Chapter 18
Future Directions: Policy Implications, Model Extensions, and Institutional Innovation

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This concluding chapter looks ahead to the future of the SIMPLE-G framework, exploring its potential for further development, policy applications, and wider adoption. Having applied the flexible theoretical framework to a wide range of applications, we hope that the reader can now appreciate how this powerful tool can contribute to our understanding of land and water sustainability challenges. By integrating economic and biophysical data and methods at a high spatial resolution, SIMPLE-G provides an ideal platform for analyzing complex interactions among human and natural systems. In addition, this framework can lead to important policy insights by quantifying unintended consequences and market-mediated spillover effects within a comprehensive global framework. This is a critical missing piece of many previous sustainability policy evaluations and impact assessments.

We hope that this introduction to the SIMPLE-G framework will be the beginning of your journey through research to a brighter and more sustainable future.

1 Policy Applications and Impact Assessment

Effective policies are at the heart of achieving sustainable development goals. We believe that the widespread adoption of SIMPLE-G will allow for novel policy applications and impact assessments related to food security and environmental sustainability. This includes policies and regulations to improve air and water quality, increase food security, reduce food loss and waste, promote research and development for sustainable agriculture, increase resilience, improve infrastructure,

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and encourage dietary shifts and related policy combinations. Here we look at several possible extensions and novel policy applications.

1.1 Inform Policy Decisions with Spatially Explicit Information

Most decision-making about the allocation of scarce land and water resources is performed at the local level. This approach is appropriate given the localized nature of the underlying physical and socioeconomic systems and the critical importance that local governance plays in guiding natural resource use. However, these decisions are rarely informed by broader "boundary conditions" that characterize the ways in which higher-level governance (e.g., state and national) and the global economy are likely to impinge on local resource demands. However, SIMPLE-G, with its integrative, multiscale, gridded representation of local, national, and global activity, can provide local decision-makers with a consistent set of boundary conditions to inform their decision-making. These conditions might include anticipated local cropland demand, groundwater withdrawals and depth, surface water availability, commodity prices, fertilizer costs, and labor market conditions. These boundary conditions are likely to vary depending on higher-level governance decisions and the global scenarios being considered, thereby providing useful ingredients for local planning exercises.

For example, SIMPLE-G can be used to identify policy options for promoting sustainable land and water management or reducing deforestation. This type of analysis can include rich spatial information about land types, cropland areas, yields, water requirements, and market connections. This framework can assist in the design of targeted interventions to improve water quality and fertilizer applications in areas at risk of water quality issues. It is also an appropriate framework for evaluating the effect of agricultural subsidies and taxes on environmental sustainability. By providing geospatial insights and understanding about complex interactions, SIMPLE-G can help identify actionable policies to transform ideals into reality.

1.2 Market-Mediated Spillover Effects

Another area in which SIMPLE-G can offer novel policy guidance relates to the spillover effects of local policies (Cisneros-Pineda et al. 2023). As shown in Chaps. 12 and 13, among others, localized policies are likely to generate market-mediated spillovers. That is, when output is curtailed—or enhanced—in one locality due to a policy intervention, prices increase (or decrease), and this market information is conveyed to other localities, where producers can be expected to respond accordingly. In general, these spillover effects will be stronger when policy interventions are more aggressive and the targeted region is more extensive.

We expect that these spillover effects will often moderate the gains from direct policy intervention. Thus, in the case of wetland restoration in the Midwestern United States, aimed at improving water quality, the ensuing price increase results in farmers elsewhere expanding production, partially offsetting direct gains (Chap. 14). When excessive groundwater pumping is curtailed to preserve an aquifer's long-run sustainability, the reduction in crop output results in expansion elsewhere, with potentially adverse environmental consequences (Chap. 12). SIMPLE-G can assist policymakers by anticipating these spillovers and allowing for the analysis of countervailing policies that have a broader spatial scope (e.g., the nitrogen fertilizer tax considered in Chap. 14).

Spillover effects are not restricted to market-driven effects. They may also be ecological in nature and relate to the surrounding spatial characteristics of the grid cell. Conservation actions in specific grid cells influence neighboring grid cells via species movement or ecosystem connections. For example, honeybees may take refuge in protected areas and then pollinate nearby cropland. A good example of neighboring spillover effects is the US Conservation Reserve Program, which creates conservation buffers around retired land that prevent runoff from polluting nearby water bodies. Grass filters and riparian buffers intercept contaminants before they can enter waterways. The disaggregation of SIMPLE-G into grid cells is useful not only for determining the market-mediated impacts of policies but also for assessing the social benefits deriving from the positive externalities of conservation actions.

