Chapter 1
Introduction

Thomas W. Hertel

The world faces significant sustainability challenges in the decades ahead (United Nations 2019). Of the 17 UN Sustainable Development Goals, nine bear directly on the world's land and water resources (Fig. 1.1). These goals cannot be attained without prudent management of these natural resources, yet growing populations and rising incomes place unprecedented stress on them. Of the four planetary boundaries identified as being at risk, three—genetic diversity, land system change, and nitrogen and phosphorous flows—are directly linked to land use—and the fourth—climate change—is also substantially driven by developments in global land use (Steffen et al. 2015). The challenge posed in assessing potential sustainability solutions is that these stresses do not respect disciplinary boundaries. And while stresses are often highly localized, the drivers of these stresses are often global (e.g., Haqiqi et al. 2023), and local responses can influence national and international outcomes. For this reason, underlying risks, as well as solutions, are typically assessed using a suite of models with increasingly complex approaches. Unfortunately, this complexity often renders replication and use by researchers outside the core group impossible (Obersteiner et al. 2016; Springmann et al. 2018).

To date, only a few open-source, bottom-up, economic-environmental modeling frameworks have been capable of analyzing global sustainability at the resolution of individual grid cells (Lotze-Campen et al. 2008; Valin et al. 2013). There is clearly a trade-off between complexity and accessibility. Models used in teaching and

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T. W. Hertel (✉)
Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University, West Lafayette, IN, USA
e-mail: hertel@purdue.edu

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Fig. 1.1 United Nations Sustainable Development Goals, representing a blueprint for a better future. Of the 17 goals, nine are related to food, water, and land – the focus of this book. Image source: United Nations Sustainable Development Goals (https://www.un.org/sustainabledevelopment/). The content of this publication has not been approved by the United Nations and does not reflect the views of the United Nations or its officials or Member States.

academic research are generally simpler than those developed by national and international laboratories and research institutions. A relatively simple, global, grid-resolving sustainability framework that could also be run "in-cloud" would allow wider participation in sustainability discussions and facilitate more crowdsourcing of new ideas, data, and parameters to enrich the representation of local stresses, policies, and adaptations. This book documents one such modeling framework: SIMPLE-G, a Simplified International Model of agricultural Prices, Land use, and the Environment, Gridded version.

The SIMPLE-G framework allows researchers to analyze the interplay between economic and environmental systems. In doing so, it accounts for the actions of local agricultural producers with respect to land and water use within the context of regional and global commodity markets. This model integrates economic theories with environmental sciences to analyze the biophysical and economic impacts at different geospatial scales. The model's economic supply of land and water accounts for information about local institutions, biophysical characteristics, sustainability criteria, and physical availability. Consequently, heterogeneous local constraints lead to different rates of change in land and water use. On the demand side, growth in income and population lead to changes in food consumption baskets and changes in agricultural trade patterns.

Integrating human and earth system analysis within a single global economic framework is a challenging task and often focuses on one-way linkages, such as those used in downscaling regional results to a grid cell level (Reilly et al. 2012). It has also been common practice to extrapolate from sophisticated grid-level analyses to the national scale, assuming that the share of grids in national aggregate of production or land use are unchanging (Schlenker and Roberts 2009). Bridging local, national, and global scales within a single, integrated framework is essential if we wish to consider the influence of local decision makers' behavior on global sustainability outcomes. In the SIMPLE-G framework, these local decisions are endogenous to the model and account for local biophysical characteristics and institutions as well as the simultaneous determination of local input prices and globally determined commodity prices.

This book features eight applications of the SIMPLE-G framework to illustrate its versatility in sustainability analyses. Chapter 10 introduces the reader to the SIMPLE model (nongridded) through an exploration of the role of agricultural productivity growth in ensuring both environmental sustainability and food security. Chapter 11 builds on Chap. 10 by introducing the simplest possible representation of economic and biophysical processes, dubbed SIMPLE-G1-US: two inputs (land and nonland), with just one region (i.e., the United States) represented at a fine scale. Subsequent applications gradually introduce greater complexity, including groundwater and surface water withdrawals (Chap. 12), labor markets (Chap. 13), and nitrogen fertilizer applications (Chap. 14), represented at a fine scale. Some examples of sustainability challenges that have been assessed using these versions of SIMPLE-G range from the implications of public research and development for agricultural productivity and greenhouse gas emissions (Chap. 10) to the consequences of groundwater conservation policies for employment, production, and trade (Chap. 16). Another application (Chap. 14) focuses on mitigating agricultural nonpoint source water pollution and one other (Chap. 15) focuses on the spatial environmental impacts of infrastructure development (i.e., road and rail construction) in Brazil. A final application (Chap. 17) aims to understand the global interplay between future pandemics and adverse climate shocks. In short, this book offers a rich array of SIMPLE-G applications for the reader to replicate and build upon in their own future research. All of the files required for replication are available at https://gtap.agecon.purdue.edu/simple-g/.

