ABSTRACT

A COMPREHENSIVE AND ABSOLUTE CORPORATE SUSTAINABILITY ASSESSMENT AND ENHANCED INPUT OUTPUT LIFE CYCLE ASSESSMENT

by

Joseph M. Wright

Stresses due to economic activity are threatening to exceed environmental and societal limits with the potential to jeopardize local communities and create global crises. This research establishes new methodologies and analytic techniques to comprehensively assess corporate sustainability and enhance the efficiency of estimating environmental and social impacts with Input Output Life Cycle Assessment (IOLCA).

Sustainability assessments and management require consideration of both social and environmental impacts as outflows of economic activity. There are a number of assessment tools available to gain insight into environmental and social impacts; but in most cases, these approaches lack essential components for a comprehensive and absolute sustainability assessment.

This dissertation establishes a new quantitative method for assessing sustainability across all the interrelationships within multiple domains of sustainability—economic, social, environmental, and potentially others. The comprehensive sustainability target method (CSTM) is a novel extension to an existing environmental burden sustainability technique. CSTM applies the science-based targets and concept of absolute sustainability to social burdensome and beneficial impacts, environmental beneficial impacts, and the interdependencies between the sustainability domains. CSTM is contrasted with an example of the relative assessments that appear in many sustainability disclosures. In addition to science-based targets for environmental burdens, companies should attempt to meet science-based targets for social and beneficial impacts.

Another area of research is focused on IOLCA, a widely used method of estimating environmental impacts based on economic sector level data and analysis. These IOLCA models rely on sector averages and require practitioners to combine impact estimation models to describe specific companies or “custom products”. This research presents a novel extension to environmental input-output modeling that increases the usability and responsiveness of the technique to perform custom product-specific assessments.

This enhancement models direct impacts from emissions (and other stressors) attributable to direct spending on commodities across the economy that cause those impacts. The proposed extension directly calculates the internal impact (II); hence, the model implemented is referred to as the IOLCA-II. The IOLCA-II extension directly produces impact estimates in the categories typically used to manage and report greenhouse gas (GHG) emissions: Scope 1, Scope 2, and Scope 3. In addition to the IOLCA-II enhancement for environmental assessment, selected social impacts are incorporated into the extended model to permit social impact estimation. IOLCA-II impacts are estimated for two scenarios: first, a solar energy application at a university; and second, driverless operation of a long-haul trucking company. The baseline and scenarios are modeled using IOLCA-II and compared to explore the impacts and consequences of the proposed scenarios. These case studies reveal the advantages of using the new methodology and the efficiency of the input-output model results compared to conventional IOLCA hybrid/custom product assessment.

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A Dissertation
Submitted to the Faculty of
New Jersey Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy in Industrial Engineering

Department of Mechanical and Industrial Engineering

May 2020

APPROVAL PAGE

A COMPREHENSIVE AND ABSOLUTE CORPORATE SUSTAINABILITY ASSESSMENT AND ENHANCED INPUT OUTPUT LIFE CYCLE ASSESSMENT

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This dissertation is dedicated to
Nate and Thatcher
<u>You</u> <u>can</u> achieve anything.
And to Maria,
With you, we can achieve anything
And to my brother John Collado, Sr. who was taken from us too soon,
Friendly neighborhood provocateur, felicitator, Good Samaritan
You remind me to always oppose injustice.

ACKNOWLEDGEMENT

Thank you to Dr. Reggie Caudill for your guidance, apparently inexhaustible patience, support and leadership as my Dissertation Advisor. Thank you to my Dissertation Committee, Dr. Sanchoy Das, Dr. Zhiming Ji, Dr. Paul Ranky, Dr. Athanassios Bladikas, and Dr. Maurie Cohen for your vital input, diversity of views, particular insight, specific expertise and general attention in developing this work.

Funding is gratefully acknowledged for a grant from PSE&G to develop an advanced management and engineering tool for New Jersey industry. This work was produced in part as a resource for, and to be fully compatible with, that tool, referred to as the New Jersey Industry Eco-efficiency and Sustainability (NJ-IES) Guide, providing New Jersey business and industry with the ability to assess eco-efficiency and sustainability and to create sound business strategies that drive the corporation towards sustainability.

The work of the developers of Sustainability Target Method, with Dr. Caudill, Joseph Mosovsky, David Dickinson, Joseph Morabito and others is absolutely fundamental to this research. Likewise, the EIOLCA team, at Carnegie Mellon H. Scott Matthews, Christopher Weber, Deanna Matthews, Aryana Venkatesh and Christine Costello. This research is built upon their efforts. Thanks to all for the foundation they provided for this work.

I would like to acknowledge the other Industrial Engineering department MS students and PhD candidates who worked alongside me and helped throughout the program, especially, Dr. Nadi Atalla, Dr. Sufian Ikmeis, Dr. Shivon Boodhoo and Zhenqing Zheng.

I must thank Assured Guaranty and the support of many managers through the process whose interest in my ongoing efforts made pursuit of this program of study something that I could consider in the first place.

Last, but not least, I thank my spouse, Maria Collado-Wright and children, Nate and Thatcher for the sacrifices they made to allow me to pursue this work, and their love and support that fueled me throughout.

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CHAPTER 1

INTRODUCTION

1.1 Overview

The quest for sustainability has been an elusive pursuit among academia, activists, political leaders, and business interests for decades [1]. There are numerous challenges for human society to achieve sustainability. This dissertation defines new and enhanced tools, methods and analytics intended for corporations and other organizations to more simply and effectively measure, evaluate, and interpret their sustainability performance.

1.2 Domains of Sustainability

The 1987 United Nation's Brundtland Commission describes sustainability from a holistic and comprehensive perspective that encompasses three interconnected and interdependent domains or pillars: environmental, economic and social [2]. Sustainability is the characteristic of fulfilling human needs without compromising the capability of any of the domains [3]. From that definition evolved the goal of "fulfilment of basic needs, improved living standards for all, better protected and managed ecosystems and a safer, more prosperous future" [4] and a progression of other definitions and conceptions of sustainability [5-9] and others, but operationalizing a definition remains elusive.

Economic concerns are the primary driver behind most corporate decision making; consequently, sustainability measures in the economic domain, such as profitability, capital, and infrastructure investment, are typically well recognized at least in the near term. However, economic performance may not be well-served in the long run by strictly economic-focused decision making, due to less attention on the other domains of sustainability and the short term planning horizon that many corporations pursue [10]. Climate change due to greenhouse gas (GHG) emissions may represent the single greatest current environmental challenge of human society [11], but over consumptions of resources and other waste streams and emissions are potentially a concern. Movement to incorporate fresh water impacts and other environmental impacts into corporate sustainability discussions is becoming more commonplace [12], especially in light of the recent water shortage in California [13, 14] and around the globe [15] and the growing concerns connecting water and energy consumption. Significant pressures are emerging globally emphasizing the need to incorporate the social dimension into sustainability assessment [16]. Although social considerations have always been integral to the formal definitions of sustainability, the social dimension is being embraced by local communities and regions explicitly as part of regional sustainability programs, for example in Washington DC [17] and New York City [18]. Even commercial interests are recognizing the tension that exists within and between the three sustainability domains: economic, environmental, and social [19].

1.3 Scholarly Contributions and Problem Statement

Corporate sustainability in the economic domain is fundamental to economic vitality, growth, and security; but challenges remain in estimating and assessing sustainability in the social and environmental domains. Recognition of planetary boundaries and societal limits, interrelationships between impact domains, and efficient impact estimation are all areas of concern. Comprehensive and quantitative assessments are necessary to any effort to manage sustainability effectively and ensure that corporate decisions move the company towards sustainability goals.

The research presented in this dissertation is focused on achieving the following three objectives that describe the primary scholarly contributions of this research to the field of corporate sustainability assessment:

- To create the Input Output Life Cycle Assessment Internal Impact (IOLCA-II), a more efficient and robust method for estimating impacts using expense by commodity inputs to generate impact estimates for a custom product or system boundary and to allocate impacts into the typical categories used in corporate social responsibility (CSR) reports.

- To create the Comprehensive Sustainability Target Method (CSTM), a quantitative and *absolute* sustainability assessment method, addressing impacts in the economic, environmental and social domains.

- To expose interdependencies between the basic sustainability indicators from CSTM to assess sustainability within and between sustainability domains and to extract meaningful insights that other assessment techniques fail to provide.

1.3.1 More Efficient and Robust IOLCA

Although sustainability assessment and sustainability reporting are becoming more common practice [20], there remain multiple areas of debate [16] and of development to pursue. Among the topics that challenge current practitioners of sustainability assessment, there are needs for improved scenario modeling and quantitative assessment for social and beneficial impacts [21] and questions of social justice [16]. The dissertation research directly addresses each of these challenges and opportunities.

Input-output life cycle assessment (IOLCA) uses industry average economic and environmental impact data, limiting its capability in specific process modeling [22]. The IOLCA models estimate direct impacts by a final supplier and all upstream impacts from the entire supply chain using industry average spending patterns and production processes, causing significant estimation error when direct impacts vary from the industry averages [22]. This research proposes a more robust impact estimate than a typical IOLCA custom product assessment, using a methodological extension to assess Internal Impacts (II): impacts that are directly generated within the corporation. The resulting extended model is referred to as the IOLCA Internal Impact or IOLCA-II assessment.

While much research has focused on environmental and economic assessments, one area of industrial sustainability that should also receive significant attention is social justice impact assessments [16, 23]; hence, this research also incorporates social impacts into the IOLCA-II assessment. In addition to the new computational method, sample social impacts are added to simultaneously estimate impacts encompassing the social domain.

The scope, boundary and goals for this research are to illustrate the methods proposed and explore the consequences of two proposed scenarios with impact inventories being estimated for the production supply chain for the baseline sectors in Economic Input Output Life Cycle Assessment (EIO-LCA), a commonly used implementation of IOLCA developed at Carnegie Mellon [22]. The first scenario involves the colleges and universities sector and converting from grid-based electric power for a university to solar power. The second scenario considers the truck transportation sector and automation of the driver function of a long-haul trucking company. For these case studies, the economic impacts are final demand and profitability; the environmental impact is carbon-equivalent GHG emissions; and, the social impacts are employment and workplace safety. The techniques are capable of assessing any number of impacts; however, these few included here are sufficient to demonstrate the capabilities of the methodology to model and assess different real-world applications. The new model impact inventories for the scenarios are analyzed and compared to impact inventories from the standard EIO-LCA model for the baseline universities sector and truck transportation sector and scenario impact inventories from a common EIO-LCA custom product formulation.

The scenarios were selected to illustrate the validity of the output and the robustness of the proposed methodology for two types of cases: those where impacts are driven by activities in the supply chain (e.g., emissions from electricity generation purchased from utilities) as opposed to impacts driven by activities within the corporation itself (e.g., combustion of fossil fuels to operate vehicles). In the first case, it is critical to show that the model is consistent with the original assessment outcomes; whereas in the second case, it is critical to show that the new methodology correctly diverges from other techniques, as designed. In addition to these illustrative imperatives, the scenarios analyzed provide interesting results for renewable energy sources and autonomous vehicle systems that are of significant interest in industry and academia [24, 25, 26, others].

1.3.2 Comprehensive and Absolute Sustainability Assessment

After decades of intensive research and international study, much debate still continues as to the basic definition of sustainability, the general acceptance of alternative approaches and methodologies for sustainability assessment, or even what constitutes a meaningful sustainability assessment framework commensurate with the complexity and scope of the ecosystems involved [16, 27]. Clearly significant questions remain to incorporating impacts comprehensively, assessing sustainability effectively, and extracting meaningful insights to help guide decision making toward sustainability. Among these critical research challenges are assessing societal impacts and assessing positive (beneficial) impacts [21].

The STM is one of the earliest frameworks for quantitative assessment of environmental burdens with economic value-added impacts [28]. The STM is based on a specific definition of ecoefficiency that incorporates environmental carrying capacity as a limit on economic activity. The STM is focused primarily on business organizations—such as corporations, value chain partners, production sites, industry sectors, or even national economies—that create economic activity through value-added goods and services that satisfy society's economic demand. Unfortunately, business operations also create negative environmental impacts that harm the environment and consume natural resources. The underlying principle for the STM methodology exploits this fundamental relationship between economic value-added and associated environmental burdens. From the STM perspective, sustainability is achieved when the proportionate economic contribution of the business is equal to, or greater than, it's proportionate environmental responsibility.

This approach establishes an environmental threshold sustainability assessment metric or, as referred to herein, an *absolute* assessment of sustainability, with reference to earth carrying capacity values as opposed to traditional relative measures referenced to previous year performance or other arbitrary targets. The seminal work on the STM was reported in 1999 by Dickinson, Morabito, and Mosovsky at AT&T/Lucent Technologies Bell Labs (currently Nokia Bell Labs), with further research collaboration with Caudill and his team at the Multi-lifecycle Engineering Research Center at New Jersey Institute of Technology. The STM has been used to conduct assessments for a variety of system and spatial boundaries, including individual products, firms, and supply chains, as well as national and global economies. In addition, the STM is specifically designed to accommodate multiple lifecycle assessment (LCA) based environmental impacts, lifecycle phases, and spatial boundaries and impacts ranging from global warming/climate change and resource depletion to hazardous and toxic substances. [29-37].

STM determines *absolute* sustainability between the environmental and economic domains by generating a limit-constrained ecoefficiency for each environmental impact referenced to earth carrying capacity. Sustainability is assessed and indicated quantitatively for each impact category sequenced by theory of constraints. In this context, the term “absolute” refers to whether the impacts exceed sustainability threshold limits or not; are these impacts sustainable; and if not, how far these impacts are from being sustainable. Pope et al. refer to these outcomes as “assessment for sustainability” [27]. The overall system (product/process/firm, etc.) is deemed to be sustainable if and only if each and every impact ecoefficiency is sustainable [31]. Based on planetary boundaries, or as used here, “limits” [30], the STM avoids the necessity to assign arbitrary impact weighting factors or introduce personal biases into the integrated analysis of multiple impact categories relevant to sustainability: problems frequently associated with other sustainability metrics, multi-criteria assessments and LCIA techniques. This is not to say that the STM, or the extension presented here, is without bias or data limitations. In fact, STM-based approaches are subject to many of the same sources of bias, such as aspect selection, analysis spatial or temporal boundary, value orientation, and target selection that face other methods [38]; however, the STM avoids the bias associated with weighting and aggregating various impact indicators. The resulting set of sustainability indicators, each normalized to its respective environmental limit or threshold target, is extendable to a large number of impacts reducing the complexity to communicate and interpret results.

The primary weakness of the original STM is that it does not address societal impacts and social justice, emerging concepts in evaluating sustainability [16, 21, 23], nor does the technique address beneficial impacts, such as carbon capture or sequestration. Extending sustainability assessment to the societal and other potential domains of interest and to assess directly beneficial impacts are critical to comprehensive sustainability assessment. Sustainability that extends the concept of environmental limits on human activities to social impacts (and justice) declares sustainability boundaries with upper limits for burdens on the environment and lower limits on social beneficial categories [9, 16].

A new framework is proposed which expands the STM approach to incorporate additional sustainability domains, provide consistency and uniformity for analyzing burdens and benefits, and maintain scientific rigor and flexibility with regard to normalized sustainability reference targets and carrying capacities. The CSTM provides metrics and normalized indicators to assess any given system spatial boundary and corporate scope. The normalized indicators establish the threshold for *absolute* sustainability that is clear and universal across all impact categories within each sustainability domain of interest, including economic, environmental, and social. In addition, a novel visualization graphic is presented to better communicate and interpret outcomes and assessment results to help guide decision makers towards sustainability.

The STM approach has the following basic properties: recognition of limits in the environment, threshold sustainability decisions, multiple environmental impact categories, normalized indicators, capacity for a variety assessment subjects, and capacity for assessment on a variety of geographic impact boundaries. CSTM retains all of the properties of STM and incorporates the social and societal justice domain, recognition of minimal limits for benefits, and extensibility to any other domain of benefits and burdens. These core CSTM characteristics respond to several challenges and limitations of other emerging and developing sustainability assessment concepts, as described above. To illustrate the applicability and practitioner aspects of the technique, an existing case study is used to demonstrate a practical application of the CSTM, assemble relevant data, and compare and contrast the results and conclusions of an earlier traditional impact assessment study.

1.3.3 Interdependence of Sustainability Domains

Additional recognized shortcomings of the current state of sustainability assessment is lacking quantitative measures and tools supporting the understanding of interrelationships within and across the sustainability domains [21, 39] and lacking methods for clear communication of sustainability results [21]. Practical applications of interdisciplinary and interdependent sustainability assessments are lacking [40, 41]. A further consequence of the normalized indicators CSTM establishes across all impact categories is the capability to determine a threshold for *absolute* sustainability among the interrelationships between and within each sustainability domain of interest, including economic, environmental, and social.

The scope, boundary and goals for this research are to identify and codify the basis for the interdependence of the basic indicators established by the CSTM. The relationships from CSTM’s interdependent indicators extract new meaningful insights form the CSTM case study. The CSTM indicators of the interdependent relationships are entirely consistent and compatible with the other CSTM with the same clear, consistent definition of sustainability. The interdependent indicators of CSTM generate meaningful insights into sustainability questions that are not otherwise at hand. The universality of interpretation of the indicators produces sustainability assessment results across all impact domains that are more accessible and easier to interpret and understand.

1.3.4 System and Spatial Boundaries

There is active debate about what boundaries are appropriate to use when investigating corporate sustainability. Embedded in the boundary debate is whether or not the corporation should be considered responsible for impacts only from within the corporation, or from the corporation plus direct suppliers, or from the entire corporate supply chain including remote upstream suppliers [42, 43]. In addition, some argue that impacts from customers using the product should also be considered the responsibility of the corporation that sold the product [44]. This gap emphasizes the sensitivity of system boundary selection when choosing a subject for sustainability assessment.

In addition to sensitive system boundary questions, different environmental and social impacts have various spatial scales for which they are relevant [7, 9, 32]. For example, GHG emissions and climate change are global impacts. Whereas water use would be a local or regional concern; and, employment may have local, regional or national relevance.

These two boundary issues, system boundary and impact spatial boundary, are critical to meaningful application of any sustainability assessment technique. To demonstrate the full comprehensiveness and scope of the CSTM, an additional case study is used to illustrate the correct selection and alignment of system boundaries.

Today, renewable energy sources (excluding hydropower) account for only 11% [45] of the total 2019 U.S. energy consumption; however, this portion is expected to increase dramatically in the coming decades. This potential shift in electric power generation raises some interesting questions: Will renewable energy technologies—solar panels or wind power, for example—lead to sustainability? How far from sustainability is the current U.S. power grid and which of these evolving renewable technologies have the greatest potential to improve sustainability?

Several renewable energy technologies are contrasted with the United States electrical power grid as a baseline. Four solar power technologies are evaluated ranging from 3 kW mono-crystalline and poly-crystalline panels to 22kW thin-film amorphous panels and a utility scale photovoltaic (PV) solar farm. Similarly, three wind turbine technologies are evaluated and compared: 30 kW, 100kW and a utility scale turbine from a wind farm.

CSTM is used to assess each renewable energy technology and determine if the technology is environmentally sustainable for GHG emissions and freshwater consumption. The case study is used to navigate system and spatial boundary issues when applying CSTM to assess systems for sustainability and to produce meaningful comparisons of assessments for multiple systems.

For various renewable energy technologies, this research demonstrates the application of CSTM, proposes a method to estimate freshwater carrying capacity and reference economy for local/regional scale environmental impacts.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

The literature review summarizes previous research in the field of sustainability assessment. The review also provides the analytical and theoretical foundation for the new methodologies and quantitative techniques developed for estimating corporate environmental and social impact inventories and for extending the theoretical basis of absolute sustainability assessments across all impact domains. Table 2.2 below, using the coding in Table 2.1, outlines the key foundational sources and contribution to sustainability assessment topics addressed in this dissertation.

Table 2.1 Coding for Literature Review Table

Coding	Topics/Columns
S = Seminal work	Ref. = Reference number
E = Important extension	IOLCA = Input Output LCA/ custom products
G = Illustrates a gap in the literature	STM = Sustainability Target Metric
D = Discussion/Debate	Social = Social pillar recognition
	SA = Sustainability Assessment
	CSR = Corporate Social Responsibility
	Bound = Limits on human activity

Table 2.2 Key Literature Sources in Literature Review and Contribution to Topical Areas of Research

Author	Ref.	Year	IOLCA	STM	Social	SA	CSR	Bound
Isard W.	[46]	1951	S					
Friedman, M.	[47]	1970					D	
Leontief, W.	[48]	1970	S					
Daly, H.	[49]	1974						S
Carroll, A. B.	[50]	1979					S	
Leontief, W. W.	[51]	1986	S					
Klenow, P. and A. Rodriguez-Clare	[52]	1997			S			
Levett, R.	[53]	1998			G			S
Carroll, A. B.	[54]	1999					E	
Dickinson, D.	[28]	1999		S				
Joshi, S.	[55]	1999	S					
Matthews, H. S. and M. J. Small	[22]	2000	S					
Mosovsky, Dickinson, Morabito	[30]	2000		S				
Luo, Wirojanagud and Caudill	[35]	2001		E				
Mosovsky, Dispenza, Dickinson, Morabito, Caudill, and Alli	[34]	2001		E				
Dyllick, T. and K. Hockerts	[56]	2002		G	S			
McDonough, W. and M. Braungart	[57]	2002						G
Yossapol, C., R. Caudill, L. Axe, D. Dickinson, D. Watts and J. Mosovsky	[32]	2002		D				S
Gao, Zhou, Dickinson and Caudill	[36]	2003		E				
Smith, H. J.	[58]	2003					D	
Wilkinson, R. G. and M. G. Marmot	[59]	2003			D			
Pope, J., D. Annandale and A. Morrison-Saunders	[27]	2004				D		G
Hendrickson, C. T., L. B. Lave, H. S. Matthews and A. Horvath	[60]	2006	S					

Table 2.2 Continued Author	Ref.	Year	IOLCA	STM	Social	SA	CSR	Bound
Moneva, J. M., P. Archel and C. Correa	[43]	2006					G	G
Amaeshi, K. M., O. K. Osuji and P. Nnodim	[42]	2008						D
Cohen, B., B. Smith and R. Mitchell	[61]	2008						D
Huijbregts, M. A., S. Hellweg, R. Frischknecht, K. Hungerbühler and A. J. Hendriks	[62]	2008			G			
Rockström, J., W. Steffen, K. Noone, Å. Persson, F. S. Chapin III, E. F. Lambin, T. M. Lenton, M. Scheffer, C. Folke and H. J. Schellnhuber	[7]	2009						S
Dickinson	[63]	2010		E				
Heijungs, R., G. Huppes and J. B. Guinée	[41]	2010			G	G		S
Jeswani, H. K., A. Azapagic, P. Schepelmann and M. Ritthoff	[64]	2010	D		G			
Arrow, K. J., P. Dasgupta, L. H. Goulder, K. J. Mumford and K. Oleson	[65]	2012			S			
Raworth, K.	[9]	2012			S			S
Schwartz, M. S. and D. Saiia	[66]	2012					D	
Wright, J. M., Z. Zheng and R. J. Caudill	[29]	2012						
Hugé, J., T. Waas, F. Dahdouh-Guebas, N. Koedam and T. Block	[67]	2013				D		
Norris, C. B., G. Norris and D. Aulisio	[68]	2013			S			
Onat, N. C., M. Kucukvar and O. Tatari	[69]	2014					D	
Caudill, R.J. and J.M. Wright	[70]	2015		E	S			
Fang, K., R. Heijungs, Z. Duan and G. R. De Snoo	[71]	2015		D				S
Glasmeier, A. K.	[72]	2015			S			
Jang, M., T. Hong and C. Ji	[73]	2015	D					
McBain, D.	[23]	2015			G			
Sala, S., B. Ciuffo and P. Nijkamp	[39]	2015		G	G	G		G
Carnegie Mellon Green Design	[74]	2016	S					

Table 2.2 Continued Author	Ref.	Year	IOLCA	STM	Social	SA	CSR	Bound
GRI.	[75]	2016					S	
Guinée, J.	[21]	2016	G		G	G		G
Hardadi, G. and M. Pizzol	[76]	2017			S			
Matthews, H. S., C. T. Hendrickson and D. H. Matthews	[77]	2017	G		G			
Pope, J., A. Bond, J. Huge and A. Morrison-Saunders	[16]	2017			G	D		G
Crawford, R. H., P.-A. Bontinck, A. Stephan, T. Wiedmann and M. Yu	[78]	2018	G					
Dragicevic, A. Z.	[79]	2018						D
SBTI	[80]	2019		D	G		G	D
This Dissertation Research			S/E	S/E	S/E	E	E	E

2.2 More Efficient and Robust IOLCA

IOLCA and process life cycle assessment (PLCA) are two tools that are used extensively to evaluate burdens of environmental impacts associated with a product, service, or other economic system boundary as part of an LCA. IOLCA relies on the economic flows of purchases between sectors and environmental burdens based on sector average impact rates to estimate impacts throughout the supply chain that result from final product demand [22]. PLCA is produced from a database of product flows and processes, which generate a bottom-up estimate of impacts that are dependent on the boundary of analysis [22, 81].

An advantage of using PLCA to assess environmental impacts of industrial activities is that it can be adapted precisely to a specific and detailed target of analysis, providing the user accepts the expense and practical demands of data gathering [77]. Alternatively, IOLCA includes all indirect effects in the entire value chain [82] and allows rapid and inexpensive modeling. However, the IOLCA advantages come at the cost of using fixed, linear, industry average data rather than product- or company-specific data [77]. Using the sector averages, the IOLCA analysis is only as detailed as the sectors established in the applied economic data; in addition, point-in-time sector averages do not capture distinctions between different technology options between producers, but rather provide a simplified average in linear input-output relationships [77]. There are well-developed techniques to account for industry-specific inflation to update the input-output models for relevant price moves and changes in technology [77]. Similarly, there are techniques to account for and address uncertainty [77] and to identify and address uncertainty due to parametric correlations that may be relevant in results from the IOLCA standard model [83]. Although the input-output model is derived from economic flows in the supply chain, it is a significant question to consider the entire life cycle [84]. There are existing techniques for applying input-output models to other phases of the product life cycle [73, 77]. Note here that temporal considerations or timing of impacts are also not addressed directly within the standard IOLCA model nor in the proposed IOLCA-II model; however, these considerations can be addressed [77, 85]. Instead, all impacts are assumed to be concurrent with expenditures. The consistency of the mathematical underpinning of IOLCA-II with the original IOLCA suggest that IOLCA-II is complementary with the existing adjustment techniques listed above.

There are a variety of hybrid LCA models that integrate IOLCA and PLCA techniques to generate impact inventories [78]. Matrix augmentation, for example, is a custom product IOLCA modeling approach that adapts the IOLCA form to isolate a custom product from the standard environmental impact matrix and substitute a product-specific direct impact vector to generate environmental impacts for a custom product [55, 78]. The matrix augmentation model requires measurement, calculation, or estimation of the direct impact vector (for all relevant impact categories) in order to estimate custom product impacts [55]. Another common application of EIO-LCA is as a part of a tiered hybrid LCA, where a process LCA is supplemented with IOLCA to compute indirect impacts caused by the supply chain, so that the IOLCA data reduces truncation error of the PLCA [69, 77, 78]. Different techniques have different advantages and disadvantages making them better suited to specific applications [78], but all of the hybrid methods include some element of expense by commodity calculation. This aspect of spend by commodity is the principle input of the IOLCA-II technique proposed here. Critically, the hybrid models further require the development of the PLCA and integration of PLCA and IOLCA models; these are efforts that the IOLCA-II avoids.

2.2.1 Economic Input-Output Life Cycle Assessment

The EIO-LCA model [22, 77, 86], described below, is an IOLCA implementation based on the input-output model of the economy [46, 48, 51] and sector impact rates [86] and is an accepted tool for estimating environmental impacts of business activity [87]. The input-output model of the economy, estimating the economic flows between supplier sectors to produce the final demand by output sector is expressed in Equation (2.1).

$$x = (I - A)^{-1}y \tag{2.1}$$

In Equation (2.1), y is a vector of final demand by output sector, A is the matrix of direct requirements in each input sector for each output sector, and x is the total supply chain output. This can be expanded to show the incremental steps in the supply chain as in Equation (2.2).

$$x = (\mathrm{I} + \mathrm{A} + \mathrm{AA} + \mathrm{AAA} + \mathrm{AAAA} + \cdots)y \tag{2.2}$$

Here, direct requirements of the final producer (*A*), of their suppliers (*AA*), suppliers of suppliers (*AAA*), etc., representing the economic flows of the entire supply chain. Shorthand for the flows throughout the supply chain is shown as (Equation 2.3).

$$x = Ty \tag{2.3}$$

The resulting sum throughout the supply chain is the total requirements (T) matrix. Environmental impact estimates based on these economic flows are represented in Equation (2.4).

$$B = (R)Ty \tag{2.4}$$

Here, B, i.e., the vector of environmental impacts by output sector, is obtained by matrix multiplication of Ty by R, i.e. the vectors of environmental impact rates in each sector. Final demand by output sector generates the impacts for all sectors required to produce that output.

2.2.2 Custom Product Hybrid Life Cycle Assessment

The proposed IOLCA-II model described herein modifies the mathematical foundation of IOLCA to support improved direct impact estimation directly within the input-output model. The new model produces a meaningful increase in impact estimation data with no increase in data collection effort (or permits the avoidance of direct impact estimation effort), increasing the efficiency of impact estimation. A common representation of GHG categorizes emissions by operational boundary "Scopes". In the context of the supply chain. Scope 1 represents the emissions for combustion of fossil fuels within the corporation itself, Scope 2 represents emissions of direct suppliers of electricity, and Scope 3 represents the emissions of direct suppliers other than electricity and further upstream suppliers of all types [88, 89]. The IOLCA-II model also elaborates the impact estimates into the Scope 1, Scope 2, and Scope 3, categories.

A published hybrid LCA with scope based impacts [69] details the process flow, enhanced with additional narrative details, as shown in Figure 2.1 and described here. After defining the boundary and goals of the LCA are established in step 1, two distinct data collection efforts comprise step 2. Expense by commodity sector data is collected to supply the IOLCA. Process and component data are collected as sources for the PLCA. Step 3 also entails two distinct pathways, inputting the expense data into the IOLCA to produce supply chain impact inventories and modelling the process in a PLCA to produce impact inventories for direct emissions. Integrating the inventories from the IOLCA and PLCA are also part of step 3. In step 4 the impact inventories are allocated to each of the Scopes depending on the sectors of the IOLCA and sources of impacts from the PLCA.

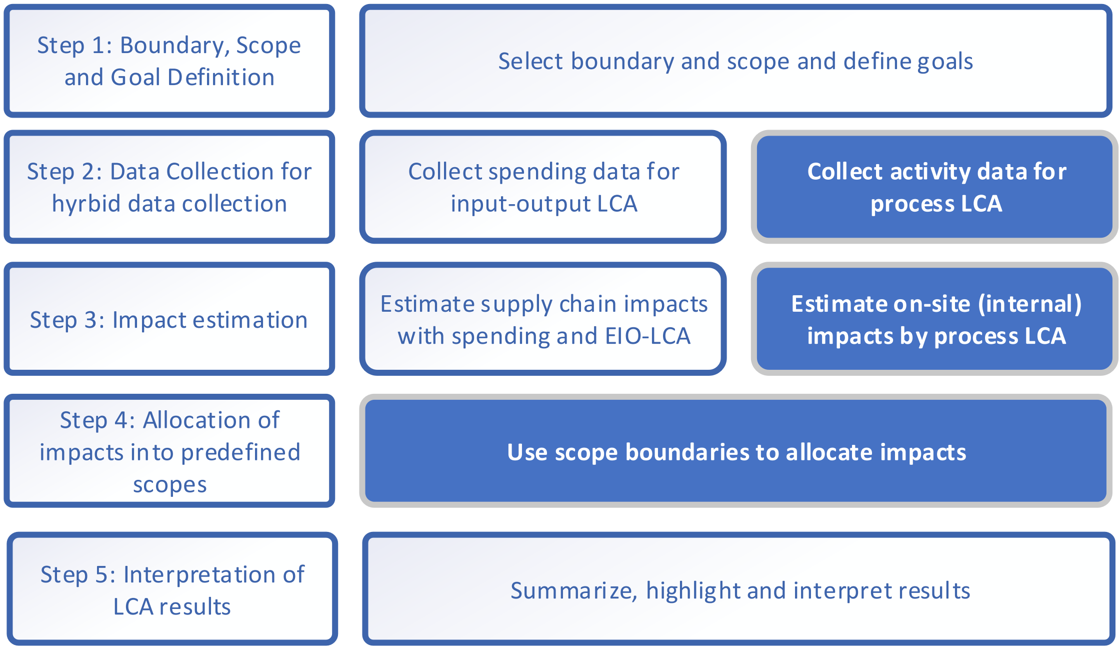


Figure 2.1 A hybrid LCA process flow with details to identify the process LCA and scope allocation that this research can reduce or eliminate, depending on boundary, scope and goals

Source: Adapted from [69]

The diagram also identifies the process steps that the IOLCA-II proposal can reduce or eliminate for many applications. Specifically, that for impact categories that are dependent on commodity spending that is already part of the supply chain data collection, the IOLCA-II will produce an estimate of the complete impact inventory without additional data collection, modeling and integration of a PLCA. The IOLCA-II also allocates impacts into Scopes as part of the standard model output without further manipulation.

2.2.3 Social and Economic Impacts

Among the challenges to effective sustainability assessment across all sustainability domains are the needs for quantitative social impact assessments and analysis of the interrelationships and interdependencies between sustainability domains [21]. There are use cases where it is germane to leverage various sustainability approaches into a single analysis, incorporating environmental, economic and social impacts [64]. IOLCA models tend to focus on environmental or social impacts, the EIO-LCA is based on an economic input-output model and estimates environmental impacts [22], and is lacking elements to support the estimation of social impacts. An occupational safety analysis has been previously demonstrated in a modified, reduced sector version of EIO-LCA [60], but it has not been made available in the current implementation. The key shortcomings of the previous demonstration of social impacts in EIO-LCA that are overcome by the research contribution of this dissertation are the following:

- The previous demonstration was limited to summarized sectors, less detailed than the standard model
- The previous demonstration could not be aligned with the environmental impacts of the standard model.

- The previous demonstration only explored sector level results, with no application to a custom product.

To illustrate and investigate economic and social impacts of the scenarios analyzed in this research, social impacts for two impact categories, employment and workplace safety and an additional economic impact, profitability, are added to the IOLCA-II analysis.