1.3 Distributional Impacts

SIMPLE-G also enables users to evaluate the distributional impact of local conservation policies. By design, most conservation policies aim to take natural resources out of production, conserving them for nature and the enjoyment of future generations. However, doing so has a direct, and sometimes significant, impact on local economic activity. By disaggregating these impacts both spatially and by factors of production, SIMPLE-G can allow for robust analysis of the distributional impacts of conservation policies. In Chap. 13, Ray et al. show that a policy targeting excessive groundwater withdrawals can have significant impacts on local labor markets, depressing employment and wages. A particularly important point made by the authors is that the effectiveness of conservation policies is also likely to be influenced by the functioning of the labor market. If households and workers are reluctant to leave the region due to strong local ties to family and geography, then the attempted withdrawal of natural resources from market activity is likely to prove more challenging. Providing quantitative insights about equity implications of policies and shocks paves the way to design fair and just transformative strategies toward a sustainable future.

1.4 Assessing the Impact of Policies and Shocks on Food Security

SIMPLE-G is a powerful tool for assessing the impact of policies on food security. Baseline projections for the food sector draw out the implications of expected changes in population, income, and technology. By simulating changes in food production, prices, and trade flows arising from policy interventions (e.g., subsidies, tariffs, and land-use regulations), the model can identify vulnerable regions and populations susceptible to disruptions in the food system. These changes can stem from market-based policies (e.g., subsidies or taxes), land-use regulations (e.g., conservation programs or wetland restoration), climate effects (e.g., heat stress or water stress), or unprecedented events (e.g., pandemics or conflicts). This allows policymakers to evaluate the effectiveness of interventions designed to improve food security at the national and regional levels, ensuring targeted support for those most in need.

Recent research has also extended the SIMPLE framework to examine the double burden of caloric malnourishment, which refers to the fact that undernourishment and obesity coexist in many countries, localities, and even households. Lopez Barrera and Hertel (2023) incorporate both metrics using the SIMPLE framework and examine the implications of future scenarios and alternative sustainability policies for undernourishment, obesity, and related health burdens.

1.5 Assessing the Impact of the Food System on Environmental Sustainability

The SIMPLE-G framework is a valuable tool for analyzing the environmental consequences of agricultural policies and allows researchers to identify synergies and tradeoffs between sustainability goals by evaluating the impact of sustainability policies on food security. By quantifying changes in land use, water consumption, and greenhouse gas emissions triggered by food consumption decisions, the model can assess the impact of food system changes on land, water, biodiversity, and ecosystem services. These changes can be prompted by changes in all or part of the food supply chain (e.g., reduction in postharvest loss, consumer food waste, transportation, or storage). This type of analysis enables policymakers to identify policy options that promote sustainable agricultural practices, thereby minimizing environmental damage and safeguarding ecological integrity while ensuring food security. The contribution of SIMPLE-G to this literature can be through measuring the spillover effects and feedback between environmental and human systems, which is difficult to capture without a spatially resolved economic model.

1.6 Linkages from/to Other Models

The capabilities of SIMPLE-G can be further amplified through one-way linkages with other models, both as a recipient of inputs and as a provider of outputs, allowing researchers to leverage the strengths of each model to address complex sustainability challenges. For example, SIMPLE-G can benefit from the detailed hydrological insights provided by the water balance model (WBM), as described in Chap. 17. By incorporating WBM water availability estimates as an input, SIMPLE-G can produce more accurate simulations of agricultural production and land-use change responses to climate change and related policies. Similarly, integrating the outputs of Agro-IBIS, a process-based agroecological model, into SIMPLE-G can enhance its ability to capture the nuances of yield response to fertilizer application and leaching to aquatic systems (see Chap. 14). Agro-IBIS's detailed simulations of biophysical processes also contribute to a more realistic representation of substitution elasticities in SIMPLE-G. Alternatively, linking SIMPLE-G to the Environmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) model unlocks new avenues for analysis. The ENVISAGE model can evaluate the economic impact of policy interventions, including carbon taxes. By including ENVISAGE data on the economic consequences of carbon taxes on fertilizer and energy prices, SIMPLE-G can incorporate the resulting changes in fertilizer prices and availability into its simulations, providing insights into the water quality co-benefits of climate policy (Zuidema et al. 2023).

One-way linkages to other models are an attractive way to provide a more complete picture of the impacts of policy interventions aimed at achieving the UN's Sustainable Development Goals related to food security, hunger eradication, and sustainable land management. By integrating geospatial economic models with other disciplines (e.g., environmental science, health, and energy), we gain a holistic understanding of critical interactions of these complex systems. These interdisciplinary connections allow us to address sustainability challenges more comprehensively.