To take full advantage of the SIMPLE-G framework and resources, readers need deeper insights into the theory, data, parameters, and analysis tools underpinning these models. In Part II, we review the economic theory underlying the SIMPLE-G model. Using this theory, we can obtain important insights about the likely consequences of sustainability policies (e.g., changes in agricultural productivity or the withdrawal of natural resources for conservation purposes). We encourage model users to go beyond simply reporting results and instead provide in-depth analysis of the channels through which these external shocks to food and environmental systems affect key social and environmental outcomes. The analytical results developed in Part II also highlight the critical parameters that drive these findings, which are typically obtained from statistical studies or from transfer functions developed through simulations of biophysical systems models, as described in Part III. These parameters are inherently uncertain; understanding how parameter uncertainty translates into uncertainty in key metrics is an important part of any SIMPLE-G analysis. Part IV illustrates these principles in a series of applications.

An important and novel innovation documented in this book is the use of what we refer to as minimodels, which we have developed to address the challenge of understanding the critical drivers of local responses in a clear and transparent manner. This concept represents our effort to take the reader beyond the maps that are typically used to report results from global gridded models. Of course, the problem with in-depth analysis of any individual grid cell/activity lies in the fact that it is connected, in some way, to all the other grid cells in this type of bottom-up, multiscale analysis. The trick is to find a way to isolate the grid cell from its neighbors to permit a more in-depth analysis of local changes.

The benefit of the minimodel concept comes into play once the user has identified certain grid cells that respond in an extreme or perhaps even counterintuitive manner. These grid cells can be extracted for deeper analysis: This extracted minimodel consists of all the data, parameters, and equations describing behavior in a given grid cell. The minimodel also includes the solution values for all communicating variables for the focus grid cell, solved using the full model. The *communicating variables* are those variables that are determined in concert with the other grid cells and other world regions. In the simplest application (SIMPLE-G1-US), this is just the crop commodity price. In that model—illustrated in Chap. 11—the crop price is a sufficient statistic summarizing all of the developments in the national and global markets. In the minimodel, this price is treated as an exogenous variable and is shocked by the solution value of said variable, emerging from the full model simulation. When this communicating variable is shocked, along with any other grid-specific exogenous variables being perturbed in the full model simulation (e.g., total factor productivity in the case of Chap. 11), the user should obtain identical solutions from both the minimodel and the full SIMPLE-G model simulations. In this manner, a pared-down minimodel opens a way into in-depth analysis of behavioral responses in a particular grid cell.

More complex applications of the model contain more communicating variables across grid cells. The other applications in Part IV include wage changes determined within a commuting zone, national fertilizer prices, and natural resource shadow prices, among others. Therefore, the structure of the minimodel will vary across the applications. Once the particular minimodel is obtained and the equivalence of the two solutions is verified, the user can employ the powerful AnalyseGE software, embedded in the GEMPACK software suite, to analyze grid cell behavior, focusing on one equation at a time. This allows the user to isolate the source of unexpected or counterintuitive results as well as the key parameters driving these outcomes. Upon identifying the source of the surprising result, the researcher can scrutinize the reason for this outcome—possibly reevaluating the underlying data or parameters—or simply register this as a new finding.

To enhance the reader's experience and provide further motivation and insights into the SIMPLE-G framework, all of the chapters in this book are accompanied by voice-over PowerPoint presentations available here: https://gtap.agecon.purdue.edu/simple-g/. Readers may wish to view these short lectures before reading the associated chapter. These presentations also facilitate the use of this book as a text for courses utilizing SIMPLE-G.

We believe that this book will facilitate widespread use of the SIMPLE-G framework. By discussing the issues of database construction and model parameterization as well as model implementation and validation (Part III) in detail, along with providing a range of diverse applications for readers to replicate, we anticipate the construction of many new versions of SIMPLE-G. As this work develops, we plan to assemble a common global repository for data, parameters, and model specifications. This repository will allow researchers to draw on previous work to develop their own variants of SIMPLE-G or to use existing versions in new ways to assess the sustainability dimension of policies bearing on the world's land and water resources. Further discussion of these future directions for SIMPLE-G may be found in Chap. 18.

1 Summary

The SIMPLE-G framework represents a significant step forward in the computational modeling of human and environmental systems. This model incorporates market-mediated effects and feedback from human systems to natural systems and informs spatially heterogeneous economic decisions. It provides a framework for measuring spillover effects transmitted from one location to another location through markets and accounts for telecoupled distant regions, enabling analysis of interregional dependencies at a global scale. The model is particularly useful for evaluating the potential impacts of changes in government policies, technological improvements, and climate change on food production, consumption, and prices. With its ability to address the spatial distribution of activities and explicitly model the spatial heterogeneity associated with biophysical and socioeconomic systems, SIMPLE-G offers a valuable tool for designing effective conservation strategies and sustainability policies.

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