2.3 Comprehensive Sustainability Target Method

Tremendous efforts have been expended over the past three decades to better understand and address sustainability from the environmental and economic perspectives. More recently, societal impacts and social justice have become an emerging research area for operationalized sustainability assessment techniques. Along with recognition of limits on human activity, integration of environmental and development goals, and directed change toward sustainability [16, 67], the area of resilience and justice has been proposed as an important distinguishing feature of sustainability assessment tools within a recently developed sustainability assessment classification framework [16]. One of the first researchers to explore the systematic integration of resilience into sustainability frameworks was Fiksel at Ohio State University [90]. As this area develops and expands, a lack of tools for social sustainability assessment has been identified as a critical issue facing the comprehensiveness of sustainability assessment [21] and an important next step in managing impacts of human activity [23].

One view that has helped to influence the concept of corporate sustainability is CSR. Largely developed by Carroll, it states that there exists a spectrum of responsibilities to which corporations are bound – “the social responsibility of business encompasses the economic, legal, ethical, and discretionary expectations that society has of organizations at a given point in time” ([50], p. 500).

An alternative view, often seen as contradictory to CSR that has also been influential on the culture of business management and possibly even more influential on the public’s perception of business [58] is Friedman’s shareholder value concept. Friedman contends that the only social responsibility of business is to maximize profits within the law and ethical custom [47]. Some supporters and opponents of Friedman’s idea incorrectly exclude the ethical constraint and simply focus on maximizing profit as the only element [66].

The debate over whether shareholder value or CSR is correct has continued over the years [54] [58] [66], and in the end, it might come down to where one draws the “ethical” line [66]. That line, this research proposes, must be to operate within the carrying capacity constraints of the common resources that are used in the life cycle of products and services in the economy. This is the foundation for the obligation of all firms to adopt CSR and the rationale to extend CSR to include an absolute sustainability.

In the context of environmental burdens, limiting human activity within planetary boundaries, so that environmental carrying capacities are not exceeded [7], is a common, but not universal, fundamental principle of sustainability assessments [16, 67]. Applying the same principle of limitation boundaries to social justice and resilience restricts the operating space below the maximal limits for environmental burdens and above the minimal limits for social impacts [9]. The Pope, Bond, et al conceptual framework for sustainability assessments mentioned above incorporates integration of environment and developmental goals, as well as the addition of justice [16].

Over the decades, numerous methodologies, tools, and techniques have been developed and used in sustainability assessments [39, 91, 92]. A comparison of some of these commonly used sustainability assessment tools highlights their comparative strengths and weaknesses. Sala, Ciuffo, et al. propose key classification features and value ranges for comparison of sustainability assessment tools. Their assessment nomenclature and criteria are given below with feature name followed by criteria ranges given as low value, intermediate value, and high value [39]:

- Boundary-orientedness: no reference, relative to status quo or scenarios, science-based or policy-based thresholds
- Comprehensiveness: one pillar, two pillars, three or more pillars
- Integratedness: single discipline, multiple or cross discipline, trans-disciplinary
- Stakeholders' involvement: communication, resonance, interaction
- Scalability: single scale or time frame, only temporal or spatial scale, multiple spatial and temporal scales
- Strategicness: accounting, sustainability-oriented, change-oriented
- Transparency: closed model, partially open model, open model/transparent values

Using this framework, they compare four common sustainability assessment methods [39], Environmental Impact Assessment, Human Development Index, Ecological Footprint and Life Cycle Assessment. The radar charts showing the primary results from Sala, Ciuffo, et al. are presented as Figure 2.2 (source: Sala, Ciuffo et al. 2015). For further illustration, the STM and CSTM have been evaluated using the Sala, Ciuffo, et al.

framework and the results are shown in Figure 3.3 using the same classification features, assessment criteria, and radar chart format.

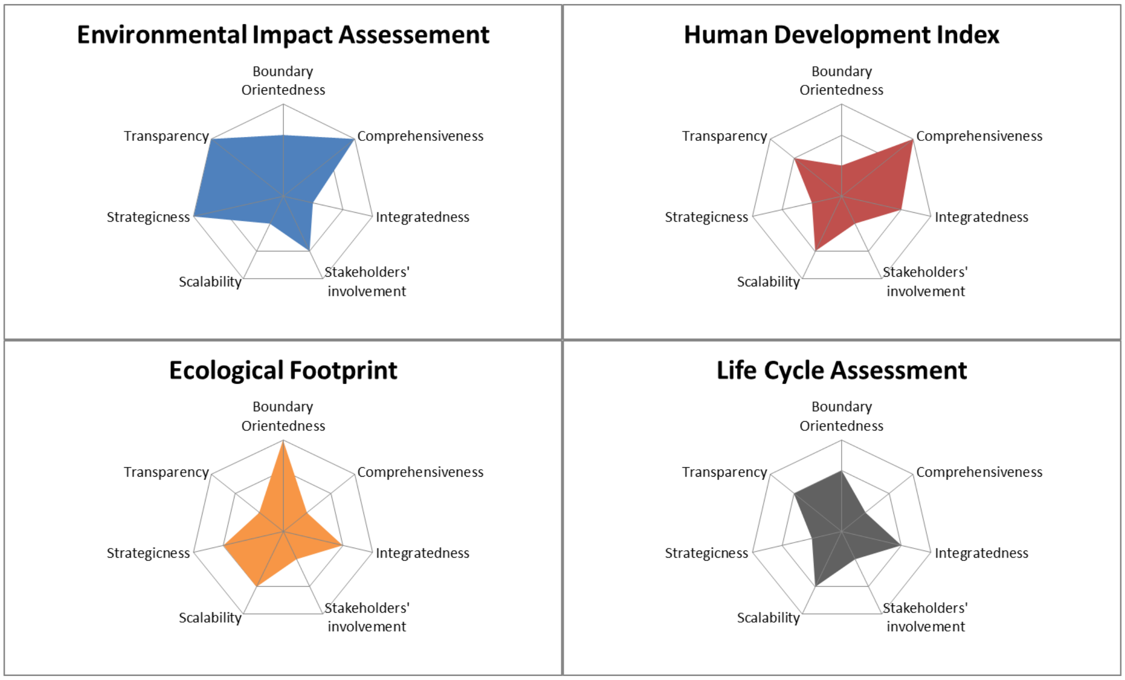


Figure 2.2 Sala, Ciuffo, et al. comparison of common sustainability assessment tools
Source: [39]

The Sala, Ciuffo et al. comparison reveals the following: the Ecological Footprint shows a high level of boundary-orientedness, medium scalability, and low level of comprehensiveness. The Ecological Footprint compares available land to a representation of environmental burdens of activities by translating impacts to land required to produce nutrients and absorb wastes [93]. This approach effectively recognizes environmental limits and has been applied to a variety of applications [62, 91, 94] illustrating its scalability. The Ecological Footprint, however, does not account for economic or social concerns [94] nor does the technique seem easily adaptable to incorporating social impacts into the analysis where the “capacities” are largely independent of any land-mass measure.

One of the most commonly discussed sustainability assessment indicators is ecoefficiency; however, the intended meaning of the term ecoefficiency itself is often subjective [95] and disagreement exists between the applicability of efficiency measures or effectiveness measures as a guide towards sustainability [61, 96]. Underlying this disagreement is that ecoefficiency measures typically employed are frequently arbitrary or unclear choice decisions: relative comparisons reporting improvement (or deterioration); performance differences cited between options but with no clear definition of the target threshold for sustainability; and/or no determination of sustainability compared to environmental limits [7, 27, 57, 96-98]. The absence of carrying capacities or limits in ecoefficiency assessments can lead to erroneous conclusions, as well as rebound or induced demand effects, resulting in worse environmental performance [41, 56, 71, 98]. This absence of limits means that these definitions of ecoefficiency are missing key foundational elements for understanding and assessing sustainability, including limits on human activity and guidance toward sustainability goals and objectives. By incorporating carrying capacity limits into the ecoefficiency normalization process, the STM definition of ecoefficiency avoids these concerns.

As presented in the previous section, CSTM proposed here extends and expands the structure and methodology of STM into a more comprehensive sustainability assessment tool. Consequently, it is important to describe more fully the STM approach and its underlying principles and construct. The STM establishes ecoefficiency as a non-dimensional relationship between economic value-added by the business and the resulting environmental impact caused normalized by overall economic activity and earth carrying capacity limits. Simply stated, the STM quantifies and answers the question: Does your business generate sufficient value relative to the resources consumed and environmental impact caused? More than just giving a binary answer to this question, the STM indicates how far away the business is from being sustainable; and, by analyzing alternative proposed strategies and projects, the STM provides a rationale and quantitative basis to make decisions that move the business towards sustainability. The underlying assumption of the approach is that sustainability thresholds can be reasonably estimated for relevant impacts and that human activity can be modified to be constrained by those limits. Both of these assumptions are significant and neither are unique to STM or CSTM, but should be emphasized and acknowledged. It is also clear that a single process, company or nation cannot achieve sustainability on its own for the economy or society as a whole; however, it is important to know if individual corporations are providing contributions to society that exceed the burdens created.

While different industries face different challenges regarding environmental impacts, all businesses today are concerned with global warming and climate change; consequently, consider the following discussion of an STM analysis related to climate change due to GHG emissions.

The spatial or geographic boundary for this sustainability analysis related to climate change is global, rather than being regional or local in scope. As noted above for the STM, sustainability for an impact is achieved when the share of economic value added is at least proportionate to the share of environmental impact created. For the global analysis boundary, the share of economic value added by a business is the ratio of its annual value-added generated to the overall annual level of global economic activity, assumed here as the global GDP. Monetary value is one of many ways of measuring activity with many assumptions and value judgments embedded therein [38]; however, in this context for STM, the monetary value, be it for GDP or value-added, is used only as a reference measure of economic activity. In theory, other economic activity measures could be substituted here as well. Similarly, the share of climate change impact created by the business is the ratio of its total annual GHG emissions to the sustainable level of annual global GHG emissions allowable, so as not to create irreparable or permanent environmental damage—that is to say that emissions have not exceeded the Earth's Carrying Capacity. This sustainable level of global GHG emissions is referred to as the Earth's Carrying Capacity and varies with time as the concentration level of GHG in the atmosphere changes.

Over the past three decades, climate change research has examined various scenarios and potential futures based on various models and empirical data. The UN Intergovernmental Panel on Climate Change (IPCC) has issued several reports and predictions from which Earth Carrying Capacity estimates can be made. While still being debated, the evolving consensus amongst climate experts is that irreparable damage to the planet will occur if the global average temperature increases more than two degrees Celsius above pre-industrial levels. Note: The most recent 2018 IPCC report indicates that perhaps the two degree limit is too optimistic and suggests a revised limit of 1.5 ° C may be necessary. In addition, previous work at NJIT has provided initial estimates for the Earth's Carrying Capacity for other environmental impact categories, including Ozone Depletion, Eutrophication, Photochemical Smog and others [32]. Note: For other spatial boundaries, such as regional impacts, e.g., smog or fresh water consumption, the economic activity must also be considered at a spatial boundary consistent with the impact being assessed [29].

2.3.1 Sustainability Target Method

Using notation from Dickinson, Mosovsky, and Morabito, the value productivity (VP) of the business is expressed as ratio of its annual value added (USD) to the amount of annual GHG emissions (kg-CO_{2eq}). Similarly, the value productivity for sustainability (VPS) is the ratio of total annual global economic activity (Global GDP in USD) to the Earth's carrying capacity (kg-CO_{2eq} of annual GHG emissions). By definition, this sustainable environmental productivity rate does not exceed the carrying capacity for the impact while producing all the value required in the economy, and therefore, is the threshold for sustainability. According to STM, the non-dimensional ecoefficiency ratio of VP to VPS must be greater than or equal to one for the business to be sustainable. Also, note that VP is the inverse of *emission intensity*, a commonly used measure of relative environmental assessment and reporting. By normalizing the business's annual economic contribution to global GDP and its annual GHG emissions to Earth carrying capacity, the STM ecoefficiency metric, EcoE as in Equation (2.5), provides an *absolute* measure of sustainability, which indicates quantitatively how far the business is from its target of sustainability.

$$EcoE = \frac{VP}{VPS} = \frac{Value\ Added / Environmental\ Impact}{GDP / Earth's Carrying\ Capacity} \tag{2.5}$$

This approach operationalizes STM's definition of ecoefficiency, defining sustainability for any environmental impact, which has been recognized or adopted recently by other researchers and organizations [80, 99, 100]. Clearly, defining threshold or carrying capacity limits for the relevant critical impact categories that sustainability assessment techniques may address is a significant and highly sensitive undertaking: the environmental cycles in question are complex; the limits to these systems are variable with significant uncertainty and randomness; and the interdependencies, failures or recovery of these ecosystems are not well understood [7]. Like all threshold techniques, the STM (and CSTM) relies upon estimates for these limits and any uncertainty will result in uncertainty in assessments made using those limits. For forecast or *ex ante* assessment purposes, a sustainable productivity estimate needs to assume some specific level or range of economic activity. Even if the environmental impact limit is known with reasonable certainty, there is a risk that the economic activity estimate results in an incorrect sustainable productivity estimate that results in unsustainable impact rates.

The STM has appeared mostly in IEEE international conference and symposium proceedings and industrial ecology papers beginning in 1999; however recently, other researchers and international environmental reporting organizations have recognized the merits of this approach to perform sustainability assessment. Presented as a comprehensive *absolute* (threshold) framework for sustainability assessment, Chandrakumar and McLaren developed a robust method for screening environmental burden impacts subject to sustainability assessment, focusing on burdens that impact midpoint and endpoint measures, as well as supporting multiple Global Reporting Initiative (GRI) sustainable development goals [99]. Although it appears to comprehensively capture environmental burden assessment, their method neither addresses the direct social impacts of production (such as worker safety and employment) nor supports the beneficial impacts. Notably, they explain that *absolute* sustainability assessment of a burden must quantify the impact(s) of a system by life cycle assessment or other means, allocate the limit or carrying capacity of those impacts, and evaluate the impact performance of the system against the target allocation to determine sustainability [99]. They specify that sustainability assessment methods should address three questions: (1) What are the impacts of the subject system? (2) What is the allocation of capacity limits to the system? (3) Can intervention bring impacts within limits? [99] Without stating a method to allocate limits, these questions express a conception of sustainability that is remarkably similar to that in the STM. Other research that proposes allocation of planetary boundary limits to undertake national sustainability assessments points out several valid options available for allocating limits, "population size, economic output, territorial area, or historical responsibility" [100], of these options, economic output is the one best suited to allocate limits to corporate impacts.

The Science Based Target Initiative (SBTI) is another group that has adopted STM's approach and methodology, seeking to provide tools for effective target setting in corporate sustainability reporting. The SBTI is a joint effort of several major organizations, including the UN Global Compact, Carbon Disclosure Project, World Resources Institute, and the World Wide Fund for Nature, with a mission supporting corporate target setting for GHG reduction that respect absolute planetary limits [101]. In fact, SBTI has also adopted the STM definition of sustainability as one of the options for setting a science based target for GHG emissions, even using the same method to allocate capacity limits in the economic-based approach; [80] allocates the planetary limit to companies based on value generation proportional to size of the economy. The SBTI initiative further validates the STM methodology and approach as an effective framework for sustainability assessment; however, SBTI focuses strictly on environmental burdens, providing additional rationale and justification for the more comprehensive CSTM proposed.

Companies that follow the GRI guidelines already collect, and in some cases already disclose, the primary corporate data needed for a complete CSTM sustainability assessment. GRI reporting includes multiple economic, social and environmental impact measures in the context of disclosing corporate sustainability [75] and it is becoming more widely adopted. On the other hand, the GRI has been criticized for, among other issues, lacking impact limits, failing to integrate measures across sustainability domains, lacking clearly defined system boundaries, [43], and failing to specify the relevance of those boundaries that are used [42]. With CSTM's explicit use of impact capacity limits, standardized interrelated metrics across impact categories, and boundary flexibility, the GRI impact data could produce a more informative report that resolves many of these lingering criticisms.

2.3.2 Extending STM

As a guide and strategy to extend STM, the literature details the interaction between the three domains or pillars of sustainability productivity and intensity rates, efficiencies, and effectiveness [e.g., 56, 57, 61, 96, 102]. The Russian doll or concentric circle model of sustainability [49, 53] graphically represents strong sustainability and the societal constraints, caused by capacity limits to the natural environment, and economic constraints caused by society and the environment [79]. By incorporating the interrelationships between and within the social, economic, and environmental domains and the dimensional constraints of the concentric circle model for both positive and negative impacts, the basic STM can be extended into a more comprehensive sustainability assessment technique.

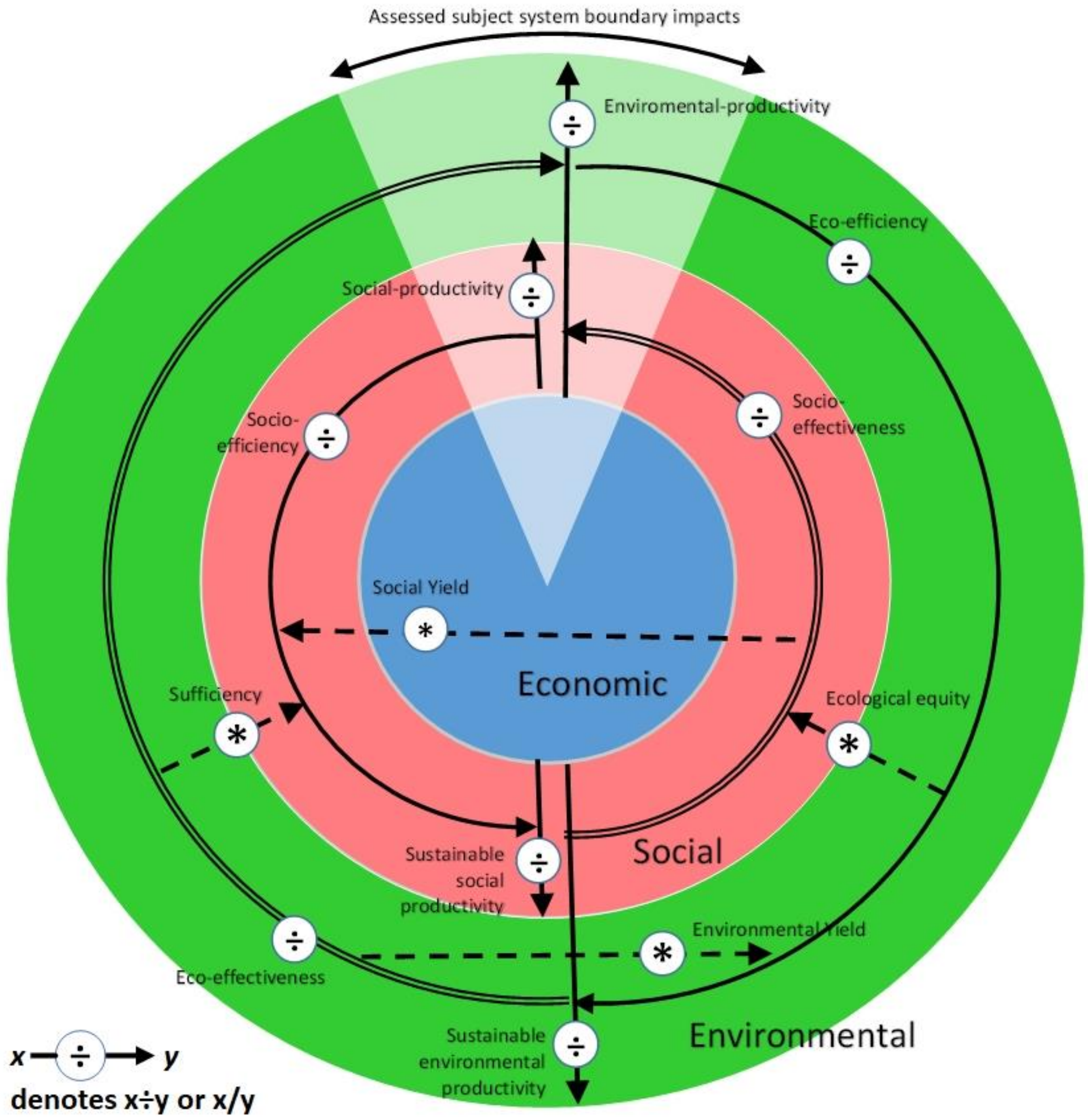


Figure 2.3 Synthesizing Dyllick and Hockerts' (2002) sustainability triangle and concentric domains from Daly (1974) and concentric model of sustainability Daly (1974) and Levett (1998) overlaid with Dickinson's (1999) STM pie chart proportionate responsibility illustration

Figure 2.3 illustrates how the CSTM extends STM to define metrics for environmental and social impacts proportionate to economic impact, across all of these sustainability domains. Whether an impact is a burden or benefit determines whether the sustainability assessment indicator is considered as an *efficiency* or effectiveness metric.

The figure captures the terminology for the triangle of sustainability relationships from Dyllick and Hockerts [56], the dimensional boundaries [49, 53], and operationalized absolute STM sustainability from Dickinson [28]. The result is reminiscent of Raworth's safe and just sustainable "doughnut" [9].

The circular model in Figure 2.3 synthesizes Dickinson's [28] STM pie chart, Dyllick and Hockerts' [56] three pillars (or domains) triangle and the concentric domains model of sustainability [49, 53] and represents the CSTM—a system of normalized sustainability indicators across these sustainability domains. The concentric circles represent the hierarchy of the sustainability domains: economy bounded by society, bounded by the environment. The social and environmental circles represent the carrying capacity for burden impacts or commitment targets for beneficial positive impacts; and, the economic circle represents the value generation of the economy (i.e., gross domestic product). The pie slice across the domains represent the proportionate impacts in each domain associated with the product, service, company, national economy or other system boundary under analysis.

Relationships are denoted by the arrows, with each arrow pointing from the first operand to the second and labeled with the operator defining the relationship. Productivities are denoted by straight solid arrows. Whereas, primary sustainability measures are represented as curved arrows. In this representation, sustainability indicators for burden impacts (referred to as *efficiency*), given as single-line curved arrows, are sustainable when the ratio of Productivity to Sustainable Productivity is greater than or equal to one. Conversely, sustainable beneficial indicators (referred to as *effectiveness*), denoted by double-line curved arrows, are sustainable when the inverse ratio of Sustainable Productivity to Productivity is greater than or equal to one.

2.4 Interdependencies of Sustainability Domains

The addition of social impacts and resilience enhances the comprehensiveness and expands the relevant space for sustainability applications and impacts; however, this additional complexity compounds the question of integration and complicates the ability to assess and interpret the interdependencies and relationships within and across the sustainability impact domains [21]. There is a lack of practical applications of structuring interdisciplinary and interdependent sustainability assessments [40, 41]. As noted, addressing sustainability in any domain has been a challenge that continues to remain out of reach. It may be no surprise that the interdependence of the sustainability domains has not been practically addressed.

Figure 2.3 further illustrates the capacity of CSTM to assess the interdependent relationships for sustainability. In addition to the basic sustainability indicators of CSTM which characterize social and environmental burdens and beneficial impacts in reference to economic impacts, secondary sustainability indicators, e.g. the relationship between impacts in the societal domain and the environmental domain, are depicted as dashed straight arrows between pairs of primary measures. CSTM's more robust conceptualization contributes quantitative insight into sustainable interdependencies, a new context that other sustainability assessments lack [21, 39, 103].

2.5 New Social Impact Categories

The progress in operationalizing social sustainability assessment identifies new areas that might be meaningful to corporate sustainability. One of the chief societal impacts of commercial activity is employment: People and communities gain significant well-being benefits from employment. Employment status has significant non-economic impacts on the worker. Studies show that unemployed and underemployed individuals are two to three times more likely than full-time workers to suffer from depression, chronic illness, and poor mental health [59]. In their study, Wilkinson and colleagues aptly note “Societies that enable all citizens to play a full and useful role in the social, economic, and cultural life of their society will be healthier than those where people face insecurity, exclusion, and deprivation” [59, p. 11]. Educational attainment improves incomes, productivity, employment opportunity, job satisfaction, job security, and increases other beneficial social outcomes [104, 105].

An existing social measure that is central to the United Nations’ concept of social sustainability that captures the education dimension of the population is human capital [106], The calculation for HC is based on the Klenow [52] method, wherein “human capital per worker is proportional to e^{rt}, where r is the appropriate rate of interest…and t is the average number of years of educational attainment. The stock of human capital is the human capital per worker multiplied by the number of workers” [65, 331].

$$HC = e^{rt} \tag{2.6}$$

To compute inclusive wealth in monetary units, the United Nations goes on to estimate values of the HC using demographics and wage rates [52, 106]. Environmental and social impacts are all in non-monetary units, so the human capital units computed as shown in Equation (2.6) are perfectly adequate to measure HC for the purposes of this research.

In addition to fulfilling general employment opportunities, the economic means obtained from employment is itself an important consideration for individuals and society at large. Income inequality is a key social consideration of employment and has been a focus of recent U.S. presidential candidates from both major political parties, the chair of the Federal Reserve, and many others [107-109]. It is self-evident that income inequality is most critical and least sustainable when employment compensation falls below the minimum required to meet the local cost of living.

A Living Wage (LW) is the wage level “required to meet minimum standards of living” [110] in a given area. Differences in estimated LW requirements for a household are dependent upon family compositions (e.g., adults and children in a family, employed family members) and geographic location [72]. The LWE, another newly proposed social impact for assessment in the social dimension, is based on a comparison of the market-wage distribution to LW.

CHAPTER 3

METHODOLOGY

3.1 Overview

This section describes the new analytical frameworks for estimating corporate environmental and social impact inventories and the proposed extensions to the theoretical and methodological bases of absolute sustainability assessments across sustainability domains.

3.2 More Efficient and Robust IOLCA

This work proposes methodological enhancements to IOLCA which are implemented in EIO-LCA. The first is a novel enhancement to the IOLCA computation using custom product direct input purchases to estimate direct environmental impacts of the custom product. Hence, it computes the internal impacts (II); to reflect this, the new model is referred to as IOLCA-II. The second modification is to incorporate social impacts along with environmental and economic impacts already represented in the EIO-LCA. Profitability impacts of the case study scenarios are analyzed as well. Social impacts have been implemented in other IOLCA databases [68, 76] and even demonstrated in EIO-LCA before [77], however, the demonstration did not have full sector detail, did not attempt a custom product assessment and current EIO-LCA model does not include social impacts.

The model extension implemented here has full sectorial detail and the extended model is applied to analyze custom product case scenarios with fully aligned environmental, social economic impacts. Profitability, as part of the economic tables that underpin the EIO-LCA, and dependent on the spending and employee compensation changes proposed in the case scenarios, is an informative addition to include in the analysis.

3.2.1 Internal Impact

In many cases, the impact rates for a sector are driven by spending on direct inputs to that sector. For example, the carbon equivalent GHG emissions column in R_E of Equation 2.4 is a vector, *r*, of the GHG emissions by output sector that is principally based on the industry average input spending on and combustion (or other use) of fossil fuels [111]. With industry average spending on and combustion of fuels fixed in the impact rate used in the IOLCA model, changes in direct spending on fossil fuels are not reflected in the direct emissions from R_E for a modeled custom product. In fact, direct emissions are not modeled within an IOLCA hybrid model, rather, those are left for the user to estimate separately by other means—and therefore referred to as a "hybrid" model [55, 77].

This research proposes to modify the methodology by incorporating matrices that explicitly track the input sector sources of impacts so that changes in spending in the input sectors that induce these impacts will be reflected in the direct impact rates of a modeled custom product. This induced input is referred to in the literature as the direct component of economic flows, i.e., final demand plus purchases from the immediate suppliers of final producers, is shown in Equation (3.1).

$$x_{direct} = (I + A)y \quad [77] \tag{3.1}$$

In Equation (3.1) x_{direct} is the direct output, y is final demand, and A is the direct requirements matrix. The variable y, interpreted as "per dollar of demand" is excluded from the rest of this derivation. Taking the input-output model, as in Equation (2.2), since A is composed only of decimal elements that are zero or fractions of 1, and higher-order terms (e.g. A^{10}) are negligible, the total requirements matrix T is preserved if an incremental direct input spending matrix is appended, as in Equation (3.2)

$$I + A(T) = I + A(I + A + AA + AAA + \cdots) = I + A + AA + AAA + \cdots = T \qquad (3.2)$$

Here, as above, direct requirements matrix of the final producer is A, of their tier one suppliers is AA, of their tier two suppliers of suppliers is AAA, etc. (representing the economic flows of the entire supply chain), and the total requirements matrix is T. The standard model is normally expressed in terms of the entire economy matrix, including all output sectors. Isolating a selected output sector appears in Equation (3.3) which restates Equation (3.2) for a single output sector.

$$Ts = (I - A)^{-1}s = (I + A(I - A)^{-1})s = s + a_s(I - A)^{-1} \qquad (3.3)$$

Here, s is a standard basis vector (consisting of all zeroes except a single element = 1 for a specific output sector), and a_s is the single sector vector of the direct requirements matrix A. Equation (3.4) computes the impact vector for a single sector.

$$bs = Rxs = RTs = R(I - A)^{-1}s \qquad (3.4)$$

Here, bs isolates an impact vector for a subject sector. Combining Equation (3.3) with Equation (3.4) yields Equation (3.5), single sector impacts with the supplemental direct output operation.

$$bs = RTs = R(I - A)^{-1}s = R(s + a_s(I - A)^{-1}) = r_s + Ra_s(I - A)^{-1} \tag{3.5}$$

In Equation (3.5), r_s represents direct emissions/impacts within the sector, and $Ra_s(I\text{-}A)^{-1}$ represents the upstream supplier impacts.

Whereas, R is a matrix of r_t output sector vectors for impact category t, Q_t is a set of t impact attribution matrices by input and output sector (dimensionally equivalent to A) used to trace the impacts by output sector generating the direct impacts to the direct input sector purchases, as in Equation (3.1), from which they are derived. In Equation (3.6), for impact category t, the Q_t matrix consists of the contributions to direct environmental impact in R to impact t per dollar spent for each input sector of the direct economic impact.

$$r_t = Q_t(I + A) \tag{3.6}$$

For a single sector and impact, a single element of the R matrix is defined in Equation (3.7).

$$r_{ts} = Q_t s(s + a_s) \tag{3.7}$$

Hence, each t category and s sector element in R is the dot product of direct spending by the output sector s and that sector vector from the Q_t matrix. The diagonal of each Q_t matrix represents the direct *t* category impacts for the output sector, independent of spending on inputs, and each of the other elements represent the impact for the output sector due to spending in each input sector. For example, the element of Q_{GHG} for the truck transportation output sector and the petroleum refinery input sector represents the GHG emissions per direct dollar spent by the trucking sector on purchases from the oil refinery sector. Thus, the direct impact for an output sector is the sum of the products of spending by input sector and impact per dollar for the input sector to that output sector. Some input sectors do not contribute directly to the impact, the elements of Q_t for those input sectors are zero, and spending on other sectors may generate upstream impacts. For a sector (or impact category) where some or all of the impact is independent of spending on inputs, that proportion of the impact will be in the diagonal element of Q_t, where the input sector equals the output sector. For example, consider water consumed from bodies of water rather than from a utility. There may be no input sector spending that induces the impact, in which case the impact will simply be associated with the output sector itself (on the diagonal of the Q_t matrix). Impacts that are not driven by direct spending will not benefit from the IOLCA-II formulation.

To model a sector s using the IOLCA-II (with spending unchanged), Equation (3.8) from Equation (3.5) and Equation (3.7), is used for each impact category *t*;

$$b_t s = Q_t s(s + a_s) + r_t a_s (I - A)^{-1} \tag{3.8}$$

and for a specific product with spending of a_S^*, different spending than the baseline a_S , and with impact for purchase rates from sector s**.** Equation (3.9) is the general mathematical form of the IOLCA-II model generating, by IOLCA, a spending sensitive direct impact and indirect impact inventory for impact *t* for a specific product.

$$b_t^* s = Q_t s(s + a_s^*) + r_t a_s^* (I - A)^{-1} \tag{3.9}$$

Assuming that a sector with suitable impact per dollar of direct expense rates (as a sector vector of Q_t) can be identified, this model will generate an impact estimate for a specific product directly within the IOLCA-II model, with all of the benefits of using an IOLCA. This expression identifies the incremental impact information produced by the IOLCA-II model, where $r_t a_s^* (I - A)^{-1}$ represents the IOLCA upstream hybrid model and $Q_t s(s + a_s^*)$ represents the internal impact. By virtue of the distinct expression for emissions within the operation in IOLCA-II and immediate supplier context of direct impacts in the EIO-LCA model the impacts can also be further segmented, as shown in Equation (3.10).

$$\begin{aligned} b_t^* s = {} & Internal\colon Q_t s(s + a_s^*) + Direct\ suppliers\colon\ r_t a_s^* \\ & + Upstream\colon (\ r_t a_s^* (I - A)^{-1} - r_t a_s^*) \end{aligned} \tag{3.10}$$

The EIO-LCA model supports the estimation of multiple environmental impacts, and IOLCA-II is also capable of supporting all of those impacts. Implementing the IOLCA-II model requires the development of distinct Q_t matrices for each impact to be modeled. As the environmental impact that is the most pressing current concern, carbon-equivalent GHG (inclusive of all GHGs stated in terms of carbon-equivalent emissions) is the only environmental impact analyzed in the IOLCA-II case scenarios.

Generating distinct Q and R matrices that coincide with expressions of the Scope 1, 2, and 3 operational boundary definitions commonly used for GHG emission reporting [88, 89]. These boundary definitions identify scope determined by the type of emissions (which are related to the spending sector) and whether the emission is within the company or by a direct or remote supplier, as in Equation (3.11).

$$\begin{aligned} b_t^* s = {} & Scope\ 1{:}\ Q_{C1} s(s + a_s^*) + Scope\ 2{:}\ Q_{C2} s(s + a_s^*) + r_{c2} a_s^* \\ & + Scope\ 3{:}\ Q_{C3} s(s + a_s^*) + (r_{c3} a_s^* + (r_{c2} + r_{c3}) a_s^* (I - A)^{-1}) \end{aligned} \tag{3.11}$$

As a reminder of the Scope definitions, Scope 1 represents the emissions for combustion of fossil fuels within the corporation itself, Scope 2 represents emissions of direct suppliers of energy and Scope 3 the emissions of direct suppliers other than energy and further upstream suppliers [88, 89]. Here, Q_{C1} is the carbon equivalent GHG emission by direct spending matrix for Scope 1, Q_{C2} for Scope 2 and Q_{C3} for Scope 3, and r_{C2} is the supplier carbon emission vector for Scope 2, r_{C3} for Scope 3. This formulation of the model should support extremely efficient fully expense-data driven carbon emission estimates in agreement with current reporting standards. By definition of Scope 1 and the Q_{C1} matrix, Q_{C2} and Q_{C3} are most likely all zeroes, but Equation (3.11) permits for the possibility that emissions from some direct emission is categorized as other than Scope 1. The vectors $\mathrm{r}_{\mathrm{c}2}$ and $\mathrm{r}_{\mathrm{c}3}$ differentiate emissions from direct suppliers that are categorized as Scope 2 (e.g., energy utilities) and emissions from Scope 3 direct suppliers (e.g. input manufacturers). The sum of $\mathrm{r}_{\mathrm{c}2}$ and $\mathrm{r}_{\mathrm{c}3}$ multiplied by the further upstream purchases recognizes that emissions from indirect suppliers of all sectors generate the balance of Scope 3 emissions in the supply chain.