1.7 Multiresolution and Multiscale

The resolution of production units in the SIMPLE-G framework can vary from grid cells (e.g., 250 meter, 5 arcmin, 15 arcmin, and 30 arcmin) to subregional, national, and aggregate regional production units. The versatility of this multiscale and multiresolution approach enables researchers to tailor the model to specific research questions and investigate scenarios with varying levels of detail. The critical rule for determining the optimal resolution is to capture the right amount of spatial heterogeneity required for the analysis. Excessive detail will result in challenging parameterization and potentially more difficult analysis. Insufficient detail for a given policy will limit the value of the ensuing analysis.

2 Model Extensions

SIMPLE-G can be extended in multiple ways. For example, authors can zoom in on specific regions by breaking them out from the global model. This unlocks local nuances and lets researchers tailor policies, pinpoint vulnerable populations, and assess impacts with greater accuracy. Exploring bilateral trade flows is another exciting frontier. Merging Global Trade Analysis Project (GTAP) data with SIMPLE-G could allow researchers to analyze specific trade partners and shocks, like the US-China soybean trade. Furthermore, livestock systems and diverse production factors (e.g., labor) have the potential for expansion. Finally, while SIMPLE-G aggregates crops, modeling multiple outputs within a grid cell is on the horizon. These extensions pave the way for even deeper dives into sustainability and food security challenges at local and global scales.

2.1 Extension to Other Regions

A natural way to extend the work presented in this book is to break out new regions. SIMPLE-G is designed with this possibility in mind and offers two avenues for doing so. One avenue would involve starting with a global version of SIMPLE-G, drawing on Chap. 17, for example, and further refining the global groundwater data, parameters, and policies for a particular country. However, in our experience, this is not the best approach. Using the full global gridded model in the context of a region-specific application is inefficient and, absent a global policy scenario, does not add value to the study. Rather, our preferred approach is to start with the aggregate regions in SIMPLE and break out the focus country. This is the approach taken in the applications focusing on the United States and Brazil in Part IV. In this way, researchers can preserve the global behavior in SIMPLE while focusing attention on the region of interest. The model is much faster to run and includes far less scope for computational problems.

Using a country-specific rather than a global dataset has several advantages when analyzing complex issues (e.g., food security and environmental sustainability) at regional scales. First, this approach increases accuracy and reliability: Country-specific datasets capture nuances and local variations that global datasets often miss. These nuances can impact food production and environmental pressures. In addition, country-specific data often undergo rigorous local validation and quality control processes, ensuring their accuracy and relevance to the specific context. This eliminates potential biases and inaccuracies inherent in global datasets aggregated from diverse sources and with less local validation. Second, the country-specific approach enables a deeper understanding of the specific dynamics within a particular region. This approach facilitates the identification of hotspots and populations most susceptible to food insecurity and environmental degradation. It allows for targeted policy interventions and strategies that address the region's unique needs and vulnerabilities effectively. By tracking policies and changes within a specific country or region, researchers can evaluate policies' effectiveness with greater accuracy. This facilitates evidence-based decision-making and informs future policy adjustments to ensure their effectiveness and impact.

The SIMPLE-G code is designed to facilitate this type of region-focused breakout. The only thing that changes is the mapping file that maps grid cells to regions. Open-source scripts are available for converting gridded data in raster format to GEMPACK-readable SIMPLE-G input files. This approach facilitates the construction of consistent gridded datasets and shocks for use in SIMPLE-G. We have also made advances in the development of country-specific databases in SIMPLE, which are publicly available (https://gtap.agecon.purdue.edu/simple-g/). Using this tool, users can change regional aggregation as well as assumptions about data and parameters to fit their own research work. In the future, we plan to link this regional dataset to the SIMPLE-G database workflow so that users can easily disaggregate regions into grid cells to facilitate their own global-local-global analysis.

2.2 Extension to Bilateral Trade Flows

In Part III of this book, we noted that the current SIMPLE-G framework includes a pooled global market for crop exports and imports (assuming that all crop exports enter the global market and that all crop imports come from the global market). This setting simplifies the international trade system and is the most suitable approach for modeling international trade in the long run, over which the bilateral geography of trade is less dominant. However, in the near term, empirical evidence suggests that current bilateral trade patterns are quite persistent. For example, the United States trades disproportionately with Canada, Mexico, China, and Europe. For this reason, it is important to offer users the option of modeling bilateral trade patterns explicitly (as is the case for the GTAP model mentioned previously). This can also have important policy implications. For example, during the US-China trade war, China imposed a retaliatory tariff on soybean imports from the United States in response to the US tariffs on Chinese imports. This sharply reduced US-China soybean trade but raised soybean imports from Brazil, China's other main soybean supplier. These bilateral relationships are not well captured when modeling trade via a global pool of commodities.

