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The time-to-sustainability optimization strategy for sustainable supply network design

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ABSTRACT

In response to sustainability challenges such as global climate change or poverty in parts of the world, decision makers in corporations and politics are setting sustainability targets requiring the transformation of industry supply chains towards a more sustainable level. In our study, we address the question, if and how fast these long-term sustainability targets can be reached and how the underlying transformation path develops. We focus on the long-term design of sustainable industry supply networks. As integral part of a comprehensive linear optimization model "Minimize the Time-to-Sustainability" (TTS) is proposed as a novel optimization strategy for this problem. The TTS strategy is based on the triple bottom line sustainability concept which incorporates multiple and often incompatible objectives for the environmental, economic and social dimension of sustainability, e.g. reducing greenhouse gas emission, maintaining supply network cost competiveness, and creating new job opportunities. In contrast to conventional optimization strategies, TTS minimizes the time until pre-defined target values for all sustainability objectives are achieved and thus the supply chain reaches a sustainable steady state. With this approach, TTS delivers new insights on how supply networks transform towards a sustainability steady state and allows decision makers to validate the feasibility and impact of long-term sustainability targets. Three variants of the TTS approach are presented and evaluated using the transition towards more electrified vehicles in the automotive industry as a specific application.

1. Introduction

Today the world is confronted with existential sustainability challenges such as climate change, resource, food and water scarcity, biodiversity losses and continuing growth of the world's population towards 10 billion people with high unemployment and poverty in many parts of the world (Emmott, 2013). Civil societies, policy makers and companies increasingly understand and accept that current resource and emission-intensive industry supply chains and product designs are not considered sustainable given the future generations' social, ecologic and economic needs. Specifically in climate change, the world runs out of time to cut greenhouse gas emissions in order to limit global warming to a 2° temperature increase, while analyses show that we are on a 3–4° temperature increase trajectory with potentially severe and irreversible consequences for nature and human civilization as well as drastic economic losses and costs (IPCC, 2014; Randers, 2012).

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With sustainability, we refer to the Brundland Report (1987) which defines: "Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This overall, society-oriented definition has been specified for industries and the corporate world. Most companies today follow the triple bottom line concept (also called the 3Ps "people, planet, profit") of balancing social, environmental, and economic performance (Elkington, 1998) in order to operationalize sustainability in corporate decision making (see Fig. 1). The triple bottom line concept is specifically suited to derive sustainability key performance indicators and to set related targets. For instance, environmental objectives can be measured in terms of CO_2 emissions, renewable energy used, resource consumptions or recycling quotas. Financial objectives may include reaching target profitability or maintaining cost efficiency. To measure social sustainability, creating new job opportunities, fostering employment welfare or ensuring fair trade conditions throughout the supply chain are meaningful objectives depending on the individual industry.

In particular in view of global climate change, the aspect of *time* is critical as developments like global warming or biodiversity

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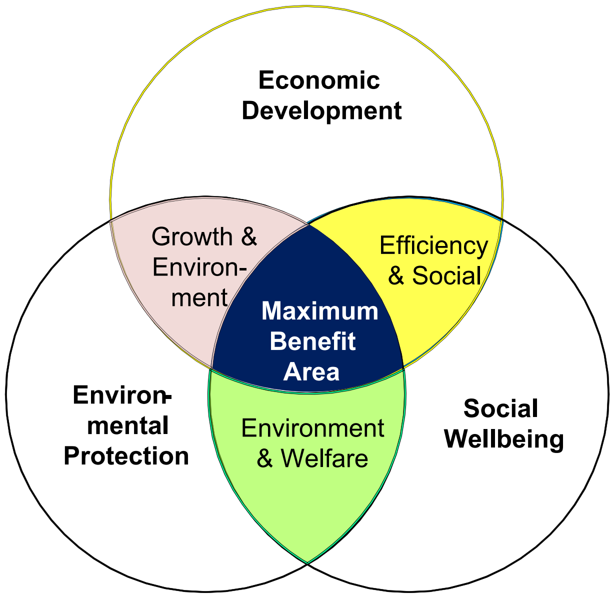

Fig. 1. Triple bottom line of sustainability (based on Elkington, 1998).

losses are irreversible for long time. Hence, it is of vital importance *when* certain sustainability targets are reached to keep the economic, ecological and social developments in balance. In this context the concept of *steady state* is of crucial importance in order to prevent the economic, ecological and social sub-systems from falling back into unsustainable performance levels, e.g. reversing the transition of energy generation or delay the development of clean production technologies.