This model and set of scope-based impact matrices generates the supply chain emissions by scope boundary using nothing more than categorized expense data that most corporations collect for financial reporting.

For this research, GHG emission factors by direct spending sector (as sector vectors of Q_t) have been developed for the baseline sectors, the colleges and universities sector, and the truck transportation sector. The IOLCA-II impact factors are calculated using the EIO-LCA fuel source data, energy density per dollar by fuel source sector, emission factors for energy by fuel source [111], output sector emission rates—GHG rate per dollar for the output sector, from the matrix R [112]—and direct spending by the fuel source sector [112, 113]. This decomposes the single element output sector emission rate from R_E into the emission rate by the direct spending sector vector that causes emissions within the corporation dependent on, and responsive to, direct spending by the input sector, instead of the impact rates in R_E that are unresponsive to, or independent of, spending.

3.2.2 Social Impacts

Employment, a social beneficial impact, and workplace fatalities, a social burden impact, are two of the most important direct social impacts of economic activities and they are standard in corporate sustainability reports [114, 115]. It was beyond the scope of this research to define an IOLCA-II relationship for employment or fatalities based on direct spending, therefore scenario social impacts are estimated using the hybrid LCA method. In Equation (2.4), EIO-LCA uses the matrix R to represent the environmental impact rates per dollar in each input sector. Two new vectors are added to R to introduce social impacts into the model. Of note, the EIO-LCA model itself includes human health and toxicity characterization results following the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI), which uses emissions inventories to estimate human health consequences [116]. The workplace safety fatality impact introduced here is based on workplace employee fatalities of all causes within each sector, inclusive of toxic exposure, accidents, and other causes.

Following the method described to estimate direct employment [117] and used in the reduced sector occupational safety implementation with EIO-LCA [60], the nominal 2002 employment productivity (to conform to the EIO-LCA economic data) rate per dollar of output from by output sector [118], are used to populate the employment impact vector of the impact matrix R. Fatality rates by output sector [119] are multiplied by the employment vector to compute the fatality impact by sector vector of R_E. To account for differences in sector granularity between the sources, some of the sector rates are from less detailed sector groups and are mapped to the EIO-LCA sectors. The employment and fatality vectors by sector are included in the appendix.

3.2.3 Profitability

The economic profitability is obtained from the 2002 benchmark version of the Bureau of Economic Analysis (BEA) Use table [120] corresponding with the input-output data used to produce the economic element of the EIO-LCA model. Profitability for each scenario is adjusted based on the spending and employment changes.

3.3 Comprehensive Sustainability Target Method

Following the suggested framework and terminology from the literature review, an extension of the STM is presented here. To facilitate its presentation, the definition for Value Productivity and Sustainable Value Productivity are represented mathematically with the following variables and parameters, permitting generalization into the social domain and beneficial impacts. The definitions below are in reference to the assessed system boundary, representing the business organization, product lifecycles, value chain, industry sector, national economy, or any subset or superset thereof, and the temporal boundary with analysis performed typically on an annual basis.

3.3.1 Impacts

d_i = value generated or other economic impact (i) within the assessed system boundary.

D_{gi} = total value generated or other economic impact (i) within the geographic or spatial boundary (g).

b_j = burden or beneficial impact (environmental, social or other domain) within the assessed system boundary for impact category (j).

B_{gj} = impact limit or target commitment (carrying capacity for burden impact and commitment level for beneficial impact) within the geographic or spatial boundary (g) for impact category (j). Note: the economic and impact boundaries must be the same.

3.3.2 Impact Productivity Ratios

$p_{ij} = d_i / b_j$ = productivity for burden or beneficial impact (j), associated with the economic value or other economic impact (i) per unit of environmental, social or other impact within the assessed system boundary.

$SP_{gij} = D_{gi} / B_{gj}$ = the sustainable productivity for burden or beneficial impact (j), associated with the total economic value or other total economic impact (i) per unit of impact limit capacity/target commitment for burden or beneficial impact (j) within the geographic or spatial boundary (g).

3.3.3 Efficiency and Effectiveness Indicators

$E_{gij} = \frac{p_{ij}}{SP_{gij}}$ = efficiency for an economic impact (i) and burden impact (j) within a geographic or spatial boundary (g).

$E_{gij}^{\oplus} = \frac{SP_{gij}}{p_{ij}}$ = effectiveness for an economic impact (i) and beneficial impact (j) within a geographic or spatial boundary (g), with the $\oplus$ symbol denoting that this indicator applies to positive impacts.

Effectiveness, as expressed here, is a non-dimensional ratio and adopts a usage from sustainability terminology with application to beneficial impacts [56, 96]—especially social impacts, but also for environmental impacts, as well. Whereas efficiency is a non-dimensional relationship between productivities, effectiveness is the non-dimensional relationship between intensities. As noted earlier, intensity is the inverse of productivity; consequently, effectiveness is the mathematical inverse of efficiency.

To illustrate the application of the definitions and nomenclature above, consider the climate change STM example described in the previous section: Equation (3.12) represents the efficiency for climate change impact by letting i = annual economic value added (V) and j = annual carbon-based GHG emissions (C) with the geographic boundary being global (G). Note the alignment of the geographic boundary for both the value generation in the global economy and the global carrying capacity for emissions in the sustainable productivity ratio and the system (corporate) boundary alignment for both value added and GHG emissions in the corporate productivity ratio. As stated previously, sustainability is indicated when the efficiency ratio of impact productivity to sustainable impact productivity, E_{GVC}, is greater than or equal to one.

$$E_{GVC} = \frac{p_{VC}}{SP_{GVC}} \tag{3.12}$$

By substituting specific impact values given above, the efficiency can be written as:

$$E_{GVC} = \frac{{d_V}/{b_C}}{{D_{GV}}/{B_{GC}}} \tag{3.13}$$

The following Equations (3.14)-(3.15) generalize the STM definition of sustainability, by replacing specific impact category and boundary subscripts with economic impact *i*, environmental burden *j*, on geographic boundary *g*. Sustainability for system burden j indicated when

$$ {d_i}/{b_j} \geq {D_{gi}}/{B_{gj}} \text{ or } p_{ij} \geq SP_{gij} \tag{3.14}$$

And, in terms of efficiency, sustainability for system burden *j* is achieved when

$$\frac{p_{ij}}{SP_{gij}} \geq 1 \; or \; E_{gij} \geq 1 \tag{3.15}$$

The STM threshold of sustainability generally holds for social burdens under CSTM: the burden is sustainable when system productivity equals or exceeds the sustainable productivity, as in Equation (3.14), based on the total economic impact within the geographic boundary and capacity for the burden within the geographic boundary. This elementary generalization extends STM to evaluate social burdens in exactly the same manner as environmental burdens. This extension addresses one of the challenges in sustainability assessment reported by Guinée [21].

Another key challenge to sustainability assessment is consideration of positive (beneficial) impacts [21]. While environmental impacts are predominately burdens, social impacts are often beneficial (e.g., employment, human capital, etc.). It is important to note that several new and innovative environmental technologies with beneficial impacts are in development, including carbon capture, freshwater synthesis, and others. Furthermore, sustainability strategies such as cradle-to-cradle describe multi-lifecycle behaviors where waste streams are reengineered to become valuable feedstocks [8, 121, 122], inputs which could demand minimum commitment threshold levels.

Efficiency *greater than or equal to one* indicates if the burden impact is less than the carrying capacity allocated to the system being assessed. However, for beneficial impacts the inverse is true: the goal is for the impact to be greater than the commitment level allocated to the system being assessed. If efficiency is used to assess sustainability of beneficial impacts, communicating sustainability results could be more confusing than necessary. To overcome this situation and simplify communication of sustainability assessment [21] and provide consistent presentation of sustainability assessment results, the CSTM assesses sustainability of beneficial impacts using effectiveness indicators. Recall, effectiveness is the inverse of efficiency. To derive this sustainability relationship for effectiveness, the inverse of the sustainable efficiency relationship of a burden impact *j* as in Equation (3.14), defines sustainability for a beneficial impact (k), as set forth in

Equation (3.16). For beneficial social impacts, the sustainability indicator is socio-effectiveness, the inverse of socio-efficiency. Likewise, for beneficial environmental impacts, the sustainability indicator is ecoeffectiveness instead of ecoefficiency. Sustainability for system benefit k is indicated when ${}^{b_k}\!/_{d_i} \geq {}^{B_{gk}}\!/_{D_{gi}}$

$$ {}^{b_k}\!/_{d_i} \geq {}^{B_{gk}}\!/_{D_{gi}} \text{ is equivalent to } {}^{d_i}\!/_{b_k} \leq {}^{D_{gi}}\!/_{B_{gk}} \text{ or } p_{ik} \leq SP_{gik} \tag{3.16} $$

And, in terms of effectiveness, sustainability for system benefit k is indicated when

$$ \frac{SP_{gik}}{p_{ik}} \geq 1 \text{ or } E_{gik}^{\oplus} \geq 1 \tag{3.17} $$

To achieve sustainability under CSTM, based on the theory of constraints and normalization construct, the system efficiency and effectiveness indicators must all equal or exceed one for each assessed burden or beneficial impact. The CSTM framework is sufficiently robust and scalable to accommodate sustainability assessment beyond the economic, environmental and social domains to any other arbitrary domain with burdens and benefits deemed relevant to the system being evaluated.

Table 3.1 Comprehensive Sustainability Target Method Sustainability Indicators

Name	**Importance**	**Formula**	**Impact example**
Ecoefficiency = Environmental Productivity/Sustainable Environmental Productivity (Dickinson 1999)	Critical Primary metric	$E_{gij} = \frac{p_{ij}}{SP_{gij}} = \frac{d_i/b_j}{D_{gi}/B_{gj}}$	Global (g) geographic boundary value generation (i) and carbon equivalent greenhouse gas emissions (j)
Eco-effectiveness = Sustainable Environmental Productivity/Environmental	Potentially important, as technology for beneficial environmental impacts develops Primary metric	$E_{gik}^{\oplus} = \frac{SP_{gik}}{p_{ik}} = \frac{D_{gi}/B_{gk}}{d_i/b_k}$	Watershed (g) value generation (i) and freshwater synthesis (k)
Socio-efficiency = Social Productivity/Sustainable Social Productivity	Critical Primary metric	$E_{gij} = \frac{p_{ij}}{SP_{gij}} = \frac{d_i/b_j}{D_{gi}/B_{gj}}$	Metropolitan area (g) value generation (i) and work-related illness (j)
Socio-effectiveness= Sustainable Social Productivity/Social Productivity	Critical Primary metric	$E_{gik}^{\oplus} = \frac{SP_{gik}}{p_{ik}} = \frac{D_{gi}/B_{gk}}{d_i/b_k}$	Global (g) value generation (i) employment (k)
Ecological equity= Ecoefficiency * Socio-effectiveness	Important Secondary metric	$E_{gjk} = E_{gij}E_{gik}^{\oplus} = \frac{b_k/b_j}{B_{gk}/B_{gj}}$	Global (g) greenhouse gas emissions (j) and employment (k) —value generation (i) cancels
Sufficiency= Eco-effectiveness *Socio-efficiency	Less important; the significance of these interactions is less intuitive Secondary metric	$E_{gjk} = E_{gij}E_{gik}^{\oplus} = \frac{b_k/b_j}{B_{gk}/B_{gj}}$	Watershed (g) water synthesis (k) and work-related illness (j) —value generation (i) cancels
Economic Yield = system economic impact/required economic impact	Critical Primary metric	$E_i = {}^{d_i}/_{D_i}$	System bound profit rate (i) and target profit rate (required rate of return)
Social Yield = Socio-effectiveness * Socio-efficiency	Important Secondary metric	$E_{gjk} = E_{gij}E_{gik}^{\oplus} = \frac{b_k/b_j}{B_{gk}/B_{gj}}$	Metropolitan area (g) employment (k) and work-related illness (j) —value generation (i) cancels
Environmental Yield = Eco-effectiveness* Ecoefficiency	Less important Secondary metric	$E_{gjk} = E_{gij}E_{gik}^{\oplus} = \frac{b_k/b_j}{B_{gk}/B_{gj}}$	Global (g) freshwater synthesis (k) and greenhouse gas emissions (j) —value generation (i) cancels

3.3.4 Interdependencies of Sustainability Domains

An additional advantage of assessing benefits with effectiveness and burdens with efficiencies is the capability to assess the interdependencies between impacts, which is another key challenge for sustainability assessment [21]. In addition to the primary sustainability indicators: *ecoefficiency, socio-efficiency, ecoeffectiveness and socio-effectiveness*, the CSTM also includes secondary indicators composed of the product of pairs of the primary indicators. These secondary indicators measure the interrelationship between the environmental and social domains for a given assessed system economic impact level. For example, the secondary indicator *sufficiency* depicted in Table 3.1 is composed of the ecoeffectiveness of a beneficial environmental impact multiplied by the socio-efficiency of a social burden. The secondary measure referred to as *ecological equity*, is obtained directly by multiplying the socio-effectiveness of a social beneficial impact by the ecoefficiency of an environmental burden. This formulation projects the overt sustainability triangle and STM relationships onto the concentric circle model, operationalizing the sustainability relationships into the set of comprehensive CSTM metrics.

To assess sustainability for a given pair of non-economic (environmental and/or social) impacts using the secondary indicators, the following conditions must be satisfied in order for the multiplicative procedure to generate meaningful results: (1) one impact must be a burden and the other one must be beneficial impact; and, (2) the geographic boundaries must be aligned. To illustrate this procedure, the secondary indicator, ecological equity E_{gjk} is derived in Equation (3.18) for geographic boundary g, economic impact i, environmental burden impact j, and social beneficial impact k. These secondary indicators measure sustainability with the result being an efficiency in which sustainability is achieved when its value is greater than or equal to one.

$$E_{gjk} = E_{gij} * E_{gik}^{\oplus} = \frac{p_{ij}}{SP_{gij}} * \frac{SP_{gik}}{p_{ik}} = \frac{d_i/b_j}{D_{gi}/B_{gj}} * \frac{D_{gi}/B_{gk}}{d_i/b_k} = \frac{b_k/b_j}{B_{gk}/B_{gj}} \qquad (3.18)$$

The CSTM can also assess economic sustainability without regard to impacts in the environmental or social domains by setting corporate-level economic targets, e.g., profitability expressed as the actual profit rate divided by the target rate of return. Stated this way, a profitability assessment or any other economic measure can be framed as a ratio of actual-to-target values. The *economic yield* ratio indicates economic sustainability when it equals or exceeds one and is compatible with and completes the CSTM assessment framework.

The complete set of CSTM sustainability indicators and metrics are listed in Table 3.1. Although as discussed above, secondary indicators are determined by primary sustainability indicators and express interdependencies between the environmental and social domains. These measures are critical to understanding sustainable practices and strategies, especially in cases wherein one or more of the primary indicators show impacts to be unsustainable.

3.3.5 System and Spatial Boundaries

Water withdrawal and consumption creates a local and regional environmental burdens, the carrying capacity must be estimated for each local area and a local GDP must be estimated to perform an STM assessment for water.

Net water availability is provided for each of the 23 Water Supply Planning Areas (WSPA) in New Jersey, including both surface ground water resources. Figure 3.1 shows the WSPAs and their intersection with the county boundaries, the differences have to be reconciled to relate carrying capacity to the county level. Estimates of New Jersey water supply were obtained from [123]. The WSPAs were analyzed using ArcView GIS with shapefiles from [124] and [125] to attempt to allocate water supply to county by area, treating the WSPAs as uniform sources of water.

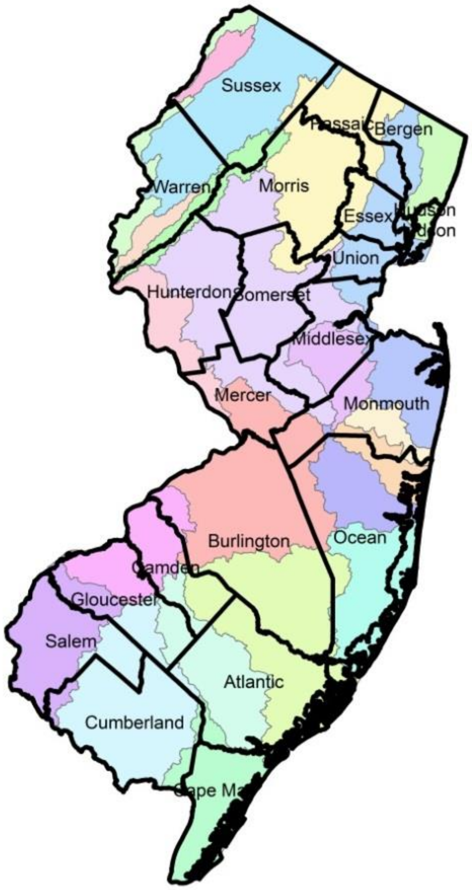


Figure 3.1 Arcview GISMap of New Jersey Counties (outlined) and water supply planning areas (shaded)
Source: [124, 125]

The BEA publishes national GDP, GDP by state, and GDP by Metropolitan Statistical Area (MSA), and county [126]. The county GDP estimates and water supply estimates are used to produce local sustainable productivity values by county. The results varied widely. Ranging from 46 USD/m^3 Water in Salem County to 543 USD/m^3 water in Camden County, these results mean that these estimates impact CSTM by a factor of 10 when comparing these two counties. Some key shortcomings of these results are:

- Water movement between water supply areas, especially for the urban areas with large economies was not considered but is important.
- Further investigation into the validity of subdividing the water supply and GDP needs to be undertaken.

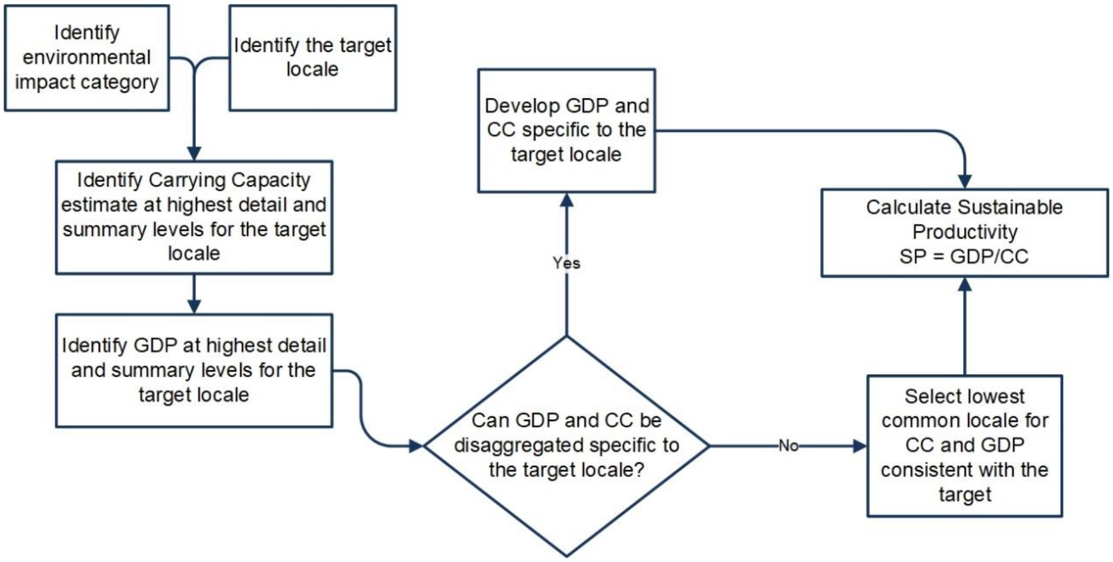


Figure 3.2 Flowchart of selecting reference carrying capacity and GDP for a regional level impact to calculate sustainable productivity for STM analysis

In light of these shortcomings and the process for selecting reference locale as described in Figure 3.2, the state level GDP and Carrying Capacity are used to calculate sustainable productivity for freshwater in New Jersey, and compare those results to the national sustainable productivity for freshwater. New Jersey and national GDP, carrying capacity, and sustainable productivities for are shown in Table 3.2.

Table 3.2 Freshwater Carrying Capacity, Gross Domestic Product and Sustainable Productivities for the United States and New Jersey

Geographic Area	GDP 10^6 USD [126]	CC 10^6 m^3 Water	Sustainable Productivity USD/m^3 Water
New Jersey	439,275	2,426 [123]	181.10
United States	13,029,325	3,069,000 [127]	4.25

Aside from the spatial impact boundaries, there is also the question of selecting the correct system boundary for analysis. As a global impact, the location of GHG emissions is not considered to be consequential, so system boundary selection will not conflict with the spatial boundaries of GHG impact, any arbitrary subset of the full lifecycle will still contribute to global GHG concentrations. As a local impact, the spatial boundary of the local water resource may be relevant to the system boundary selection as well. For example, the system boundary representing operation phase for a renewable energy system installation will consume water in the location where the installation is. A system boundary that includes the full supply chain will include impacts in other regions and nations depending on where components are sourced, impacts outside the boundary of a specific water supply resource are not relevant to that spatial boundary.

Finally, with spatial and system boundaries selected, a valid application of CSTM requires that the boundaries are applied consistently across the sustainability domains. Consistency in boundaries is fundamental to the CSTM indicators providing meaningful insights into the assessed systems.

3.3.6 CSTM Compared to Other Techniques

To summarize the scope, comprehensiveness, and robustness of the CSTM, the Sala, Ciuffo, et al. framework categories, criteria, and ranges described in the previous section is used to assess the STM and CSTM and compare core features and characteristics against other commonly used sustainability assessment tools. Figure 3.3 presents the results of this assessment in terms of radar charts which should be compared directly with the charts in Figure 2.2 for other sustainability tools and techniques.

Following Sala and Ciuffo's assessment protocol, the outcomes of the sustainability framework assessment for STM and CSTM are as follows: The STM is defined by carrying capacity boundaries which can be established by policy or determined by science, and relate to two domains—the economic and environmental. Applying the categories and value ranges of Sala and Ciuffo's framework, STM's *Integratedness* is categorized as being interdisciplinary in its interdomain relationships. Stakeholder involvement in the STM is determined by how targets are set and that is still an open issue. STM is highly scalable to any subject and impact where economic and environmental impacts can be aligned. STM's *Strategicness* and *Transparency* is driven in part by how thresholds are set; consequently, these two features are assessed and evaluated to be at the medium levels. The CSTM adds social domain with extensibility to any other domain of burden and directly includes analysis of positive impacts, generalizing sustainability assessment to cover multiple domains and increasing *Comprehensiveness*. CSTM also adds interrelationships within and between all sustainability domains, which is at the trans-disciplinary level of *Integratedness*. Note: it is acknowledged that scoring for this category is dependent on the sustainability impact limit thresholds and how these are determined, as well as the system boundary and impact category selections when CSTM is applied.

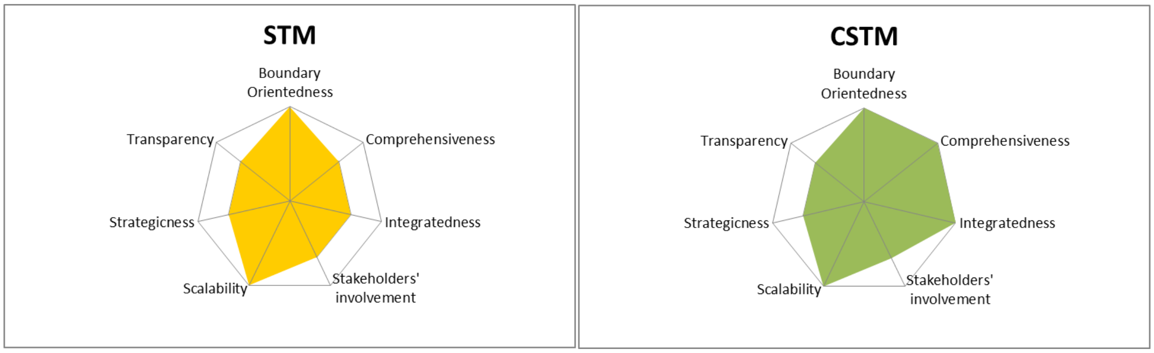


Figure 3.3 Sustainability assessment tool comparison for sustainability target method and comprehensive sustainability target method
Source: Prepared using criteria and format from [39]

3.4 CSTM Sustainable Corporation Principle

Taken together, several of the issues that this dissertation addresses suggest that the lack of recognition of a sustainable corporation principle has hampered absolute/threshold sustainability assessment that accommodate environmental and social domains for burden and positive impacts and interrelationships between sustainability domains [21]. Building on the previous definitions of sustainability, as operationalized under CSTM, a sustainable corporation's profit maximization is subject to all sustainability constraints. As noted, there are a variety of definitions of the term *sustainability* [16, 128]. The unique comprehensiveness and absolute basis of the CSTM make it possible to establish a meaningful and quantifiable principle for sustainable corporations:

> ***CSTM principle for corporate sustainability:*** *To be sustainable under CSTM, the corporation must meet profitability targets and remain within the proportional*

carrying capacity for all environmental and social burden impacts and meet the proportional commitment for all beneficial environmental and social impacts.

3.5 New Social Impact Categories

Two new social impact categories are proposed that illuminate some aspects of the quality of employment opportunity offered by economic activity. Simple employment opportunity is only one feature of the relationship between the corporation and society, another question relates to the quality of employment opportunities. Different employment options offer different levels of individual fulfillment and engagement from the nature of the work and financially from the compensation it offers [105]. Detailed below, Human Capital Employment (HCE) is proposed to measure fulfillment and engagement; Living Wage Employment (LWE) is proposed to measure economic quality of employment.

The value generated by economic activity, over and above purchases for intermediate inputs, ultimately flows to profits, employee compensation, or taxes. Compensation and poverty statistics are compared with corporate profits to examine the state of the social impacts of the economy, both in utilization, for an employment impact prognosis, and compensation, which impacts living wage questions. In a newly developed comparison of statistics, to explore the status of the labor force both for utilization and compensation, profit, compensation and poverty rates are compared. The trend of annual percentage change from the base year (1989) trend for the U.S. poverty rate %, the after tax corporate profits as % of Gross Domestic Income (GDI) and employee compensation as % of gross domestic product (GDP) are compared in Figure 3.4. The U.S. economy is used for this assessment due to availability of data and the importance of the U.S. as the world’s largest economy.

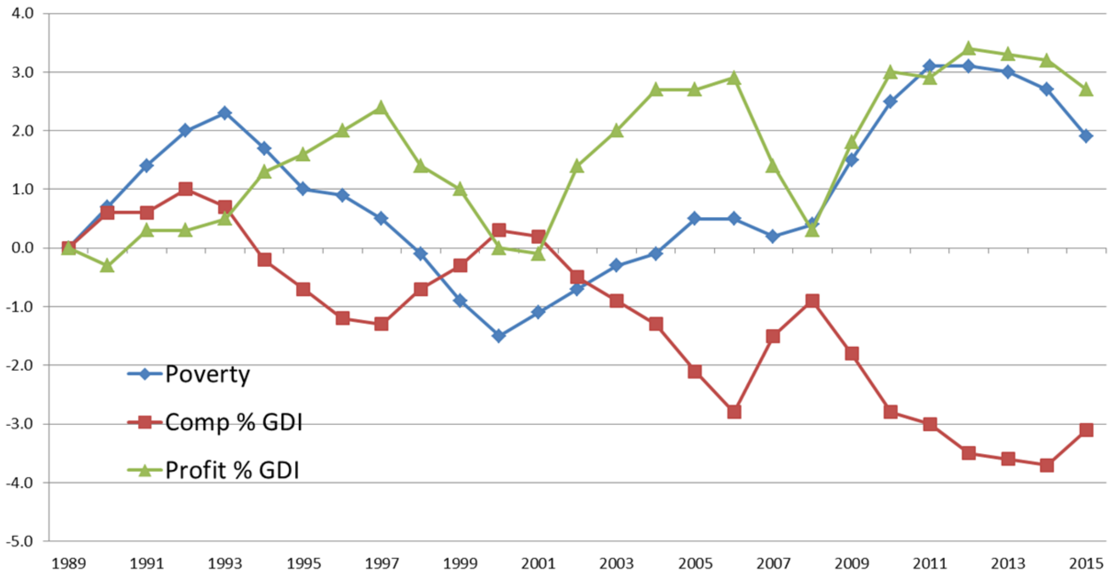


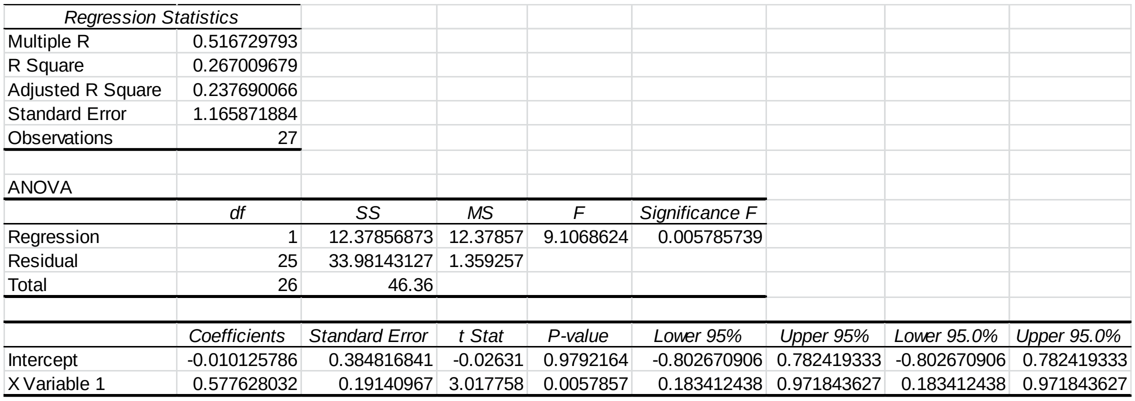
Figure 3.4 Percent change from 1989 for the U.S. Poverty Rate %, U.S. Corporate Profits % of GDI, U.S. Employee Compensation % of GDI 1989-2015
Source: [129]

Figure 3.4 shows that in the period from 1989 to 2015 corporate profits as % of GDI have increased 3% (3.6% to 6.3% [129]) while compensation as % of GDI has declined by 3% (56.2% to 53.1%[129]) and at the same time the poverty rate has increased from 12.8% to 15.5% in 2014 [129]. This suggests increased profits are coming directly from compensation and employment and resulting in increased poverty rates. Reducing labor utilization and/or compensation rates represent a cost savings to the firm and it is standard practice to increase profits. Unfortunately, aside from profit rate and poverty rate looking related, a statistical analysis illustrates the degree of correlation. The annual change in compensation as a % of GDI is highly negatively correlated with the annual change corporate profit as % of GDI—this is obvious: value added goes to profit or compensation, increase one and the other falls. Critically, the annual change in the poverty rate is also well correlated with the annual change in corporate profit as % of GDI. The ANOVA table for the analysis is in Table 3.4 showing the model explains the relationship of changes in poverty rates with changes in corporate profit as % of GDI at a 0.6% level of significance. This is a statistically significant result.

Table 3.3 Statistical Analysis of Profit, Compensation and Poverty Rate

Measure	***1989***	***2015***	***Annual Change R to Profit % GDI***
Corporate Profits % of GDI	3.6	6.3	1.00
Compensation % of GDI	56.2	53.1	-0.91
Poverty Rate %	12.8	14.7	0.52

Table 3.4 ANOVA of Annual Change in Corporate Profit % of GDI and Poverty Rate



Regression Statistics	
Multiple R	0.516729793
R Square	0.267009679
Adjusted R Square	0.237690066
Standard Error	1.165871884
Observations	27

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	12.37856873	12.37857	9.1068624	0.005785739
Residual	25	33.98143127	1.359257		
Total	26	46.36			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.010125786	0.384816841	-0.02631	0.9792164	-0.802670906	0.782419333	-0.802670906	0.782419333
X Variable 1	0.577628032	0.19140967	3.017758	0.0057857	0.183412438	0.971843627	0.183412438	0.971843627

3.5.1 Human Capital

The new proposed social impacts are calculated to incorporate into EIO-LCA as with employment and fatalities, above. The HCE demanded by an industry is defined here as the total supply chain employment (direct and indirect employment) multiplied by Human Capital (HC) per position based on the weighted average employee educational requirement and the discount rate. HCE impact rate vectors by sector are developed following the method used to add workplace safety (fatalities) to the IOLCA-II. To estimate per capita HCE by industry, occupations by industry data [130] are used to weight education by occupation statistics [131] and to calculate weighted average education by industry. The HCE-output ratio vector by industry is computed as industry employment-output ratio*e^{rt}. The HCE vector is included in the appendix.

The weighted average educational attainment for schools is 14.7 years of education with a per capita HC of 3.241. The industry HC is multiplied by industry employment per 10E06 USD of output to generate the direct HCE/output rate for the industry. For schools, the industry employment-output ratio is 31.34/10E06 USD [132] multiplied by an HC of 3.241, which equals 101.56. For comparison, college, junior college, and university (hereafter collectively referred to as universities) employees have an educational attainment of 15.0, and a direct HCE is calculated as employment-output ratio 11.24/10E06 USD [132] multiplied by an HC of 3.324, which equals 37.36.

Note, the assumption here is that the education levels and occupation composition by industry in the global supply chain is consistent with the U.S. economy. With significant investment it may be possible to identify input by country and use appropriate education and employment statistics by country to accurately represent global supply chain impacts.

A proposed commitment target for HCE is represented by the labor force multiplied by the respective per capita HC estimate.

