SIMPLE-G Model and Database for Global Food Security and GHG Emissions

Multiscale Adaptations to Climate and Pandemic Shocks

Chapter 17 of the SIMPLE-G Book

Iman Haqiqi[1]

October 26, 2024

Abstract

To address sustainability challenges with considerable spatial heterogeneity, a gridded economic analysis is necessary. On the other hand, global shocks, such as pandemics, may have a significant impact on environmental footprints as well as food security in the short run. Assessing the impacts of combined weather and pandemic shocks necessitates quantitative frameworks that address sustainability and food security at different scales. This manuscript provides an overview of the SIMPLE-G-Global model, a multiscale gridded economic framework designed to facilitate the study of food security, emissions, water, and land. The model codes, data, and outputs are described here. As an application, the results of a pandemic-weather compound scenario are illustrated. The results highlight the significance of different drivers in determining the final impacts on metrics of food security and environmental sustainability.

Keywords: computational economics, gridded economic model, sustainability, food security, agriculture, water resources, equilibrium, system of equations, policy.

Acknowledgments

The model introduced here is a product of long-term collaborations. The idea behind the SIMPLE-G model started with Tom Hertel and Uris Baldos. Mark Horridge created the first pilot code in TABLO. His suggestions and guidance were invaluable in the computation of the model. Uris Baldos, Jing Liu, and Iman Haqiqi initiated the first SIMPLE-G-US models and databases. Multiple grants supported the development of the model introduced here. I acknowledge the support from the United States Department of Energy, Office of Science, Biological and Environmental Research Program, Earth and Environmental Systems Modelling, MultiSector Dynamics Contract DE-SC0022141; I also acknowledge infrastructure support from the National Science Foundation HDR award #2118329: NSF Institute for Geospatial Understanding through an Integrative Discovery Environment (I-GUIDE).

[1] Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University
Mailing address: 403 Mitch Daniels Blvd., West Lafayette, Indiana 47907-2056 USA
Email: ihaqiqi@purdue.edu

Code and data availability

The SIMPLE-G model introduced here is an open-source model used in Chapter 17 of the SIMPLE-G Book. To run simulations, users will need GEMPACK software, along with the accompanying model codes, input data, parameters, and command files available at: https://www.gtap.agecon.purdue.edu/simple-g/

Useful resources

- SIMPLE Book: https://doi.org/10.1007/978-3-319-22662-0
- SIMPLE-G Book: https://doi.org/10.1007/978-3-031-68054-0
- SIMPLE-G Webpage: https://www.gtap.agecon.purdue.edu/simple-g/
- SIMPLE-G YouTube Videos: https://tinyurl.com/SIMPLE-G-Book
- SIMPLE-G Short Course: https://mygeohub.org/courses/sustainability_shortcourse_2024
- SIMPLE-G visualization:
  - Analyze SIMPLE-G Results in Jupyter Notebook and R: https://tinyurl.com/simpleg-handout
  - SIMPLE-G Web Application: https://mygeohub.org/resources/simpleus
  - SIMPLE-G Online: Computation: https://mygeohub.org/resources/simplegus

Table of contents

Abstract 1
Code and data availability 2
Useful resources 2
1 Introduction 5
1.1 Economic theory 5
1.1.1 Consumption 5
1.1.2 Production 5
1.1.3 Trade 5
1.1.4 Market Equilibrium: 5
1.2 SIMPLE-G (Global, Allcrops, 2017, 5 arc-min) 5
1.2.1 Spatial resolution and scope 6
1.2.2 Time steps and reference year 6
1.2.3 Commodity aggregation 6
1.2.4 Land types 6
1.2.5 Water sources 6
1.3 Potential applications of the SIMPLE-G model 7
1.3.1 SIMPLE-G and hydrological sciences 7
1.3.2 SIMPLE-G and agricultural sciences 7
1.3.3 SIMPLE-G and environmental sciences 7
1.3.4 SIMPLE-G and climate sciences 7
1.3.5 SIMPLE-G and nutrition & food sciences 7
1.4 Models 8
1.4.1 Main model (simpleg.exe) 8
1.4.2 No-adapt nutrition model (simpleg_noAdapt_nutr.exe) 8
1.4.3 No-adapt emission model (simpleg_noAdapt_ghg.exe) 9
1.5 Software requirement 9
1.6 Operating systems 9
2 Model files 10
2.1 TAB file for variables and equations 10
2.2 EXE file as pre-compiled executable 10
2.3 Other files 10
3 Data files 11
3.1 Nutrition data 12
3.2 Emission data 12
3.3 GRIDDATA includes the reference value of variables 12
3.4 GRIDPARM includes the value of behavioral parameters 12
3.5 GRIDSETS includes set elements and mappings 13
3.6 Model dimensions 13
4 Command files 14
4.1 Overall options 14
4.2 Section 1: paths for old and new files 15
4.3 Section 2: model closure 15
4.4 Section 3: solution method 16
4.5 Section 4: experiment design and shocks 17
5 Results 17
5.1 Running the model with a batch file 17
5.2 View solution files: SL4 and TXT 18
5.2.1 A note on condensation 20
5.2.2 A note on the coefficients 20
5.2.3 Simple plots and charts 20
5.3 The pandemic shock 20
5.3.1 Percentage change in income 20
5.3.2 Absolute change in per capita income 20

