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Sustainability assessment of U.S. final consumption and investments: triple-bottom-line input–output analysis

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ABSTRACT

The U.S. final demand categories such as household consumption, private fixed investments, government purchases and investments, and export of goods and services have a wide range of environmental, economic, and social impacts. Analysis of these impacts, termed as the Triple Bottom Line (TBL), stimulated a tremendous interest by policy makers over the last decade. Therefore, current research aims to analyze the TBL of U.S. final demands from a systems perspective. To accomplish this goal, the supply and use tables published by the U.S. Bureau of Economic Analysis are merged with a range of environmental, economic, and social metrics. The results show that household consumption has the largest indirect TBL sustainability impacts compared to other final demand categories with shares that range between 43% and 88%. Industrial sectors including manufacturing, utilities, agriculture, construction, transportation, and mining are generally found to be responsible for the highest impacts for most of the environmental impact categories. Service sectors generally have the highest impacts on the economic and social indicators of sustainability. Analysis results also indicate that while meeting the household demand, agriculture, utilities, and manufacturing sectors have relatively more environmental impacts than their contributions to gross domestic product (GDP), whereas service sectors contribute to GDP with a higher share than their environmental burdens. Furthermore, it is envisioned that significant reductions in environmental footprints of U.S. households can be achieved if environmental policies that aim to reduce the household consumption are also supported with sustainable growth through greener and resource efficient economy.

1. Introduction

The World Summit for Sustainable Development (WSSD) in Johannesburg identified the sustainable consumption of goods and services, as well as the protection of social and economic development as the primary objectives to promote global sustainability (WSSD, 2002). They identified the unsustainable way of production and consumption as the major cause of today's complex ecological problems. In the plan of implementation of this international summit, the importance of adoption of effective tools, policies, and assessment models based on life cycle assessment (LCA) was highlighted to promote sustainable patterns of production and consumption, as well as increase the eco-efficiency of products and services (Hertwich and Peters, 2009). In this regard, LCA gained a tremendous interest worldwide to quantify the environmental burdens of production and consumption in a systematic way. LCA aims to quantify the environmental impacts of products or processes from cradle to grave. It primarily consists of goal and scope definition, life-cycle inventory analysis, life-cycle impact assessment, and interpretation of results (Gradel and Allenby, 2003). Process-based LCA (P-LCA), economic input output-based LCA (EIO-LCA), and hybrid LCA are the most widely used LCA approaches in the literature (Suh and Huppes, 2005).

EIO analysis is a widely used methodology, which was theorized and developed by Wassily Leontief in the 1970s, based on his earlier works in the late 1930s, for which he received the Nobel Prize (Leontief, 1970). The EIO analysis consists primarily of financial

Abbreviations: EIO-LCA, Economic Input Output-based Life Cycle Assessment; GDP, Gross Domestic Product; GFN, Global Footprint Network; GHG, Greenhouse Gas; GOS, Gross Operating Surplus; GPI, Genuine Progress Indicator; GTAP, The Global Trade Analysis Project; MRIO, Multi Region Input Output; P-LCA, Process-based LCA; TBL, Triple Bottom Line; UNFAO, United Nation's Food and Agriculture Organization; WSSD, The World Summit for Sustainable Development.

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flows and interdependencies between different sectors of the nations' economy (Suh et al., 2004). In the literature, single and multi-region EIO models are widely used in order to analyze the environmental impacts of consumption activities (Huppes et al., 2008; Hubacek et al., 2009; Wiedmann, 2009; Steen-Olsen et al., 2012). In this research, the system boundaries cover all cradle-to-gate environmental, economic, and social interventions for U.S. final demand categories such as household consumption, private fixed investments, government purchases and investments, and export of goods and services. Since the primary goal of this research is an analysis of the total sustainability impacts of U.S. final consumption and investments at the most detailed level practically achievable (discerning 426 sectors of U.S economy), we used a single-region input–output framework which provides the most detailed analysis for U.S final demands. In this model, products imported into U.S are assumed to be produced with the same technology as in U.S. The importance of using highly disaggregated input–output tables for environmental analysis of production and consumption has already been discussed in previous studies (Huppes et al., 2008; Lenzen, 2011).

Environmentally extended input–output analysis has been used for analyzing the environmental impacts of household demands (Kok et al., 2006). For example, Cohen et al. (2005) analyzed the energy requirements of twelve household consumption categories with different income levels in Brazil. Huppes et al. (2008) investigated the environmental impacts of consumption in European Union using an environmentally extended input–output model. Munksgaard et al. (2008) studied CO_2 requirement of eight household consumption categories in Denmark from 1966 to 1992. Masanet et al. (2009) developed a carbon footprint estimation model to analyze the direct and indirect carbon emission associated with energy, goods, and services consumption of households in California and the United States. In another research, Hubacek et al. (2009) studied environmental impacts of urbanization and life style change in China using input–output analysis in combination with the ecological and water footprint analysis. Cellura et al. (2011) developed an environmentally extended input–output model in order to quantify the energy and environmental impacts related to the consumption of the Italian households in the period 1999–2006 and to identify the economic sectors involving the highest impacts.

