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Syntheses of sustainable supply networks with a new composite criterion – Sustainability profit

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ABSTRACT

This study proposes a new concept and a new metric for multi-criteria evaluation of sustainable systems. The new metric, termed "sustainability profit", is composed of economic, environmental and social indicators. Since all of these are expressed by monetary terms, the different criteria are now merged, and a multi-objective optimization problem can be reduced to a single-objective one. The new concept for measuring sustainability is based on micro-economic (company's viewpoint) and on wider macro-economic perspectives (combined government's and company's viewpoint). The concept and metric presented are illustrated by three examples of supply networks including a large-scale biorefinery supply network. The obtained results give the insights into sustainable technologies from the overall sustainability viewpoint, and also evaluate the stimulations from governments in the form of subsidies and taxes for deployment of (un-)sustainable systems. The results also indicate that this metric provides good compromise solutions between economic, environmental and social pillars of sustainability.

1. Introduction

Sustainable development has gained much attention due to environmental and social concerns such as environmental degradation and societal inequity (Sikdar, 2003). In the last few decades, the trend towards consideration of sustainable development by applying sustainability indicators in the decision-making process has grown considerably. Plenty of metrics for quantifying sustainability have been developed in recent decades (Singh et al., 2012). Until the middle of the 20th century, it was mainly economics that was important; the environmental movement started in the mid-20th century, while the social movement gained ground at the end of the century, with significant progress in the last decade. Economics, however, is still the key driver for most systems (Seay, 2015). Also, estimation of environmental indicators is a well-established practice (Martín, 2016).

Concerns regarding environmental issues began on a larger scale in 1962, when *Silent Spring* (Carson, 1962) was published. Attention was drawn to the relation between economic growth and environmental degradation. A few years later the U.S. Environmental Protection Agency was formed (in 1970) for the purpose of protecting human health and the environment (US EPA, 2016). Two years later, the first major conference on international environmental issues was held (UNEP, 1972). Energy crises in the 1970s demonstrated the vulnerability of the energy supply, as well as global dependence on non-renewable energy sources (Dunlap and Jorgenson, 2012). As a consequence, an awareness of the need for more sustainable living began to emerge. Concerns about environmental sustainability were widely recognized by the end of the 20th century but accelerated and became generally accepted only at the beginning of the 21st century.

There have been several environmental indicators developed, such as indicators of resource use, solid waste, material and energy intensity, product durability and other (Azapagic and Perdan, 2000), mid-point indicators of potential environmental impacts, such as global warming potentials, acidification potentials, ozone depletion potentials and other (von Blottnitz and Curran, 2007), end-point categories of impacts, such as human health impacts in terms of disability adjusted life years, climate change, changes in biodiversity and other (Bare et al., 2000), environmental footprints, such as carbon, water, nitrogen and other (Čuček et al., 2012b), and aggregated measures that are defined by applying certain weights to single environmental indicators (Guillén-Gosálbez, 2011), such as eco-indicator 99 (Geodkoop and Spriensma, 2000), Environmental Priority Strategy EPS (Steen, 1999), eco-scarcity method (Grinberg et al., 2012), pollution index (Hilaly and Sikdar, 1994) and other.

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Social sustainability, on the other hand, is the least defined/understood component of sustainability, and could be called the "missing pillar" (Boström, 2012). It still receives less attention compared to economic and environmental sustainability; however, in recent years there has been significant progress on how to address and integrate the social pillar into the framework of sustainability. Unemployment is currently one of the most severe problems of society (Gontkovičová et al., 2015), along with the wealth gap, the number of people living below the poverty line, occupational health and safety, child labor (Andrews et al., 2009), issues concerning discrimination, violation of human rights and other (Azapagic et al., 2002). Societal aspect has been thought of socially responsible systems or systems that provide quantifiable benefits for all (Sikdar, 2003).

Social indicators could be divided into ethics and welfare indicators (Azapagic and Perdan, 2000). Among ethics indicators are child labor, fair prices, corruption, intergeneration equity and other, and among welfare indicators are income distribution, work satisfaction and other (Azapagic and Perdan, 2000). Both positive and negative impacts have been developed and used to measure social sustainability (Di Cesare et al., 2016). Examples of positive impact are e.g. accrued local jobs (You et al., 2012) and other indirect benefits to the society, such as to local community (Azapagic et al., 2002). Social indicators could be qualitative, quantitative and semi-quantitative (qualitative by using scoring system) (Di Cesare et al., 2016).

Sustainability awareness in general was significantly enhanced after the release of the Brundtland report (WCED, 1987). Sustainability is typically defined as the practice of preserving resources for future generations, and is related to the carrying capacity of natural systems. Formally, it was endorsed by most countries at the Rio Earth Summit in 1992 (Meadowcroft, 2000), and it is currently experiencing increasing recognition among people from a variety of fields (Smith et al., 2015). It is usually comprised of three segments: economic, environmental and social. Sometimes it incorporates additional factors, such as institutional, cultural or technological concerns (Sala et al., 2013). The goal of sustainability is to find a balance among these concerns. Sustainable development is related to a wise balance of societal equity, environmental quality and economic prosperity (Sikdar, 2003) or 3Ps – People, Planet and Profit (Mukherjee et al., 2015).