5.4 The impacts on crop production 21
5.5 Changes in malnutrition 22
5.6 Changes in GHG 23
5.7 Changes in exports and imports 24
5.8 Decomposing the drivers of change in exports 25
5.9 Changes in prices by region 26
5.10 Changes in per capita consumption 26
5.11 Body Mass Index by age and sex 27
6 Conclusions 27
7 Reference 28

List of boxes

Box 1. List of files in the main folder of SIMPLE-G-Adapt 10
Box 2. List of data files for SIMPLE-G-Adapt 11
Box 3. List of command files for SIMPLE-G-Adapt 14
Box 4. Options in the CMF file for SIMPLE-G-Adapt 14
Box 5. List of options for CMF files 15
Box 6. Introducing files in the CMF file for SIMPLE-G-Adapt 15
Box 7. Closure in the CMF file for SIMPLE-G-Adapt 16
Box 8. Solution methods in the CMF file for SIMPLE-G-Adapt 17
Box 9. Simulation scenario in the CMF file for SIMPLE-G-Adapt 17
Box 10. List of batch files for SIMPLE-G-Adapt 18
Box 11. Content of a batch file used for SIMPLE-G-Adapt 18
Box 12. List of output files for test simulation for SIMPLE-G-Adapt 18

List of Figures

Figure 1. Headers available in GRIDDATA.har 12
Figure 2. Headers available in GRIDPARM.har 13
Figure 3. Screenshot of the home screen of the SL4 file in ViewSOL 19
Figure 4. Changes in per capita income assumed in the climCov scenario 21
Figure 5. Changes in crop production 22
Figure 6. Changes in crop yields 22
Figure 7. Changes in malnutrition count 23
Figure 8. Changes in CO2 emissions 24
Figure 9. Changes in exports and imports due to the climCov scenario 25
Figure 10. Drivers of change in exports 25
Figure 11. Changes in prices (p_P) due to the climCov scenario 26
Figure 12. Changes in consumption (p_QCONS) due to the climCov scenario 26
Figure 13. BMI by age (A20-A85) for selected regions 27

1 Introduction

The SIMPLE Model, the Simplified International Model of agricultural Prices, Land use, and the Environment, is developed for global analysis of sustainability and food security (Hertel and Baldos, 2016). Its gridded version, SIMPLE-G, is a model designed for multiscale gridded economic analysis with a focus on land, water, and the environment. As detailed in the SIMPLE-G Book (Haqiqi and Hertel, 2024), the model captures interactions across regions, providing insights into resource use and policy impacts at fine spatial resolutions. The SIMPLE-G Global Allcrops model has been used in Chapter 17 of the SIMPLE-G Book and published in Environmental Research Letters (Haqiqi et al., 2023).

1.1 Economic theory

The SIMPLE-G model is built on economic theories that describe how various factors influence agricultural production, food consumption, and trade.

1.1.1 Consumption

In the SIMPLE-G model, consumption is driven by factors such as population, per capita income, and prices. The model assumes that as income increases, the demand for food also increases overall. This relationship is represented by a demand function that incorporates both income elasticity (how sensitive consumption is to changes in income) and price elasticity (how sensitive consumption is to changes in prices).

1.1.2 Production

Agricultural production in the SIMPLE-G model is a function of inputs such as land, labor, water, and capital. The model uses a nested constant elasticity of substitution (CES) production function to represent the substitution possibilities between different inputs. This means that the model can simulate how changes in the availability or cost of one input (e.g., water) can affect the overall production process. Additionally, the model accounts for technological changes and improvements in productivity.

1.1.3 Trade

Trade in the SIMPLE-G model is influenced by relative prices. This is represented by a trade function that links domestic prices to world prices.

1.1.4 Market Equilibrium:

The standard SIMPLE-G model ensures that markets are cleared by adjusting prices until supply equals demand in each market. This involves solving a system of equations that represent the supply and demand for various agricultural commodities and production factors. The model's equilibrium prices and quantities reflect the interactions between consumption, production, and trade, as well as the effects of external factors such as climate change and policy interventions.

1.2 SIMPLE-G (Global, Allcrops, 2017, 5 arc-min)

The model described here includes three versions: (1) standard SIMPLE-G model plus nutrition and GHG modules, (2) modified SIMPLE-G model with nutrition module assuming no adaptation, (3) modified SIMPLE-G model with GHG module assuming no adaptation.