Triple Bottom Line (TBL) concept focuses on the three main pillars of sustainability such as environment, economy, and society (Elkington, 1998). In addition to the environment, social and economic dimensions of the sustainability have been integrated with the EIO analysis in order to develop a comprehensive sustainability accounting framework. Foran et al. (2005a) applied an approach for EIO based TBL analysis for environmental, economic, and social indicators for the industrial sectors of an entire Australian economy. This model has been named as *Balancing Act* that integrates the supply and use tables with environmental, economic, and social metrics for 135 sectors. Researchers from the University of Sydney established the foundation of the EIO model for the *Balancing Act* study and created a TBL software tool for the Australia, United Kingdom, and Japan economies. Several studies were conducted using the TBL version of the EIO by presenting first examples of TBL accounting in the EIO literature (Foran et al., 2005b; Wiedmann and Lenzen, 2009; Wiedmann et al., 2009). TBL model of the 426 U.S economic sectors, named as TBL-LCA, was also created by Kucukvar and Tatari (2013). This model was initially used to quantify the TBL implications of the seven U.S. construction sectors. Later on, the TBL-LCA model was jointly used with multi-criteria decision making tools to analyze the sustainability of food manufacturing sectors and pavement designs in U.S. (Tatari et al., 2012; Egilmez et al., 2014; Kucukvar et al., 2014). In a recent study, Onat et al. (2014) employed a hybrid approach by integrating TBL input–output analysis into life cycle sustainability assessment framework for the U.S. residential and commercial buildings.

Among the TBL sustainability indicators, employment, income, tax, and work-related injuries were considered as social indicators, while gross domestic product, gross operating surplus, and imports were categorized as key economic indicators (Hendrickson et al., 2005; GTAP, 2008; Wiedmann et al., 2009; Wood and Garnett, 2010; WIOD, 2012). Tax, which is also referred to as government revenue, is considered as a positive social indicator since collected tax are used for supporting the national health and education systems, public transportation, highways, and other civil infrastructures (Foran et al., 2005a, 2005b). In addition, the ecological footprint is measured in terms of global hectares for several land types such as fishery, grazing, forest land, cropland, built-up land, and CO_2 uptake land (Kitzes et al., 2009). In the literature, the ecological, energy, water, and carbon footprint indicators are also considered as a part of the environmental dimension of TBL, and these indicators have already been used as a measure of environmental sustainability in previous input–output studies (Turner et al., 2007; Huang et al., 2009; Blackhurst et al., 2010; Ewing et al., 2012; Steen-Olsen et al., 2012; Egilmez et al., 2013; Galli et al., 2013; Weinzettel et al., 2013).

The Global Trade Analysis Project (GTAP) database version 8.1 produces an extensive database of trade-linked input–output tables for the world economy, which involves about 57 sectors and 134 regions in the world (Aguiar, 2013). GTAP is a widely used database for the modeling of the role of international trade in goods and services. In recent studies, GTAP database is combined with environmentally extended input–output analysis in order to develop global MRIO models. For example, Weber and Matthews (2008) analyzed American household carbon footprint developing a MRIO model considering the impacts of international trade. Ewing et al. (2012) introduced a new MRIO method for conserving the high degree of product detail for calculating ecological and water footprints. Steen-Olsen et al. (2012) used a MRIO model to assess three environmental footprint categories (ecological, water, and carbon) for the member states of the European Union. Feng et al. (2011) used a global MRIO model to calculate water footprint for China. In other study, Weinzettel et al. (2013) developed a global MRIO model in order to understand the land utilization by humans for production and consumption.

As can be seen from environmentally extended input–output studies reviewed here, the land, carbon, energy, and water footprint of final consumption have been analyzed from a holistic perspective. The same input–output methodology can also be utilized to quantify the TBL sustainability impacts of different final demand categories by quantifying the economic and social impacts in addition to environment; however there has been a limited research considering all of the three dimensions of the sustainability, simultaneously. In this regard, this research has several novel elements such as:

(i) inclusion of several macro-level socio-economic indicators, (ii) analysis of consumption and investments using high resolution U.S. input–output tables with detailed TBL extensions, (iii) integration of ecological footprint categories (defined by the Global Footprint Network) with detailed U.S. input–output tables, and (iv) sustainability analysis of U.S. final demands, including not only household consumption, but also private fixed investments, government purchases and investments, and export of goods and services. Consequently, this paper aims to answer the following research questions:

- What are the environmental burdens of final demands in terms of energy, water, and carbon footprints?