Given the need to analyze bilateral trade flows, an important future direction for extending SIMPLE-G is to combine its gridded supply system with a bilateral trade system. Given the ready availability of reconciled trade and tariff data from GTAP (Aguiar et al. 2019, 2022), we propose merging the bilateral trade in the GTAP crop database with the SIMPLE-G model. This extension will retain the advantages of SIMPLE-G for capturing the spatial heterogeneity of crop production and spillover effects at the local level and incorporate detailed GTAP data on regional-level trade in order to analyze more specific shocks and responses by trade partners.

2.3 Extension to Other Production Systems

The SIMPLE-G framework outlined in this book focuses on cropping systems as the gridded economic activity. However, it is entirely possible to add additional systems, provided that the necessary data can be obtained. Perhaps the most obvious are livestock systems, particularly those relying on pastureland. A large share of the world's agricultural lands comprises pasture, the demand for which is linked to ruminant livestock systems. Incorporating a gridded representation of ruminant livestock would allow users to explore issues involving the conversion of pastures to cropland and vice versa. Gridded data on ruminant and non-ruminant livestock are available (Gilbert et al. 2018). Incorporating these data would also allow users to explore environmental issues related to ruminant livestock production, including greenhouse gas emissions and water pollution, at a fine scale. To relate regional livestock production to pasture at the gridded level, one possible direction is to introduce the land allocation module from the GTAP-Agro-ecological Zone (GTAP-AEZ) model (Hertel et al. 2009, 2010), which presents the revenue-maximizing land-use decisions for crops, pasture, and forest. This modeling approach—together with gridded land-use datasets—would allow researchers to simulate the competition of land between crop and livestock production, which is necessary for researching questions on, for example, diet change or nutrition.

A further step would involve disaggregating confinement animal feeding operations from the regional level to the gridded level in order to better capture related air and water pollution. Given data limitations, it is unlikely that modelers will be able to track the movement of crop production from specific locations to these facilities. Rather, the feedstuffs would draw on a more aggregated regional supply pool for crop inputs.

2.4 Extension to Other Factors of Crop Production

As shown in Chap. 13, identifying key factors of production—in this case, labor—can be critical for understanding system behavior and the distributional consequences of sustainability policies. In that application, labor market rigidities are shown to limit the effectiveness of the conservation policy and generate significant losses for workers. However, labor is an extremely heterogeneous input, with significant differences in both labor supply and demand characteristics between, for example, family labor, hired labor, and migrant labor. Further disaggregation of this factor of production will be important for some applications. In general, further disaggregation of production factors is warranted when: (1) supply and demand characteristics vary significantly across factors of production, (2) there is empirical evidence supporting the specification of these supply/demand responses, and (3) the production factor in question plays a significant role in the policy under consideration.

2.5 Extension to Multiple Crops

Another challenge comes from SIMPLE-G's crop aggregation approach. In the current SIMPLE-G model, we first aggregate all crops to a single commodity (e.g., corn-equivalent output) with price-based weights and use the single crop to represent the response of crop production to shocks, assuming that the crop composition in this aggregate does not change much. While this approach simulates the general response of crop production to various policies, it is difficult to model the shock and response to a specific crop or the change in crop composition in the face of new socioeconomic drivers. Considering the example of soybean trade from above, another factor that influences China's soybean import in addition to the tariff shock is the domestic consumption of cooking oil and livestock production (the latter uses soy meal as a major input). These drivers will cause crop-specific shocks to the model and change the crop composition that was imposed in the initial aggregation stage. For these reasons, disaggregating crops will be important in some cases. However, in keeping with the SIMPLE philosophy, we believe that this should be done in a parsimonious way. Our goal is not to replicate the detailed, complex models of agricultural commodity markets that have been developed over the past decades. Rather, we would seek to find an intermediate ground in which important sustainability challenges can be addressed without making the framework too demanding to allow parameterization, replication, and validation.

There are different approaches for modeling multiple crops in SIMPLE-G while using the most reliable data sources and keeping the model simple enough to facilitate analysis and provide policy insights. One issue in modeling multicrop production is the low accuracy of satellite imagery in determining the type of crops grown. While the USDA provides high-resolution cropland data layer products, information for much of the rest of the world is less reliable. For example, Brazil's *MapBiomas*, an important collaborative network of more than 70 organizations that produces annual maps of land cover and land use in Brazil, does not report maize cropland. According to the *MapBiomas Brasil* website, it does not have a maize category because maize is included in the broader class of "other temporary crops." Maize is one of the most important temporary crops in Brazil, accounting for about 17% of the total harvested area in 2022. However, it is not distinguished from other temporary crops because of the limitations of satellite imagery and the classification methods used by *MapBiomas*.