Table 1. SIMPLE-G- Global Model specifications

Model name	simpleg_adapt
Grids	Global 5 arc-min
Terrestrial coverage	All agricultural land
Year	Around 2017
Version	v22p2
Crop details	Allcrops composite
Production technology	Irrigated and rainfed
Water module	Groundwater, surface water, irrigation equipment
Labor module	Embedded in non-land
Land module	Quantity preserving constant elasticity of transformation (QCET)
Product differentiation	Sub-regional Armington
Nutrition module	Regional malnutrition and over-acquisition
Emission module	Regional CO2, N2O, CH4, linear linked to production levels

1.2.1 Spatial resolution and scope

SIMPLE-G operates at a global scale, with spatial resolution varying depending on the specific application. For this application, it uses a gridded approach, dividing the world into cells of 5 arc-min size. A 5 arc-minute grid cell at the equator is approximately 8.5 kilometers on each side. This is calculated by converting 5 arc-minutes into degrees (5 arc-minutes = 5/60 degrees), and then using the Earth's circumference (about 40,075 kilometers) to determine the distance represented by that angular measurement at the equator. Specifically, each degree of latitude or longitude at the equator is roughly 111.32 kilometers, so 5 arc-minutes is 5/60 or 0.0833 in degrees and roughly 9.28 kilometers each side at the equator.

1.2.2 Time steps and reference year

The model is comparative static, illustrating the change from one economic equilibrium state to a new economic equilibrium state. It can simulate both historical and future scenarios. Time steps can range from annual to short-run or long-run, depending on the specific research question. A reference year, often a recent year with extensive data availability, is used as a baseline for simulations.

1.2.3 Commodity aggregation

SIMPLE-G includes markets for crops, livestock, and processed food. Commodities are often aggregated into groups based on their production and consumption patterns. This aggregation level can vary depending on the specific analysis. For this version, all crops are aggregated into one composite crop, which varies by grid cell. Composite crops are differentiated by the production location and irrigation vs rainfed technology.

1.2.4 Land types

The model distinguishes between different land types, such as irrigated and rainfed cropland. This allows for the analysis of cropland conversion and its impact on agriculture and the environment.

1.2.5 Water sources

SIMPLE-G incorporates the decisions about water resources into its simulations, considering both surface water and groundwater in combination with an index for irrigation technology.

1.3 Potential applications of the SIMPLE-G model

While the SIMPLE-G model is developed with a powerful economic engine, it can use information from biophysical sciences as input. Also, the outputs of the SIMPLE-G model can be used by other sciences with a focus on economic decisions. SIMPLE-G evaluates the impacts of scenarios of local and remote environmental and economic changes. This includes taxes and subsidies, sustainability restrictions, changes in technology, crop yield shocks, changes in water availability, etc.

1.3.1 SIMPLE-G and hydrological sciences

The SIMPLE-G model can calculate the impacts of various economic and environmental scenarios on decisions about water use and irrigation extent. This information can be used as input to the hydrological models to provide a more comprehensive assessment of the impacts of changes on hydro-economic systems.

1.3.2 SIMPLE-G and agricultural sciences

Agricultural sciences can help construct scenarios of yield changes due to policies or climate change. Then, SIMPLE-G can compute the new extent of cropland and fertilizer applications. This information can be used to evaluate the impacts of policies and environmental changes on fertilizer leaching and water quality.

1.3.3 SIMPLE-G and environmental sciences

A major output of the SIMPLE-G model is the decision on land and water use at the grid cell level. The change in agricultural land area and irrigation water use has direct and indirect impacts on the environment, habitat area, biodiversity, and other ecosystem services. So, the outputs of SIMPLE-G can help understand the impacts of local and global changes on sustainability and environmental stresses.

1.3.4 SIMPLE-G and climate sciences

The SIMPLE-G model can be used to evaluate the impact of different local and remote economic policies or environmental changes on GHG emissions from food systems that can be used as input for climate models.

1.3.5 SIMPLE-G and nutrition & food sciences

The SIMPLE-G model can be used to evaluate the impact of different local and remote economic policies or environmental changes on food security metrics. This includes the consumption of crops, livestock, and processed food. The nutrition module on the model provides the impacts of different technological, economic, and environmental scenarios on:

- BMI by gender and age
- Undernourished population
- Over-acquisition and obesity
- Caloric consumption and caloric gaps

This information can be used to evaluate the impacts of changes and policies on diets, health, and inequality.

1.4 Models

The model described here is an extension of the SIMPLE-G1 (Liu et al., 2017), SIMPLE-G-US (Baldos et al., 2020), and SIMPLE-G Global (Haqiqi et al., 2022). It adds food security and GHG emissions with adaptation possibilities. This manuscript provides essential details to learn about the file structure of the model. To learn about the databases, validation, and other applications, look at the SIMPLE-G Book.

1.4.1 Main model (simpleg.exe)

The main model follows the standard structure of SIMPLE-G introduced in Chapter 5 of the SIMPLE-G Book (Haqiqi, 2025) with detailed information about irrigated and rainfed production, surface water withdrawals, groundwater withdrawals, land allocation, agricultural production, trade, and food consumption. In the standard model, the decisions are a function of relative prices determined by supply and demand forces. The change in market prices can affect the spatial distribution of agricultural activities as well as land and water use. There are two modules added here:

- The GHG Module links emissions to the production level in each economic activity with energy embedded in a composite intermediate input commodity.
- The Nutrition Module links the decision about food consumption to caloric intake and malnutrition metrics.