3.5.2 Living Wage

To evaluate and compare employee compensation to LW requirements, it is crucial to recognize that both represent wage distributions and that many factors contribute to an individual employee's compensation and other factors to LW levels. Together, these factors determine if the supply chain employment wage distribution meets or exceeds the required LW distribution for the households in the economy. Wage distributions are commonly compared using the median wage data, a population parameter; however, CSTM and EIO-LCA work in terms of impact inventories, specifically the quantity of impact units: economic, environmental, or social. To account for the difference in a population parameter and the required quantity of impact units, the measure proposed is LWE—i.e., the number of persons employed who earn at least the median LW.

Except for the very highest and lowest levels of compensation, wages are observed to have a lognormal (LN) distribution [133]. As lognormal distributions, the Cumulative Distribution Function (CDF) of each varies dependent on the location parameter (μ) and scale parameter (σ). When comparing the CDFs of 2 lognormal distributions that vary by σ with a fixed μ as seen in Figure 3.5, the distribution with a higher σ exceeds the lower σ curve (is to the right of the lower σ curve) above the median (the 50th percentile, where half the population is higher and half is lower), but is less than the lower σ curve (to the left of the lower σ curve) below the median and vice versa. For example, the CDF for LN(μ=ln($15.00), σ=$1.00) falls below the CDF of LN(μ=ln($15.00), σ=$0.50) for wages below the median of $15.00, but is higher above the median. Comparing to CDF of LN(μ=ln($20.00), σ=$0.50) the entire curve shifts to higher wages when the μ is higher. More generally, the curve with a higher σ will exceed another CDF for all points above an intersection of the two curves.

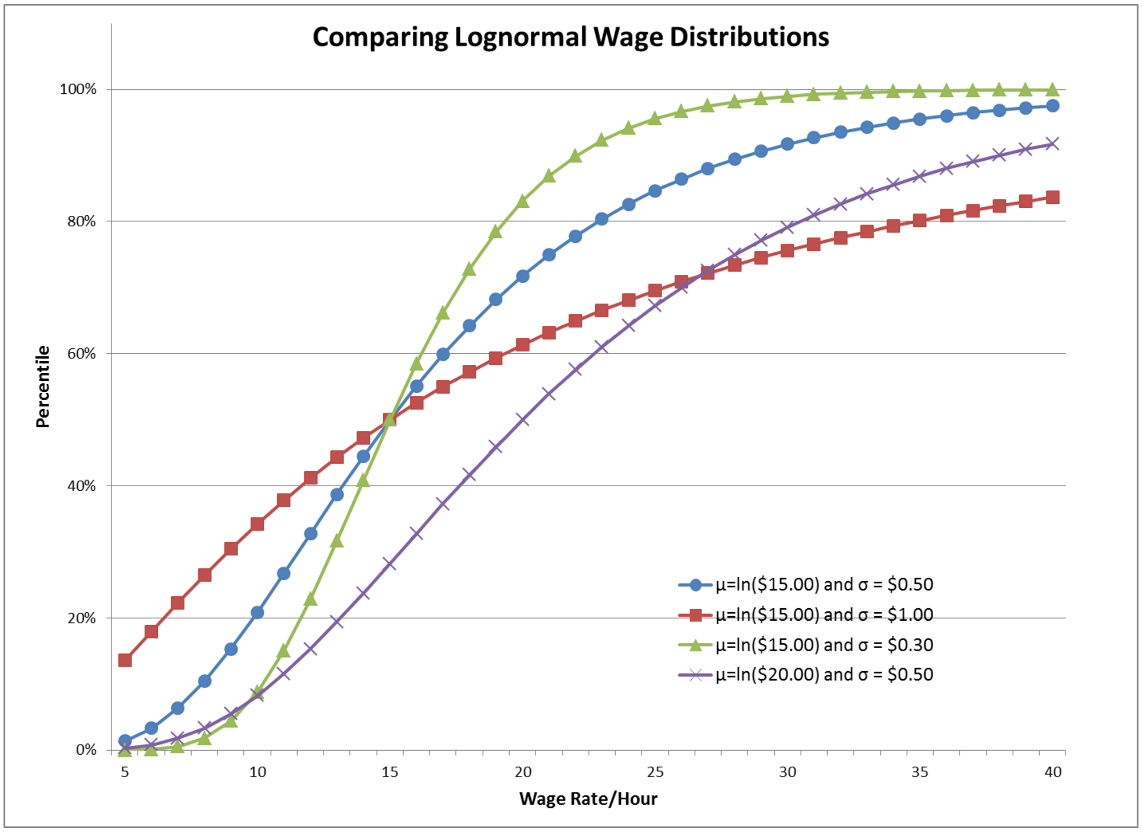


Figure 3.5 Comparing hypothetical CDFs of lognormal wage distributions under varying location or scale parameter values

The LW is a minimum, i.e., what is the minimum compensation required to fulfill basic economic needs for a given family composition and geographic location? As such, the σ for the LW is expected to be and observed to be lower than that for any of the industry wage distributions. From Figure 3.5, since σ of the wage distribution is higher than the LW distribution, the concern is that lower compensation percentiles fall below the LW, even when medians of the distributions are equal. Minimum wage laws help to limit this concern, even if the distribution is generally lognormal, compensation rates cannot be below the applicable legislated minimum wage, resulting in a compression of the distribution at lower compensation rates.

So, if the median employment compensation is less than the median LW, then the compensation distribution certainly does not meet the LW requirement. Since σ is typically higher for a given wage distribution than the LW distribution, it is not feasible that the given wage distribution where the median exceeds the median LW also fails to exceed the living wage at higher percentiles. Finally, the wage distribution compresses when close to legislated minimum wage rates, so it is also highly unlikely that when the median of a wage distribution exceeds the median LW, that the given wage distribution also fails to exceed the LW at lower percentiles. Based on this, it is proposed to compare the median of a given wage distribution against the median of the LW distribution to determine if the compensation distribution exceeds LW requirements.

To align this measure with other impact inventory measures used in STM and EIO-LCA, the median (which is synonymous with: 50% of the population is above wage x.xx USD) is converted to a population measure. For industry LWE, an estimate of the number of employees above the median LW is calculated. A proposed minimum commitment for LWE is a compensation distribution that provides at least half of the labor force compensation in excess of the median required living wage.

The state LW's are weighted by state population and household composition to derive a national LW distribution. Each of the state LW profiles of LW requirements by household composition [110] are weighted by each state’s proportion of the total labor force [134] and national statistics for household size composition [135] and the number of workers by household size [136]. The median required LW is identified from this population and household composition weighted LW distribution.

To generate a vector of LWE by industry sector, each industry’s 10th, 25th, 50th, 75th, or 90th percentile wage-distribution compensation rates [137] are used to estimate, by linear interpolation, the proportion of industry employment that exceeds the median LW. The LWE rates by industry are then multiplied by the employment-output ratio vector, resulting in a vector of LWE-output ratios for the EIO-LCA model, which is included in the appendix.

Rather than the median LW, any target percentile (p) of the LW distribution could be selected depending on the purpose of the inquiry; then the metric would be calculated by enumerating the employees whose compensation exceeds (100 – p) percentile of the LW distribution. One strategy for a complete compensation sustainability assessment might be to assess the minimum LWE such that $p = 0$, to capture all the employment needs of the labor force and the median LWE to capture the wage distribution.

The LWE measure informs an analysis of the suitability of the compensation from the employment generated in the supply chain for a good or service to meet the economic needs of the population.

CHAPTER 4

DATA FOR SCENARIOS

4.1 Overview

The new methods and frameworks are demonstrated using a variety of scenarios. The data sources and assumptions for each of the scenarios are described in this section.

4.2 IOLCA with Internal impacts

The IOLCA-II scenarios presented herein use baseline EIO-LCA sectors modified with differential expense estimates to implement the proposed scenarios and are modeled using IOLCA-II to generate scenario impact inventories. The scenario inventories are then compared the baseline sectors and to a standard hybrid EIO-LCA. Replacing grid electricity with solar is a common sustainability project and additional insight is of value to many constituencies. Transportation automation, particularly autonomous driving, is a very active research area that industry, academia, and various stakeholders are closely watching.

For clarity, as determined by the EIO-LCA model, the system boundary is the production supply chain for final demand in the selected baseline industry sectors and the scenarios modeled for comparison. Within that system boundary, impact categories are selected for assessment. Of obvious interest, climate change impact measured in GHG emissions is the environmental impact that is analyzed. As noted, employment is assessed as a beneficial social impact category and workplace safety measured in fatalities as a social burden. Finally, profitability outcomes of the scenarios are analyzed.

4.2.1 Scenario Data

It is important to note that although IOLCA economic flows within the model typically include only operating expenses and exclude capital or depreciable asset investments [77], this illustration estimates all expense differences between each of the baseline scenarios and the technology proposals of them, including investment changes in depreciable assets. By modeling fixed asset differences in the scenario, the estimate of the difference due to the scenario is complete, but the impacts from baseline fixed assets are excluded. This approach permits a more informative comparison model result and improved illustration of the new IOLCA-II model. Other IOLCA analyses include fixed asset purchases [77] and one can conceive of a number of real-world rationales for this device of expensing what may be a typical capital expenditure. For example, as newer technology options, they may be available from providers only as operating leases or annual service agreement expenses, or the company may roll out a project at a pace that follows the assets' useful lives, resulting in an annualized cost pattern for the entire project. To generate the expense differential, project costs are estimated. The EIO-LCA model is stated in USD_{2002} [111]; to conform to the underlying data, project costs are converted into expense rates per final demand of the sector in USD_{2002}.

The scenarios assume that the baseline sector remains unchanged, and a single representative company from that sector adopts the proposed technology change. The scenario entity is assumed to be precisely industry average, with the exception of the proposed technology change. Therefore, the custom products modeled are precisely average examples of the baseline sectors, modified only to model the proposed projects.

This is not a requirement of IOLCA-II in general, it is simply how the examples are designed to best illustrate the model.

The first baseline scenario is the colleges and universities (hereafter, universities) sector in the EIO-LCA data. The technology proposal to be modeled as a case scenario is for a precisely average member of the universities sector (i.e., an institution whose expense spending precisely matches the economic input-output model sector) which deploys commercial-scale solar photovoltaic electricity generation plants (referred to here as solar) that replaces all the energy that the university purchases from the grid utility. Actual project expenditures by sector for a commercial-sized solar project [138] are used to estimate the expenditure impacts per kWh of electricity.

The second baseline scenario is the truck transportation (hereafter, trucking) sector from the EIO-LCA data. The technology proposal modeled, as another case scenario of this sector, is automation of long-haul truck operation. To estimate project expenses by sector, several sources are used including industry estimates [25] and a specific automation case study including staffing impacts by function [139]. The expense rate for the project is developed using a vehicle maintenance expense in the baseline trucking sector to scale the project costs.

Baseline sector impacts and impacts for the new scenarios are estimated using the proposed IOLCA-II model. In addition to expense differences, direct employment differences are also identified and analyzed. As explained above, employment (a social benefit) and workplace fatalities (a social burden) are newly added to the IOLCA-II model here. However, the impacts are modeled using the existing EIO-LCA hybrid product method. Staffing changes and related employment expenses, as well as the other expense impacts, are also reflected in updated profitability estimates for the scenarios.

UNIVESITY SECTOR BASELINE - The EIO-LCA model [112] and documentation [111] provided the bulk of the baseline data using industry averages. The GHG emissions impact for a million USD_{2002} of demand (value-added) are obtained directly from the model [112], and employment and fatality impacts are calculated using the social impact rate vectors added to the model, as described above. Baseline profitability is obtained from the 2002 benchmark version of the BEA Use table [120] corresponding with the input-output data used to produce the economic element of the EIO-LCA model. Baseline employment is obtained from Bureau of Labor Statistics (BLS) employment requirements.

UNIVERSITY SOLAR SCENARIO - To estimate the impact of replacing grid energy used by the university with solar-generated electricity, cost [138] and power-production data [140] from a mid-sized (250-kW) municipal solar farm project installed by a third party contractor are used to generate direct spending changes for the scenario model. The universities sector does not rely on on-site electricity generation [111], therefore, all emissions impacts due to a change of the electricity source are reflected in changing the direct purchase amounts from the power generation and supply sector. Aside from the change in direct purchases, addition of solar generating systems represents a negligible change to the overall physical capital of the university, so there is no change to staffing or compensation. Similarly, there is no change in job category employment so there is no indication that the scenario would result in a change in sector fatality rates, so no process analysis is required for either of the social impacts. To estimate profit impacts, the changes in direct spending are passed through scenario profit to calculate the scenario profit rate, as noted there are no employment changes and therefore no change in employment costs. The project which is used as a data source for commodity costs benefited from a Department of Energy (DOE) cost-sharing grant [141]. To reflect the potential of a similar grant for other projects, the scenario is also modeled, with the grant added back to profit for assessment in that aspect, in addition to the scenario direct spending changes.

Table 4.1 Solar Photovoltaic Project Lifetime Costs by Component per kWh

Component	Service Life Years†(A)	Component cost†‡ USD$_{2002}$ (B)	Cost per kWh USD$_{2002}$/kWh $\frac{B * {}^{A}/_{30}}{10.334\ 10^{6}\ \text{kWh}}$	Commodity
Solar modules	30	308,867	0.02989	Semiconductor and related device manufacturing
Steel support racks	30	68,607	0.00664	Ornamental and architectural metal products manufacturing
Inverter	15	69,028	0.01366	Electric power and specialty transformer manufacturing
Monitoring	5¶	13,890	0.00253	Electronic computer manufacturing
Landscaping	30	66,502	0.00202	Services to buildings and dwellings
Fencing	30	59,768	0.00181	Fabricated pipe and pipe fitting manufacturing
Electrical installation	30	207,083	0.00627	Other nonresidential structures
Civil construction	30	143,948	0.01393	Other nonresidential structures
All other	30	117,796	0.00357	Other nonresidential structures
Baseline grid energy spending			-0.02471‖	Power generation and supply

Source: † [138], ‡ [119], § [140], ¶ [142], ‖ [112]

Actual project expenditures by sector for a commercial-sized solar project are used to estimate the expenditure impacts per kWh of electricity. To calculate the replacement system spending per dollar of final demand, the total electricity used in the baseline sector is estimated by dividing the direct spending amount on power generation and supply of 0.02471 per USD$_{2002}$ of sector output [112] by the cost of electricity to commercial sectors of 0.0789 USD/kWh [111], yielding 0.313 kWh/USD_{2002} of universities sector output. The cost by commodity of the 250-kW solar farm, discounted to USD_{2002} and divided by system lifetime electricity generation of 10.334 million kWh—based on 370,088 kWh actual first-year production [140], a 30-year life, and a 5% annual degradation rate [138]--and the resulting scenario expense adjustment amounts appear in Table 4.1.

The scenario change to direct spending is modeled in IOLCA-II to generate the environmental, social, and economic impacts. The university solar scenario and universities sector baseline impact inventory estimates are compared in the results.

TRUCKING TRANSPORTATION BASELINE - In the same manner as the universities baseline, the EIO-LCA model [112] and documentation [111] provide the bulk of the baseline trucking sector data. The GHG emissions impact per million USD_{2002} of demand (value-added) are obtained directly from the model [112], and employment and workplace fatality impacts are calculated using the social impact rate vectors added to the model, as described above. Baseline profitability is obtained from the 2002 benchmark version of the BEA Use table [120] corresponding with the input-output data used to produce the economic element of the EIO-LCA model.

AUTONOMOUS TRUCKING SCENARIO - The main purposes of the scenario project are to reduce the number of drivers employed by the firm, increase profits, and avoid current and forecasted driver shortages [24] at present compensation levels. Since automation is also expected to improve fuel efficiency [25], GHG emissions need to be addressed both in the supply chain and as a direct impact. To implement the scenario, there are costs of new direct inputs to provide the automation systems and changes to compensation costs and profit to be considered as part of the analysis. This analysis also reflects safety improvements anticipated as a result of automation [25], at least in part, by reflecting changes in fatality rates due to changes in employment by job category.

Table 4.2 Adjustment Rates for Impacted Job Categories to Automate Interstate Truck Operations, per Heavy and Tractor-Trailer Truck Driver Position Automated, Compensation and Fatalities

Action	Job Category	# of Positions per driver replacement†	Average Annual compensation USD_{2014}‡	Fatality rate per 100,000 employees§
Remove	Heavy and tractor-trailer truck drivers	1.0000	42,900	28.2
Remove	Dispatchers, except police, fire, and ambulance	0.0233	42,110	0.7
Add	Transportation, storage, and distribution managers	0.0116	86,520	3.4
Add	Computer user support specialists	0.0698	46,670	0.7
Add	Computer operators	0.0930	42,120	0.7
Add	First-line supervisors of transportation and material-moving machine and vehicle operators	0.0194	58,390	3.2

Source: †[139], ‡[137] and [119], § [144]

Staffing impacts and workplace safety measured in fatalities are estimated using a standard hybrid LCA analysis after adding social impacts to the IOLCA-II database. Automation in the trucking industry will alter the staffing requirements of the scenario firm, including removal of drivers and the addition of remote management of routes, maintenance of automation systems, and management of additional in-office staff [139]. In this model, the staffing impact changes are estimated proportionally to a reduction in the heavy and tractor-trailer truck driver category based on the percentage of mileage best suited to automation. The roads best suited to automation are rural and urban interstates and other arteries, representing approximately 70% of the miles traveled by combination trucks [143]. The staffing changes by job category, average annual compensation, and fatality rates are shown in and are proportionate to the total number of heavy truck drivers

(70%) to estimate the full-scenario direct employment impact, and change to the total compensation amount per USD 10 E06 of final demand.

By applying these staffing changes to industry wage and employment data by job category [137], estimated direct employment is reduced to 65.8% of the baseline and direct compensation is reduced to 66.8% of baseline employment levels. The change to employment by job category is also used to develop the adjusted direct fatalities per USD of sector output; scenario direct fatalities are 40.0% of the baseline fatality rate.

Automating truck operation requires purchasing navigation, automation, and monitoring technologies. The truck automation model for the scenario is referred to as level 5, or full automation, i.e., “situation independent automated driving—the driver has no responsibility during driving” [145, p. 19]. Such full automation is dependent upon a combination of technologies, some of which are already available while others require “incremental innovation” or “advanced development” [25, p. 16]. All of these technologies are well defined and sufficiently developed to permit cost estimation, an estimate of 23,400 USD_{2016} has been proposed for level 5 automation [25] that is used for the scenario; this estimate is approximately comparable to a 30,000 USD_{2017} cost for an automation retrofit package that has undergone recent testing [24]. The cost of automation per vehicle is allocated to the commodities for each of the functional components based on the costs per automation level and the components and capabilities associated with each level [25]. To estimate this cost impact in terms of the IOLCA-II model, a known operating cost and rate are used to factor the automation system costs.

A single tractor-trailer requires approximately 4,000 USD_{2017} per year in tire costs [146]; the EIO-LCA model carries an operating expense cost of tire manufacturing of

0.005136 USD per dollar of trucking sector final demand [112]. Also, as noted above, 70% of the miles traveled are on major highways [143] which are best suited to automation, and each of the automation components is estimated to have a 5-year useful lifetime [142]. Assuming that only vehicles that are fully automated incur conversion costs, input-output conversion costs are estimated by multiplying the annual cost of each of the automation commodities by this translation factor (percentage of miles automated * [tire manufacturing expense per dollar of final demand/4000 USD]) ÷ [component useful life in years] = (0.7*[0.005136/4000])/[5]=1.798 E-07.

Table 4.3 Direct Costs Impact of Truck Automation

Input Commodity	**Baseline†**	**Adjustment**	**Revised**
Automation Systems			
Software publishers	0.00 E-00	+19,900‡*(1.798 E-07)	3.58 E-03
Motor vehicle parts manufacturing	2.58 E-02	+1,000‡*(1.798 E-07)	2.59 E-02
Search, detection, and navigation instrmts	0.00 E-00	+500‡*(1.798 E-07)	8.99 E-05
Analytical laboratory instrument manuf	0.00 E-00	+500‡*(1.798 E-07)	8.99 E-05
Audio and video equipment manuf	1.10 E-05	+300‡ *(1.798 E-07)	6.49 E-05
Other communications equipment manuf	9.76 E-05	+200‡*(1.798E-07)	1.33 E-04
Electronic computer manufacturing	0.00 E-00	+1,000‡*(1.798E-07)	1.79 E-04
Fuel Efficiency			
Petroleum refineries	5.67 E-02	*(1.000-0.073)	5.25 E-02
Office and Equipment			
Power generation and supply	2.59 E-03	*(1.00+0.10)	2.85 E-03
Nonresidential maintenance and repair	1.10 E-03	*(1.00+0.10)	1.21 E-03
Computer terminals and other computer peripheral equipment manufacturing	6.73 E-04	*(1.00+0.10)	7.40 E-04
Telecommunications	9.39 E-03	*(1.00+0.10)	1.03 E-02
Real estate	1.62 E-02	*(1.00+0.10)	1.78 E-02
Facilities support services	1.48 E-03	*(1.00+0.10)	1.63 E-03
Services to buildings and dwellings	8.25 E-03	*(1.00+0.10)	9.08 E-03
Electronic equipment repair and maint	1.01 E-03	*(1.00+0.10)	1.11 E-03

Source: †[112], ‡[25]

Changes to staffing levels also change office space and equipment needs, and the impact of automating the routes increases office staff by approximately 20%. Allowing for multiple shift impacts and lesser impact on shared spaces and conversion of some driver space, the estimated impact on office-related commodities indicates a 10% increase.

An additional impact of automation is increased fuel efficiency resulting from optimized acceleration and braking and platooning wherein coordinated automated vehicles travel as a group of three or four vehicles with reduced-wind resistance in non-lead trucks [147]. Optimized acceleration and braking improves fuel efficiency by 7.5%— based on "lead-truck" improvement [147]— on major roadways which constitute 70% of the miles traveled by combination trucks [143]. Platooning will contribute an additional 6.5% efficiency increase, estimated by subtracting lead truck improvement from the mean overall improvement [147] for a further subset of 45% of total highway miles where platooning is most likely [25]. The benefits and complexity of platooning are dependent on traffic conditions – 45% of total highway miles is an industry "base case" estimation of platooning coinciding with vehicle automation [25]. The combination of these figures translates to a total reduction in fuel consumption of 7.3% across all miles traveled; the automation scenario reduces direct purchases from petroleum refineries resulting in both a direct impact change and supply chain impact change which are incorporated into the model. A conventional hybrid estimate would require developing the direct GHG emissions impact change due to the increased fuel economy, whereas IOLCA-II calculates this impact directly from the spending. Vehicle, fuel, and office impacts on direct spending are detailed in Table 4.3.

Profit rates are affected by the changes in direct spending for automation, fuel, office facilities, and employee compensation. The net difference of these changes is used to adjust the baseline profit rate to calculate the scenario profit for assessment. The automation scenario and trucking baseline impact estimates and sustainability assessments are compared in the results.

4.3 Comprehensive Sustainability Target Method

The case study presented here draws data from multiple sources, including the Lodhia and Martin analysis [148] of corporate sustainability data from BHP Billiton (BHP), one of the world’s largest global mining companies. This sustainability data is supplemented by additional BHP financial details and the geographic-specific data associated with selected mining operation sites. In addition, the associated carrying capacity estimates and target commitments are based upon the following impact categories: climate change (measured by GHG emissions), freshwater use, employment, workplace safety (measured by worker fatalities), and corporate profitability. The stated purpose of the Lodhia and Martin’s study is to investigate the value of sustainability indicators for a company and sustainability stakeholders [148]; consequently, this case study provides a relevant baseline to compare the CSTM assessment with traditional corporate sustainability indicators.

Clearly, the mining industry is an important sector in the context of sustainability for not only its global economic significance but also for its massive environmental and social footprint. Based in Australia, BHP mines and extracts mineral resources as well as coal, petroleum, and natural gas and maintains a robust sustainability management and reporting system [149]. A significant gap in BHP’s sustainability reporting is the absence of impacts from the use phase of the fossil-fuel energy products they mine. To directly compare and contrast sustainability assessments using the BHP case study, it is necessary to maintain consistent analysis boundaries between the Lodhia and Martin study and the

CSTM assessment presented here. Consequently, the case study analysis will focus strictly on the mining extraction and production phase. It is important to note that when emissions from sold product are included, from 1988 to 2015, a date range which includes the case study, BHP is one of the top 25 emitters in the world: by itself being responsible for 0.9% of industrial GHG emissions for the time period [44].

For revenue and GHG emissions, a system boundary approximating the entire supply chain for production-phase only is reported [148, 150]. For water use, employment and fatalities, production-phase impacts strictly within the corporate boundary are reported. However, further illustrating the boundary issues described above, full supply chain revenue is used to compute impact intensities [148, 150].

4.3.1 CSTM Analysis Goal and Scope Definition

The source study presents corporate sustainability indicators that were evaluated by engaging a variety of BHP internal and external stakeholders to determine relevance and utility [148]. Lodhia and Martin’s research provides commentary on the performance data that is contrasted with the CSTM analysis and includes trend data for a variety of economic, social, and environmental indicators. As noted above, the analysis will focus on value generation, climate change (GHG emissions), freshwater consumption, employment, worker safety (workplace fatalities) and profitability. Assessments are made using two system boundaries, full BHP supply chain boundary or direct impacts within the corporate boundary, depending on the impact. Value generation is estimated for each of the system boundaries with total revenue used to estimate full supply chain value generation. The sum of earnings before taxes and employee expense are used to approximate value generation within the BHP corporate boundary, consistent with the value added definition used in GDP calculations [151].

For the impact categories selected for assessment, spatial or geographic boundaries of the carrying capacities for burdens and commitment targets for benefits are specified by the type of impact, and system boundary is determined by BHP's disclosure boundary. As such, climate change due to GHG emissions is a global impact, and therefore, the boundary for impact carrying capacity is global. Whereas, the system boundary for BHP GHG emissions is the full supply chain. The approximate full supply chain impact rate for the supply chain value generation is provided directly by BHP's corporate disclosure.

Freshwater use is a local or regional resource assessed normally at a watershed or regional level. However, limited location-specific impact or revenue data are reported by BHP and none were considered in the source study. In addition, boundary definitions of the water use data disclosed are inconsistent between the environmental and economic domains. Due to the inconsistent boundaries for water use and value added in the source study, the water productivity has been recalculated to align water use and value generation to the corporate system boundary. A single water use intensity is reported in the source study, but water use varies for different mining operations. To demonstrate CSTM's capability to support impact categories with different spatial boundaries, two major assumptions are made.

The first is that the boundary adjustment for the economic boundary using corporate level totals is a valid estimate for specific locations. The second assumption is related to the water use amount in the disclosed intensity itself. Water use differences by commodity/sector are available from the EIO-LCA [22, 77]. Data from the EIO-LCA tool shows that the coal mining industry averages using approximately 0.75 liters of direct water consumption within the corporate boundary per USD of coal output, 0.25 liters per USD of petroleum output and approximately 134 liters of water per USD for copper output [112]. Metal mining requires almost 140 times the water consumption for coal mining, on a per dollar output basis. Petroleum and coal, with much lower water use rates, represent one third or more of BHP's total revenues [152] as such, BHP's copper mine locations almost certainly use water at a substantially higher rate than the average water productivity levels BHP discloses for all mining operations. Therefore, the resulting CSTM sustainability indicator for water use is a maximum estimate of BHPs sustainability for direct water use within the corporate boundary for an individual copper mining operation. BHP has a major copper mining operation in Atacama, Chile that is used to assess for water use sustainability the regional impact level.

Both social impacts—employment and workplace safety (fatalities)—are relevant for various spatial boundaries, and therefore, of interest at the local, national, and global boundaries. A single impact rate is disclosed for all of BHP, but different mining operations have different employment needs with varying worker accident levels and risks. Data regarding the types of mining extraction technologies BHP operates show that, per million USD of revenue, oil and natural gas employ 1.2 people, coal mining employs 3.4 people, metal mining employs 3.5 people, and non-metal mineral mining employs 4.8 [153]. Again, the employment rate reported by BHP may not be informative for assessment of oil drilling operations, but serves as a suitable minimal impact productivity rate for coal or metal mining operations and for the corporate system boundary as a whole. Again, the productivities for these impacts needed to be recalculated from the source study to align the value added and impact rates to the corporate system boundary. In addition to the full corporate system boundary, social impacts are assessed locally for the Atacama, Chile copper mining operations, a Bernalillo County, New Mexico, United States Coal mine and Australia national presence.

Table 4.4 Subscripts and Notation for CSTM Assessment for BPH Case Study

Category	Notation	Description
Spatial boundary		
	Subscript a	Australia
	Subscript b	Bernalillo County, New Mexico, United States
	Subscript d	Atacama Administrative Region, Chile
	Subscript g	Global
System boundary		
	In text “supply chain”	BHP entire supply chain
	In text “corporate”	BHP internal corporate boundary
Economic		
	Subscript V	Value generation
	Subscript R	Return
Environmental		
Burden	Subscript C	Climate change (GHG emissions)
Burden	Subscript W	Water use
Social		
Positive (Beneficial)	Subscript L	Employment
Burden	Subscript F	Workplace safety (fatalities)

Economic return, expressed as the profit rate, is strictly a corporate boundary impact. Since the spatial boundaries dictated by the impact targets determine the geographic boundaries for analysis, the economic value-added boundaries are local, national or global, coinciding with the impact boundary. With these parameters determined, the subscripts and notation used for the CSTM analysis are given in Table 4.4 with categories and descriptions.

4.3.2 Carrying Capacities, Commitment Targets, and Sustainable Productivities

Dependent on the selected impact category scope and spatial boundaries, the next step is to determine the carrying capacities of burdens and commitment targets for benefits.

Climate Change: The GHG emissions target used in this CSTM analysis is the annual level of GHG for each year during the study period representing a linear projection from a global emissions target for the year 2000 to the 2050 level that would keep global temperature change within 2^{O} C above pre-industrial levels [154] proposed in the time frame of the original study. Starting from the year 2000 target at 31.2 Gt [32, 155] and declining linearly until 2050 to meet a target of 10 Gt of annual GHG emissions [154] translates to an annual reduction of 0.424 Gt of global annual GHG emissions. As noted earlier, more recent IPCC climate change impact studies indicate that a more accelerated reduction in global GHG emissions than originally thought will be needed which will make GHG emission target levels more stringent to achieve net zero emissions around mid-century [156]; the selected carrying capacity target is consistent with the time frame of the case study and source study data.

Freshwater: The assessment for water consumption is spatially bound as being the administrative region of Atacama, Chile, one of the most arid regions in the world [15]. The average annual renewable water resource for the region is taken as the freshwater capacity estimate [157].

Employment: As a beneficial impact, employment requires a minimum commitment impact level for CSTM assessment. The minimal commitment impact level proposed here for employment is the annual labor force for each geographic spatial boundary.

Worker Safety: The proposed target for workplace safety is measured in terms of worker fatalities and is based on the observed work-related fatality rate of the European Union [158] multiplied by the size of the labor force of each geographic boundary. The low worker fatality rate of the European Union was selected as the target to represent achievable worker safety thresholds for a large diverse labor force with best practice performance. Using the same worker safety rates with the respective global, national or county labor forces produces a maximal fatality limit for each geographic boundary.

Economic: The annual economic value-added impacts occur at the same geographic boundaries as the environmental and social impact carrying capacities and limits described above; consequently, economic value-added impacts must be determined at the local, national and Global GDP totals in USD_{2011}, with purchasing power parity accounting for foreign exchange fluctuation. In addition to value generation, the analysis includes the financial return (defined here as ratio of net income to revenue) as an additional economic impact for the economic yield measure. An analysis of United States corporate profit rates based on required rates of return on capital show the profit rate ranged from 6% to 18% annually during the years of the study period [159]. For the purposes of this analysis, the economic return target is established as 12% annually for BHP during the time frame analyzed.

Sustainable Productivity Calculations: The target levels and sustainable productivity rates are presented in Table 4.5 using notation from Table 4.4. The sustainable productivities in Table 4.6 are calculated using the target levels from Table 4.5 and the definitions and formulas given in Table 3.1.

Table 4.5 Impact Carrying Capacities and Commitments for BHP Case Study

	Units	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Economic										
Australia GDP D_{aV}†	Billion USD_{2011}†	690.7	718.3	739.8	769.4	793.9	816.4	847.3	878.3	895.2
Bernalillo GDP D_{bV}*	Billion USD_{2011}†	27.5	28.1	29.4	31.3	31.4	31.8	31.8	31.9	32.3
Atacama GDP D_{dV}†‡	Billion USD_{2011}†	3.5	3.6	3.8	4.0	4.3	4.5	4.7	4.9	4.8
Global GDPD_{gV}†	Trillion USD_{2011}†	64.9	66.7	69.2	72.9	76.3	80.4	84.7	87.1	86.8
Environmental										
Global GHG B_{gC} §	Trillion kg CO_{2e}	30.8	30.4	29.9	29.5	29.1	28.7.	28.2	27.8	27.4
Atacama renewable waterB_{dW}!	Billion l H_2O	85.2	85.2	85.2	85.2	85.2	73.4	73.4	73.4	73.4
Social										
Australia employment B_{aL} †	Million Employees	9.8	10.0	10.1	10.2	10.6	10.8	11.0	11.3	11.5
Bernalillo employment B_{bL} #	Thousand Employees	290.9	294.3	296.5	301.3	305.8	310.8	312.3	313.5	310.1
Atacama employment B_{dL} †‡	Thousand Employees	101.9	102.9	105.9	109.2	112.4	116.0	119.5	124.7	126.7
Global employment B_{GL} †	Billion Employees	2.8	2.9	2.9	3.0	3.0	3.1	3.1	3.1	3.1
Australia fatalities B_{aF}†‖	Fatalities	265	269	274	277	285	292	296	304	311
Bernalillo fatalities B_{bF}#‖	Fatalities	8	8	8	8	8	8	8	8	8
Atacama fatalities B_{dF}†‡‖	Fatalities	3	3	3	3	3	3	3	3	3
Global fatalities B_{gF}†‖	Fatalities	75,555	76,714	77,911	79,232	80,495	81,467	82,509	83,444	84,310

Table footnotes: Atacama GDP and employment are estimated on national Chile values and regional proportions for sample years. Workplace safety Fatality capacity is based on the geographic boundary labor force and the European Union fatal accident rate for 2003, approx. 37,000 employees per fatal accident [158].

