Chapter 2
Modeling the Sustainable Development Nexus as a Complex-Coupled System:
System Dynamics Modeling

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ABSTRACT

This chapter begins with defining complex systems, presents an overview of the applied science of dynamical systems by focusing on the main components of complexity and chaos, and introduces the concept of dimensionality of systems. Systems have structural and temporal (dynamic) components – they exist in space and time. This chapter focuses on the time dimension, called temporality. The authors classify a third dimension, chaos (randomness), and illustrate that all systems can be defined according to their structure, dynamics, and chaos. These three dimensions constitute the dimensionality of systems, which can be used to define and categorize all types of systems. A system dynamics model to quantify the progress and interactions among the United Nation's Sustainable Development Goals (SDG) is introduced. The benefits and limitations of a system dynamics modeling approach in this context are then discussed.

INTRODUCTION

There are many types of systems (e.g., simple, complicated, complex, and so on), but they all have a structural and temporal (dynamic) dimension – they exist in space and time (Krakauer, 2019). It is recommended – but not necessary – that the reader looks at the first chapter for a detailed discussion of

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the spatial (structure) component. This chapter will cover the dimension of time (temporality) using the overarching concept of complexity, as well as system dynamics (SD) modeling.

The analysis herein is based on the rationale that sustainable development issues form an anthropocentric network and coupled system consisting of many structural and spatial interactions among its subsystems (i.e., sectors). This holds true for the dynamic aspect of systems through time, so the Sustainable Development Goals (SDGs) will function as a case study in the second part of this chapter.

Although many authors have acknowledged the interactions among the SDGs in the sustainable development literature little has been done to model how the SDGs influence or depend on one another through time, and their long-term system dynamics have been relatively unexplored (see Allenet et 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; Daher et al., 2018; Stephan et al., 2018). Some notable works do exist including the SDGs and their targets as a network (Allen, Metternicht, & Wiedmann, 2019; Zhou & Moinuddin, 2017); the SDGs as various interacting sectors (Collste, Pedercini, & Cornell, 2017); and the SDGs as a dynamic system (Collste, Pedercini, & Cornell, 2017; Millennium Institute, n.d.; Zelinka & Amadei, 2019a). It is the goal of this chapter to show that the dynamics of the SDGs can be modeled in a way that is not too complex to understand while still producing informative results. Following this introduction section, the rest of the chapter is organized as follows:

Section 2 defines a complex system and presents an overview of the applied science of dynamical systems by focusing on the main components of complexity and chaos and introducing the concept of dimensionality of a system

Section 3 describes the limitations of more static approaches (see the previous chapter) to modeling systems and how system dynamics can be used to complement them, and it provides a brief overview of the components of causal-loop diagrams, stock-and-flow diagrams, and system dynamics modeling

Section 4 introduces the lower-level of the system dynamics model from the context of system archetypes based on the logistic diffusion model for the SDGs

Section 5 finishes building the system dynamics model by connecting the many structures in the lower-level together using a nested cross-impact matrix based on the nexus approach

Section 6 discusses the benefits and limitations of system dynamics modeling

Section 7 provides a brief overview of potential future work and then concludes

SYSTEMS SCIENCE: DYNAMICAL SYSTEMS

Interconnectivity and hierarchy describe a system's spatial and structural dimension, but systems and particularly complex ones, also have a time dimension called **temporality**. Systems for which time has an impact on their state and function are called dynamical systems as their temporality is strong. More accurately, though, the change in time is mathematically governed by a well-specified rule or set of rules, like an equation or algorithm (Feldman, 2019). This well-defined rule also makes the system deterministic by definition.

The effect of time is characterized by **iterative** cycles (recurring sequences) and **oscillations** (periodic movement between two bounded thresholds) and is inferred through the concept of feedback and causal