1.4.2 No-adapt nutrition model (simpleg_noAdapt_nutr.exe)

To illustrate the value of economic adaptation, a modified version of the SIMPLE-G model is developed with no price effect. The modified model with a no-adapt nutrition module follows a supply-push approach, transferring the shocks from the supply side of the economy (land, water, yield) to the consumer. This module does not model markets and prices but considers a "Leontief Quantity Model" in production and trade. This means the model may imply excess demand or supply. A shock to water availability is linearly transferred to crop production, then linearly transferred to domestic supply and global trade, which are linearly transferred to the consumer in terms of change in food availability. Here, the share parameters and interlinkages play a significant role.

This section briefly describes the simplified linearized model. A typical food security index (γ) is a function of food consumption following the SIMPLE Nutrition Module (Baldos and Hertel, 2014). Let $qc_{r,f}$ show the percentage change in consumption of food commodity *f* in region *r*. The change in consumption is determined by the % change in import (*qm*) and domestic supply (*qd*) and their shares. The change in imports follows the change in global trade (*qw*), which is a function of the % change in regional exports (*qx*). The change in regional export by itself is a function of % change in domestic production (*qs*). This is determined by changes in gridded production ($qs_{g,l}$) and gridded agricultural inputs, including land (*L*), groundwater (*GW*), surface water (*SW*), and other inputs (*H*).

$$\gamma_i = f_r(qc_{r,f})$$

$$qc_r = (\theta_r^m * qm_r + \theta_r^d qd_r)$$

$$qm_r = qw = \sum \theta_w^x qx_r$$

$$qx_r = qs_r$$

$$qs_r = \sum \theta_{r,g,l} qs_{g,l}$$

$$q_{g,l} - a_{g,l} = \theta_{g,l}^L \left(q_{g,l}^L + a_{g,l}^L\right) + \theta_{g,l}^{GW} \left(q_{g,l}^{GW} + a_{g,l}^{GW}\right) + \theta_{g,l}^{SW} \left(q_{g,l}^{SW} + a_{g,l}^{SW}\right) + \theta_{g,l}^H \left(q_{g,l}^H + a_{g,l}^H\right)$$

Here, the price changes and substitutions in production and trade are omitted. For more information about the original model equation and analysis, look at the SIMPLE-G Book.

1.4.3 No-adapt emission model (simpleg_noAdapt_ghg.exe)

The no-adapt GHG model follows a demand-pull approach, transferring the income shock and demand changes to the producer. This module does not model markets and prices but considers a "Leontief Quantity Model" in production and trade. This means the model may imply excess demand or supply. A shock to income is transferred to demand for food and linearly transferred to producers. The change in production scale is linearly translated to emissions using emission factors (χ) based on GTAP Dataset (Aguiar et al., 2022).

$$\Delta GHG_{i,r=} \sum_f \Delta GHG_{i,r,f}$$

$$ghg_{i,r,f} = \chi_{r,f} qc_{r,f}$$

Note that the emission factors may vary by region, economic sector, and commodity.

The following sections of the manuscript describe the model codes and data files for the model. The files are available in the "simpleg_global_adapt.zip" archive on the SIMPLE-G webpage. This document contains three sections.

- Section 2 provides an overview of files for the SIMPLE-G model files.
- Section 3 introduces the data and parameters for the gridded world.
- Section 4 describes the command files and model closures.

1.5 Software requirement

The model is solved in GEMPACK, the General Equilibrium Modelling PACKage (Horridge et al., 2018). The input data is prepared in a format that is efficient for use in GEMPACK. For simulating SIMPLE-G, you need to have access to a machine with the software or install the GEMPACK software on your computer. A free-trail version of GEMPACK is available at https://www.copsmodels.com/gpeidl.htm

1.6 Operating systems

The model is tested on the Windows systems. For MacOS, users may try to install GEMPACK as a container or with a virtual machine with several third-party options:

- CrossOver (https://www.codeweavers.com/crossover/)

- Virtual Box (https://www.virtualbox.org/wiki/Downloads)
- Parallels Desktop (http://www.parallels.com/products/desktop/)
- VMWare Fusion (http://www.vmware.com/products/fusion.html)

For the latest updates on Linux version, please look at:

- The Centre of Policy Studies: https://www.copsmodels.com/,
- Installation and Use on Linux PCs: https://www.copsmodels.com/gpdocl.htm,
- Demonstration Version for Linux: https://www.copsmodels.com/gpdemol.htm

2 Model files

The "simpleg_global_adapt.zip" includes model data files and codes. Under the main folder of SIMPLE-G, users will find the following files needed to run the executable "simpleg.exe" and other exe programs.

Box 1. List of files in the main folder of SIMPLE-G-Adapt

```
simpleg.tab
simpleg.exe
simpleg.axs
…

simpleg_noAdapt_ghg.tab
simpleg_noAdapt_ghg.exe
simpleg_noAdapt_ghg.axs
…

Simpleg_noAdapt_nutr.tab
simpleg_noAdapt_nutr.exe
simpleg_noAdapt_nutr.axs
…

gfortran_link_ltg.fig
LTG.LOG
parcomp.log
```

2.1 TAB file for variables and equations

The file "simpleg.tab" provides the original script containing variable names, parameter labels, relevant headers in SIMPLE-G data source, and equation definitions in TABLO language for use in GEMPACK.

