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A Systems Approach for Modeling Interactions Among the Sustainable Development Goals Part 2:
System Dynamics

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ABSTRACT

This article presents a methodology using system dynamics to model the time-dependent progress of each one of the 17 Sustainable Development Goals (SDGs), as well as their mutual interactions. The hard-systems approach presented herein complements a soft-systems, cross-impact analysis approach presented in part 1. To accomplish this, a modified logistic innovation-diffusion model is used to represent the progress of individual SDGs over time. Then, matrix transposition is used to model the SDGs' interactions. Combining these two techniques into one system dynamics model, the authors propose an analytical, quantifiable, and easily learned tool to understand the complex interplay among the SDGs as a system. The new web-based tool can be used to analyze several scenarios of the SDGs over time to understand the impact of a certain policy or economic intervention. This article is the second of a sequence of two papers analyzing the interactions between the SDGs in a systemic manner.

KEYWORDS

Hard System, Interactions, Interface, Modeling, Scenario Analysis, Sustainable Development Goals, System Dynamics, Systems Approach, Systems Thinking

1. INTRODUCTION

In a companion paper (Part 1), the authors advocated the need for using a systems approach, based on cross-impact analysis (CIA) combined with network analysis, to analyze the interaction among the 17 Sustainable Development Goals (SDGs). The analysis was based on the rationale that the SDGs form an *anthropocentric network* consisting of many interactions at the goal- and/or target-level. As reviewed in the companion paper, although the interactions among the SDGs have been acknowledged by many authors in the sustainable development literature (Allenet al., 2017; Coopmanet et al., 2016; Le Blanc, 2015; Nilsson et al., 2016; Nilsson, 2017; Nilsson et al., 2017; Nilsson et al., 2013; UN Water, 2016; United Nations Economic and Social Council, 2015; United Nations General Assembly, 2015; Vladimirova & Le Blanc, 2016; Weitz et al., 2014), little has been done to model how the SDGs influence or depend on one another.

Cross impact analysis originated in the 1960s (Gordon, 2014; Gordon & Hayward, 1968) to analyze "weak [soft] structured systems" (Weimer-Jehle, 2006, p.336) for which theory-based computational

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(hard) models do not work well due to system complexity and disciplinary heterogeneity. Since its inception, cross-impact analysis has been used a general method for assessing the "interrelations between the most important influential factors in a system by experts who evaluate [subjectively] pairs of these factors" (Weimer-Jehle, 2006, p.336). Cross -impact analysis is a *soft* systems approach that uses a systemic process of inquiry.

As discussed in Part 1, combining cross-impact analysis and network analysis has many advantages when analyzing the SDGs. More specifically, the approach enables decision makers to: (1) attain a better qualitative and quantitative understanding of the way the SDGs interact; (2) detect emerging patterns resulting from those interactions; (3) use context-specific information about direct impacts to identify indirect effects; and (4) identify leverage points hidden within the SDGs.

Cross impact analysis also has limitations. As noted by Checkland and Poulter (2006), the limitation of a soft systems approach is that it uses an action-oriented learning process for learning to address problem areas and not the content of the problems. The second limitation of cross-impact network analysis is that it is static; it represents a snapshot of a system in time and cannot handle dynamic (time-dependent) issues.

A third limitation is that cross-impact analysis is entirely based on human input, ideally, expert judgement. The cross-impact matrix, which is at the fundamental core of cross impact analysis, requires judging experts to estimate how variables interact with each other, the degree of their interactions, and the possible results of their impacts (Weimer-Jehle, 2006). Essentially, the quality of the analysis depends on the accuracy and expertise of the people undertaking that analysis. The experts filling out the cross-impact matrix are "expected to possess insights which rather should be the results of an analysis (Weimer-Jehle, 2006, p.337)." This is the classic *Catch-22*, where input depends on output, rendering the analysis ineffective through *circle-logic*.

We present below an alternative *hard* systems approach to analyze the interactions among the SDGs which helps address the limitations mentioned above. The approach uses system dynamics which, as the name suggests, accounts for how the components of systems and their linkages change with time. Furthermore, it takes under consideration the components of a system in addition to following a systemic process of inquiry. Unlike cross-impact analysis that can be carried out using simple tables in Excel, system dynamics analysis requires using more sophisticated software packages. The system dynamics (SD) models presented in this paper use the STELLA (Systems Thinking Experiential Learning Laboratory with Animation) Professional software by ISEE Systems, Inc. v1.2.1.

It should be noted that both cross-impact analysis (combined with network analysis) and system dynamics are not mutually exclusive from each other when addressing the SDGs; they may appear to be dissimilar but, in reality, complement each other. It is recommended, for instance, to first carry out cross-impact analysis and network analysis to map how the SDGs interact. They also force decision makers to, at least, semi-quantify the strength and centrality of each component within the SDG network as well as the strength of the linkages among the goals. The results of that analysis are critical to developing robust and meaningful SD models. In system thinking lingo, they help develop so-called mental models of how the SDGs interact and outline hypotheses of their interaction dynamics.

An earlier version of the model discussed herein was originally presented at the United Nations' Multi-Stakeholder Forum on Science, Technology and Innovation for the SDGs held in New York on 14-16 May 2017, which focused on six of the 17 SDGs, namely, SDG 01 (Poverty Eradication), SDG 02 (Food Security), SDG 03 (Health), SDG 05 (Gender Equality), SDG 09 (Infrastructure), and SDG 14 (Oceans). That presentation served as a catalyst for this paper. The model presented herein can be extended further to include all SDGs in the future as well as a more detailed and complex model representing sustainable development in general.

The rest of the paper is organized as follows: section 2 presents an overview of system dynamics modeling by discussing its definition, major components, causal-loop diagrams, and stock-and-flow diagrams; section 3 describes a system dynamics archetype based on the logistic, innovation diffusion model; section 4 details how to connect many structures together using a nested cross-impact

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