Source: Data trends were retrieved as noted, but report the years under assessment.[126] † [160] ‡ [161, 162] § [32, 154] ! [157] # [163] ‖ [158]*

Table 4.6 Sustainable Productivities for BHP Case Study

	Units	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Global GHG SP_{gVC}	USD$_{2011}$/kg CO2e	2.108	2.198	2.313	2.469	2.624	2.804	3.000	3.133	3.169
Atacama water SP_{dVW}	USD$_{2011}$/l water	0.058	0.060	0.062	0.067	0.071	0.075	0.079	0.082	0.080
Australia employment SP_{aVL}	Thousand USD$_{2011}$/ Employee	70.6	72.2	73.1	75.1	75.2	75.6	77.3	78.0	77.9
Bernalillo employment SP_{bVL}	Thousand USD$_{2011}$/ Employee	94.6	95.5	99.2	104.0	102.7	102.4	101.7	101.8	104.1
Atacama employment SP_{dVL}	Thousand USD$_{2011}$/ Employee	34.3	35.0	35.4	36.8	37.8	3.90	3.97	3.95	3.80
Global employment SP_{GVL}	Thousand USD$_{2011}$/ Employee	23.2	23.5	24.0	24.9	25.6	26.7	27.7	28.2	27.8
Australia workplace safety SP_{aVF}	Billion USD$_{2011}$/ fatality	2.61	2.67	2.70	2.78	2.78	2.80	2.86	2.89	2.88
Bernalillo workplace safety SP_{bVF}	Billion USD$_{2011}$/ fatality	3.50	3.54	3.67	3.85	3.80	3.79	3.76	3.77	3.85
Atacama workplace safety SP_{dVF}	Billion USD$_{2011}$/ fatality	1.27	1.30	1.31	1.36	1.40	1.44	1.47	1.46	1.41
Global workplace safety SP_{GVF}	Billion USD$_{2011}$/ fatality	0.86	0.87	0.89	0.92	0.95	0.99	1.03	1.04	1.03
Corporate profitability SP_{R}	% Annually	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00

4.3.3 System Productivities

The case study annual impact rate data [148] is used to compute the system productivity rates and trends. The GHG disclosed approximates the full corporate supply chain emissions for the supply chain system boundary and total revenue. However, the annual water consumption and social impact data are reported by BHP as being within the corporate boundary as opposed to impacts across the full supply chain. This inconsistency was unrecognized in the source study as their discussions assumed the BHP water and social impacts as rates against total revenue and not value-added solely by corporate BHP, thereby mixing boundaries. To align properly the system boundary for freshwater use and social impacts, total revenue is replaced here with value-added within the corporate boundary to correctly produce freshwater and social impact productivities within the BHP corporate boundary. The resulting productivities are presented in Table 4.7, with all productivity measures adjusted to USD_{2011} and using the CSTM assessment formulas in Table 3.1.

The Lodhia and Martin source study includes the following analysis and evaluation of the data trends for sustainability conclusions and commentary [148, p. 111]. *Note, the comments below denoted in quotes are directly extracted from the referenced study*. Lodhia and Martin point to improving environmental productivity trends as affirmation that BHP is successfully competing in the market while "managing negative environmental impacts." They also identify small general improvements in employment and describe environmental impacts and employment as being roughly proportional. Increasing revenue accompanied by increasing employment is interpreted as BHP's growth "being leveraged for the creation of positive social outcomes, such as direct employment and contract engagements in communities". Finally, the source study notes that the decline in revenue per work-related fatality indicates "the company's attempts to minimize the negative impacts of expanding business activity". According to Lodhia and Martin, one of BHP's stakeholders describes these results as follows: “sustainable investments have not only improved profit, productivity, and community outcomes but appear to have increased organizational competitiveness“ [148, p. 112]. Clearly, the Lodhia and Martin assessment is overall very positive characterizations of BHP’s progress towards sustainability. However, the deeper and more comprehensive CSTM assessment reveals new insights into the sustainability of BHP and evaluates how far BHP still remains from achieving its sustainability goals. The CSTM assessment is presented and discussed in the following section.

Table 4.7 BHP Case Study Impact Productivity Rates

	Units	2001	2002	2003	2004	2005	2006	2007	2008	2009
System Economics										
Supply chain value added d_V †	Billion USD$_{2011}$‡	13.0	19.3	18.6	26.5	30.0	35.0\	50.4	61.9	51.9
Corporate profitability d_R (Net Income/Revenue)†	%	9.70	10.37	11.92	14.87	23.94	32.50	28.26	25.88	11.70
Corporate value added d_V †	Billion USD$_{2011}$‡	3.6	5.7	5.5	6.6	12.8	21.0	26.5	34.2	24.6
Productivity rates §†										
Supply chain GHG p_{VC}	USD$_{2011}$/kg CO$_{2e}$	0.411	0.357	0.441	0.580	0.702	0.908	1.061	1.157	1.148
Corporate water p_{VW}	USD$_{2011}$/l H_2O	0.020	0.008	0.016	0.018	0.038	0.057	0.062	0.073	0.050
Corporate employment p_{VL}	Thousand USD$_{2011}$/ Employee	110	123	169	191	370	565	571	695	504
Corporate workplace safety p_{VF}	Billion USD$_{2011}$/ fatality	0.216	0.158	0.173	0.097	0.044	0.052	0.077	0.087	0.053
Corporate profitability p_R (Net Income/Revenue)†	%	9.70	10.37	11.92	14.87	23.94	32.50	28.26	25.88	11.70

Source: † [164] data retrieved in 2018 for the periods analyzed ‡ [160] discounting of nominal amounts to 2011 § [148]

4.3.4 Renewable Energy Comparison with Varied Boundaries

This case study analyzes GHG and water consumption. LCAs were selected for the renewable energy technologies to furnish GHG data and with enough detail to complement use of water consumption from [165]. In addition, LCAs were used that describe a life cycle boundary inclusive of raw material extraction to end of life management. Functional units (kWh of electricity) and lifecycle inventories (water and GHG) conducive to the intended analysis were critical as well.

The impact inventories for the systems appear in Table 4.8, along with identification of the source for the data and the installation location used in the source studies. Water impacts are identified for Lifecycle Water (LCW) and Operation Phase (use stage) Water (OPW) consumption.

GHG emissions reported for the U.S. Grid in [45] include emissions only from converting fuel to electricity. Emissions from the rest of the lifecycle are not considered. U.S. Grid OPW is estimated from median water use by fuel from [166] and fuel mix from [45].

Table 4.8 Impact Inventories for Renewable Energy Technologies and the United States Grid

	Environmental Impact			Location & Data Source		
System	GHG kg CO$_2$Eq/ kWh	LCW m^3/ kWh	OPW m^3/kWh	GHG	LCW	OPW
US Grid	0.579	.0298	2.58 E-03	US [45]	US[165]	US[166]
m-Si	0.271			SG[167]		
p-Si	0.085	5.60E-04		CA[168]	SW[165]	
a-Si	0.038	2.04E-03		US[169]	SW[165]	
PV-Ut			1.09 E-04			US[166]
W30	0.040	1.03E-03		CA[168]	SW[165]	
W100	0.025			CA[170]		
W-Ut	0.013	5.62E-04	4.21 E-06	US [171]	SW[165]	US[166]

Abbreviations: CA = Canada, SG = Singapore, SW = Switzerland, US = United States

All renewable system environmental impact results are scaled to reflect a 20 year system life and 10 year inverter life, and unless noted, a 90% inverter efficiency for renewable systems and 90% transmission efficiency for utility systems. The Solar PV a-Si system came from a hybrid system of 22.6 kW a-SI and 10.5 kW crystalline modules, all impacts of the crystalline components are excluded.

LCW is collected using the network inventory analysis from [165] for the following water inventory categories: 1) cooling, unspecified natural origin; 2) lake; 3) river; 4) unspecified natural origin; 5) well, in ground. To estimate LCW for the wind systems, the Environmental Impact from the 500 kW inverter in [15] is scaled for each system and included in the total.

The B_{GHG} used is the global natural removal capacity, 2.0 E+13 kg GHG [172]. This estimate is supported by a very similar estimate of 1.8 E+13 kg GHG produced using global warming potential and atmospheric capacities of constituent gases from [173]. As GHG is treated as a global impact, CSTM specifies using the global economy as economic reference value. The 2010 global economy was 62.2 trillion USD [174], the relationship from section 3.3.2 yields a SP_{GHG} of 3.11 USD/kg CO_2.

CHAPTER 5

RESULTS

5.1 Overview

In this section the scenario results using the new methodologies and techniques are presented and interpreted.

5.2 More Efficient and Robust IOLCA

The addition of social impacts and profitability to the EIO-LCA, and combining IOLCA-II with scope allocation and hybrid techniques generates representative scenario impact estimates across the economic, social and environmental domains. The overall production phase supply chain impacts and GHG scope allocations for the baselines and scenarios are presented in Table 5.1.

5.2.1 University Solar Scenario Compared to Universities Sector Baseline

In summary, per million USD_{2002} of final demand, the solar scenario significantly improves the GHG emissions for the universities baseline from 767,886 kg CO_{2e} to 557,211 kg CO_{2e}, a 38% improvement. Employment was slightly improved in the solar scenario from 17.9 employees to 18.2. Workplace safety measured in fatality rate per 100 thousand employees falls from 43.2 to 45.3, the scenario causes this to deteriorate slightly. The change in costs for the scenario causes profit rate to fall from 4.48% to 3.34%. However, if the project can obtain a subsidy of 50% of the project costs, as described above, profitability actually increases to 4.93%.

Looking more closely at the universities baseline and scenario (since GHG emissions for universities are mostly from the supply chain, rather than direct combustion of fossil fuels) and the standard hybrid LCA estimates supply chain impacts, the IOLCA-II model generates a result that is consistent with an EIO-LCA custom product using the same expense adjustments; specifically, 557,211 kg of CO_{2e} per million USD_{2002} of final demand from IOLCA-II and 559,466 kg of CO_{2e} from the EIO-LCA custom product hybrid LCA [74]. The difference between the model results is less than 0.5%, illustrating that the IOLCA-II preserves the standard estimation for supply chain impacts as intended. However, the IOLCA-II also allocates scope 1, 2 and 3 impacts. Comparing the scopes between the baseline and scope 1 is relatively static. Scope 2, with no purchased electricity, goes to zero as expected, and scope 3 increases for the additional solar system components required. Of note, the IOLCA-II employment estimate is significantly higher than the BLS employment requirements [153], this difference is due principally to the fact that the input output model used by BLS does not have any spending for local or state government inputs into the university sector production. This difference preserves correct alignment of social impacts in IOLCA-II with the EIO-LCA model structure.

5.2.2 Autonomous Trucking Compared to the Trucking Baseline

In summary, per million USD_{2002} of final demand, the automation scenario marginally improves the GHG emissions, calculated with the IOLCA-II, for the trucking baseline from 1,400,089 to 1,326,210 kg CO_{2e} with the automation scenario. Employment is appreciably reduced by the automation scenario from 15.4 to 12.9 employees per million USD_{2002} of final demand. Workplace safety measured in fatality rate per 100 thousand employees improves dramatically from 214.5 to 147.2. The change in purchases and employment costs for the scenario causes profit rate to increase from 15.3% to 24.9%.

Further inspection of the automated trucking scenario result shows that the GHG emissions internally within the corporation's operation in the IOLCA-II model are explicitly calculated from the change in spending on petroleum. Therefore, GHG-emissions are very different from an EIO-

LCA custom product model with the same spending profile, specifically 1,392,839 kg of CO_{2e} per million USD_{2002} of final demand from the EIO-LCA custom product hybrid LCA [74] compared to 1,326,210 kg from IOLCA-II. This difference is precisely the purpose of the IOLCA-II model design. Note also the bulk of the GHG reduction is from scope 1 with a smaller amount in scope 3 and partially offset by an increase in scope 2.

To further explore the impact of automating long-haul truck operation, consider that heavy truck driver occupations represent 2.7% of the entire United States workforce [175]. This cohort earns an average compensation of 32,000 USD_{2012} per year [175] with an average educational attainment of 12.95 years [131]. In the case of widespread adoption of automation in the sector, leading to 70% of these drivers being displaced (representing 1.89% of the total workforce) the impact on the labor market and those employees would be dramatic. The wage of non-driver employees in the labor force with equivalent to up to an additional half-year of education is only 87% of the wage for heavy truck drivers [131, 175]. The wage of non-drivers with equivalent or up to a year of additional education is only 93% of driver wage rates [131, 175]. Specialized truck driver training may not provide significant advantage to workers with other occupations, so significant investment in training or education would be required to prepare displaced drivers to compete for employment at similar income levels. This interpretation does not take into account other possible automation strategies that would have different staffing impacts on the corporation. Possible increases in other job opportunities throughout the economy due to more efficient freight transportation is outside of the sector's productive supply chain system boundary. There may be economy-wide responses that more than make up for the job losses in the sector, but the displaced drivers represent a large enough cohort that those responses need to be understood as part of a large scale move toward automation.

5.2.3 Limitations and Constraints

As noted, there are impact inventory questions that are beyond the IOLCA-II model to compute where other models are a better fit [78, 176]. Users of the IOLCA-II need to use care in calculating expense by commodity, normal granularity of expense tracking may not be sufficiently detailed to generate impact estimates correctly.

The IOLCA-II model is a point in time snapshot of the economy and technology, like any database. If significant changes impact the estimates, steps to adjust for those changes may be necessary to produce more accurate impact estimates. Uncertainty can be an issue in LCA and IOLCA-II, and it may be necessary to account for it using existing methods that are beyond the scope of this work.

IOLCA-II does not overcome all issues that challenge users of IOLCA or hybrid LCA methods, but allows the input output model to produce more impact detail with little or no additional effort. IOLCA-II delivers the additional data in a way that should be compatible with the solutions that exist for many of those aforementioned challenges.

Table 5.1 Economic Input-Output Life Cycle Assessment with Internal Impacts results for the baseline industries and scenarios for 1 Million USD$_{2002}$ final demand

	Units	Universities EIO-LCA	Universities IOLCA-II	University Solar EIO-LCA	University Solar IOLCA-II	Trucking baseline EIO-LCA	Trucking baseline IOLCA-II	Automated Trucking EIO-LCA	Automated Trucking IOLCA-II
Total GHG	kg CO$_{2e}$	767,888§†	767,886	559,466§	557,211	1,400,089†	1,400,118	1,392,829§	1,326,210
Scope 1	kg CO$_{2e}$	n/a	138,683	n/a	136,430	n/a	925,773	n/a	859,124
Scope 2	kg CO$_{2e}$	n/a	220,380	n/a	0	n/a	23,142	n/a	25,456
Scope 3	kg CO$_{2e}$	n/a	408,823	n/a	420,781	n/a	451,204	n/a	441,630
Employment	Employees	14.99‡	17.91	n/a	18.27	14.91‡	15.38	n/a	12.86
Workplace safety	fatalities/ 100k employees	n/a	43.2	n/a	45.3	n/a	214.5	n/a	147.2
Profit rate	%	n/a	4.48‖	n/a	3.34	n/a	15.3‖	n/a	24.9

Source: *† [112] ; § [74]; ‡ [153] ; ‖ [120]*

5.3 Comprehensive Sustainability Target Method

The primary sustainability indicators from the CSTM assessment are presented in Table 5.2. These indicators are calculated using the data from Table 4.6, Table 4.7, and the efficiency and effectiveness formulas from Table 3.1. With the exception of economic yield, the CSTM results for the selected boundaries and impacts show that BHP's impacts are far from sustainability in the primary efficiency and effectiveness measures. The CSTM results presented diverge significantly from the tone and conclusions of the Lodhia and Martin source study analysis, except for the assessment of economic yield/profitability. Because of the significant increase in profitability, BHP is generally economically sustainable, at least from 2004 through 2008 given the target annual return of 12%. CSTM economic yield efficiency result agrees with the source study while incorporating profitability directly into the sustainability assessment. The CSTM assessment shows that there are several areas where BHP can improve its sustainability through wisely investing in sustainability projects to reduce energy consumption and GHG emissions, increase labor utilization, and improve workplace safety.

Figure 5.1 presents an overview and graphical visualization of the progress accomplished and challenges that remain for BHP. In this diagram, the CSTM primary sustainability indicators are presented to compare BHP sustainability performance at the end of the study period in 2009 to results in the 2001 baseline year. Each CSTM measure indicates distance from the sustainability threshold, a non-dimensional ratio normalized to one. In accordance with the basic CSTM sustainability measures, indicator values above one are shown as sustainable on the circular graph with radii on a logarithmic scale to visualize highly unsustainable results. The grey sector in an impact pie-shaped segment represents the lower value between the two assessments being compared, 2001 and 2009. A blue arc indicates starting at the inner perimeter (at the border with the grey sector) in 2001 and improving to the outer perimeter of the blue sector in 2009. A red arc indicates a decline in sustainability starting from the outer perimeter in 2001 to the inner perimeter (border with the grey sector) of the red sector in 2009. This representation was inspired by a similar radial pie chart [177] and the design modified for the reporting needs of CSTM.

BHP's stated climate change goal was to reduce GHG emission intensity by 6% from the 2006 rate over a 5-year period [150]. The carrying capacity context of CSTM can provide a more meaningful perspective through which performance against this goal can be evaluated from a sustainability perspective. Examining E_{gVC}, BHP's global supply chain ecoefficiency for GHG emissions, as shown in Table 5.2 in 2006 $E_{gVC} = 0.324$ with global supply chain GHG productivity $p_{VC} = 0.908$ $USD_{2011}/kg\ CO_{2e}$ from Table 4.7. A 6% improvement from 2006 to 2011 would result in $p_{VC} = 0.962$ $USD_{2011}/kg\ CO_{2e}$. However, during this five-year period the sustainable target level in global annual GHG emissions became more stringent, declining to 28.7 trillion kg CO_{2e} in 2011 while the global economy in 2011 grew to 95.1 trillion USD_{2011}. As such BHP's ecoefficiency E_{SGVC} actually fell to 0.290 from 0.324 moving BHP further away from being sustainable even though it met its stated emission reduction goal. This critical insight demonstrates that a relative improvement in productivity may sound good, but in reality, is not a viable decision measure that moves a company toward sustainability. Clearly, this analysis of BHP illustrates the need for corporate decision making based on *absolute* sustainability goals and the importance of sustainability assessment recognizing impact limits and carrying capacity thresholds. It is important to also note that BHP achieved a 26% improvement in its environmental productivity within the first three years, which dramatically surpassed their internal target by 2009. Certainly, this is a notable achievement and a substantial stride of improvement; however, it is still far from sustainable at $E_{gVC} = 0.362$ and without the boundary reference of CSTM, the company has no means to evaluate this performance.

As previously noted, due to the lack of location-specific reported impact rates, the following assessment assumes the employment impact rates are uniform for all localized impact assessments. BHP has significantly increased its system socio-productivity rates (the revenue per employee) over the assessment period. As a beneficial impact, the sustainable productivity of employment must exceed the system productivity to achieve sustainability. Sustainable productivity increases for each spatial boundary over the study period, but that growth is insufficient to overcome the dramatic increase in labor productivity by BHP. Lodhia and Martin report a positive assessment of BHP's employment growth, while CSTM arrives at the opposite conclusion: reported employment, while increasing, is insufficient and yields a decline is socio-effectiveness with dramatic movement away from social sustainability. Generally, growth in labor productivity is perceived to be a positive, the output generated per unit of labor input, providing the basis for improving standards of living [178]. This is the case under CSTM also, growing labor productivity of the economy is a positive outcome. However, the outcome must be assessed with reference to the sustainability target to determine if the positive outcome is sufficient to move the company towards sustainability. As a proportional question, for a specific firm or system boundary, the labor productivity for employment can only be sustainable if the system being assessed employs its proportional share of the labor force. There are certainly other employment concerns, such as labor share of output and real hourly wages [178], job quality, including human capital or educational engagement [105, 106] and other factors and impacts. CSTM analysis of the labor productivity of employment considers proportional employment, not as the only consideration, but as one consideration of the employment impacts of the system being assessed.

It is acknowledged that a negative connotation to labor productivity growth may be surprising, but it is a necessary consequence of assessing the social impacts of economic activity with the same consideration of limits and thresholds demanded for environmental impacts.

From the workplace safety perspective measured by worker fatality rate, BHP is unsustainable within each of the spatial boundary assessments and deteriorates significantly over the study period. The negative outcome is very different from the source study's relative assessment that BHP's results illustrate its effective investment in safety [148]. Each spatial boundary has somewhat different sustainable productivities, but the indicator trends all move in the wrong direction for the stated sustainability goal.

There are recent reports that indicate that over-consumption of water resources in Atacama have critically depleted non-renewable groundwater reserves, threatening wildlife, residents and industry in the area [15]. In 2009 BHP started to use recycled water to support its Atacama mining [179]. Although none of this was mentioned as an area of concern in the source study or contemporaneous BHP sustainability reports, BHP has more recently invested in a massive water desalination plant to source their Atacama operations [180] and initiate a complete transition from ground water by 2030 [181]. The relative improvement in water use rates BHP reports from 2001 to 2009 is significant, but with the knowledge that the water resource is extraordinarily limited shows that the still unsustainable CSTM result for water use during the study period is correct. Would BHP have initiated corrective action sooner in Atacama if the level of unsustainability of corporate water use was known explicitly during the period from 2001 to 2009?

Table 5.2 Comprehensive Sustainability Target Method Primary Sustainability Indicators

Indicator	Name	2001	2002	2003	2004	2005	2006	2007	2008	2009	Comment
E_{SGVC}	Global supply chain Ecoefficiency for GHG	0.195	0.163	0.191	0.235	0.267	0.324	0.354	0.369	0.362	Unsustainable – modest improvement
E_{dVW}	Atacama Corporate Ecoefficiency for water	0.352	0.127	0.258	0.265	0.531	0.755	0.784	0.888	0.626	Unsustainable – improvement
$E_{aVL}^{\oplus}$	Australia Corporate Socio-effectiveness for employment	0.642	0.587	0.432	0.393	0.203	0.134	0.135	0.112	0.155	Unsustainable – significant decline
$E_{bVL}^{\oplus}$	Bernalillo Corporate Socio-effectiveness for employment	0.861	0.777	0.586	0.544	0.278	0.181	0.178	0.147	0.207	Unsustainable – significant decline
$E_{dVL}^{\oplus}$	Atacama Corporate Socio-effectiveness for employment	0.312	0.285	0.209	0.193	0.102	0.069	0.070	0.057	0.075	Unsustainable – significant decline
$E_{gVL}^{\oplus}$	Global Corporate Socio-effectiveness for employment	0.211	0.191	0.142	0.130	0.069	0.047	0.049	0.041	0.055	Unsustainable – significant decline
E_{aVF}	Australia Corporate Socio-efficiency for workplace safety	0.083	0.059	0.064	0.035	0.016	0.019	0.027	0.030	0.018	Unsustainable – significant decline
E_{bVF}	Bernalillo Corporate Socio-efficiency for workplace safety	0.062	0.045	0.047	0.025	0.011	0.014	0.020	0.023	0.014	Unsustainable – significant decline
E_{dVF}	Atacama Corporate Socio-efficiency for workplace safety	0.170	0.122	0.132	0.071	0.031	0.036	0.052	0.060	0.038	Unsustainable – significant decline
E_{gVF}	Global Corporate Socio-efficiency for workplace safety	0.598	0.429	0.486	0.341	0.095	0.085	0.149	0.168	0.124	Unsustainable – significant decline
E_R	Corporate Economic yield	0.808	0.864	0.993	1.239	1.995	2.708	2.355	2.156	0.975	Mostly sustainable

Table footnotes: Sustainability is assessed here for primary measures only. Some selected secondary measures appear in the text.

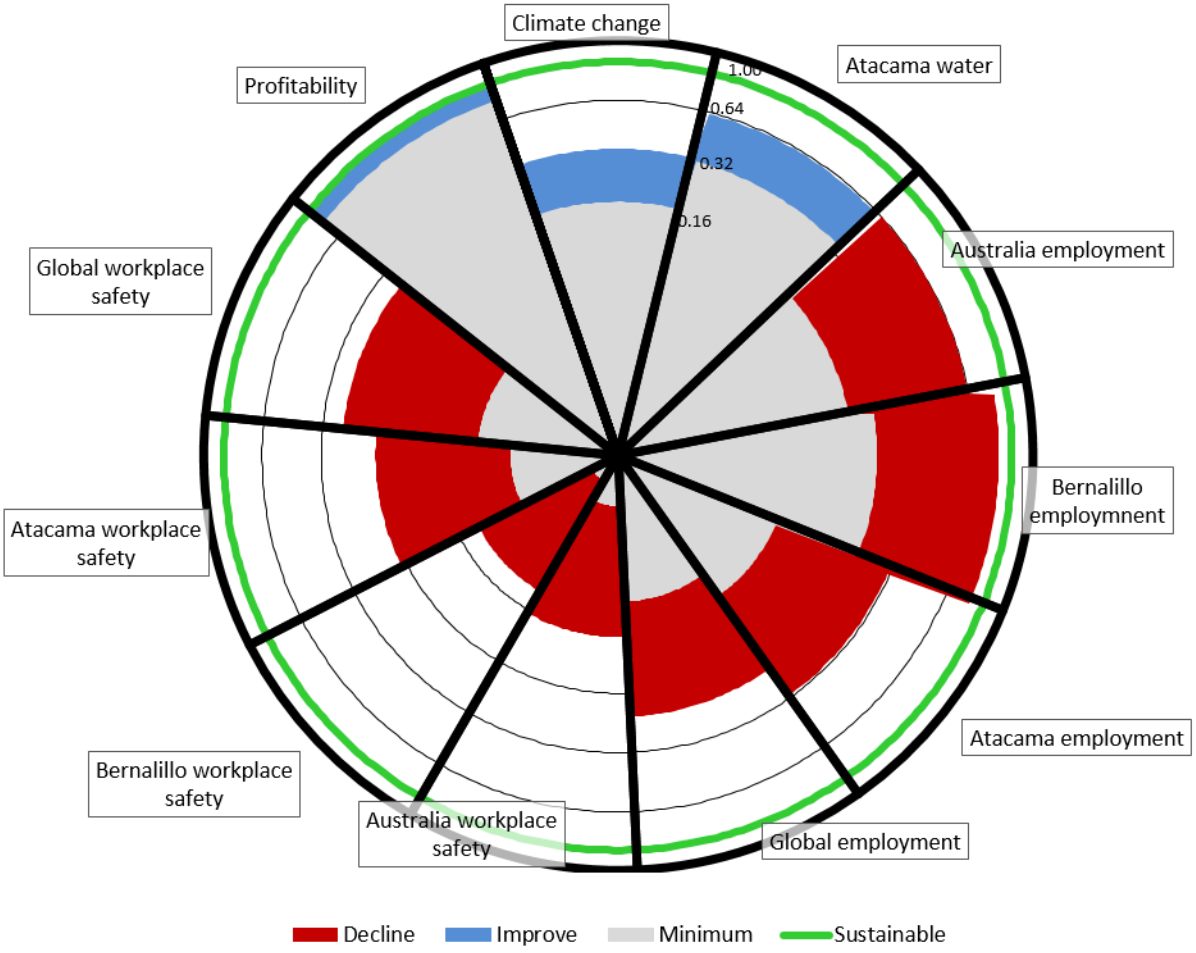


Figure 5.1 Comparison radial sector chart comprehensive sustainability target metric assessment of BHP for years 2001 and 2009, logarithmic scale radius

5.3.1 Interdependence of Sustainability Domains

The normalized efficiency and effectiveness metrics of CSTM facilitate assessment of social and environmental sustainability interdependencies with the secondary sustainability indicators that are products of pairs of the primary measures. Using the values from Table 5.2 for 2009, global ecological equity for GHG emissions and employment can be calculated as $E_{gVC}E^{\oplus}_{gVL}=$

0.362*0.055 = 0.020; the highly unsustainable result for both primary measures leads to a dramatically unsustainable ecological equity. Another secondary measure is the social yield, pairing a social burden and benefit, is the product of socio-effectiveness and socio-efficiency, these measure share the same system boundary, avoiding that concern. As an example, BHP's Corporate Australian social yield of employment for workplace safety in 2001 is $E_{aVF}E_{aVL}^{\oplus}$ = 0.018*0.155 = 0.003, which is also a dramatically unsustainable result. As expected—based on the challenges described in [21, 43]—the source study makes no attempt to explore or interpret secondary sustainability relationships [148]. The consistency and uniformity of CSTM's framework for each impact, boundary, and metric, makes the assessment results straightforward to interpret and communicate even for a larger number of sustainability indicators.

5.3.2 Limitations, Robustness, and Data Quality Concerns

The underlying principle for deriving the CSTM sustainability indicators is that any entity engaged in economic activity has a shared and proportionate responsibility for environmental and social stewardship. This principle is not amenable to rigorous mathematical proof or scientific discovery; however, it has a commonsense appeal that several other academic researchers and global sustainability reporting organizations are beginning to explore. The impacts assessed here illustrate the comprehensiveness of the CSTM methodology to assess all three of the traditional sustainability impact domains, including both burdens and beneficial impacts, global and localized spatial scales, and the interrelationships between impact domains. This assessment is quantitative and uses data from multiple sources, including corporate sustainability reports and other relevant climate and social science research and site-specific data. As such, qualitative metrics are beyond the scope of the CSTM; however, qualitative measures can augment the analytic approach and sustainability indicators presented here to provide additional insights or interpretation of outcomes.

Case Study Limitations: There are several limitations to this case study analysis based on the available data provided by BHP and the sustainability indicators used by Lodhia and Martin. Further, only a subset of potential impacts relevant to mining activity [182] are considered for this illustration. The CSTM is not limited to use within this context or impacts, but the analysis reveals some of the limitations of data included in typical corporate sustainability reports that are of concern. The lack of clarity regarding system boundaries in corporate sustainability reports [43] hinders any sustainability assessment, including the CSTM which is dependent on clear and consistent boundaries across sustainability domains. Corporate sustainability reports often lack location specific impacts [183] especially across all domains. This information is critical when analyzing social, environmental and economic impacts that are local, regional or national in scope. The CSTM must have boundaries that are consistent across domains to calculate productivity ratios and sustainability indicators.

Regarding boundary consistency, an issue discussed earlier is the selection of lifecycle boundary for the study. In the case study presented here, the downstream value chain and the use, recycling and reuse phases are not included; however, the CSTM framework is sufficiently robust to directly accommodate these additional system components and business activities within the analysis boundary. Clearly setting the scope and boundary for the system and analysis and maintaining boundary consistency are critical.

Data Uncertainty and Variability: Uncertainty and variability in estimating economic activity, impacts, and targets may result in erroneous sustainability conclusions. The CSTM is fully compatible and compliant with the ISO 14040 lifecycle assessment (LCA) framework and methodology from Goal and Scope Definition and Inventory Analysis to Interpretation but with broader and more comprehensive impact assessment capabilities [184]. Consequently, problems with data uncertainty and variability that affect LCA data quality also affect CSTM sustainability assessment. Another data quality concern is combining data from various sources, as was necessary in the case study to demonstrate how regional boundaries for water and employment impacts were assessed. Care must be taken to assure the temporal and geographic data are consistent across the economic, environmental, and social impact domains. Many of these problems are well recognized in the LCA literature [185]. Although it is not detailed here, incorporating data uncertainty distributions to compute assessment ranges rather than the single assessment values and using sensitivity analysis would provide additional confidence in assessment results.

Consistency and Transparency: Developing meaningful carrying capacities for burdens and commitment targets for benefits at various spatial boundaries will expand the potential for target-based approaches like the CSTM to be more consistent and more widely accepted. Due to the complexity and uncertain behavior of the sustainability domains, setting capacity limits and threshold values will require substantial research [7]. Consistency and transparency in specifying these target levels and aligning impact boundaries are critical to any meaningful comparison between organizations and assessments, in general. As seen in the case study presented here, there may be some locales where data is not currently available for specific boundaries (e.g., GDP by watershed, or employment by watershed), necessitating new granularity in economic data, refined allocation methods, and further sensitivity analysis.

5.3.3 Renewable Energy Comparison with Varied Boundaries

The price of electricity per kWh from a utility is used as the economic value of the life cycle functional unit, USD 0.175/kWh [30], dividing this by the environmental impacts per kWh as in section 3.3.2 yields p_{GHG}, and p_{LCW}. Since OPW treats the environmental impact from operation phase only, it is appropriate to estimate the value added for that phase only. The value of the operational phase of the electricity generation lifecycle is estimated by using the operating margin (operating income/total revenue) of a representative large power and gas utility. The reasoning is that the value added by operation (converting fuel to electricity and delivering it to customers) is similar to the difference between total revenue and operating costs. The value estimate for the operations phase is 17% from the 2011 operating margin in [31] of the total value or USD 0.029/kWh, yielding the p_{OPW} values. Table 5.3 presents the impact productivity results for the various technologies.

By the productivity, sustainable productivity and Table 3.1 the CSTM indicators are calculated with E_{GHG}, in Table 5.4 and Figure 5.2 for GHG, Table 5.5 for E_{OPW} and E_{LCW} for New Jersey and Table 5.6 for E_{OPW} and E_{LCW} for the United States.