The path forward that we propose for multicrop versions of SIMPLE-G involves specifying multiple output production functions at the grid-cell level. In this way, we do not require separate inputs for each individual crop, which can be difficult to obtain at a fine spatial scale. These crops can be exported or may compete with imports from other regions. Following the aggregation of domestic and imported crop commodities, these different categories of crops substitute for one another in the same three demand categories used in the standard SIMPLE model (recall Chap. 4): direct consumption, food processing, and livestock consumption (Fig. 18.1).

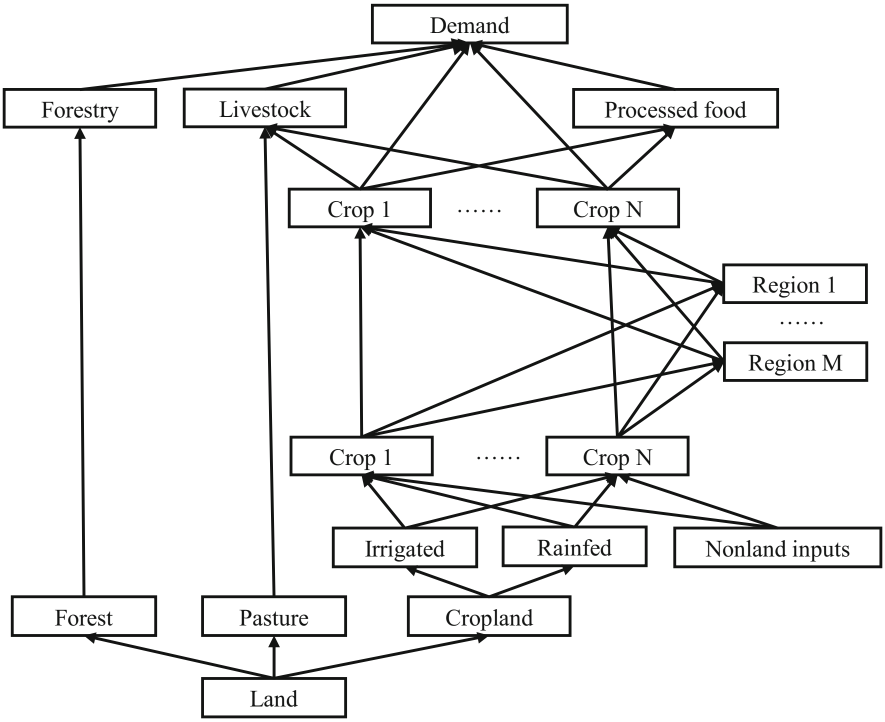

Fig. 18.1 Nesting SIMPLE-G within the GTAP-AEZ framework. Livestock and forestry demand for land are derived from a national production function, while crop production is modeled at the grid-cell level

2.6 Integration into GTAP-AEZ

Once a version of SIMPLE-G has been extended to handle bilateral trade and multiple crops, it is a relatively short step to embed this gridded framework in a general equilibrium model such as the GTAP model. Why might one wish to do so? Doesn't this violate the principle of simplicity? We believe that this should be done only when it is necessary to place this fine-scale economic analysis in a broader context. In a sense, this is really just an extension of the GTAP-AEZ model (Hertel et al. 2009, 2010), which is widely used to look at land-based sustainability policies (e.g., renewable fuels standards and other climate mitigation strategies) in an economy-wide context. More recently, the GTAP-AEZ model has been paired with fine-scale ecological modeling to uncover the macroeconomic benefits of local conservation policies (Johnson et al. 2023). A key limitation of previous work is the need to downscale economic results from the AEZs to the local level. By embedding SIMPLE-G in the GTAP model, the economic responses to conservation policies could be incorporated at the local level. Alternatively, for some purposes, it may be sufficient to link SIMPLE-G with the fine-scale ecological models.

Figure 18.1 provides an overview of how this embedding might be accomplished. As with the GTAP-AEZ model, the demand for land is derived from the forest, livestock, and crop sectors. In the case of forestry and ruminant livestock, the production functions are modeled at the national level, with demand for land services by AEZ treated as a constant elasticity of substitution nest within the national production function. This approach captures the spatial pattern of land competition across uses without modeling the full production functions for forestry and livestock at the AEZ level. These national sectors now demand land services at a finer scale (the grid cell), but nothing else has changed. However, in the case of crop production, we model the full production function at the grid cell, including the competition between rainfed and irrigated production. This analysis is more demanding, in terms of data requirements and computation, but it allows us to address the type of sustainability challenges highlighted above.