2.2 EXE file as pre-compiled executable

The "simpleg.exe" file is the pre-compiled executable model for running simulations. Modification of the equations and variables in the TABLO code requires compiling a new model version. Note that "simpleg_nut.exe" is related to the modified model with no adaptation for nutrition variables. Similarly, "simpleg_ghg.exe" is related to the modified model with no adaptation for GHG emission variables.

2.3 Other files

All other files are automatically generated when the model is compiled using GFortran.

3 Data files

The SIMPLE-G Global database includes more than 10 million data records. The data inputs are organized in three main files. Each simulation may contain additional files depending on the model extensions or scenario experiments. If GEMAPCK is installed, users can open and view these input "*.HAR" files using "viewHAR.exe" which is one of the utilities available in GEMPACK. The data is stored in headers. In addition to main values, each header includes the following metadata:

- Header: 4-character label
- Type: real, integer, string
- Dimension: either in the form of numbers or embedded set labels
- Coefficient: the long coefficient label of the parameter, variable, or set
- Name: description of the header
- Total, min, max, etc.: Numerical summaries of all data in each header

The folder "in" contains the input data, stored as header array files (*.har). As their names suggest, GRIDDATA, GRIDPARM, and GRIDSET contain the data, parameters, and sets of the model, respectively. These files provide the key information for conducting simulations with SIMPLE-G.

Box 2. List of data files for SIMPLE-G-Adapt

```
in\
       GRIDDATA.har
       GRIDPARM.har
       GRIDSETS.har

       LANDDATA.har
       LANDPARM.har
       LANDSETS.har

       XTRDATA.har
shf\
       USERDATA.har
```

The folder "shf" contains the shock files as "USERDATA.har" which includes data for determining the experiment and scenarios. They can also be used in experiments with the command file to determine what variables are to be mounted. For this version, the headers are:

- INC: the shock to income due to the pandemic by 17 global regions
- AFP: the shock to productivity due to the pandemic by 17 regions
- GRDW: the shock to groundwater availability due to weather by grid cell
- SRFW: the shock to surface water availability due to weather by grid cell
- YLDI: the shock to irrigated crop yields due to weather by grid cell
- YLDR: the shock to rainfed crop yields due to weather by grid cell
- Y15: other yield shocks by 135 countries/regions

3.1 Nutrition data

The folder "in" contains the nutrition module data, stored as header array files (*.har). This includes LANDDATA, LANDPARM, and LANDSET, which contain the data, parameters, and sets related to the nutrition module. The data are available for the year 2017 by region.

3.2 Emission data

The folder "in" contains the GHG module data, stored as header array files (*.har). This includes XTRDATA, which contains data about CO2, N2O, and CH4 emissions from crop production, livestock, and processed food sectors by region for the year 2017.

3.3 GRIDDATA includes the reference value of variables

The "GRIDDATA.har" file includes regional and gridded information to show the value of the variables for the reference year (2017 for this version). These variables are related to the production, demand, and supply of agricultural commodities as well as other relevant information such as consumption, exports, imports, income, population, etc. Figure 1 is the screenshot showing some of the headers in this file. Here, ID includes the reference year, while ID2 includes information about the module name and versions. More details about the dimensions of these variables (GID, TYPE, REG, etc.) are available in the "GRIDSETS.har" file.

griddata.har in C:\H\simpleg_global_adapt\in

File Contents Edit Sets Export Import History Search Aggregation Programs Help

	Header	Type	Dimension	Coeff	Total	Min	Max	Name
1	ID	1C	1 length 12					Set BASEYEAR SIMPLE Database
2	ID2	1C	5 length 12					Additional Information about the Data
3	VCRP	RE	GRID*LTYPE	VCROPgl	2566326396	0.023	62283	Value of crop output by g&l (1000 USD)
4	VLND	RE	GRID*LTYPE	VLANDgl	497340487	0.001	14098	Payment to land by g & l (1000 USD)
5	VWOR	RE	GRID*LTYPE	VWEQPTgl	22329577	0.000	1072	Value of water equipment by g & l (1000 USD)
6	VSRF	RE	GRID*LTYPE	VWATSRFgl	52242206	0.000	2976	Value of surface water by g & l (1000 USD)
7	VGRD	RE	GRID*LTYPE	VWATGRDgl	29025399	0.000	2688	Value of groundwater by g & l (1000 USD)
8	QLND	RE	GRID*LTYPE	QLANDgl	1567447	0.001	10.5	cropland area by g & l (1000 HA)
9	QCRP	RE	GRID*LTYPE	QCROPgl	16346028	0.000	397	crop output by g&l
10	QBIO	RE	REG	QCRPBIOF	549523	1.04	395788	Crop demand: Biofuel feedstock (in 1000 MT: Corn-eq.)
11	QFD	RE	REG	QCRPFEED	3347785	18467	1278972	Crop demand: Livestock feeds (in 1000 MT: Corn-eq.)
12	QPR	RE	REG	QCRPFOOD	5675040	6738	1829787	Crop demand: Proc. food inputs (in 1000 MT: Corn-eq.)
13	QCON	RE	CONS_COMM*REG	QCONS	63071793489	26210	13615084544	Comm. consumption (in 1000 USD, in 1000 MT: "Crops")
14	VCON	RE	CONS_COMM*REG	VCONS	64128487547	4114908	13615084544	Value of comm. consumption (in 1000 USD)
15	YPC	RE	REG	INC_PC	290991	1378	58330	Per capita income (in USD)
16	POP	RE	REG	POP	7534898	29287	1755775	Population (in 1000 persons)
17	QDCP	RE	REG*FOOD_COMM*MKT	QDCROPr	15796505	410	1805503	regional crop demand by use and by source
18	QSCP	RE	REG*MKT	QSCROPr	16346028	3415	4536076	regional crop supply and by source