Companies incorporating sustainability principles into their business strategies typically set long-term sustainability targets and indicate the timeframe for reaching these targets. For instance, Daimler announced plans to reduce its production and product greenhouse gas emissions by 20% in 2020 compared to the early 1990s (Daimler, 2015). Similarly, policy makers such as in the EU commissions or national ministries of economics and environment, define the period until which sustainability regulations should become effective, e.g. the EU target to reduce absolute annual greenhouse gas emissions by 20% in 2020 compared to 1990 (European Commission, 2014). Given pre-defined sustainability targets, the natural objective is to minimize the time span until these targets can be realized.

Thus, to clearly model the relationship between the decision maker's action plans and the development of the sustainability key performance indicators over time, enhanced decision support tools are needed. So far, in the academic literature these challenging but complex questions are tackled with static approaches which do not reflect the achievement of a steady state in which the often conflicting objectives are balanced.

In a first attempt to close this research gap, Kannegiesser and Günther (2014) proposed “Time-to-Sustainability” (TTS) as an optimization strategy for minimizing the time span needed to reach pre-defined targets for sustainability performance indicators. However, the performance of the related mixed-integer linear programming (MILP) model was not satisfactory with respect to its significant solution times, specifically when applied to practical industry problems with comprehensive real-world datasets. In addition, the validity of the model was confined to yes/no results indicating whether a period is considered sustainable or not, i.e. it did not deliver relevant insights on how far targets have been missed during the transition towards a sustainability steady state.

Hence, this paper attempts to extend and improve the basic TTS approach by introducing more advanced model formulations and demonstrate its applicability by means of an empirical database of the automotive industry and its transition towards environmentally friendly electrified powertrains. Apart from improving the computational performance, the advanced TTS models not only indicate whether a sustainability target is achieved by a certain period (or not), but they provide information on how much the period's sustainability performance deviates from the pre-defined targets. This capability significantly enhances the basic TTS approach. Therefore, in a practical application more meaningful results and insights as well as enhanced decision support are provided, which makes the approach even more suitable and applicable for larger practical industry problems.

A key feature of the TTS approach is that it can handle a broad number of incompatible sustainability objectives without using weighting factors to aggregate these objectives into one composite objective function. Hence, decision makers are not forced to make trade-offs sacrificing one sustainability objective for the sake of another objective. In this way, the TTS approach enables decision makers to validate in which timeframe *all* self-defined long-term sustainability targets are achievable and how the considered supply network develops over time towards a sustainable steady state. Originally, the TTS principle has been proposed by Kannegiesser and Günther (2014) to support policy makers in order to analyze entire industry supply chain transformations, e.g. in the automotive industry. Nevertheless, the TTS approach can be applied in the same way to model company supply networks or in any other long-term development studies.

The remainder of this article is structured as follows. We start in Section 2 with a brief review of the relevant literature. In Section 3, the principle idea behind the TTS optimization strategy is explained. This is followed in Section 4 by the presentation of three versions of the TTS optimization strategy. In Section 5, the numerical efficiency of the proposed TTS versions is tested. Section 6 presents exemplary numerical results based on real-world data from the automotive industry. Finally, Section 7 provides a closing discussion of the TTS strategy in the context of quantitative sustainability system studies and gives an outlook into further development and application areas of the TTS approach.

2. Relevant literature

In our study we exemplify the TTS concept by analyzing the sustainable development of industry supply chains. Designing the structure and long-term development of company or product supply chains has been a topic of research in supply chain management since many years, cf. Meixell and Gargeya (2005), Goetschalckx and Fleischmann (2008), Melo et al. (2010) and Corominas et al. (2015). The respective papers focus on long-term network structures taking into account total demand, production capacities, the location of production and distribution facilities as well as transportation lanes and the mode of transportation. Factors that drive the development of supply networks are typically economic, for instance, maximizing after-tax profit or minimizing total landed costs in the supply chain taking into account exchange rates and investment/divestment scenarios as well as location-specific taxes. Environmental and social objectives are mostly not considered or at most reflected by constraints, e.g. severance payments in the case of employee dismissals, or by avoiding high environmental footprints in globally-distributed supply chains.

Sustainability in supply chains in general and specifically so called green supply chain management has received increasing interest in the last years (Fahimnia et al., 2015). Comprehensive literature reviews have been provided with a special focus on