2.7 Beyond Integration: Collaborative Research for Understanding Human–Environment Linkages

Multidisciplinary research—where experts from diverse fields collaborate on a common problem—is crucial for addressing complex challenges such as food security and environmental sustainability. While each field possesses unique expertise, attempting to tackle these intricate issues within single disciplines often leads to incomplete solutions and missed opportunities. Given the importance of natural resources and the environment in SIMPLE-G, some users might consider extending SIMPLE-G to directly incorporate detailed hydrology or agroecology relationships. However, here we draw the line. We prefer not to make SIMPLE into COMPLEX! Rather, we suggest linking SIMPLE-G to a compatible hydrologic model, such as WBM, as shown in Chap. 17, or to an agroecological model, such as Agro-IBIS, as described in Chap. 14. This approach allows each field to contribute its specific knowledge and expertise, leading to a more comprehensive and robust understanding of the interconnected systems. This collaborative approach not only leverages the strengths of each field but also avoids the dilution of expertise that can occur when one discipline attempts to encompass the entirety of a complex modeling challenge. By working together, researchers can achieve greater depth and breadth in their analysis, ultimately leading to more effective and sustainable solutions for the interconnected challenges of our world.

Significant challenges must be overcome to achieve seamless collaboration. One major obstacle lies in the inherent differences between disciplinary approaches and the models themselves. Temporal and spatial resolutions differ, with hydrological and ecological models often operating at finer scales and shorter timeframes than economic models. This disparity requires careful data aggregation and interpolation to ensure compatibility across models. Furthermore, the computational software used to develop and run different models can be incompatible, hindering communication and data exchange. Additionally, conflicting definitions and terminology across disciplines can lead to misinterpretations and inconsistencies when attempting to link models. Finally, the computational demands of running large-scale linked models can be immense, requiring access to high-performance computing (HPC) resources. The lack of readily available HPC resources for many researchers can limit the feasibility of collaborative modeling approaches.

The C3F framework (Woo et al. 2022) offers a promising solution for overcoming the challenges of collaborative linkages between human and environmental models. The authors apply the C3F framework to link SIMPLE-G to WBM for the United States. By leveraging container technology, C3F enables researchers to independently develop and package their models with their specific software and data dependencies. This modular approach facilitates communication and data exchange between models while avoiding potential conflicts due to incompatible software environments. Furthermore, containerization facilitates the standardization of temporal and spatial dimensions across models, allowing researchers to define and configure consistent timeframes and spatial resolutions within each container, regardless of the models' inherent differences. This eliminates the need for complex data manipulation and interpolation, ensuring smooth communication and data exchange between models operating at different scales.

The unique feature of C3F is that it breaks away from the traditional model-coupling approach that seeks convergence between models, which is a time-consuming and often computationally expensive process. Instead, it leverages the concept of adaptive expectations. This allows each model to learn from the outputs of other models and adjust its own inputs accordingly, creating a dynamic and iterative process in much the same way as is done by real economic decision-makers. C3F facilitates this by running models consecutively, where each model receives and integrates the latest outputs from other models before making its own runs. In other words, in SIMPLE-G, farmers in each grid cell make decisions based on past WBM simulations of climate and weather and then make decisions about the extent and intensity of irrigation. Then, the WBM generates water balances considering the farmers' decisions at the beginning of the season. This eliminates the need for a single, unified solution, allowing the models to adapt and evolve in real time, reflecting the dynamic nature of the coupled human–environment system. This adaptive approach significantly reduces the computational burden compared with traditional convergence methods, making collaborative modeling more accessible and efficient. This approach also allows for a more flexible and realistic representation of the system, where model predictions are continuously updated based on the latest information, reflecting the dynamic interplay between human and environmental processes.

2.8 SIMPLE-S: A Tool for Model Development, Calibration, and Education

While the applications in Part IV demonstrate the importance of incorporating spatial heterogeneity of shocks and responses at the gridded level in SIMPLE-G, one may wonder whether it is always better to develop and work with the gridded version than with a more aggregated version. Let us consider the following circumstances under which an alternative formulation (SIMPLE-Subregion or SIMPLE-S) might be relevant:

Model Development and Testing At the model development stage, researchers may initially seek "reasonable" results—responses that are consistent with economic theory and real-world observations in direction and relative magnitude—as opposed to obtaining more precise results with considerably greater time costs. Although favored by model users, the gridded feature of SIMPLE-G can render it unnecessarily bulky for model developers, especially when the model needs to be solved repeatedly for testing purposes.