Double-Click on an item to view it (or arrow keys + space bar)

Figure 1. Headers available in GRIDDATA.har

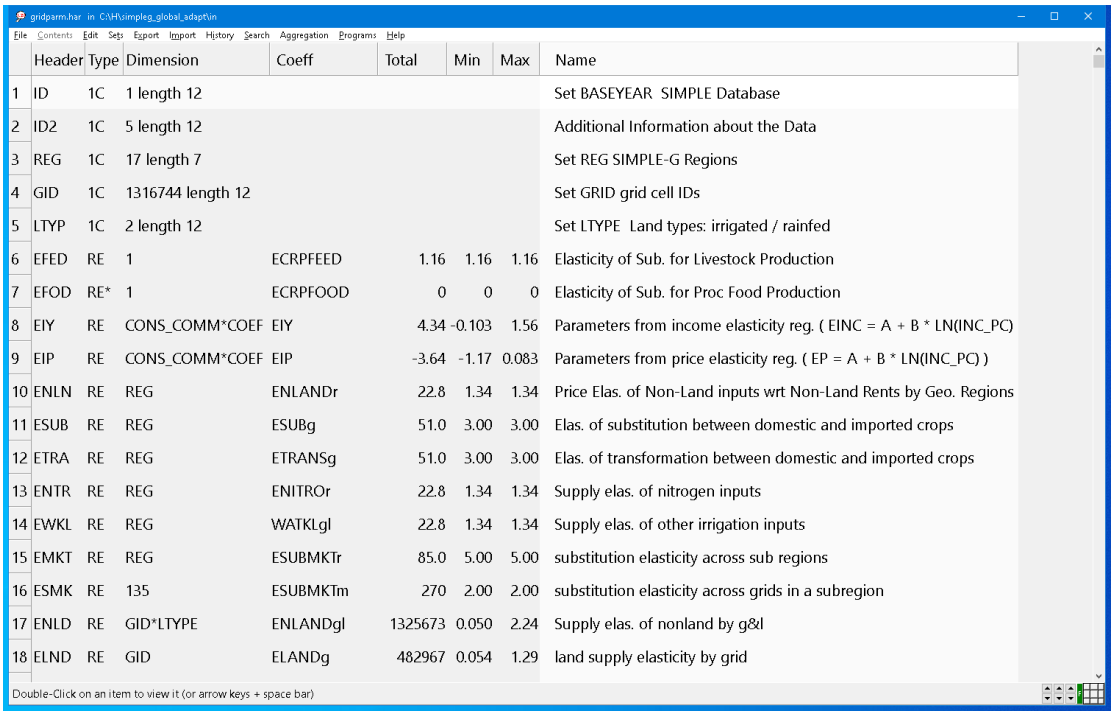
For example, the file shows that the total value of crop production was around 2.6 trillion USD, as shown by header VCRP. Also, the header QLND shows around 1.6 billion hectares of cropland area in 2017.

3.4 GRIDPARM includes the value of behavioral parameters

The "GRIDPARM.har" file includes the value of the model parameters. These are

mostly elasticity parameters. The parameters are those components of the model that are not allowed to change during the simulation, contrary to variables that are allowed to change.

For example, the file shows that the gridded land supply elasticity in header ELND has a coefficient labeled ELANDg and ranges from 0.054 to 1.29.