Table 5.3 Value Productivities for GHG, Operational Phase Water and Lifecycle Water for Renewable Energy Technologies

System	Description	p_{GHG} kg USD/ CO_2Eq	p_{LCW} USD/m^3	p_{OPW} USD/m^3
US Grid		0.23	5.89	11.42
m-Si	Solar PV mono-crystalline	0.65		
p-Si	Solar PV poly-crystalline	2.05	313.02	
a-Si	Solar PV thin film	4.61	85.97	
PV-Ut	Utility Scale Solar PV			269.90
W30	30kW Wind	4.38	170.49	
W100	100kW Wind	7.01		
W-Ut	Utility Scale Wind	13.48	311.94	6,988.01

Table 5.4 Ecoefficiency for GHG and Sustainability Assessment for United States Grid and Renewable Energy Technologies

System	E_{GHG}	Sustainable?
US Grid	0.1	No
m-Si	0.2	No
p-Si	0.7	No
a-Si	1.5	Yes
W30	1.4	Yes
W100	2.3	Yes
W-Ut	4.3	Yes

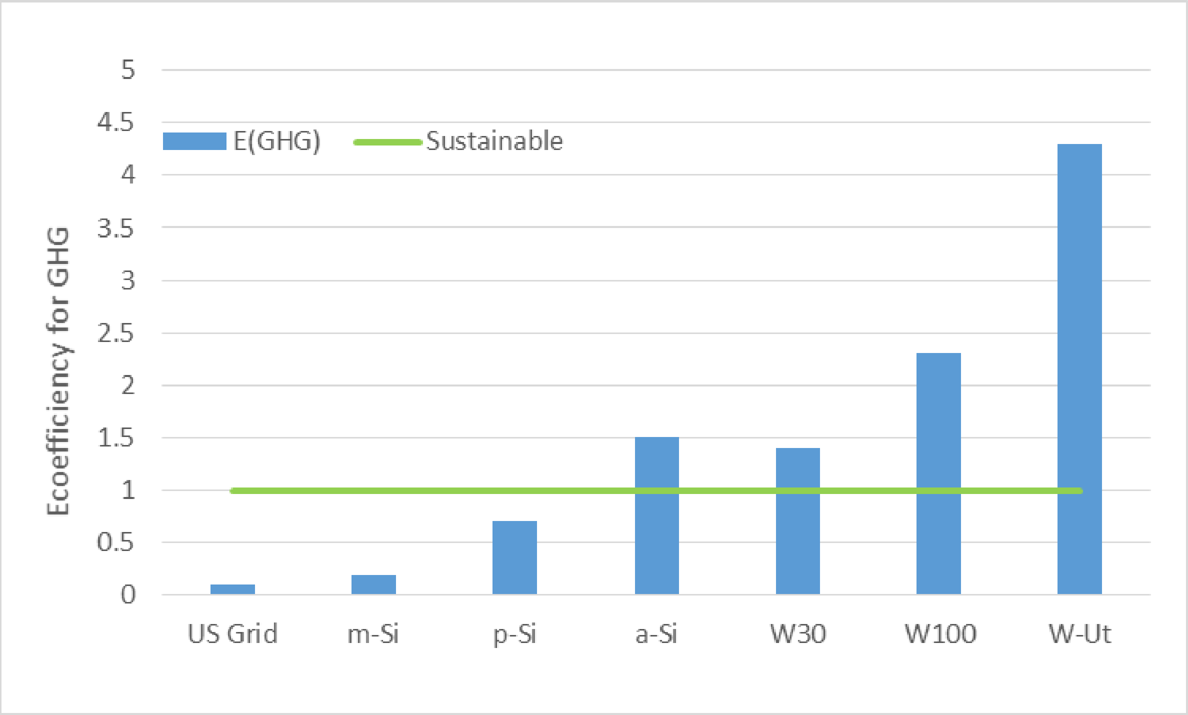


Figure 5.2 Ecoefficiency for GHG and sustainability assessment for United States Grid and renewable energy technologies

Not surprisingly, the U.S. Grid is clearly not a sustainable source of energy at these prices (V and GDP) and GHG emissions. Large scale wind is most attractive, with the other wind sources and Solar PV a-Si also providing sustainable solutions. The crystalline solar technologies incur relatively significant GHG emissions in the silicon manufacturing process, limiting their benefit over the conventional grid.

With regard to water use, there are two important caveats. The LCW analysis assumes all of the water is consumed in New Jersey (or in the U.S. for the national analysis). This is a limitation of the data, and a well-understood weakness of LCAs in general—lack of sensitivity to temporal and spatial attributes of environmental impacts across the product/process lifecycle. Also, when discussing the sustainable productivity for water it was noted that there appears to be a wide range of sustainable productivity results in different geographical regions of the state, that range suggests that there are a range of E_{LCW} outcomes for different locations in the state. When considering the E_{LCW} results, these caveats imply that the environmental impact, economic value of the product, regional carrying capacity, and regional GDP need to be carefully considered for the specific case: product, life cycle phase, and geographic location.

The E_{LCW} results for New Jersey, treating all water consumption as occurring within the state, show the grid is unsustainable by a wide margin. Although PV a-Si is very attractive from a GHG perspective, its manufacture is water intensive compared to crystalline systems which is evidenced by the p_{LCW} results. On average, PV a-Si consumes an unsustainable LCW, but the range of carrying capacities and SP_{LCW} in the state suggest that locations could be found in New Jersey that could support the entire life cycle of PV a-Si. The same applies to the smallest wind system, W30. All other renewable are sustainable on average in the state.

The operation phase of all the renewable technologies are sustainable in New Jersey. And at the national level, even the Grid is sustainable with regard to water use, both LCW and OPW.

Table 5.5 Ecoefficiency for Operational and Lifecycle Water and Sustainability Assessment for United States Grid and Renewable Energy Technologies in New Jersey Spatial Boundary

System	E_{LCW}	Sustainable?	E_{OPW}	Sustainable?
Grid	0.03	No	0.06	No
PV p-Si	1.7	Yes	2.7	Yes
PV a-Si	0.5	No		
PV-Ut			1.5	Yes
W30	0.9	No		
W-Ut	1.7	Yes	38.6	Yes

Table 5.6 Ecoefficiency for Operational and Lifecycle Water and Sustainability Assessment for United States Grid and Renewable Energy Technologies in United States Spatial Boundary

System	E_{LCW}	Sustainable?	E_{OPW}	Sustainable?
Grid	1.4	Yes	2.7	Yes
PV p-Si	73.7	Yes		
PV a-Si	20.27	Yes		
PV-Ut			63.5	Yes
W30	40.17	Yes		
W-Ut	73.4	Yes	1,644.2	Yes

CHAPTER 6

CONCLUSION

6.1 Overview

This section presents brief concluding remarks to summarize important research outcomes, highlight the primary scholarly contributions of this dissertation research, and discuss potential areas for future research.

6.2 Research Contribution 1: More Efficient and Robust IOLCA

The IOLCA-II model improves the capability of input-output LCA models to estimate additional impact detail that are driven by spending on specific input sectors, and adding social impacts and profitability extends the breadth of the assessment domain.

The techniques proposed in this research provide an effective method to produce impact inventory estimates using the IOLCA-II with additional Scope allocations, social impact and profitability data to analyze impacts in the environmental, social and economic domains. The resulting impact inventories demonstrate the important potential impact of solar electricity generation on a universities sector baseline. Moreover, these techniques also show that automation has the potential to make significant positive impacts on profitability and fatality rates of truck transportation and a small positive impact on GHG emissions, but may also carry the cost of a large negative impact on employment and potentially negative impacts on the labor force at large.

6.3 Research Contribution 2: Comprehensive Sustainability Target Method

The corporate world has a critical role in creating a sustainable future and helping to overcome the greatest challenges facing society today. The need to comprehensively assess strategies and manage operations wisely requires an understanding of how decisions by the corporation drive the company towards its sustainability goals, and when necessary, to adjust directions and behaviors. A quantitative and comprehensive approach to assessing sustainability is essential to meeting this global challenge. There are a number of fundamental requirements for *absolute* sustainability assessment; including, recognizing environmental and social limits, supporting societal goals and social justice, assessing beneficial impacts, analyzing the interrelationships between impact domains, and communicating sustainability assessment results effectively.

The research presented here provides the fundamental approach and methodologies for the CSTM, a framework for a more comprehensive and *absolute* (sustainability threshold) sustainability assessment based on the three traditional domains of sustainability: economic, environmental, and societal. The CSTM is derived from the STM and extended to support any specific burdensome or beneficial impact measures that are of interest and operationalizes sustainability indicators to assess the complex interrelationships and interdependencies across these domains. This approach defines and quantifies a set of non-dimensional sustainability efficiency and effectiveness metrics to clearly identify if the target system is sustainable, and if not, how far it is from being sustainable. In addition to supporting corporate decision makers, the CSTM provides the ability to simplify communications and present results and outcomes clearly for all stakeholders.

The case study presented demonstrates the importance of having a more comprehensive and *absolute* technique like the CSTM to establish corporate sustainability goals and guide the company forward towards the goal. Results of the case study revealed critical new insights showing that the relative performance targets for GHG emissions intensity currently used by the company do not assure that progress towards sustainability is achieved even if the corporate target is met.

6.4 Research Contribution 3: Interdependencies of Sustainability Domains

Economic activity generates impacts that propagate to other domains of sustainability, resulting in stresses on ecosystems and society. The subtle interrelationships between impacts in the environmental and societal domains are potentially pathways for disruption that creates critical sustainability issues beyond the source domains.

The BHP case study illustrates the insights that assessing absolute sustainability of interdependencies between and within the sustainability domains. The interdependent sustainability indicators of CSTM illuminate a previously recognized sustainability topic that has not been adequately addressed. The non-dimensional simplicity and consistency of the standard threshold CSTM indicators are key benefits to quantitatively assess and better understand these interrelationships. Although there are already numerous potential impact categories of consequence for sustainability, the CSTM technique provides a unified approach for adding additional categories with associated combinatorial pairs of indicators without losing simplicity and consistency to communicate and interpret results.

6.5 Renewable Energy with Varied Spatial Boundaries Sustainability Assessments

The case study illustrates the sensitivity of selecting and aligning system boundaries and spatial boundaries and how the proposed approach can assist in properly analyzing these boundary issues, The STM analysis provides a clear assessment of the sustainability of various renewable energy technologies—not all renewable technologies are sustainable for all impacts. As well known, the conventional grid is not sustainable with regard to GHG at current valuations and fuel mix. Of the renewable energy options, thin film (a-Si) silicon and wind options provide the sustainable solutions.

The relatively large New Jersey GDP and limited water resource compared to the U.S. as a whole, SP_{LCW} and SP_{OPW} are high relative to the U.S. sustainable productivity. The LCW sustainability analysis here assumes all of the water consumed is in the area of analysis, which is not accurate. Raw materials and fuels are extracted in other locations and the materials and components are manufactured in other locations and transported to the installation location. To partially address this simplifying assumption, a use-stage OPW analysis was conducted which shows that for the conventional grid, New Jersey does not provide a location that would permit sustainable water use (on average, this result will vary for a specific plant).

Finally, a regional-level STM analysis with freshwater reference values based on the local environmental carrying capacity and economic activity was conducted using the general methodology presented. Results indicate that locations for lifecycle stage processes—e.g., manufacturing—is critical in determining the sustainability of the technology.

6.6 Further Research

To make the IOLCA-II model truly operational for general purpose use, various avenues of research should be investigated. Numerous techniques to address uncertainty, inflation, impact timing and other issues in IOLCA assessments. Research should be undertaken to confirm that each of them remain mathematical and practically valid within the IOLCA-II. Decomposition of the remaining sectors and impact categories, including social impacts, and. constructing impact matrices with distinct emission factor matrices and disposition matrices (to reflect consumption of purchases that result in different emissions) would make IOLCA-II more robust. There are other commonly used IOLCA models [186] that are also adaptable to the IOLCA-II extension, and developing the impact matrices for those models would make the technique available to additional users. Increasing the system boundary to include other product life cycle phases and a broader selection of impacts for analysis would shed additional light on the consequences of a proposed project.

IOLCA-II will produce estimates of impacts subject to uncertainty concerns and are based on data at a specific point in time. The thresholds used in CSTM likewise will be subject to uncertainty. Bounded impact estimates and sustainability assessments with analysis into data quality and uncertainty consequences are topics that need to be more fully explored.

There are several aspects of the CSTM and its case study application that suggest important opportunities and directions for future research. One area of exploration currently underway is to develop a sustainability decision space with analytics and assessment to assist decision makers as to which sustainability projects are most viable and which have higher sustainability returns on investments. Initial work on the economic and environmental domains show significant promise. Additional extensions and practical applications of the CSTM in terms of impact categories and indicators for assessment would be valuable; developing tools and survey data to estimate impacts that are not currently supported by lifecycle assessment or other techniques will broaden the reach of CSTM; and, comparing and contrasting the CSTM with other common sustainability assessment tools will provide additional insights into the strengths and weaknesses of each approach.

The new proposed social impacts for the human capital and living wage compensation aspects of employment quality require further development and application to assessments to advance the investigation of their relevance. CSTM is dependent on sustainable thresholds, carrying capacity estimates for burdens and commitment targets for beneficial impacts. Developing reliable, evidence-based thresholds, including for the new social impacts proposed, that are widely accepted and lead to accurate sustainability assessments is a significant research challenge. Performing assessments of companies and products using the proposed impacts, investigating their interdependencies and comparing them to other sustainability assessment techniques will illustrate the insights they can offer. Sources for sufficiently detailed, granular data and targets in each of the sustainability domains will also be needed for assessments of impacts that have varied spatial boundaries.

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APPENDIX

NEW SOCIAL IMPACT MEASURES The described methodology was used to produce the distribution of living wage requirements in the United States.

Table A.1 Living Wage and Labor Force by Household Composition, Number of Workers and State

	Household composition	**1 Adult**	**1 Adult 1 Child**	**1 Adult 2 Children**	**1 Adult 3 Children**	**2 Adults (1 Working)**	**2 Adults (1 Working) 1 Child**	**2 Adults (1 Working) 2 Children**	**2 Adults (1 Working) 1 Children**	**2 Adults**	**2 Adults 1 Child**	**2 Adults 3 Children**	**2 Adults 3 Children**
	Code	**A1C0W1**	**A1C1W1**	**A1C2W1**	**A1C3W1**	**A2C0W1**	**A2C1W1**	**A2C2W1**	**A2C3W1**	**A2C0W2**	**A2C1W2**	**A2C2W2**	**A2C3W2**
State	**% of Labor Force**	**12.9%**	**4.5%**	**2.7%**	**1.4%**	**13.6%**	**2.8%**	**2.6%**	**1.5%**	**32.8%**	**8.8%**	**10.5%**	**5.8%**
Alabama	**1.40%**	10.17	19.86	24.59	31.49	16.35	19.22	21.81	23.93	8.17	11.02	13.64	16.04
Alaska	**0.23%**	11.17	23.90	28.88	37.46	17.73	21.88	24.46	28.29	8.87	13.08	15.80	19.13
Arizona	**1.95%**	10.47	22.37	28.02	37.00	17.40	21.11	23.76	27.33	8.70	12.34	15.40	18.91
Arkansas	**0.87%**	9.56	19.29	24.60	32.14	15.68	18.85	21.40	23.58	7.84	10.71	13.63	16.36
California	**11.90%**	12.34	25.26	28.82	36.44	19.23	23.56	26.20	30.48	9.61	13.78	15.79	18.63
Colorado	**1.75%**	10.69	23.51	28.16	36.14	17.31	21.18	23.87	27.44	8.65	12.93	15.49	18.49
Connecticut	**1.21%**	11.97	26.36	31.00	38.29	18.71	23.25	25.82	28.73	9.35	14.30	16.85	19.56
Delaware	**0.28%**	11.68	23.37	28.12	35.50	18.29	22.19	24.77	27.35	9.15	12.77	15.41	18.04
Washington DC	**0.24%**	14.84	30.42	37.81	49.19	21.65	25.69	28.33	32.28	10.82	16.31	20.27	24.90
Florida	**6.01%**	10.94	23.01	27.08	34.05	17.76	21.62	24.11	26.97	8.88	12.55	14.84	17.31
Georgia	**3.10%**	10.69	20.92	24.73	30.91	16.86	20.09	22.63	24.96	8.43	11.53	13.69	15.75
Hawaii	**0.42%**	13.74	26.86	33.26	45.08	20.39	25.01	27.67	33.33	10.20	14.59	18.02	22.95
Idaho	**0.50%**	9.59	19.69	24.18	31.27	15.92	19.13	21.80	24.63	7.96	11.01	13.49	16.05
Illinois	**4.27%**	11.08	22.96	27.64	34.70	17.55	21.02	23.60	25.99	8.78	12.57	15.17	17.67
Indiana	**2.03%**	9.74	20.36	24.44	30.62	16.05	19.50	22.04	24.15	8.02	11.26	13.55	15.62
Iowa	**1.06%**	9.93	21.27	25.81	32.63	16.38	19.71	22.33	24.64	8.19	11.75	14.28	16.64
Kansas	**0.96%**	9.82	20.92	25.34	32.22	16.36	19.79	22.36	24.84	8.18	11.55	14.01	16.43
Kentucky	**1.34%**	9.71	18.67	23.61	30.77	15.68	18.93	21.50	23.66	7.84	10.41	13.14	15.67
Louisiana	**1.34%**	10.47	20.90	23.58	28.38	16.94	20.42	23.01	25.08	8.47	11.53	13.14	14.48
Maine	**0.45%**	10.61	22.36	26.71	33.42	17.31	20.85	23.48	26.12	8.65	12.33	14.74	17.14
Maryland	**2.00%**	13.07	25.82	29.92	37.30	19.72	23.58	26.14	29.38	9.86	13.99	16.29	18.94
Massachusetts	**2.23%**	12.60	26.38		37.18	19.00	22.95	25.52	28.44	9.50	14.32	16.58	19.01
Michigan	**2.97%**	9.98	21.31	25.67	32.41	16.35	19.81	22.37	24.76	8.17	11.74	14.17	16.52
Minnesota	**1.92%**	10.65	22.83	27.83	35.70	17.28	20.92	23.54	26.43	8.64	12.53	15.28	18.17

	Household composition	**1 Adult**	**1 Adult 1 Child**	**1 Adult 2 Children**	**1 Adult 3 Children**	**2 Adults (1 Working)**	**2 Adults (1 Working) 1 Child**	**2 Adults (1 Working) 2 Children**	**2 Adults (1 Working) 1 Children**	**2 Adults**	**2 Adults 1 Child**	**2 Adults 3 Children**	**2 Adults 3 Children**
	Code	**A1C0W1**	**A1C1W1**	**A1C2W1**	**A1C3W1**	**A2C0W1**	**A2C1W1**	**A2C2W1**	**A2C3W1**	**A2C0W2**	**A2C1W2**	**A2C2W2**	**A2C3W2**
State	**% of Labor Force**	**12.9%**	**4.5%**	**2.7%**	**1.4%**	**13.6%**	**2.8%**	**2.6%**	**1.5%**	**32.8%**	**8.8%**	**10.5%**	**5.8%**
Mississippi	**0.85%**	9.95	19.99	23.87	29.88	16.52	19.71	22.30	24.40	8.26	11.08	13.28	15.24
Missouri	**1.94%**	9.64	20.06	23.79	29.77	15.89	19.46	21.97	24.25	7.94	11.10	13.20	15.20
Montana	**0.33%**	9.72	20.34	26.25	34.58	15.76	18.87	21.50	24.15	7.88	11.32	14.50	17.70
Nebraska	**0.66%**	9.48	20.96	25.75	32.66	15.96	19.44	21.98	24.13	7.98	11.56	14.20	16.64
Nevada	**0.87%**	10.66	23.08	27.10	34.68	17.45	21.03	23.62	27.39	8.72	12.67	14.91	17.74
New Hampshire	**0.48%**	11.43	24.24	28.06	34.67	17.83	21.74	24.30	27.37	8.91	13.25	15.37	17.75
New Jersey	**2.97%**	12.51	24.79	28.66	35.65	18.70	22.63	25.13	28.50	9.35	13.49	15.64	18.23
New Mexico	**0.60%**	10.13	20.78	24.86	31.51	16.64	19.83	22.49	25.29	8.32	11.55	13.83	16.17
New York	**6.15%**	12.75	26.19	33.92	44.64	18.96	22.75	25.31	28.56	9.48	14.21	18.30	22.74
North Carolina	**3.06%**	10.53	21.63	25.83	32.34	16.89	20.46	23.09	25.35	8.44	11.92	14.28	16.47
North Dakota	**0.25%**	9.79	20.39	24.73	31.60	15.84	18.96	21.45	24.01	7.92	11.25	13.67	16.11
Ohio	**3.72%**	9.39	19.93	24.18	30.55	15.41	18.67	21.16	23.30	7.71	11.02	13.39	15.58
Oklahoma	**1.18%**	9.49	20.30	24.27	30.42	15.84	19.42	21.94	24.08	7.92	11.21	13.45	15.50
Oregon	**1.27%**	10.68	22.56	27.09	34.88	17.60	21.16	23.91	27.40	8.80	12.48	14.99	17.87
Pennsylvania	**4.21%**	10.40	21.79	26.83	34.00	16.60	19.97	22.49	24.88	8.30	12.00	14.74	17.41
Rhode Island	**0.37%**	11.01	23.37	28.48	35.74	17.18	20.44	22.98	25.41	8.59	12.80	15.57	18.29
South Carolina	**1.38%**	10.49	20.22	23.30	28.56	16.70	20.09	22.67	24.80	8.35	11.19	13.00	14.57
South Dakota	**0.29%**	9.48	19.74	23.64	29.81	15.87	18.95	21.42	23.70	7.93	10.92	13.11	15.21
Tennessee	**2.00%**	10.26	20.29	23.80	29.60	16.83	20.15	22.78	25.03	8.41	11.25	13.27	15.10
Texas	**8.15%**	10.20	21.06	24.48	30.40	16.69	20.30	22.80	25.26	8.34	11.58	13.54	15.48
Utah	**0.88%**	10.29	20.69	24.60	31.32	16.60	20.03	22.73	25.77	8.30	11.52	13.72	16.08
Vermont	**0.23%**	11.13	22.77	27.55	34.67	17.25	20.92	23.45	26.05	8.62	12.49	15.11	17.75
Virginia	**2.80%**	12.36	23.94	28.32	35.75	18.52	22.34	24.91	27.92	9.26	13.04	15.49	18.17
Washington	**2.23%**	10.34	22.40	26.55	34.03	16.82	20.43	23.01	26.55	8.41	12.32	14.63	17.42
West Virginia	**0.51%**	9.90	19.38	24.40	31.44	15.91	18.60	21.18	23.17	7.96	10.77	13.54	16.01
Wisconsin	**1.97%**	10.13	22.38	28.88	37.71	16.53	19.90	22.50	24.85	8.27	12.29	15.79	19.18
Wyoming	**0.20%**	9.93	20.80	26.82	35.28	15.82	19.16	21.75	24.41	7.91	11.53	14.77	18.04

Sources: [104, 130, 131, 182] Abbreviations: A = adults; C = children; W = workers

Table A.2 Abbreviated Living Wage Cumulative Distribution Function, 5-percentile Precision

State	HH Code	LW USD$_{2015}$	(HH*State) % of LF	Cum %
Ohio	A2C0W2	7.71	1.22%	1.22%
Arkansas	A2C0W2	7.84	0.29%	1.51%
Kentucky	A2C0W2	7.84	0.44%	1.95%
Montana	A2C0W2	7.88	0.11%	2.05%
Wyoming	A2C0W2	7.91	0.06%	2.12%
…				
New Mexico	A2C0W2	8.32	0.20%	9.42%
Texas	A2C0W2	8.34	2.67%	12.09%
…				
Georgia	A2C0W2	8.43	1.02%	14.94%
North Carolina	A2C0W2	8.44	1.00%	15.95%
…				
Nevada	A2C0W2	8.72	0.29%	18.86%
Illinois	A2C0W2	8.78	1.40%	20.26%
…				
Connecticut	A2C0W2	9.35	0.40%	24.28%
New Jersey	A2C0W2	9.35	0.97%	25.25%
…				
Idaho	A1C0W1	9.59	0.06%	28.93%
California	A2C0W2	9.61	3.90%	32.83%
…				
Mississippi	A1C0W1	9.95	0.11%	34.71%
Michigan	A1C0W1	9.98	0.38%	35.09%
…				
Colorado	A1C0W1	10.69	0.23%	39.92%
Georgia	A1C0W1	10.69	0.40%	40.32%
…				
Delaware	A1C0W1	11.68	0.04%	44.85%
Michigan	A2C1W2	11.74	0.26%	45.11%
…				
Florida	**A2C1W2**	**12.55**	**0.53%**	**49.70%**
Illinois	**A2C1W2**	**12.57**	**0.38%**	**50.08%**
…				
Indiana	A2C2W2	13.55	0.21%	54.93%
Arkansas	A2C2W2	13.63	0.09%	55.03%
…				
Washington DC	A1C0W1	14.84	0.03%	59.73%
Florida	A2C2W2	14.84	0.63%	60.37%
…				
Montana	A2C0W1	15.76	0.04%	64.67%
California	A2C2W2	15.79	1.25%	65.92%
…				
Massachusetts	A2C2W2	16.58	0.23%	69.60%
Pennsylvania	A2C0W1	16.6	0.57%	70.17%
Arizona	A2C0W1	17.4	0.26%	74.77%
Pennsylvania	A2C3W2	17.41	0.25%	75.01%
…				
Ohio	A2C1W1	18.67	0.11%	79.94%
New Jersey	A2C0W1	18.7	0.40%	80.35%
…				
Ohio	A1C1W1	19.93	0.17%	84.98%
Pennsylvania	A2C1W1	19.97	0.12%	85.10%
…				
New York	A2C3W2	22.74	0.36%	89.85%
New York	A2C1W1	22.75	0.18%	90.03%
…				
Rhode Island	A2C3W1	25.41	0.01%	94.98%
Massachusetts	A2C2W1	25.52	0.06%	95.04%
…				
Connecticut	A1C3W1	38.29	0.02%	99.90%
New York	A1C3W1	44.64	0.09%	99.99%
Hawaii	A1C3W1	45.08	0.01%	100.00%
Washington DC	A1C3W1	49.19	0.00%	100.00%

Sources: [104, 130, 131, 182]

Abbreviations: A = adults; C = children; W = workers

Table A.3. Full Living Wage Cumulative Distribution Function

State	HH Code	LW USD$_{2015}$	(HH*State) % of LF	Cum %
Ohio	A2C0W2	7.71	1.22%	1.22%
Arkansas	A2C0W2	7.84	0.29%	1.51%
Kentucky	A2C0W2	7.84	0.44%	1.95%
Montana	A2C0W2	7.88	0.11%	2.05%
Wyoming	A2C0W2	7.91	0.06%	2.12%
North Dakota	A2C0W2	7.92	0.08%	2.20%
Oklahoma	A2C0W2	7.92	0.39%	2.59%
South Dakota	A2C0W2	7.93	0.09%	2.68%
Missouri	A2C0W2	7.94	0.64%	3.32%
Idaho	A2C0W2	7.96	0.16%	3.48%
West Virginia	A2C0W2	7.96	0.17%	3.65%
Nebraska	A2C0W2	7.98	0.22%	3.86%
Indiana	A2C0W2	8.02	0.67%	4.53%
Alabama	A2C0W2	8.17	0.46%	4.99%
Michigan	A2C0W2	8.17	0.97%	5.96%
Kansas	A2C0W2	8.18	0.32%	6.28%
Iowa	A2C0W2	8.19	0.35%	6.63%
Mississippi	A2C0W2	8.26	0.28%	6.90%
Wisconsin	A2C0W2	8.27	0.65%	7.55%
Pennsylvania	A2C0W2	8.3	1.38%	8.93%
Utah	A2C0W2	8.3	0.29%	9.22%
New Mexico	A2C0W2	8.32	0.20%	9.42%
Texas	A2C0W2	8.34	2.67%	12.09%
South Carolina	A2C0W2	8.35	0.45%	12.54%
Tennessee	A2C0W2	8.41	0.66%	13.20%
Washington	A2C0W2	8.41	0.73%	13.93%
Georgia	A2C0W2	8.43	1.02%	14.94%
North Carolina	A2C0W2	8.44	1.00%	15.95%
Louisiana	A2C0W2	8.47	0.44%	16.39%
Rhode Island	A2C0W2	8.59	0.12%	16.51%
Vermont	A2C0W2	8.62	0.08%	16.58%
Minnesota	A2C0W2	8.64	0.63%	17.21%
Colorado	A2C0W2	8.65	0.57%	17.78%
Maine	A2C0W2	8.65	0.15%	17.93%
Arizona	A2C0W2	8.7	0.64%	18.57%
Nevada	A2C0W2	8.72	0.29%	18.86%
Illinois	A2C0W2	8.78	1.40%	20.26%
Oregon	A2C0W2	8.8	0.42%	20.67%
Alaska	A2C0W2	8.87	0.08%	20.75%
Florida	A2C0W2	8.88	1.97%	22.72%
New Hampshire	A2C0W2	8.91	0.16%	22.87%
Delaware	A2C0W2	9.15	0.09%	22.96%
Virginia	A2C0W2	9.26	0.92%	23.88%
Connecticut	A2C0W2	9.35	0.40%	24.28%
New Jersey	A2C0W2	9.35	0.97%	25.25%
Ohio	A1C0W1	9.39	0.48%	25.73%
Nebraska	A1C0W1	9.48	0.09%	25.82%
New York	A2C0W2	9.48	2.02%	27.83%
South Dakota	A1C0W1	9.48	0.04%	27.87%
Oklahoma	A1C0W1	9.49	0.15%	28.02%
Massachusetts	A2C0W2	9.5	0.73%	28.75%
Arkansas	A1C0W1	9.56	0.11%	28.87%
Idaho	A1C0W1	9.59	0.06%	28.93%
California	A2C0W2	9.61	3.90%	32.83%
Missouri	A1C0W1	9.64	0.25%	33.08%
Kentucky	A1C0W1	9.71	0.17%	33.25%
Montana	A1C0W1	9.72	0.04%	33.30%
Indiana	A1C0W1	9.74	0.26%	33.56%
North Dakota	A1C0W1	9.79	0.03%	33.59%
Kansas	A1C0W1	9.82	0.12%	33.71%
Maryland	A2C0W2	9.86	0.66%	34.37%
West Virginia	A1C0W1	9.9	0.07%	34.44%
Iowa	A1C0W1	9.93	0.14%	34.57%
Wyoming	A1C0W1	9.93	0.03%	34.60%
Mississippi	A1C0W1	9.95	0.11%	34.71%
Michigan	A1C0W1	9.98	0.38%	35.09%
New Mexico	A1C0W1	10.13	0.08%	35.17%
Wisconsin	A1C0W1	10.13	0.25%	35.42%
Alabama	A1C0W1	10.17	0.18%	35.61%
Hawaii	A2C0W2	10.2	0.14%	35.74%
Texas	A1C0W1	10.2	1.05%	36.79%
Tennessee	A1C0W1	10.26	0.26%	37.05%
Utah	A1C0W1	10.29	0.11%	37.16%
Washington	A1C0W1	10.34	0.29%	37.45%
Pennsylvania	A1C0W1	10.4	0.54%	38.00%
Kentucky	A2C1W2	10.41	0.12%	38.11%
Arizona	A1C0W1	10.47	0.25%	38.37%
Louisiana	A1C0W1	10.47	0.17%	38.54%
South Carolina	A1C0W1	10.49	0.18%	38.72%
North Carolina	A1C0W1	10.53	0.40%	39.11%
Maine	A1C0W1	10.61	0.06%	39.17%
Minnesota	A1C0W1	10.65	0.25%	39.42%
Nevada	A1C0W1	10.66	0.11%	39.53%
Oregon	A1C0W1	10.68	0.16%	39.69%
Colorado	A1C0W1	10.69	0.23%	39.92%
Georgia	A1C0W1	10.69	0.40%	40.32%
Arkansas	A2C1W2	10.71	0.08%	40.40%
West Virginia	A2C1W2	10.77	0.05%	40.44%
Washington DC	A2C0W2	10.82	0.08%	40.52%
South Dakota	A2C1W2	10.92	0.03%	40.54%
Florida	A1C0W1	10.94	0.77%	41.32%
Idaho	A2C1W2	11.01	0.04%	41.36%
Rhode Island	A1C0W1	11.01	0.05%	41.41%
Alabama	A2C1W2	11.02	0.12%	41.53%
Ohio	A2C1W2	11.02	0.33%	41.86%
Illinois	A1C0W1	11.08	0.55%	42.41%
Mississippi	A2C1W2	11.08	0.08%	42.49%
Missouri	A2C1W2	11.1	0.17%	42.66%
Vermont	A1C0W1	11.13	0.03%	42.69%
Alaska	A1C0W1	11.17	0.03%	42.72%
South Carolina	A2C1W2	11.19	0.12%	42.84%
Oklahoma	A2C1W2	11.21	0.10%	42.94%
North Dakota	A2C1W2	11.25	0.02%	42.97%
Tennessee	A2C1W2	11.25	0.18%	43.14%
Indiana	A2C1W2	11.26	0.18%	43.32%
Montana	A2C1W2	11.32	0.03%	43.35%
New Hampshire	A1C0W1	11.43	0.06%	43.41%
Utah	A2C1W2	11.52	0.08%	43.49%
Georgia	A2C1W2	11.53	0.27%	43.76%
Louisiana	A2C1W2	11.53	0.12%	43.88%
Wyoming	A2C1W2	11.53	0.02%	43.90%
Kansas	A2C1W2	11.55	0.08%	43.98%
New Mexico	A2C1W2	11.55	0.05%	44.04%
Nebraska	A2C1W2	11.56	0.06%	44.10%
Texas	A2C1W2	11.58	0.72%	44.82%
Delaware	A1C0W1	11.68	0.04%	44.85%
Michigan	A2C1W2	11.74	0.26%	45.11%