Parameter Calibration SIMPLE-G requires parameters defined at multiple scales (regional, subregional, and gridded). When researchers are interested in calibrating certain parameters (or iteratively narrowing the range of initial values for further calibration), it may be more efficient to work with the model aggregated to a specific level of interest (e.g., county, province, state, and region).

Education On the basis of our teaching experience, we find that using the gridded version for educational purposes faces three challenges. First, it is usually more difficult to interpret simulation results at the grid level, which are highly dependent on grid-specific parameters and baseline data; therefore, we have to aggregate these results further to the state or subregional level to allow for ready interpretation. In addition, the powerful AnalyseGE software, which enables detailed analysis of model outcomes on an equation-by-equation basis (recall Chap. 11), is not very functional when there are more than 20 grid cells in a region—hence the use of a mini model (Chap. 11). Second, solving SIMPLE-G at the grid level usually requires 8–15 min, depending on the computer and experiment, which may delay the teaching activity. Finally, for education and training purposes, students usually use a free-trial version of GEMPACK to learn the model. However, the size of the SIMPLE-G model (i.e., the number of endogenous variables and equations) is too large to be solved with this free-trial version.

Considering these three areas of need, we conclude that, in addition to the aggregated version (SIMPLE) and the gridded version (SIMPLE-G), it is also helpful to develop a version of intermediate size, which we name SIMPLE-S. SIMPLE-S may be developed based on an existing SIMPLE-G model; it maintains the same model and data structure as SIMPLE-G but aggregates grids to subregional levels. For example, in SIMPLE-S-US, the 76,651 5-arcmin grids of the United States are aggregated to nine USDA Farm Resource Regions (subregions) by

Table 18.1 Gridded (SIMPLE-G) and subregional (SIMPLE-S) versions in the case of the US-focused model from Chap. 12

	SIMPLE-G-US	SIMPLE-S-US
Grids	76,651 (US) + 15 (non-US regions)	9 (US) + 15 (non-US regions)
Model size	1,893,828 endogenous variables	2658 endogenous variables
Time cost	8 min 52 s	4 s
GEMPACK License	Formal (purchased) license	Free trial license

summing the value and quantity data and calculating a weighted average of gridded parameters, while the rest of the world remains at the regional level. The conversion from SIMPLE-G to SIMPLE-S is conducted with R script, which fully automates the development of the subregional version.

Table 18.1 briefly compares the SIMPLE-G-US model from Chap. 12 and its subregion version. By aggregating US grids into subregions, SIMPLE-S reduces the model size and allows the model to be solved almost instantaneously. SIMPLE-S also preserves all the equations and database structure from SIMPLE-G-US. From a research development perspective, SIMPLE-S can be used as a “wind tunnel model” for SIMPLE-G. Much as model planes are tested in a wind tunnel prior to building full-scale versions, researchers can use SIMPLE-S to test new functional forms and modules, or calibrate regional or subregional parameters, much more efficiently. Progress made in SIMPLE-S is readily transmissible to SIMPLE-G. For educational purposes, SIMPLE-S also serves as a “training manikin” version of the gridded version. Much as medical students learn their trade by first operating on manikins, students of SIMPLE-G can explore the model with various experiments and get immediate feedback before embarking on the full-scale model. Additionally, the results at the subregional level are often easier to interpret and compare to readily accessible statistics. Once familiar with SIMPLE-S, students can readily transfer their skills and experience to SIMPLE-G for further research.

3 Vision for a SIMPLE-G Community

In addition to the SIMPLE-G framework extensions discussed above, an important step toward its continuous development and application is to establish a SIMPLE-G community that brings together research capacities and interests from a broader range of individuals to address the serious sustainability challenges facing the world today. In our vision, the SIMPLE-G community can be summarized with a reinterpretation of the *global–local–global* approach to research (Hertel et al. 2023). We envision the SIMPLE-G community as one that connects *global* researchers, educators, and students who are interested in developing and applying SIMPLE-G models; encourages them to share *local* data, knowledge, and ideas for integrative research; and enhances research impacts on *global* audience and stakeholders.