gridparm.har in C:\H\simpleg_global_adapt\in

File Contents Edit Sets Export Import History Search Aggregation Programs Help

	Header	Type	Dimension	Coeff	Total	Min	Max	Name
1	ID	1C	1 length 12					Set BASEYEAR SIMPLE Database
2	ID2	1C	5 length 12					Additional Information about the Data
3	REG	1C	17 length 7					Set REG SIMPLE-G Regions
4	GID	1C	1316744 length 12					Set GRID grid cell IDs
5	LTYP	1C	2 length 12					Set LTYPE Land types: irrigated / rainfed
6	EFED	RE	1	ECRPFEED	1.16	1.16	1.16	Elasticity of Sub. for Livestock Production
7	EFOD	RE*	1	ECRPFOOD	0	0	0	Elasticity of Sub. for Proc Food Production
8	EIY	RE	CONS_COMM*COEF	EIY	4.34	-0.103	1.56	Parameters from income elasticity reg. (EINC = A + B * LN(INC_PC)
9	EIP	RE	CONS_COMM*COEF	EIP	-3.64	-1.17	0.083	Parameters from price elasticity reg. (EP = A + B * LN(INC_PC))
10	ENLN	RE	REG	ENLANDr	22.8	1.34	1.34	Price Elas. of Non-Land inputs wrt Non-Land Rents by Geo. Regions
11	ESUB	RE	REG	ESUBg	51.0	3.00	3.00	Elas. of substitution between domestic and imported crops
12	ETRA	RE	REG	ETRANSg	51.0	3.00	3.00	Elas. of transformation between domestic and imported crops
13	ENTR	RE	REG	ENITROr	22.8	1.34	1.34	Supply elas. of nitrogen inputs
14	EWKL	RE	REG	WATKLgl	22.8	1.34	1.34	Supply elas. of other irrigation inputs
15	EMKT	RE	REG	ESUBMKTr	85.0	5.00	5.00	substitution elasticity across sub regions
16	ESMK	RE	135	ESUBMKTm	270	2.00	2.00	substitution elasticity across grids in a subregion
17	ENLD	RE	GID*LTYPE	ENLANDgl	1325673	0.050	2.24	Supply elas. of nonland by g&l
18	ELND	RE	GID	ELANDg	482967	0.054	1.29	land supply elasticity by grid

Double-Click on an item to view it (or arrow keys + space bar)

Figure 2. Headers available in GRIDPARM.har

3.5 GRIDSETS includes set elements and mappings

The "GRIDSETS.har" file includes the metadata and elements of the sets that are used in the model. For example, the set "REG" defines a domain of the regions included in the model, as shown in Table 2.

In addition, this file includes "mapping" information that shows how a subset of elements from one set are linked to an element of another set. For example, mapping MAP1 maps set GID to REG. Each row of MAP1 represents the corresponding grid cell in GID, and it records the region (by its index) to which the grid cell is mapped.

Note that LON and LAT show the coordinates longitude or latitude for the center of grid cells at 5 arc-min size following "lon/lat WGS 84" coordinate reference system.

3.6 Model dimensions

GRIDSETS also includes details on model dimensions. For this SIMPLE-G-Global Allcrops 2017 version, we have:

- REG: set global regions: 17
- GID: set grid cells: 1,316,744
- SMKT: set countries/regions: 135 (GTAP regions)

Table 2. Regions in SIMPLE-G

No.	REG	Description
1	E_Euro	Eastern Europe
2	N_Afr	North Africa
3	SSA	Sub Saharan Africa
4	S_Amer	South America (except Brazil)
5	BRA	Brazil
6	AUS_NZ	Oceania
7	EU	European Union
8	S_Asia	South Asia
9	CC_Amer	Central America
10	S_Afr	Southern Africa
11	SE_Asia	Southeast Asia
12	CAN	Canada
13	US	USA
14	CHINA	China and Mongolia
15	M_East	Middle East
16	JPN_KR	Japan / Korea
17	C_Asia	Central Asia

4 Command files

The folder "CMF" contains command files (*.cmf). They contain important information for simulation, including the path of input and output files, parameters for model solving, closure of the current model, and shock (policy) to be changed in the experiment. Each experiment is stored in a separate command file. For this exercise, there are three main CMF files. All CMFs are showing the same scenario on the compound pandemic-weather scenario (climCov) but with different model assumptions.

Box 3. List of command files for SIMPLE-G-Adapt

```
cmf\
       simpleg_climCov_adapt.cmf
       simpleg_climCov_noAdapt-nut.cmf
       simpleg_climCov_noAdapt-ghg.cmf
```

4.1 Overall options

The CMF file usually starts with some comments followed by general options. For example, the command below will set the initial memory allocation, which can vary by model version, and users can update it after changing the model.

Box 4. Options in the CMF file for SIMPLE-G-Adapt

```
! Options
! ------------
 start with mmnz = 24566;
 LU decompose transpose = yes ;
 dpn = yes ;
 cpu = yes ;
 slc file = no;
! -------------------
```

There are other options that users may decide to use. For a list of "XXX=yes|no" commands, look at the GEMPACK manual.

Box 5. List of options for CMF files

```
CPU = yes|NO ; ! yes means report CPU times
EAA = yes|no ; ! yes means echo activity to screen
NRP = yes|NO ; ! yes means do not re-use pivots
NEQ = yes|NO ; ! yes means do no equations, only formulas
```

4.2 Section 1: paths for old and new files

The CMF file determines the name and location of the input files (data, sets, parameters). It also determines the name and location of output files that should be saved. The output files are mainly LOG files, SL4 files, and updated GRIDDATA.

This version also includes data related to the nutrition and food security module (LANDSETS.har, LANDPARM.har, and LANDDATA.har) as well as GHG Module (XTRDATA.har).

