Vandal

Joe.Vandal@vandals.uidaho.edu

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):

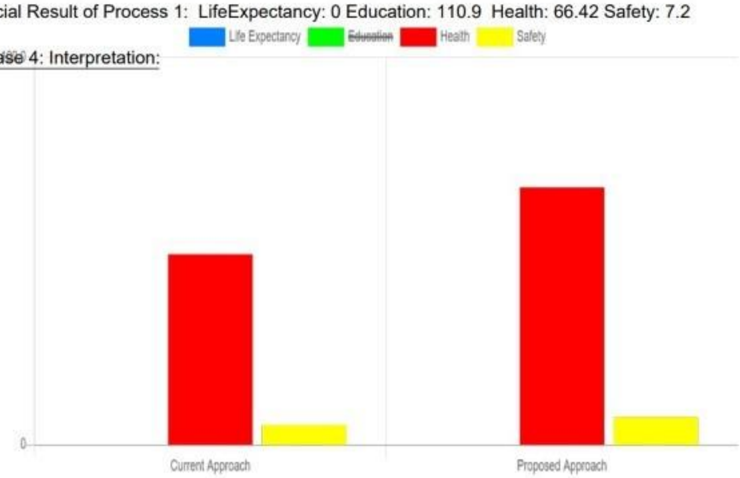
$$\overline{x}_k = \frac{\sum_{m=1}^{n_m}\sum_{i=1}^{n_c} w_i x_{mi}}{n_m}$$

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:



Created using the IDeaL LCA Tool: https://webpages.uidaho.edu/ideal/lca.html

Figure 4.17. Case Study Final Report

4.5. Conclusion and Future Work

Once the tool is completely developed, it will provide a holistic LCA tool that will be able to provide LCC, ELCA, and SLCA results on a given process or product. It will also give users the ability to input their own databases and mathematical equations. Currently it provides accurate data by referencing United States Government Agencies Research when applicable and utilizes an equation modified from an Environmental Protection Agency (EPA) study in order to quantify metrics and to provide reliable results.

The current tool has been developed to provide impact results from a social analysis, therefore further development of the tool could be beneficial to include environmental and economic analysis calculations. A predetermined equation was developed to provide the results for SLCA studies, but for some studies this may not provide the necessary information and further development of user input equations may be an interesting aspect for future research.

- Environmental LCA development
- Economic LCA development
- Import user defined equations

Acknowledgement

The authors wish to acknowledge University of Idaho, Idaho National Laboratory and Mr. Georgios Makrakis for computer science assistance.

Chapter 5. Conclusion

5.1. Summary

In chapter 2, a literature review was performed to identify methods and tools developed through previous studies of SLCA. An SLCA tool concept was proposed and compared to other LCA tools. Several methods were identified, which were broken down into qualitative and quantitative approaches, but the review showed that quantitative methods are needed in order to scientifically determine the social impact on specific processes.

Chapter 3 performed a socio-environmental analysis of a CAD best practices document. Equations were developed to mathematically compute time spent, emissions produced, and healthy population for this specific design process. The analysis compared the original document with a proposed document and the results show a 25% improvement for time consumption, 33% improvement for emissions, 60% healthy population, and 39% wellness index.

Chapter 4 provides information on the new web-based SLCA tool concept that was developed during this thesis. A case study is provided to show that the tool produces a mathematically robust solution for users to compare the social impacts of an original process next to a proposed process. The purpose is to provide decision makers with accurate data that can be used to shape policies.

5.2. Conclusions

In chapter 2, it was determined that more research was needed in SLCA to provide future researchers a solid foundation on which to build new ideas and provide a standardized method in the future. Decades of research has been conducted for environmental LCA, all of which aided the standardized method of performing that analysis. It was further determined that few studies have focused on developing mathematical modeling approaches.

In chapter 3, it was determined that small changes made to a process could add up to a large impact improvement. SLCA can be paired with either environmental or economic analysis as shown in this chapter to provide a more holistic perspective of how sustainable a process truly is. For example, the proposed process improved time consumption related to improving emissions and the employee health improvement.

In chapter 4, it was determined that mathematical modeling to produce accurate SLCA results is possible by providing numerical scores through federal government databases. The result is a web-based tool that is open-source and available to any user to perform SLCA on any process. It is customizable by allowing for importing databases in the form of a CSV file, as well as allowing for any number of metrics to be added for each indicator.

5.3. Contributions

The work in this thesis provides the following contributions:

- Established a review article that combines methods, approaches, and tools related to SLCA from previous studies.
- Provided results of a socio-environmental analysis that was performed on a design process document.
- Proposed a new tool with a new mathematical equation to calculate results for SLCA.

5.4. Opportunities for Future Research

Chapter 2 of this paper lays out different methods, approaches, and tools utilized by previous studies, most of which are from the past decade. Comparisons have been made of the most popular LCA tools, the most common qualitative and quantitative methods utilized, and any mathematical modeling that has been utilized in the past. Future research has the opportunity to utilize the information that has been accumulated in this document and build upon it.

Chapter 3 considers the socio-environmental impacts of a design process document. Equations were developed to accurately calculate time consumption and energy usage, as well as an ordinal scale developed to accurately rank employee satisfaction. The study provides a baseline for organizations that may not have performed LCA in its history. The approach taken to this analysis does not take into consideration the economic impacts, which may prove interesting in further research.

Chapter 4 lays out the steps to complete SLCA in the new web-based tool. As of the writing of this thesis, the tool has not been developed to complete environmental or economic LCA, which may prove interesting for further research. Currently, there is a predetermined equation to calculate the indicator value, but for some studies, this may not provide the information required and further development of user input equations may be found interesting for future research.