3.1 Global Network

From its origin at Purdue University, SIMPLE-G has been introduced to researchers from multiple domestic and international universities and research institutes. Currently, the most important platform for SIMPLE-G training for external researchers is the SIMPLE-G short course, held biennially at Purdue since 2019. The course consists of 3 weeks of online training on the background knowledge of the non-gridded SIMPLE model and 1 week of on-site training that focuses on SIMPLE-G applications and underlying economic theory. This short course is not restricted to passive learning: During the on-site section, participants have an opportunity to collaborate with others on a group project, laying the foundation for future research projects and long-term collaboration. Based on the basic 4-week training schedule, we have also developed a workshop version of the short course that can be taught over 2 days. This abbreviated version has been successfully implemented as part of the NSF-I-GUIDE summer school (Boulder, Colorado, United States) and the China Energy Modeling Forum's model Capacity Building Workshop (Beijing, China). By November 2023, more than 60 researchers had completed SIMPLE-G training, bringing the model from Purdue to more than 40 institutes in five countries.

The group of SIMPLE-G short course participants, together with researchers and students from Purdue's Center for Global Trade Analysis, now forms the foundation for a broader global community of SIMPLE-G users and contributors. One major challenge is that, given the requirements of time commitment and cost, as well as capacity restrictions on the number of participants, the biennial short course and occasional in-person workshops cannot satisfy the increasing interest in SIMPLE-G. This is particularly true for researchers from developing countries who may be precluded from joining the on-site short courses for budgetary reasons. With these limitations in mind, this book and its accompanying lectures and files are our attempt to provide accessible teaching and training materials for SIMPLE-G to global researchers. We welcome you, readers of the book, to join the SIMPLE-G community for broader and long-term collaboration.

3.2 Local Expertise

From our experience developing region-specific models, we have learned that building a high-quality spatially explicit model depends on strong participation from research partners with local expertise, providing data inputs, local knowledge, and research ideas. Local researchers are often aware of additional data sources that are not widely recognized by their international colleagues or are less frequently used due to language barriers. By offering these data sources, they can make important contributions to establishing gridded databases for region-specific versions of SIMPLE-G. Even if the data are already available at the global level, local knowledge can also help researchers judge whether the data correctly represent real-world situations. For example, when we developed the region-specific version of SIMPLE-G for Brazil (Chap. 15), our local collaborators indicated that an important feature of Brazilian agriculture is the rotation between crops and grazing within the same year on certain croplands. However, this land-use pattern is not accurately classified or measured by global land cover datasets. We followed the suggestion of local collaborators and used a Brazilian land cover dataset, which improved the accuracy of land-use data at the grid level. Finally, and most importantly, researchers with local expertise invariably have a better understanding of the current research and policy questions faced by decision-makers; they also have a better understanding of the political, social, and cultural factors that are critical to analyzing those questions with SIMPLE-G.

3.3 Global Impacts

Fueled by global researchers and local expertise, the SIMPLE-G community will serve as an incubator for future studies that address global and local sustainability challenges. Improving the exposure and influence of SIMPLE-G models and applications has been a continuous focus of the Purdue research team. We have organized SIMPLE-G track sessions and workshops at various academic conferences—including the annual meetings of the Agricultural and Applied Economics Association, American Geographical Union, and GTAP—and presented SIMPLE-G studies in GLASSNET and I-GUIDE webinars. These events have attracted attention from the research community, which has been particularly interested in the ease with which SIMPLE-G can facilitate multidisciplinary studies. In the future, we will continue organizing relevant sessions and workshops at academic conferences, to provide additional opportunities for members of the SIMPLE-G community to present their work to a broad audience. We will also invite representatives from global policy-making agencies, think tanks, and local stakeholders to join the SIMPLE-G community and communicate with researchers, which will promote the integration of innovative research methodology with solutions to real-world challenges.

3.4 SIMPLE-G as a Component of GLASSNET

Given the breadth of the sustainability challenges facing the world, SIMPLE-G is just one of many tools needed to inform the public debate. In an effort to mobilize a wider range of databases, tools, and interdisciplinary collaborations needed to inform the UN Sustainable Development Goals, Hertel and colleagues have initiated GLASSNET—a network of networks supported by the US National Science Foundation and focused on sustainable management of the world's land and freshwater resources (https://mygeohub.org/groups/glassnet/). The purpose of GLASSNET is to facilitate global–local–global analyses, and a wide range of disciplines and researchers are involved. In addition to the project leadership, GLASSNET has a Science Council and a Stakeholder Advisory Board drawing on a diverse set of scientists, policy advisors, and decision-makers. This network of networks can play an important role in guiding analysts and policy advisors to appropriate tools for addressing the diverse challenges posed by the UN Sustainable Development Goals. By documenting the SIMPLE-G model and pairing it with teaching materials, we hope that this framework can be employed by users from a wide range of disciplines and geographies. Readers are invited to join GLASSNET to engage with the broader community of practice seeking to address the global challenges to land and water sustainability in the coming decades.

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