There are at least 140 indicators which cover various dimensions of sustainability (Singh et al., 2012), and more than 500 efforts has been devoted to developing quantitative indicators of sustainable development (Parris and Kates, 2003). Although significant efforts have been put on measuring sustainability, only few of them integrate environmental, economic and social aspects, while in most cases the focus is on one of the three aspects (Singh et al., 2012).

Examples of composite indexes consisting of various indicators and considering all three aspects are Sustainability Performance Index (Krotscheck and Narodoslawsky, 1996), Human Development Index (UNDP, 2000), Genuine Progress Indicator (Cobb et al., 1995), eco-efficiency (Keffer et al., 1999), composite sustainable development index (Krajnc and Glavič, 2005), composite sustainability performance index (Singh et al., 2007), Dow Jones Sustainability Index (S&P Dow Jones Indices LLC, 2016) and many others. However, most of these indexes are subject to subjectivity despite lot of objectivity used in assessing the sustainability, while their major advantages are their multidimensionality and the use of normalization and aggregation based on scientific rules and methods (Singh et al., 2012).

In order to obtain the most optimal sustainable solution, single- or multi-objective optimization could be applied. Single-objective optimization is based on optimization of single criterion of sustainability (e.g. maximizing economic profit, minimizing greenhouse gas emissions etc.) or of compromise criterion (e.g. maximizing sustainability profit, maximizing composite sustainability performance index, etc.), while multi-objective optimization is based on optimization of several criteria, where one criterion is the main criterion and one or more criteria are specified as additional criterion/criteria. In case of multi-objective optimization, ε-constraint method for generation of a number of Pareto optimal solutions or feasible region of optimal solutions is typically applied (Pieragostini et al., 2012).

The techniques, methods and tools developed differ in terms of qualitative and quantitative assessments, subjectivity and objectivity and also unidimensional or multidimensional nature. In order to handle multidimensional problems, several techniques have been developed for aggregation and reduction of dimensionality of objectives, such as correlation matrices, discriminant, principal component analysis, factor analysis, distance to target, expert's opinion, analytical hierarchical process (Singh et al., 2009), Representative Objectives Method (Čuček et al., 2013) and other. The objectives of these techniques is to determine the number of key variables which influence the indexes the most (Singh et al., 2012).

Typically weighting system is applied to aggregate different indicators in order to develop composite index (Singh et al., 2012). Examples of aggregation rules are arithmetic mean, geometric mean, dictatorial ordering and other (Singh et al., 2012). Besides weighting, normalization plays an important role (Azapagic and Perdan, 2000) in order to transform the various scales of variables into unique scale (Böhringer and Jochem, 2007). The reliability of results while using composite index is crucial issue, and there are different uncertainties due to selection of data, data normalization, standardization, weighting methods, values of weights and aggregation methods (Singh et al., 2012).

Recently different economic-based methods have been proposed that overcome the limitation of weighting, normalization, multi-objective nature and multi-dimensionality of the problem. Such examples are Net Profit which is defined as economic profit reduced by the eco-costs, and Total Profit which is the summation of the economic and eco-profits (Kravanja and Čuček, 2013). Both are based on eco-costs (Delft University of Technology, 2016) which are indicators based on LCA and describe environmental burdens on the basis of preventing that burden (Vogtländer and Hendriks, 2002). However Net and Total Profit approaches do not consider the social indicator. Recently RePSIM metric (Martín, 2016) has been developed which considers all three pillars of sustainability and could be applied for the design of sustainable renewable energy production processes. However, this metric is more suitable at the process level and excludes other emissions than CO_2.

Although more and more attention has been in recent decades focused on preserving the environment and resources in particular, and the sustainability and sustainable development of systems in general, it seems, regrettably, that we are moving away from sustainability (Zhao et al., 2005), at both national and regional levels (Moran et al., 2008). It is increasingly apparent that humanity is exceeding Earth's capacity with respect to resource use and environmental pollution (Azapagic et al., 2016). Almost all of these concerns have increased in recent years (Čuček et al., 2015). Various incentives and accurate and effective accounting systems are required (Galli et al., 2014) to reverse these trends.

There are several incentives and policies for stimulating "sustainable" patterns, such as, in terms of energy efficiency in the industry, building and transportation sectors, production of renewable energy sources, waste management, etc. For example, in 2015 at least 164 countries had renewable energy targets, and most also had renewable energy support policies (Sawin et al., 2015). Several governments around the world are imposing taxes on harmful waste and emissions, as well as providing credits for energy conservation, energy efficiency and production of renewable energy in