State	HH Code	LW USD$_{2015}$	(HH*State) % of LF	Cum %
Iowa	A2C1W2	11.75	0.09%	45.21%
North Carolina	A2C1W2	11.92	0.27%	45.48%
Connecticut	A1C0W1	11.97	0.16%	45.63%
Pennsylvania	A2C1W2	12	0.37%	46.01%
Wisconsin	A2C1W2	12.29	0.17%	46.18%
Washington	A2C1W2	12.32	0.20%	46.38%
Maine	A2C1W2	12.33	0.04%	46.42%
Arizona	A2C1W2	12.34	0.17%	46.59%
California	A1C0W1	12.34	1.54%	48.13%
Virginia	A1C0W1	12.36	0.36%	48.49%
Oregon	A2C1W2	12.48	0.11%	48.60%
Vermont	A2C1W2	12.49	0.02%	48.62%
New Jersey	A1C0W1	12.51	0.38%	49.00%
Minnesota	A2C1W2	12.53	0.17%	49.17%
Florida	**A2C1W2**	**12.55**	**0.53%**	**49.70%**
Illinois	**A2C1W2**	**12.57**	**0.38%**	**50.08%**
Massachusetts	A1C0W1	12.6	0.29%	50.37%
Nevada	A2C1W2	12.67	0.08%	50.44%
New York	A1C0W1	12.75	0.79%	51.24%
Delaware	A2C1W2	12.77	0.03%	51.26%
Rhode Island	A2C1W2	12.8	0.03%	51.29%
Colorado	A2C1W2	12.93	0.15%	51.45%
South Carolina	A2C2W2	13	0.14%	51.59%
Virginia	A2C1W2	13.04	0.25%	51.84%
Maryland	A1C0W1	13.07	0.26%	52.10%
Alaska	A2C1W2	13.08	0.02%	52.12%
South Dakota	A2C2W2	13.11	0.03%	52.15%
Kentucky	A2C2W2	13.14	0.14%	52.29%
Louisiana	A2C2W2	13.14	0.14%	52.43%
Missouri	A2C2W2	13.2	0.20%	52.64%
New Hampshire	A2C1W2	13.25	0.04%	52.68%
Tennessee	A2C2W2	13.27	0.21%	52.89%
Mississippi	A2C2W2	13.28	0.09%	52.98%
Ohio	A2C2W2	13.39	0.39%	53.37%
Oklahoma	A2C2W2	13.45	0.12%	53.49%
Idaho	A2C2W2	13.49	0.05%	53.55%
New Jersey	A2C1W2	13.49	0.26%	53.81%
Texas	A2C2W2	13.54	0.86%	54.67%
West Virginia	A2C2W2	13.54	0.05%	54.72%
Indiana	A2C2W2	13.55	0.21%	54.93%
Arkansas	A2C2W2	13.63	0.09%	55.03%
Alabama	A2C2W2	13.64	0.15%	55.17%
North Dakota	A2C2W2	13.67	0.03%	55.20%
Georgia	A2C2W2	13.69	0.33%	55.52%
Utah	A2C2W2	13.72	0.09%	55.62%
Hawaii	A1C0W1	13.74	0.05%	55.67%
California	A2C1W2	13.78	1.05%	56.72%
New Mexico	A2C2W2	13.83	0.06%	56.79%
Maryland	A2C1W2	13.99	0.18%	56.96%
Kansas	A2C2W2	14.01	0.10%	57.06%
Michigan	A2C2W2	14.17	0.31%	57.38%
Nebraska	A2C2W2	14.2	0.07%	57.45%
New York	A2C1W2	14.21	0.54%	57.99%
Iowa	A2C2W2	14.28	0.11%	58.10%
North Carolina	A2C2W2	14.28	0.32%	58.42%
Connecticut	A2C1W2	14.3	0.11%	58.53%
Massachusetts	A2C1W2	14.32	0.20%	58.73%
Louisiana	A2C3W2	14.48	0.08%	58.81%
Montana	A2C2W2	14.5	0.03%	58.84%
South Carolina	A2C3W2	14.57	0.08%	58.92%
Hawaii	A2C1W2	14.59	0.04%	58.96%
Washington	A2C2W2	14.63	0.23%	59.19%
Maine	A2C2W2	14.74	0.05%	59.24%
Pennsylvania	A2C2W2	14.74	0.44%	59.68%
Wyoming	A2C2W2	14.77	0.02%	59.70%
Washington DC	A1C0W1	14.84	0.03%	59.73%
Florida	A2C2W2	14.84	0.63%	60.37%
Nevada	A2C2W2	14.91	0.09%	60.46%
Oregon	A2C2W2	14.99	0.13%	60.59%
Tennessee	A2C3W2	15.1	0.12%	60.71%
Vermont	A2C2W2	15.11	0.02%	60.73%
Illinois	A2C2W2	15.17	0.45%	61.18%
Missouri	A2C3W2	15.2	0.11%	61.29%
South Dakota	A2C3W2	15.21	0.02%	61.31%
Mississippi	A2C3W2	15.24	0.05%	61.36%
Minnesota	A2C2W2	15.28	0.20%	61.56%
New Hampshire	A2C2W2	15.37	0.05%	61.61%
Arizona	A2C2W2	15.4	0.21%	61.82%
Delaware	A2C2W2	15.41	0.03%	61.85%
Ohio	A2C0W1	15.41	0.51%	62.35%
Texas	A2C3W2	15.48	0.48%	62.83%
Colorado	A2C2W2	15.49	0.18%	63.01%
Virginia	A2C2W2	15.49	0.29%	63.31%
Oklahoma	A2C3W2	15.5	0.07%	63.37%
Rhode Island	A2C2W2	15.57	0.04%	63.41%
Ohio	A2C3W2	15.58	0.22%	63.63%
Indiana	A2C3W2	15.62	0.12%	63.75%
New Jersey	A2C2W2	15.64	0.31%	64.06%
Kentucky	A2C3W2	15.67	0.08%	64.14%
Arkansas	A2C0W1	15.68	0.12%	64.26%
Kentucky	A2C0W1	15.68	0.18%	64.44%
Georgia	A2C3W2	15.75	0.18%	64.62%
Montana	A2C0W1	15.76	0.04%	64.67%
California	A2C2W2	15.79	1.25%	65.92%
Wisconsin	A2C2W2	15.79	0.21%	66.13%
Alaska	A2C2W2	15.8	0.02%	66.15%
Wyoming	A2C0W1	15.82	0.03%	66.18%
North Dakota	A2C0W1	15.84	0.03%	66.21%
Oklahoma	A2C0W1	15.84	0.16%	66.37%
South Dakota	A2C0W1	15.87	0.04%	66.41%
Missouri	A2C0W1	15.89	0.26%	66.67%
West Virginia	A2C0W1	15.91	0.07%	66.74%
Idaho	A2C0W1	15.92	0.07%	66.81%
Nebraska	A2C0W1	15.96	0.09%	66.90%
West Virginia	A2C3W2	16.01	0.03%	66.93%
Alabama	A2C3W2	16.04	0.08%	67.01%
Idaho	A2C3W2	16.05	0.03%	67.04%
Indiana	A2C0W1	16.05	0.28%	67.32%
Utah	A2C3W2	16.08	0.05%	67.37%
North Dakota	A2C3W2	16.11	0.01%	67.38%
New Mexico	A2C3W2	16.17	0.04%	67.42%
Maryland	A2C2W2	16.29	0.21%	67.63%
Washington DC	A2C1W2	16.31	0.02%	67.65%
Alabama	A2C0W1	16.35	0.19%	67.84%
Michigan	A2C0W1	16.35	0.40%	68.24%
Arkansas	A2C3W2	16.36	0.05%	68.29%
Kansas	A2C0W1	16.36	0.13%	68.42%
Iowa	A2C0W1	16.38	0.14%	68.57%
Kansas	A2C3W2	16.43	0.06%	68.62%
North Carolina	A2C3W2	16.47	0.18%	68.80%
Michigan	A2C3W2	16.52	0.17%	68.98%
Mississippi	A2C0W1	16.52	0.12%	69.09%
Wisconsin	A2C0W1	16.53	0.27%	69.36%
Massachusetts	A2C2W2	16.58	0.23%	69.60%
Pennsylvania	A2C0W1	16.6	0.57%	70.17%
Utah	A2C0W1	16.6	0.12%	70.29%

State	HH Code	LW USD$_{2015}$	(HH*State) % of LF	Cum %
Iowa	A2C3W2	16.64	0.06%	70.35%
Nebraska	A2C3W2	16.64	0.04%	70.39%
New Mexico	A2C0W1	16.64	0.08%	70.47%
Texas	A2C0W1	16.69	1.11%	71.58%
South Carolina	A2C0W1	16.7	0.19%	71.76%
Washington	A2C0W1	16.82	0.30%	72.07%
Tennessee	A2C0W1	16.83	0.27%	72.34%
Connecticut	A2C2W2	16.85	0.13%	72.47%
Georgia	A2C0W1	16.86	0.42%	72.89%
North Carolina	A2C0W1	16.89	0.42%	73.30%
Louisiana	A2C0W1	16.94	0.18%	73.48%
Maine	A2C3W2	17.14	0.03%	73.51%
Rhode Island	A2C0W1	17.18	0.05%	73.56%
Vermont	A2C0W1	17.25	0.03%	73.59%
Minnesota	A2C0W1	17.28	0.26%	73.85%
Colorado	A2C0W1	17.31	0.24%	74.09%
Florida	A2C3W2	17.31	0.35%	74.44%
Maine	A2C0W1	17.31	0.06%	74.50%
Arizona	A2C0W1	17.4	0.26%	74.77%
Pennsylvania	A2C3W2	17.41	0.25%	75.01%
Washington	A2C3W2	17.42	0.13%	75.14%
Nevada	A2C0W1	17.45	0.12%	75.26%
Illinois	A2C0W1	17.55	0.58%	75.84%
Oregon	A2C0W1	17.6	0.17%	76.01%
Illinois	A2C3W2	17.67	0.25%	76.26%
Montana	A2C3W2	17.7	0.02%	76.28%
Alaska	A2C0W1	17.73	0.03%	76.31%
Nevada	A2C3W2	17.74	0.05%	76.36%
New Hampshire	A2C3W2	17.75	0.03%	76.39%
Vermont	A2C3W2	17.75	0.01%	76.40%
Florida	A2C0W1	17.76	0.82%	77.22%
New Hampshire	A2C0W1	17.83	0.06%	77.28%
Oregon	A2C3W2	17.87	0.07%	77.36%
Hawaii	A2C2W2	18.02	0.04%	77.40%
Delaware	A2C3W2	18.04	0.02%	77.42%
Wyoming	A2C3W2	18.04	0.01%	77.43%
Minnesota	A2C3W2	18.17	0.11%	77.54%
Virginia	A2C3W2	18.17	0.16%	77.71%
New Jersey	A2C3W2	18.23	0.17%	77.88%
Delaware	A2C0W1	18.29	0.04%	77.92%
Rhode Island	A2C3W2	18.29	0.02%	77.94%
New York	A2C2W2	18.3	0.65%	78.59%
Colorado	A2C3W2	18.49	0.10%	78.69%
Virginia	A2C0W1	18.52	0.38%	79.07%
West Virginia	A2C1W1	18.6	0.01%	79.08%
California	A2C3W2	18.63	0.69%	79.78%
Kentucky	A1C1W1	18.67	0.06%	79.84%
Ohio	A2C1W1	18.67	0.11%	79.94%
New Jersey	A2C0W1	18.7	0.40%	80.35%
Connecticut	A2C0W1	18.71	0.16%	80.51%
Arkansas	A2C1W1	18.85	0.02%	80.53%
Montana	A2C1W1	18.87	0.01%	80.54%
Arizona	A2C3W2	18.91	0.11%	80.66%
Kentucky	A2C1W1	18.93	0.04%	80.70%
Maryland	A2C3W2	18.94	0.12%	80.81%
South Dakota	A2C1W1	18.95	0.01%	80.82%
New York	A2C0W1	18.96	0.84%	81.66%
North Dakota	A2C1W1	18.96	0.01%	81.66%
Massachusetts	A2C0W1	19	0.30%	81.97%
Massachusetts	A2C3W2	19.01	0.13%	82.10%
Alaska	A2C3W2	19.13	0.01%	82.11%
Idaho	A2C1W1	19.13	0.01%	82.13%
Wyoming	A2C1W1	19.16	0.01%	82.13%
Wisconsin	A2C3W2	19.18	0.12%	82.25%
Alabama	A2C1W1	19.22	0.04%	82.29%
California	A2C0W1	19.23	1.62%	83.90%
Arkansas	A1C1W1	19.29	0.04%	83.94%
West Virginia	A1C1W1	19.38	0.02%	83.96%
Oklahoma	A2C1W1	19.42	0.03%	84.00%
Nebraska	A2C1W1	19.44	0.02%	84.02%
Missouri	A2C1W1	19.46	0.06%	84.07%
Indiana	A2C1W1	19.5	0.06%	84.13%
Connecticut	A2C3W2	19.56	0.07%	84.20%
Idaho	A1C1W1	19.69	0.02%	84.22%
Iowa	A2C1W1	19.71	0.03%	84.25%
Mississippi	A2C1W1	19.71	0.02%	84.28%
Maryland	A2C0W1	19.72	0.27%	84.55%
South Dakota	A1C1W1	19.74	0.01%	84.56%
Kansas	A2C1W1	19.79	0.03%	84.59%
Michigan	A2C1W1	19.81	0.08%	84.67%
New Mexico	A2C1W1	19.83	0.02%	84.69%
Alabama	A1C1W1	19.86	0.06%	84.75%
Wisconsin	A2C1W1	19.9	0.06%	84.81%
Ohio	A1C1W1	19.93	0.17%	84.98%
Pennsylvania	A2C1W1	19.97	0.12%	85.10%
Mississippi	A1C1W1	19.99	0.04%	85.14%
Utah	A2C1W1	20.03	0.03%	85.16%
Missouri	A1C1W1	20.06	0.09%	85.25%
Georgia	A2C1W1	20.09	0.09%	85.34%
South Carolina	A2C1W1	20.09	0.04%	85.38%
Tennessee	A2C1W1	20.15	0.06%	85.43%
South Carolina	A1C1W1	20.22	0.06%	85.50%
Washington DC	A2C2W2	20.27	0.02%	85.52%
Tennessee	A1C1W1	20.29	0.09%	85.61%
Oklahoma	A1C1W1	20.3	0.05%	85.67%
Texas	A2C1W1	20.3	0.23%	85.90%
Montana	A1C1W1	20.34	0.01%	85.91%
Indiana	A1C1W1	20.36	0.09%	86.00%
Hawaii	A2C0W1	20.39	0.06%	86.06%
North Dakota	A1C1W1	20.39	0.01%	86.07%
Louisiana	A2C1W1	20.42	0.04%	86.11%
Washington	A2C1W1	20.43	0.06%	86.17%
Rhode Island	A2C1W1	20.44	0.01%	86.18%
North Carolina	A2C1W1	20.46	0.09%	86.27%
Utah	A1C1W1	20.69	0.04%	86.31%
New Mexico	A1C1W1	20.78	0.03%	86.34%
Wyoming	A1C1W1	20.8	0.01%	86.35%
Maine	A2C1W1	20.85	0.01%	86.36%
Louisiana	A1C1W1	20.9	0.06%	86.42%
Georgia	A1C1W1	20.92	0.14%	86.56%
Kansas	A1C1W1	20.92	0.04%	86.60%
Minnesota	A2C1W1	20.92	0.05%	86.66%
Vermont	A2C1W1	20.92	0.01%	86.67%
Nebraska	A1C1W1	20.96	0.03%	86.70%
Illinois	A2C1W1	21.02	0.12%	86.82%
Nevada	A2C1W1	21.03	0.02%	86.84%
Texas	A1C1W1	21.06	0.37%	87.21%
Arizona	A2C1W1	21.11	0.06%	87.27%
Ohio	A2C2W1	21.16	0.10%	87.36%
Oregon	A2C1W1	21.16	0.04%	87.40%
Colorado	A2C1W1	21.18	0.05%	87.45%
West Virginia	A2C2W1	21.18	0.01%	87.46%
Iowa	A1C1W1	21.27	0.05%	87.51%
Michigan	A1C1W1	21.31	0.13%	87.65%
Arkansas	A2C2W1	21.4	0.02%	87.67%
South Dakota	A2C2W1	21.42	0.01%	87.68%

State	HH Code	LW USD$_{2015}$	(HH*State) % of LF	Cum %
North Dakota	A2C2W1	21.45	0.01%	87.68%
Kentucky	A2C2W1	21.5	0.04%	87.72%
Montana	A2C2W1	21.5	0.01%	87.73%
Florida	A2C1W1	21.62	0.17%	87.90%
North Carolina	A1C1W1	21.63	0.14%	88.04%
Washington DC	A2C0W1	21.65	0.03%	88.07%
New Hampshire	A2C1W1	21.74	0.01%	88.08%
Wyoming	A2C2W1	21.75	0.01%	88.09%
Pennsylvania	A1C1W1	21.79	0.19%	88.28%
Idaho	A2C2W1	21.8	0.01%	88.29%
Alabama	A2C2W1	21.81	0.04%	88.33%
Alaska	A2C1W1	21.88	0.01%	88.33%
Oklahoma	A2C2W1	21.94	0.03%	88.37%
Missouri	A2C2W1	21.97	0.05%	88.42%
Nebraska	A2C2W1	21.98	0.02%	88.43%
Indiana	A2C2W1	22.04	0.05%	88.49%
Delaware	A2C1W1	22.19	0.01%	88.50%
Mississippi	A2C2W1	22.3	0.02%	88.52%
Iowa	A2C2W1	22.33	0.03%	88.55%
Virginia	A2C1W1	22.34	0.08%	88.63%
Kansas	A2C2W1	22.36	0.03%	88.65%
Maine	A1C1W1	22.36	0.02%	88.67%
Arizona	A1C1W1	22.37	0.09%	88.76%
Michigan	A2C2W1	22.37	0.08%	88.84%
Wisconsin	A1C1W1	22.38	0.09%	88.93%
Washington	A1C1W1	22.4	0.10%	89.03%
New Mexico	A2C2W1	22.49	0.02%	89.05%
Pennsylvania	A2C2W1	22.49	0.11%	89.16%
Wisconsin	A2C2W1	22.5	0.05%	89.21%
Oregon	A1C1W1	22.56	0.06%	89.27%
Georgia	A2C2W1	22.63	0.08%	89.35%
New Jersey	A2C1W1	22.63	0.08%	89.43%
South Carolina	A2C2W1	22.67	0.04%	89.47%
Utah	A2C2W1	22.73	0.02%	89.49%
New York	A2C3W2	22.74	0.36%	89.85%
New York	A2C1W1	22.75	0.18%	90.03%
Vermont	A1C1W1	22.77	0.01%	90.04%
Tennessee	A2C2W1	22.78	0.05%	90.09%
Texas	A2C2W1	22.8	0.22%	90.30%
Minnesota	A1C1W1	22.83	0.09%	90.39%
Hawaii	A2C3W2	22.95	0.02%	90.42%
Massachusetts	A2C1W1	22.95	0.06%	90.48%
Illinois	A1C1W1	22.96	0.19%	90.67%
Rhode Island	A2C2W1	22.98	0.01%	90.68%
Florida	A1C1W1	23.01	0.27%	90.95%
Louisiana	A2C2W1	23.01	0.04%	90.99%
Washington	A2C2W1	23.01	0.06%	91.05%
Nevada	A1C1W1	23.08	0.04%	91.09%
North Carolina	A2C2W1	23.09	0.08%	91.17%
West Virginia	A2C3W1	23.17	0.01%	91.18%
Connecticut	A2C1W1	23.25	0.03%	91.21%
Ohio	A2C3W1	23.3	0.05%	91.26%
South Carolina	A1C2W1	23.3	0.04%	91.30%
Delaware	A1C1W1	23.37	0.01%	91.31%
Rhode Island	A1C1W1	23.37	0.02%	91.33%
Vermont	A2C2W1	23.45	0.01%	91.34%
Maine	A2C2W1	23.48	0.01%	91.35%
Colorado	A1C1W1	23.51	0.08%	91.43%
Minnesota	A2C2W1	23.54	0.05%	91.48%
California	A2C1W1	23.56	0.34%	91.82%
Arkansas	A2C3W1	23.58	0.01%	91.83%
Louisiana	A1C2W1	23.58	0.04%	91.87%
Maryland	A2C1W1	23.58	0.06%	91.92%
Illinois	A2C2W1	23.6	0.11%	92.03%
Kentucky	A1C2W1	23.61	0.04%	92.07%
Nevada	A2C2W1	23.62	0.02%	92.09%
South Dakota	A1C2W1	23.64	0.01%	92.10%
Kentucky	A2C3W1	23.66	0.02%	92.12%
South Dakota	A2C3W1	23.7	0.00%	92.13%
Arizona	A2C2W1	23.76	0.05%	92.18%
Missouri	A1C2W1	23.79	0.05%	92.23%
Tennessee	A1C2W1	23.8	0.05%	92.28%
Colorado	A2C2W1	23.87	0.05%	92.33%
Mississippi	A1C2W1	23.87	0.02%	92.35%
Alaska	A1C1W1	23.9	0.01%	92.36%
Oregon	A2C2W1	23.91	0.03%	92.39%
Alabama	A2C3W1	23.93	0.02%	92.42%
Virginia	A1C1W1	23.94	0.13%	92.54%
North Dakota	A2C3W1	24.01	0.00%	92.55%
Oklahoma	A2C3W1	24.08	0.02%	92.56%
Florida	A2C2W1	24.11	0.16%	92.72%
Nebraska	A2C3W1	24.13	0.01%	92.73%
Indiana	A2C3W1	24.15	0.03%	92.76%
Montana	A2C3W1	24.15	0.00%	92.77%
Idaho	A1C2W1	24.18	0.01%	92.78%
Ohio	A1C2W1	24.18	0.10%	92.88%
New Hampshire	A1C1W1	24.24	0.02%	92.90%
Missouri	A2C3W1	24.25	0.03%	92.93%
Oklahoma	A1C2W1	24.27	0.03%	92.96%
New Hampshire	A2C2W1	24.3	0.01%	92.97%
Mississippi	A2C3W1	24.4	0.01%	92.98%
West Virginia	A1C2W1	24.4	0.01%	93.00%
Wyoming	A2C3W1	24.41	0.00%	93.00%
Indiana	A1C2W1	24.44	0.05%	93.06%
Alaska	A2C2W1	24.46	0.01%	93.06%
Texas	A1C2W1	24.48	0.22%	93.28%
Alabama	A1C2W1	24.59	0.04%	93.32%
Arkansas	A1C2W1	24.6	0.02%	93.34%
Utah	A1C2W1	24.6	0.02%	93.36%
Idaho	A2C3W1	24.63	0.01%	93.37%
Iowa	A2C3W1	24.64	0.02%	93.39%
Georgia	A1C2W1	24.73	0.08%	93.47%
North Dakota	A1C2W1	24.73	0.01%	93.47%
Michigan	A2C3W1	24.76	0.04%	93.52%
Delaware	A2C2W1	24.77	0.01%	93.53%
New Jersey	A1C1W1	24.79	0.13%	93.66%
South Carolina	A2C3W1	24.8	0.02%	93.68%
Kansas	A2C3W1	24.84	0.01%	93.69%
Wisconsin	A2C3W1	24.85	0.03%	93.72%
New Mexico	A1C2W1	24.86	0.02%	93.74%
Pennsylvania	A2C3W1	24.88	0.06%	93.80%
Washington DC	A2C3W2	24.9	0.01%	93.81%
Virginia	A2C2W1	24.91	0.07%	93.89%
Georgia	A2C3W1	24.96	0.05%	93.93%
Hawaii	A2C1W1	25.01	0.01%	93.95%
Tennessee	A2C3W1	25.03	0.03%	93.97%
Louisiana	A2C3W1	25.08	0.02%	93.99%
New Jersey	A2C2W1	25.13	0.08%	94.07%
California	A1C1W1	25.26	0.54%	94.61%
Texas	A2C3W1	25.26	0.12%	94.73%
New Mexico	A2C3W1	25.29	0.01%	94.74%
New York	A2C2W1	25.31	0.16%	94.90%
Kansas	A1C2W1	25.34	0.03%	94.93%
North Carolina	A2C3W1	25.35	0.04%	94.97%
Rhode Island	A2C3W1	25.41	0.01%	94.98%
Massachusetts	A2C2W1	25.52	0.06%	95.04%

State	HH Code	LW USD$_{2015}$	(HH*State) % of LF	Cum %
Michigan	A1C2W1	25.67	0.08%	95.12%
Washington DC	A2C1W1	25.69	0.01%	95.12%
Nebraska	A1C2W1	25.75	0.02%	95.14%
Utah	A2C3W1	25.77	0.01%	95.15%
Iowa	A1C2W1	25.81	0.03%	95.18%
Connecticut	A2C2W1	25.82	0.03%	95.21%
Maryland	A1C1W1	25.82	0.09%	95.30%
North Carolina	A1C2W1	25.83	0.08%	95.39%
Illinois	A2C3W1	25.99	0.06%	95.45%
Vermont	A2C3W1	26.05	0.00%	95.45%
Maine	A2C3W1	26.12	0.01%	95.46%
Maryland	A2C2W1	26.14	0.05%	95.51%
New York	A1C1W1	26.19	0.28%	95.79%
California	A2C2W1	26.2	0.31%	96.10%
Montana	A1C2W1	26.25	0.01%	96.11%
Connecticut	A1C1W1	26.36	0.05%	96.17%
Massachusetts	A1C1W1	26.38	0.10%	96.27%
Minnesota	A2C3W1	26.43	0.03%	96.30%
Washington	A1C2W1	26.55	0.06%	96.36%
Washington	A2C3W1	26.55	0.03%	96.39%
Maine	A1C2W1	26.71	0.01%	96.40%
Wyoming	A1C2W1	26.82	0.01%	96.41%
Pennsylvania	A1C2W1	26.83	0.11%	96.52%
Hawaii	A1C1W1	26.86	0.02%	96.54%
Florida	A2C3W1	26.97	0.09%	96.62%
Florida	A1C2W1	27.08	0.16%	96.78%
Oregon	A1C2W1	27.09	0.03%	96.82%
Nevada	A1C2W1	27.1	0.02%	96.84%
Arizona	A2C3W1	27.33	0.03%	96.87%
Delaware	A2C3W1	27.35	0.00%	96.87%
New Hampshire	A2C3W1	27.37	0.01%	96.88%
Nevada	A2C3W1	27.39	0.01%	96.89%
Oregon	A2C3W1	27.4	0.02%	96.91%
Colorado	A2C3W1	27.44	0.03%	96.94%
Vermont	A1C2W1	27.55	0.01%	96.94%
Illinois	A1C2W1	27.64	0.11%	97.06%
Hawaii	A2C2W1	27.67	0.01%	97.07%
Minnesota	A1C2W1	27.83	0.05%	97.12%
Virginia	A2C3W1	27.92	0.04%	97.16%
Arizona	A1C2W1	28.02	0.05%	97.21%
New Hampshire	A1C2W1	28.06	0.01%	97.23%
Delaware	A1C2W1	28.12	0.01%	97.23%
Colorado	A1C2W1	28.16	0.05%	97.28%
Alaska	A2C3W1	28.29	0.00%	97.28%
Virginia	A1C2W1	28.32	0.07%	97.36%
Washington DC	A2C2W1	28.33	0.01%	97.36%
Louisiana	A1C3W1	28.38	0.02%	97.38%
Massachusetts	A2C3W1	28.44	0.03%	97.42%
Rhode Island	A1C2W1	28.48	0.01%	97.43%
New Jersey	A2C3W1	28.5	0.04%	97.47%
New York	A2C3W1	28.56	0.09%	97.56%
South Carolina	A1C3W1	28.56	0.02%	97.58%
New Jersey	A1C2W1	28.66	0.08%	97.66%
Connecticut	A2C3W1	28.73	0.02%	97.68%
California	A1C2W1	28.82	0.32%	97.99%
Alaska	A1C2W1	28.88	0.01%	98.00%
Wisconsin	A1C2W1	28.88	0.05%	98.05%
Maryland	A2C3W1	29.38	0.03%	98.08%
Tennessee	A1C3W1	29.6	0.03%	98.11%
Missouri	A1C3W1	29.77	0.03%	98.14%
South Dakota	A1C3W1	29.81	0.00%	98.14%
Mississippi	A1C3W1	29.88	0.01%	98.15%
Maryland	A1C2W1	29.92	0.05%	98.21%
Texas	A1C3W1	30.4	0.12%	98.33%
Washington DC	A1C1W1	30.42	0.01%	98.34%
Oklahoma	A1C3W1	30.42	0.02%	98.35%
Massachusetts	A1C2W1	30.46	0.06%	98.41%
California	A2C3W1	30.48	0.17%	98.59%
Ohio	A1C3W1	30.55	0.05%	98.64%
Indiana	A1C3W1	30.62	0.03%	98.67%
Kentucky	A1C3W1	30.77	0.02%	98.69%
Georgia	A1C3W1	30.91	0.04%	98.73%
Connecticut	A1C2W1	31	0.03%	98.77%
Idaho	A1C3W1	31.27	0.01%	98.77%
Utah	A1C3W1	31.32	0.01%	98.79%
West Virginia	A1C3W1	31.44	0.01%	98.79%
Alabama	A1C3W1	31.49	0.02%	98.81%
New Mexico	A1C3W1	31.51	0.01%	98.82%
North Dakota	A1C3W1	31.6	0.00%	98.82%
Arkansas	A1C3W1	32.14	0.01%	98.84%
Kansas	A1C3W1	32.22	0.01%	98.85%
Washington DC	A2C3W1	32.28	0.00%	98.85%
North Carolina	A1C3W1	32.34	0.04%	98.90%
Michigan	A1C3W1	32.41	0.04%	98.94%
Iowa	A1C3W1	32.63	0.02%	98.96%
Nebraska	A1C3W1	32.66	0.01%	98.97%
Hawaii	A1C2W1	33.26	0.01%	98.98%
Hawaii	A2C3W1	33.33	0.01%	98.98%
Maine	A1C3W1	33.42	0.01%	98.99%
New York	A1C2W1	33.92	0.16%	99.15%
Pennsylvania	A1C3W1	34	0.06%	99.21%
Washington	A1C3W1	34.03	0.03%	99.25%
Florida	A1C3W1	34.05	0.09%	99.33%
Montana	A1C3W1	34.58	0.00%	99.34%
New Hampshire	A1C3W1	34.67	0.01%	99.34%
Vermont	A1C3W1	34.67	0.00%	99.35%
Nevada	A1C3W1	34.68	0.01%	99.36%
Illinois	A1C3W1	34.7	0.06%	99.42%
Oregon	A1C3W1	34.88	0.02%	99.44%
Wyoming	A1C3W1	35.28	0.00%	99.44%
Delaware	A1C3W1	35.5	0.00%	99.45%
New Jersey	A1C3W1	35.65	0.04%	99.49%
Minnesota	A1C3W1	35.7	0.03%	99.52%
Rhode Island	A1C3W1	35.74	0.01%	99.52%
Virginia	A1C3W1	35.75	0.04%	99.56%
Colorado	A1C3W1	36.14	0.03%	99.59%
California	A1C3W1	36.44	0.17%	99.76%
Arizona	A1C3W1	37	0.03%	99.79%
Massachusetts	A1C3W1	37.18	0.03%	99.82%
Maryland	A1C3W1	37.3	0.03%	99.85%
Alaska	A1C3W1	37.46	0.00%	99.85%
Wisconsin	A1C3W1	37.71	0.03%	99.88%
Washington DC	A1C2W1	37.81	0.01%	99.88%
Connecticut	A1C3W1	38.29	0.02%	99.90%
New York	A1C3W1	44.64	0.09%	99.99%
Hawaii	A1C3W1	45.08	0.01%	100.00%
Washington DC	A1C3W1	49.19	0.00%	100.00%

Table A.4 Social impact Vectors for EIO-LCA

Code	Sector Description	Employment	Fatalities	Human Capital	Living Wage
1111A0	Oilseed farming	9.188525771	0.002563599	15.40	2.34
1111B0	Grain farming	9.188525771	0.002563599	15.40	2.34
111200	Vegetable and melon farming	9.188525771	0.002563599	15.40	2.34
111335	Tree nut farming	9.188525771	0.002563599	15.40	2.34
1113A0	Fruit farming	9.188525771	0.002563599	15.40	2.34
111400	Greenhouse and nursery production	9.188525771	0.002563599	15.40	2.34
111910	Tobacco farming	9.188525771	0.002563599	15.40	2.34
111920	Cotton farming	9.188525771	0.002563599	15.40	2.34
1119A0	Sugarcane and sugar beet farming	9.188525771	0.002563599	15.40	2.34
1119B0	All other crop farming	9.188525771	0.002563599	15.40	2.34
112120	Milk Production	9.878591284	0.001847297	11.06	1.66
1121A0	Cattle ranching and farming	9.878591284	0.001847297	11.06	1.66
112300	Poultry and egg production	9.878591284	0.001847297	11.06	1.66
112A00	Animal production, except cattle and poultry and eggs	9.878591284	0.001847297	11.06	1.66
113300	Logging	7.0728109	0.006231146	15.00	5.04
113A00	Forest nurseries, forest products, and timber tracts	2.090038875	0.001841324	9.70	3.31
114100	Fishing	9.2642766	0.007791257	11.28	1.57
114200	Hunting and trapping	9.2642766	0.007791257	11.28	1.57
115000	Agriculture and forestry support activities	9.700307437	0.001998263	21.24	2.19
211000	Oil and gas extraction	1.071781977	0.000166126	1.97	0.65
212100	Coal mining	3.153292333	0.000930221	4.55	1.74
212210	Iron ore mining	3.379345266	0.00098001	4.35	1.68
212230	Copper, nickel, lead, and zinc mining	3.379345266	0.00098001	4.35	1.68
2122A0	Gold, silver, and other metal ore mining	3.379345266	0.00098001	4.35	1.68
212310	Stone mining and quarrying	4.941952762	0.001433166	7.18	2.49
212320	Sand, gravel, clay, and refractory mining	4.941952762	0.001433166	7.18	2.49
212390	Other nonmetallic mineral mining	4.941952762	0.001433166	7.18	2.49
213111	Drilling oil and gas wells	1.071781977	0.000310817	1.71	0.65
213112	Support activities for oil and gas operations	7.704806763	0.002234394	14.75	5.63
21311A	Support activities for other mining	7.704806763	0.002234394	14.75	5.63
221100	Power generation and supply	1.896497087	7.58599E-05	5.13	1.78
221200	Natural gas distribution	1.411573424	5.64629E-05	4.43	1.55
221300	Water, sewage and other systems	6.240473182	0.000249619	13.30	4.22
230101	Nonresidential commercial and health care structures	8.582784107	0.000901192	22.88	7.72
230102	Nonresidential manufacturing structures	8.582784107	0.000901192	22.88	7.72
230103	Other nonresidential structures	8.582784107	0.000901192	22.88	7.72

Code	Sector Description	Employment	Fatalities	Human Capital	Living Wage
230201	Residential permanent site single- and multi-family structures	8.582784107	0.000901192	22.88	7.72
230202	Other residential structures	8.582784107	0.000901192	22.88	7.72
230301	Nonresidential maintenance and repair	8.582784107	0.000901192	22.88	7.72
230302	Residential maintenance and repair	8.582784107	0.000901192	22.88	7.72
311111	Dog and cat food manufacturing	1.971931206	6.31018E-05	3.17	0.91
311119	Other animal food manufacturing	1.971931206	6.31018E-05	3.17	0.91
311210	Flour milling and malt manufacturing	1.320967256	4.2271E-05	1.84	0.58
311221	Wet corn milling	1.320967256	4.2271E-05	1.84	0.58
311225	Fats and oils refining and blending	1.320967256	4.2271E-05	1.84	0.58
31122A	Soybean and other oilseed processing	1.320967256	4.2271E-05	1.84	0.58
311230	Breakfast cereal manufacturing	1.320967256	4.2271E-05	1.84	0.58
311313	Beet sugar manufacturing	3.41189835	0.000109181	6.86	1.77
31131A	Sugar cane mills and refining	3.41189835	0.000109181	6.86	1.77
311320	Confectionery manufacturing from cacao beans	3.41189835	0.000109181	6.86	1.77
311330	Confectionery manufacturing from purchased chocolate	3.41189835	0.000109181	6.86	1.77
311340	Nonchocolate confectionery manufacturing	3.41189835	0.000109181	6.86	1.77
311410	Frozen food manufacturing	3.451143296	0.000110437	7.42	2.03
311420	Fruit and vegetable canning, pickling and drying	3.451143296	0.000110437	7.42	2.03
311513	Cheese manufacturing	2.160656537	6.9141E-05	3.95	1.21
311514	Dry, condensed, and evaporated dairy products	2.160656537	6.9141E-05	3.95	1.21
31151A	Fluid milk and butter manufacturing	2.160656537	6.9141E-05	3.95	1.21
311520	Ice cream and frozen dessert manufacturing	2.160656537	6.9141E-05	3.95	1.21
311615	Poultry processing	4.375124317	0.000140004	7.46	1.67
31161A	Animal (except poultry) slaughtering and processing	4.375124317	0.000140004	7.46	1.67
311700	Seafood product preparation and packaging	5.178645494	0.000165717	9.38	1.82
311810	Bread and bakery product manufacturing	6.52892233	0.000208926	15.08	3.02
311820	Cookie, cracker and pasta manufacturing	6.52892233	0.000208926	15.08	3.02
311830	Tortilla manufacturing	6.52892233	0.000208926	15.08	3.02
311910	Snack food manufacturing	2.667326575	8.53545E-05	6.41	1.75
311920	Coffee and tea manufacturing	2.667326575	8.53545E-05	6.41	1.75
311930	Flavoring syrup and concentrate manufacturing	2.667326575	8.53545E-05	6.41	1.75
311940	Seasoning and dressing manufacturing	2.667326575	8.53545E-05	6.41	1.75
311990	All other food manufacturing	2.667326575	8.53545E-05	6.41	1.75
312110	Soft drink and ice manufacturing	2.489939033	7.9678E-05	5.91	1.68
312120	Breweries	2.489939033	7.9678E-05	5.91	1.68
312130	Wineries	2.489939033	7.9678E-05	5.91	1.68

Code	Sector Description	Employment	Fatalities	Human Capital	Living Wage
312140	Distilleries	2.489939033	7.9678E-05	5.91	1.68
3122A0	Tobacco product manufacturing	0.66199123	2.11837E-05	0.67	0.24
313100	Fiber, yarn, and thread mills	6.825327337	0.00021841	14.26	3.77
313210	Broadwoven fabric mills	6.825327337	0.00021841	14.26	4.00
313220	Narrow fabric mills and schiffli embroidery	6.825327337	0.00021841	14.26	4.00
313230	Nonwoven fabric mills	6.825327337	0.00021841	14.26	4.00
313240	Knit fabric mills	6.825327337	0.00021841	14.26	4.00
313310	Textile and fabric finishing mills	6.825327337	0.00021841	14.26	3.63
313320	Fabric coating mills	6.825327337	0.00021841	14.26	3.63
314110	Carpet and rug mills	6.825327337	0.00021841	14.03	3.78
314120	Curtain and linen mills	6.825327337	0.00021841	14.03	3.78
314910	Textile bag and canvas mills	6.825327337	0.00021841	14.03	3.31
314990	All other miscellaneous textile product mills	6.825327337	0.00021841	14.03	3.31
315100	Hosiery and sock mills	8.504240328	0.000272136	20.46	3.66
315210	Cut and sew apparel contractors	8.504240328	0.000272136	20.46	3.89
315220	Men's and boys' cut and sew apparel manufacturing	8.504240328	0.000272136	20.46	3.89
315230	Women's and girls' cut and sew apparel manufacturing	8.504240328	0.000272136	20.46	3.89
315290	Other cut and sew apparel manufacturing	8.504240328	0.000272136	20.46	3.89
315900	Accessories and other apparel manufacturing	8.504240328	0.000272136	20.46	4.03
316100	Leather and hide tanning and finishing	8.504240328	0.000272136	20.54	5.38
316200	Footwear manufacturing	8.504240328	0.000272136	20.54	5.28
316900	Other leather and allied product manufacturing	8.504240328	0.000272136	20.54	4.53
321100	Sawmills and wood preservation	4.767118798	0.000367068	11.58	3.12
321219	Reconstituted wood product manufacturing	4.767118798	0.000367068	11.77	3.36
32121A	Veneer and plywood manufacturing	5.747297875	0.000442542	11.99	3.42
32121B	Engineered wood member and truss manufacturing	5.747297875	0.000442542	11.99	3.42
321910	Wood windows and doors and millwork	7.752547927	0.000596946	16.51	4.26
321920	Wood container and pallet manufacturing	7.752547927	0.000596946	16.51	4.26
321991	Manufactured home, mobile home, manufacturing	7.752547927	0.000596946	16.51	4.26
321992	Prefabricated wood building manufacturing	7.752547927	0.000596946	16.51	4.26
321999	Miscellaneous wood product manufacturing	7.752547927	0.000596946	16.51	4.26
322110	Pulp mills	2.354998659	0.000181335	4.52	1.71
322120	Paper mills	2.354998659	0.000181335	4.52	1.71
322130	Paperboard Mills	2.354998659	0.000181335	4.52	1.71
322210	Paperboard container manufacturing	4.694028586	0.00036144	4.46	1.40

Code	Sector Description	Employment	Fatalities	Human Capital	Living Wage
32222A	Coated and laminated paper, packaging materials, and plastic films manufacturing	4.694028586	0.00036144	4.46	1.40
32222B	All other paper bag and coated and treated paper manufacturing	4.694028586	0.00036144	4.46	1.40
322230	Stationery product manufacturing	4.694028586	0.00036144	9.70	3.05
322291	Sanitary paper product manufacturing	4.694028586	0.00036144	9.70	3.05
322299	All other converted paper product manufacturing	4.694028586	0.00036144	9.70	3.05
323110	Printing	7.405587533	0.00057023	21.19	6.08
323120	Support activities for printing	7.405587533	0.00057023	21.19	6.08
324110	Petroleum refineries	0.557788265	1.11558E-05	0.51	0.18
324121	Asphalt paving mixture and block manufacturing	0.557788265	1.11558E-05	0.51	0.18
324122	Asphalt shingle and coating materials manufacturing	0.557788265	1.11558E-05	0.51	0.18
324191	Petroleum lubricating oil and grease manufacturing	0.557788265	1.11558E-05	0.51	0.18
324199	All other petroleum and coal products manufacturing	0.557788265	1.11558E-05	0.51	0.18
325110	Petrochemical manufacturing	1.568136065	3.13627E-05	1.99	0.71
325120	Industrial gas manufacturing	1.568136065	3.13627E-05	1.99	0.71
325130	Synthetic dye and pigment manufacturing	1.568136065	3.13627E-05	1.99	0.71
325181	Alkalies and chlorine manufacturing	1.568136065	3.13627E-05	1.99	0.71
325182	Carbon black manufacturing	1.568136065	3.13627E-05	1.99	0.71
325188	All other basic inorganic chemical manufacturing	1.568136065	3.13627E-05	1.99	0.71
325190	Other basic organic chemical manufacturing	1.568136065	3.13627E-05	1.99	0.71
325211	Plastics material and resin manufacturing	1.90697659	5.33953E-05	3.15	1.13
325212	Synthetic rubber manufacturing	1.90697659	5.33953E-05	3.15	1.13
325220	Artificial and synthetic fibers and filaments manufacturing	1.90697659	5.33953E-05	3.15	1.13
325310	Fertilizer Manufacturing	2.328877033	4.65775E-05	2.90	0.96
325320	Pesticide and other agricultural chemical manufacturing	2.328877033	4.65775E-05	2.90	0.96
325411	Medicinal and botanical manufacturing	1.865386887	3.73077E-05	4.54	1.37
325412	Pharmaceutical preparation manufacturing	1.865386887	3.73077E-05	4.54	1.37
325413	In-vitro diagnostic substance manufacturing	1.865386887	3.73077E-05	4.54	1.37
325414	Biological product (except diagnostic) Manufacturing	1.865386887	3.73077E-05	4.54	1.37
325510	Paint and coating manufacturing	2.621619059	5.24324E-05	5.62	1.80
325520	Adhesive manufacturing	2.621619059	5.24324E-05	5.62	1.80
325610	Soap and cleaning compound manufacturing	1.963606324	3.92721E-05	3.97	1.17
325620	Toilet preparation manufacturing	1.963606324	3.92721E-05	3.97	1.17
325910	Printing ink manufacturing	3.052881711	6.10576E-05	6.34	1.98

Code	Sector Description	Employment	Fatalities	Human Capital	Living Wage
3259A0	All other chemical product and preparation manufacturing	3.052881711	6.10576E-05	6.34	1.98
326110	Plastics packaging materials, film and sheet	4.710914705	0.000131906	10.41	2.91
326121	Unlaminated plastics profile shape manufacturing	4.710914705	0.000131906	10.41	2.91
326122	Plastics Pipe and Pipe Fitting Manufacturing	4.710914705	0.000131906	10.41	2.91
326130	Laminated plastics plate, sheet, and shapes	4.710914705	0.000131906	10.41	2.91
326140	Polystyrene Foam Product Manufacturing	4.710914705	0.000131906	10.41	2.91
326150	Urethane and Other Foam Product (except Polystyrene) Manufacturing	4.710914705	0.000131906	10.41	2.91
326160	Plastics bottle manufacturing	4.710914705	0.000131906	10.41	2.91
32619A	Other plastics product manufacturing	4.710914705	0.000131906	10.41	2.91
326210	Tire manufacturing	5.734511076	0.000160566	11.00	3.42
326220	Rubber and plastics hose and belting manufacturing	5.734511076	0.000160566	11.00	3.42
326290	Other rubber product manufacturing	5.734511076	0.000160566	11.00	3.42
32711A	Pottery, ceramics, and plumbing fixture manufacturing	8.861442269	0.000638024	21.62	6.61
32712A	Brick, tile, and other structural clay product manufacturing	8.861442269	0.000638024	21.62	6.61
32712B	Clay and non-clay refractory manufacturing	8.861442269	0.000638024	21.62	6.61
327211	Flat glass manufacturing	8.861442269	0.000638024	21.89	6.78
327212	Other pressed and blown glass and glassware manufacturing	8.861442269	0.000638024	21.89	6.78
327213	Glass container manufacturing	5.622404145	0.000404813	13.22	4.09
327215	Glass Product Manufacturing Made of Purchased Glass	5.622404145	0.000404813	13.22	4.09
327310	Cement manufacturing	5.241380563	0.000718069	11.06	3.60
327320	Ready-mix concrete manufacturing	5.241380563	0.000718069	11.06	3.60
327330	Concrete pipe, brick and block manufacturing	5.241380563	0.000718069	11.06	3.60
327390	Other concrete product manufacturing	5.241380563	0.000718069	11.06	3.60
3274A0	Lime and gypsum product manufacturing	4.787972126	0.000655952	9.44	3.38
327910	Abrasive product manufacturing	4.787972126	0.000344734	9.93	3.16
327991	Cut stone and stone product manufacturing	4.787972126	0.000344734	9.93	3.16
327992	Ground or treated minerals and earths manufacturing	4.787972126	0.000344734	9.93	3.16
327993	Mineral wool manufacturing	4.787972126	0.000344734	9.93	3.16
327999	Miscellaneous nonmetallic mineral products	4.787972126	0.000344734	9.93	3.16
331110	Iron and steel mills	2.295756137	8.72387E-05	2.54	0.98
331200	Iron, steel pipe and tube manufacturing from purchased steel	4.201792587	0.000159668	7.14	2.42
331314	Secondary smelting and alloying of aluminum	2.830611911	0.000107563	4.08	1.32
33131A	Alumina refining and primary aluminum production	2.830611911	0.000107563	4.08	1.32

Code	Sector Description	Employment	Fatalities	Human Capital	Living Wage
33131B	Aluminum product manufacturing from purchased aluminum	2.830611911	0.000107563	4.08	1.32
331411	Primary smelting and refining of copper	3.659169355	0.000139048	3.09	1.18
331419	Primary smelting and refining of nonferrous metal (except copper and aluminum)	3.659169355	0.000139048	3.09	1.18
331420	Copper rolling, drawing, extruding and alloying	3.659169355	0.000139048	3.09	1.18
331490	Nonferrous metal (except copper and aluminum) rolling, drawing, extruding and alloying	3.659169355	0.000139048	3.09	1.18
331510	Ferrous metal foundaries	6.72122988	0.000255407	11.41	3.59
331520	Nonferrous foundries	6.72122988	0.000255407	11.41	3.59
332114	Custom roll forming	5.316925389	0.000202043	9.88	3.08
33211A	All other forging, stamping , and sintering	5.316925389	0.000202043	9.88	3.08
33211B	Crown, closure and metal stamping manufacturing	5.316925389	0.00027648	9.88	3.08
33221A	Cutlery, utensils, pots, and pans manufacturing	5.78729666	0.000300939	12.25	3.87
33221B	Handtool manufacturing	5.78729666	0.000300939	12.25	3.87
332310	Plate work and fabricated structural product manufacturing	6.808695362	0.000354052	14.01	4.47
332320	Ornamental and architectural metail products manufacturing	6.808695362	0.000354052	14.01	4.47
332410	Power boiler and heat exchanger manufacturing	4.106564931	0.000213541	9.24	3.10
332420	Metal tank, heavy gauge, manufacturing	4.106564931	0.000213541	9.24	3.10
332430	Metal can, box, and other container manufacturing	4.106564931	0.000213541	9.24	3.10
332500	Hardware manufacturing	4.127774727	0.000214644	8.49	2.74
332600	Spring and wire product manufacturing	8.116694882	0.000422068	16.13	4.90
332710	Machine shops	7.718859314	0.000401381	19.13	6.07
332720	Turned product and screw, nut, and bolt manufacturing	7.718859314	0.000401381	19.13	6.07
332800	Coating, engraving, heat treating and allied activities	7.770787633	0.000404081	17.32	4.83
332913	Plumbing Fixture Fitting and Trim Manufacturing	5.975971822	0.000310751	13.26	4.18
33291A	Valve and fittings other than plumbing	5.975971822	0.000310751	13.26	4.18
332991	Ball and roller bearing manufacturing	5.975971822	0.000310751	13.26	4.18
332996	Fabricated pipe and pipe fitting manufacturing	5.975971822	0.000310751	13.26	4.18
33299A	Ammunition manufacturing	5.975971822	0.000310751	13.26	4.18
33299B	Ordnance and accessories manufacturing	5.975971822	0.000310751	13.26	4.18
33299C	Other fabricated metal manufacturing	5.975971822	0.000310751	13.26	4.18
333111	Farm machinery and equipment manufacturing	4.813769251	9.14616E-05	7.59	2.79
333112	Lawn and garden equipment manufacturing	4.813769251	9.14616E-05	7.59	2.79
333120	Construction machinery manufacturing	4.813769251	9.14616E-05	7.59	2.79

Code	Sector Description	Employment	Fatalities	Human Capital	Living Wage
333130	Mining and oil and gas field machinery manufacturing	4.813769251	9.14616E-05	7.59	2.79
333220	Plastics and rubber industry machinery	4.273157627	8.119E-05	8.25	2.92
333295	Semiconductor machinery manufacturing	4.273157627	8.119E-05	8.25	2.92
33329A	Other industrial machinery manufacturing	4.273157627	8.119E-05	8.25	2.92
333314	Optical instrument and lens manufacturing	5.949294545	0.000113037	10.94	3.50
333315	Photographic and photocopying equipment manufacturing	5.949294545	0.000113037	10.94	3.50
333319	Other commercial and service industry machinery manufacturing	5.949294545	0.000113037	10.94	3.50
33331A	Vending, commerical, industrial, and office machinery manufacturing	5.949294545	0.000113037	10.94	3.50
333414	Heating equipment (except warm air furnaces) manufacturing	5.284695207	0.000100409	9.22	2.87
333415	Air conditioning, refrigeration, and warm air heating equipment manufacturing	5.284695207	0.000100409	9.22	2.87
33341A	Air purification and ventilation equipment manufacturing	5.284695207	0.000100409	9.22	2.87
333511	Industrial mold manufacturing	8.807494463	0.000167342	19.41	6.27
333514	Special tool, die, jig, and fixture manufacturing	8.807494463	0.000167342	19.41	6.27
333515	Cutting tool and machine tool accessory manufacturing	8.807494463	0.000167342	19.41	6.27
33351A	Metal cutting and forming machine tool manufacturing	8.807494463	0.000167342	19.41	6.27
33351B	Rolling mill and other metalworking machinery manufacturing	8.807494463	0.000167342	19.41	6.27
333611	Turbine and turbine generator set units manufacturing	2.700253132	5.13048E-05	7.23	2.62
333612	Speed Changer, Industrial High-Speed Drive, and Gear Manufacturing	2.700253132	5.13048E-05	7.23	2.62
333613	Mechanical Power Transmission Equipment Manufacturing	2.700253132	5.13048E-05	7.23	2.62
333618	Other engine equipment manufacturing	2.700253132	5.13048E-05	7.23	2.62
333911	Pump and pumping equipment manufacturing	4.995775188	9.49197E-05	8.90	3.22
333912	Air and gas compressor manufacturing	4.995775188	9.49197E-05	8.90	3.22
333920	Material handling equipment manufacturing	4.995775188	9.49197E-05	8.90	3.22
333991	Power-driven handtool manufacturing	4.995775188	9.49197E-05	8.90	3.22
333993	Packaging machinery manufacturing	4.995775188	9.49197E-05	8.90	3.22
333994	Industrial process furnace and oven manufacturing	4.995775188	9.49197E-05	8.90	3.22
33399A	Fluid power process machinery	4.995775188	9.49197E-05	8.90	3.22
33399B	Process and oven not fluid power machinery	4.995775188	9.49197E-05	8.90	3.22
334111	Electronic computer manufacturing	3.249461229	6.17398E-05	11.09	3.47
334112	Computer storage device manufacturing	3.249461229	6.17398E-05	11.09	3.47
33411A	Computer terminals and other computer peripheral equipment manufacturing	3.249461229	6.17398E-05	11.09	3.47

Code	Sector Description	Employment	Fatalities	Human Capital	Living Wage
334210	Telephone apparatus manufacturing	2.342497523	4.45075E-05	6.19	2.06
334220	Broadcast and wireless communications equipment	2.342497523	4.45075E-05	6.19	2.06
334290	Other communications equipment manufacturing	2.342497523	4.45075E-05	6.19	2.06
334300	Audio and video equipment manufacturing	4.162908485	7.90953E-05	8.46	3.08
334411	Electron tube manufacturing	4.433913138	8.42443E-05	11.62	3.51
334412	Bare printed circuit board manufacturing	4.433913138	8.42443E-05	11.62	3.51
334413	Semiconductor and related device manufacturing	4.433913138	8.42443E-05	11.62	3.51
334417	Electronic connector manufacturing	4.433913138	8.42443E-05	11.62	3.51
334418	Printed circuit assembly (electronic assembly) manufacturing	4.433913138	8.42443E-05	11.62	3.51
334419	Other electronic component manufacturing	4.433913138	8.42443E-05	11.62	3.51
33441A	Electronic capacitor, resistor, coil, transformer, and other inductor manufacturing	4.433913138	8.42443E-05	11.62	3.51
334510	Electromedical apparatus manufacturing	4.575462579	8.69338E-05	9.79	3.26
334511	Search, detection, and navigation instruments	4.575462579	8.69338E-05	9.79	3.26
334512	Automatic environmental control manufacturing	4.575462579	8.69338E-05	9.79	3.26
334513	Industrial process variable instruments	4.575462579	8.69338E-05	9.79	3.26
334514	Totalizing fluid meters and counting devices	4.575462579	8.69338E-05	9.79	3.26
334515	Electricity and signal testing instruments	4.575462579	8.69338E-05	9.79	3.26
334516	Analytical laboratory instrument manufacturing	4.575462579	8.69338E-05	9.79	3.26
334517	Irradiation apparatus manufacturing	4.575462579	8.69338E-05	9.79	3.26
33451A	Watch, clock, and other measuring and controlling device manufacturing	4.575462579	8.69338E-05	9.79	3.26
334613	Magnetic and optical recording media manufacturing	7.111306848	0.000135115	10.79	3.50
33461A	Software, audio and video reproduction	7.111306848	0.000135115	10.79	3.50
335110	Electric lamp bulb and part manufacturing	5.827741669	0.000110727	12.36	3.91
335120	Lighting fixture manufacturing	5.827741669	0.000110727	12.36	3.91
335210	Small electrical appliance manufacturing	4.711052263	8.951E-05	9.22	3.17
335221	Household cooking appliance manufacturing	4.711052263	8.951E-05	9.22	3.17
335222	Household refrigerator and home freezer manufacturing	4.711052263	8.951E-05	9.22	3.17
335224	Household laundry equipment manufacturing	4.711052263	8.951E-05	9.22	3.17
335228	Other major household appliance manufacturing	4.711052263	8.951E-05	9.22	3.17
335311	Electric power and specialty transformer manufacturing	5.731589688	0.0001089	13.23	4.24
335312	Motor and generator manufacturing	5.731589688	0.0001089	13.23	4.24

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335313	Switchgear and switchboard apparatus manufacturing	5.731589688	0.0001089	13.23	4.24
335314	Relay and industrial control manufacturing	5.731589688	0.0001089	13.23	4.24
335911	Storage battery manufacturing	5.731589688	0.0001089	12.94	4.04
335912	Primary battery manufacturing	5.731589688	0.0001089	12.94	4.04
335920	Communication and energy wire and cable manufacturing	4.076255008	7.74488E-05	8.61	2.69
335930	Wiring device manufacturing	4.076255008	7.74488E-05	8.61	2.69
335991	Carbon and graphite product manufacturing	4.076255008	7.74488E-05	8.61	2.69
335999	Miscellaneous electrical equipment manufacturing	4.076255008	7.74488E-05	8.61	2.69
336111	Automobile Manufacturing	1.080677558	1.62102E-05	2.07	0.82
336112	Light Truck and Utility Vehicle Manufacturing	1.080677558	1.62102E-05	2.07	0.82
336120	Heavy duty truck manufacturing	1.080677558	1.62102E-05	2.07	0.82
336211	Motor vehicle body manufacturing	6.340055236	9.51008E-05	11.34	3.39
336212	Truck trailer manufacturing	6.340055236	9.51008E-05	11.34	3.39
336213	Motor home manufacturing	6.340055236	9.51008E-05	11.34	3.39
336214	Travel trailer and camper manufacturing	6.340055236	9.51008E-05	11.34	3.39
336300	Motor vehicle parts manufacturing	3.575975838	5.36396E-05	7.39	2.32
336411	Aircraft manufacturing	3.593177984	5.38977E-05	7.50	2.54
336412	Aircraft engine and engine parts manufacturing	3.593177984	5.38977E-05	7.50	2.54
336413	Other aircraft parts and equipment	3.593177984	5.38977E-05	7.50	2.54
336414	Guided missile and space vehicle manufacturing	3.593177984	5.38977E-05	7.50	2.54
33641A	Other guided missile and space vehicle parts and auxiliary equipment manufacturing	3.593177984	5.38977E-05	7.50	2.54
336500	Railroad rolling stock manufacturing	2.92320309	4.3848E-05	3.73	1.51
336611	Ship building and repairing	6.989752706	0.000104846	11.98	4.82
336612	Boat building	6.989752706	0.000104846	11.98	4.82
336991	Motorcycle, bicycle, and parts manufacturing	2.596057359	3.89409E-05	3.54	1.20
336992	Military armored vehicles and tank parts manufacturing	2.596057359	3.89409E-05	3.54	1.20
336999	All other transportation equipment manufacturing	2.596057359	3.89409E-05	3.54	1.20
337110	Wood kitchen cabinet and countertop manufacturing	9.577776212	0.000737489	23.77	6.72
337121	Upholstered household furniture manufacturing	9.577776212	0.000737489	23.77	6.72
337122	Nonupholstered wood household furniture manufacturing	9.577776212	0.000737489	23.77	6.72
337127	Institutional furniture manufacturing	9.577776212	0.000737489	23.77	6.72
33712A	Metal and other household nonupholsetered furniture	9.577776212	0.000737489	23.77	6.72
337212	Custom architectural woodwork and millwork	9.577776212	0.000737489	24.13	7.37

Code	Sector Description	Employment	Fatalities	Human Capital	Living Wage
337215	Showcases, partitions, shelving, and lockers	6.486639843	0.000499471	15.19	4.64
33721A	Office furniture manufacturing	6.486639843	0.000499471	15.19	4.64
337910	Mattress manufacturing	7.64438602	0.000588618	11.38	2.99
337920	Blind and shade manufacturing	7.64438602	0.000588618	11.38	2.99
339111	Laboratory apparatus and furniture manufacturing	5.247299111	9.96987E-05	10.76	3.23
339112	Surgical and medical instrument manufacturing	5.247299111	9.96987E-05	10.76	3.23
339113	Surgical appliance and supplies manufacturing	5.247299111	9.96987E-05	10.76	3.23
339114	Dental equipment and supplies manufacturing	5.247299111	9.96987E-05	10.76	3.23
339115	Ophthalmic goods manufacturing	5.247299111	9.96987E-05	10.76	3.23
339116	Dental laboratories	5.247299111	9.96987E-05	10.76	3.23
339910	Jewelry and silverware manufacturing	6.301487444	0.000119728	13.46	3.80
339920	Sporting and athletic goods manufacturing	6.301487444	0.000119728	13.46	3.80
339930	Doll, toy, and game manufacturing	6.301487444	0.000119728	13.46	3.80
339940	Office supplies (except paper) manufacturing	6.301487444	0.000119728	13.46	3.80
339950	Sign manufacturing	6.301487444	0.000119728	13.46	3.80
339991	Gasket, packing, and sealing device manufacturing	6.301487444	0.000119728	13.46	3.80
339992	Musical instrument manufacturing	6.301487444	0.000119728	13.46	3.80
339994	Broom, brush, and mop manufacturing	6.301487444	0.000119728	13.46	3.80
33999A	All other miscellaneous manufacturing	6.301487444	0.000119728	13.46	3.80
420000	Wholesale trade	6.532956301	0.000307049	14.38	4.17
481000	Air transportation	5.061840067	0.000399885	9.94	3.31
482000	Rail transportation	5.379371666	0.0003389	10.28	3.71
483000	Water transportation	2.081489746	0.000682729	4.12	1.32
484000	Truck transportation	7.821949605	0.002237078	17.72	5.83
485000	Transit and ground passenger transportation	15.86607647	0.002046724	33.77	8.30
486000	Pipeline transportation	1.88253352	0.000229669	5.79	2.09
48A000	Scenic and sightseeing transportation and support activities for transportation	9.17211802	0.001118998	21.62	5.34
491000	Postal service	12.64228954	0.001542359	31.38	11.05
492000	Couriers and messengers	9.522832656	0.001161786	20.46	5.98
493000	Warehousing and storage	13.20871175	0.000937819	28.36	8.30
4A0000	Retail trade	15.28056007	0.000320892	37.53	6.23
511110	Newspaper publishers	4.937002375	0.000449267	11.65	3.03
511120	Periodical publishers	4.937002375	0.000236976	11.65	3.03
511130	Book publishers	4.937002375	0.000236976	11.65	3.03
5111A0	Directory, mailing list, and other publishers	4.937002375	0.000236976	11.65	3.03
511200	Software publishers	2.243286304	0.000107678	7.09	2.15
512100	Motion picture and video industries	3.617897785	8.32116E-05	11.23	2.57

Code	Sector Description	Employment	Fatalities	Human Capital	Living Wage
512200	Sound recording industries	3.617897785	8.32116E-05	10.42	3.26
515100	Radio and television broadcasting	4.408900003	0.000101405	11.96	3.07
515200	Cable and other subscription programming	2.704661975	6.22072E-05	2.84	0.97
516110	Internet publishing and broadcasting	4.784183285	0.000110036	5.23	1.47
517000	Telecommunications	2.373380355	5.45877E-05	5.17	1.71
518100	Internet service providers and web search portals	4.784183285	0.000110036	5.34	1.54
518200	Data processing, hosting, and related services	4.784183285	0.000110036	8.83	2.54
519100	Other information services	7.988121752	0.000183727	12.15	3.86
522A00	Nondepository credit intermediation and related activities	4.685784202	2.81147E-05	14.84	4.11
523000	Securities, commodity contracts, investments	2.603101139	1.56186E-05	8.84	2.74
524100	Insurance carriers	4.559756544	2.73585E-05	9.75	3.14
524200	Insurance agencies, brokerages, and related	7.856173199	4.7137E-05	20.43	5.85
525000	Funds, trusts, and other financial vehicles	4.685784202	2.81147E-05	0.12	0.03
52A000	Monetary authorities and depository credit intermediation	4.685784202	2.81147E-05	15.05	4.36
531000	Real estate	2.026365597	3.85009E-05	4.64	1.23
532100	Automotive equipment rental and leasing	14.99944719	0.000179993	11.31	2.64
532230	Video tape and disc rental	14.99944719	0.000179993	19.99	4.21
532400	Commercial and industrial machinery and equipment rental and leasing	2.712024735	3.25443E-05	7.54	2.42
532A00	General and consumer goods rental except video tapes and discs	14.99944719	0.000179993	19.78	4.97
533000	Lessors of nonfinancial intangible assets	0.279879692	3.35856E-06	0.52	0.16
541100	Legal services	6.192768186	5.57349E-05	19.23	5.62
541200	Accounting and bookkeeping services	9.513663985	8.5623E-05	28.21	7.90
541300	Architectural and engineering services	7.604624893	6.84416E-05	18.99	5.96
541400	Specialized design services	12.01727667	0.000108155	28.73	8.14
541511	Custom computer programming services	6.379293081	5.74136E-05	23.31	7.12
541512	Computer systems design services	6.379293081	5.74136E-05	23.31	7.12
54151A	Other computer related services, including facilities management	6.379293081	5.74136E-05	23.31	7.12
541610	Management consulting services	7.92999682	7.137E-05	28.73	9.26
5416A0	Environmental and other technical consulting services	7.92999682	7.137E-05	28.73	9.26
541700	Scientific research and development services	4.061475055	3.65533E-05	11.75	3.58
541800	Advertising and related services	6.063516033	5.45716E-05	11.79	3.25
541920	Photographic services	6.063516033	5.45716E-05	11.55	2.72
541940	Veterinary services	7.799921674	7.01993E-05	24.85	5.85
5419A0	All other miscellaneous professional and technical services	7.799921674	7.01993E-05	24.85	5.85

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550000	Management of companies and enterprises	6.530127294	0.000411398	15.16	5.03
561100	Office administrative services	7.895614884	0.000497424	25.57	7.62
561200	Facilities support services	7.324260456	0.000461428	12.93	3.48
561300	Employment services	28.66504569	0.001576578	50.43	10.93
561400	Business support services	16.46229289	0.001037124	43.35	9.53
561500	Travel arrangement and reservation services	9.713903609	0.000611976	17.40	4.51
561600	Investigation and security services	21.58354125	0.00140293	59.43	11.50
561700	Services to buildings and dwellings	22.05320234	0.000639543	51.83	9.81
561900	Other support services	9.141960478	0.000575944	22.90	5.95
562000	Waste management and remediation services	6.278580446	0.001312223	15.56	4.83
611100	Elementary and secondary schools	28.58381337	0.000257254	101.56	25.28
611A00	Colleges, universities, and junior colleges	13.99522879	0.000125957	37.36	9.26
611B00	Other educational services	16.5172485	0.000148655	50.15	12.80
621600	Home health care services	20.91925323	0.000146435	66.22	11.68
621A00	Offices of physicians, dentists, and other health practitioners	7.648048812	6.11844E-05	23.57	6.13
621B00	Healthcare and social assistance	10.37796615	8.30237E-05	38.41	9.99
622000	Hospitals	10.91231326	6.54739E-05	25.59	7.44
623000	Nursing and residential care facilities	21.53364535	0.000172269	55.13	11.23
624200	Community food, housing, and other relief services, incl rehabilitation services	20.33528139	0.000162682	45.72	10.93
624400	Child day care services	38.42897947	0.000307432	92.28	13.00
624A00	Individual and family services	23.52669953	0.000188214	93.67	15.52
711100	Performing arts companies	9.544816523	0.000591779	18.07	4.28
711200	Spectator sports	6.420813847	0.00039809	12.20	2.51
711500	Independent artists, writers, and performers	11.13911557	0.000690625	39.66	10.80
711A00	Promoters of performing arts and sports and agents for public figures	5.478445835	0.000339664	14.73	3.37
712000	Museums, historical sites, zoos, and parks	14.44912703	0.000433474	39.54	8.74
713940	Fitness and recreational sports centers	13.90360883	0.000417108	57.49	9.50
713950	Bowling centers	13.90360883	0.000417108	57.49	9.50
713A00	Amusement parks and arcades	13.90360883	0.000417108	21.25	3.49
713B00	Other amusement, gambling, and recreation industries	10.78410212	0.000323523	56.91	9.36
7211A0	Hotels and motels, including casino hotels	12.30725464	0.000258452	30.17	5.22
721A00	Other accommodations	12.30725464	0.000283067	29.89	5.21
722000	Food services and drinking places	21.31686796	0.00034107	57.47	4.99
811192	Car washes	11.8921403	0.000297304	29.38	7.34
8111A0	Automotive repair and maintenance, except car washes	11.8921403	0.000523254	29.38	7.34

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811200	Electronic equipment repair and maintenance	6.625362777	0.000165634	21.56	6.18
811300	Commercial machinery repair and maintenance	9.518319354	0.000237958	22.96	7.30
811400	Household goods repair and maintenance	10.46745769	0.000261686	20.92	5.66
812100	Personal care services	24.75530713	0.000470351	58.11	9.51
812200	Death care services	9.284644023	0.000176408	18.91	4.28
812300	Drycleaning and laundry services	16.24516739	0.000308658	35.72	5.36
812900	Other personal services	6.62538729	0.000125882	19.36	2.92
813100	Religious organizations	26.5939832	0.000558474	81.12	18.67
813A00	Grantmaking, giving and social advocacy organizations	10.88181064	0.000228518	31.43	7.38
813B00	Civic, social, professional and similar organizations	12.56972668	0.000263964	44.74	10.50
814000	Private households	59.26888657	0	147.25	35.47
S00102	Other Federal government enterprises	4.834098432	0.000116018	11.88	3.76
S00201	State and local government passenger transit	27.54237288	0.002038136	59.47	14.62
S00203	Other state and local government enterprises	12.4053756	0.000248108	51.38	14.88
S00300	Noncomparable Imports	0	0	0.00	0.00
S00401	Scrap	0	0	0.00	0.00
S00402	Used and Secondhand Goods	0	0	0.00	0.00
S00500	General Federal Defense	1.331887096	3.19653E-05	3.26	1.06
S00600	General Federal non-defense government industry	6.147167254	0.000147532	16.30	5.33
S00700	General state and local government services	12.21018741	0.000244204	45.20	13.09
S00800	Owner-Occupied Dwellings	0	0	0.00	0.00
S00900	ROW Adjustment	0	0	0.00	0.00