Box 6. Introducing files in the CMF file for SIMPLE-G-Adapt

```
 ! Input files
 ! ------------
  File GRIDSETS = in\GRIDSETS.har ; !  set file
  File GRIDPARM = in\GRIDPARM.har ; !  parameters
  File GRIDDATA = in\GRIDDATA.har ; !  base data
  Updated file GRIDDATA = out\climCov_adapt.upd ;

!  Food security
  File LANDSETS = in\LANDSETS.har ;
  File LANDPARM = in\LANDPARM.har ;
  File LANDDATA = in\LANDDATA.har;
  Updated file LANDDATA = out\climCov_adapt_LAND.upd ;

! GHG emissions
  File XTRDATA = in\XTRDATA.har;
  Updated file XTRDATA = out\climCov_adapt_EXTR.upd ;


 ! Other files
 ! ------------
  LOG file      = out\climCov_adapt.LOG;
  Solution file = out\climCov_adapt;
  condensation information file = out\climCov_adapt-cond.txt;
```

4.3 Section 2: model closure

Model closure refers to the process of determining which variables in the model are exogenous (model inputs) and which are endogenous (model outputs). This defines the boundaries of changes and the scope of the analysis. Exogenous variables are variables that are assumed to be given or predetermined and do not change in response to changes in other variables within the model. Examples include yield changes, water availability, policies, technological progress, and global population growth. Endogenous variables are variables that are allowed to vary freely within the model in response to changes in exogenous variables. Examples include prices, production levels, consumption patterns, and trade flows. Closure rules also include specific assumptions that determine which

model setup to be used. Common closure rules in SIMPLE-G are:

- Integrated market closure.
- Mini model closure to fix crop prices.
- Input spatial mobility closure to select input supply equations.
- Input local allocation closure to determine the allocation to different practices.

Different closure rules can lead to different model outcomes.

Box 7. Closure in the CMF file for SIMPLE-G-Adapt

```
! Closure
! -------
!                    KEY EXOGENOUS VARIABLES
Exogenous   p_INC_PC    ;!per capita income by inc. reg.
Exogenous   p_POP       ;!population by inc. reg.
Exogenous   p_QCRPBIOF ;!crop demand for global biofuel use
Exogenous   s_QCRPBIOFr ;!crop demand for biofuel use | alternative

Exogenous   p_P(NFOOD_COMM,REG) ;!price of non-food commodities by inc. reg.
Exogenous   p_PNCRPFEED ;!price of non-feed inputs used in livestock prod.
Exogenous   p_PNCRPFOOD ;!price of non-crop inputs used in proc. food prod.

! ******* The gridded variables *******
Exogenous   s_QWATSRFgl ;! Slack to control surface water
Exogenous   s_QWATGRDgl ;! Slack to control groundwater
Exogenous   p_AOCROPgl ;! Efficiency index in crop production
Exogenous   p_AFWATERgl ;!  Efficiency index for irrigation water in crop pro
Exogenous   p_AFNLANDr; !  Efficiency index for non-land input in crop produc
Exogenous   s_QLANDr; ! Slack to control cropland area

! ********** MODULE SPECIFIC VARIABLES ***********************************
!             Food Security Module
Exogenous   CAL_COMM;! caloric content of commodity i consumed in region y
Exogenous   MIN_CAL;! minimum caloric consumption per capita in region y
Endogenous  MIN_CALW;! minimum caloric consumption per capita (global)

Endogenous  QCONS_GRAM;! food consumption
Endogenous  MAL_COUNT;! malnutrition count (inc reg)
Endogenous  MAL_GAP;! malnutrition gap (inc reg)
Endogenous  MAL_COUNTW;! malnutrition count (global)
Endogenous  MAL_GAPW;! malnutrition gap (global)

Endogenous  CALORIES;! total caloric consumption per capita in region y
Endogenous  CALORIESW;! total caloric consumption per capita (global)
Endogenous  QPC_GRAM;! grams per capita per day of commodity k consumed in re
```

4.4 Section 3: solution method

Users can determine the solution methods, steps, and sub-intervals in the CMF file. The solution methods include:

- Johanson Method: It is used for solving linearized versions of a model, where changes are calculated around a known equilibrium.
- Midpoint Method: Involves solving at the midpoint of each step for higher accuracy in approximating changes.

- Euler Method: A straightforward numerical approach that solves models by approximating derivatives through finite steps.
- Gragg's Method: An advanced, extrapolation-based approach that improves the accuracy of solutions by using Richardson extrapolation. It is often employed for more precise results.

Note that the number of subintervals is set to "1".

Box 8. Solution methods in the CMF file for SIMPLE-G-Adapt

```
! ------------------------------------
! Verbal description and solution method
! ------------------------------------
Verbal Description = pandemicWeather2015;

Method = Gragg;
Steps = 2 4 6;
subintervals = 1;
```

4.5 Section 4: experiment design and shocks

Experiment design involves introducing changes to "exogenous variables" in the model as determined by the closure. Users may apply multiple changes at a time. Box 9 shows a scenario that involves changes in yield, water supply, water requirement, income, and productivity. The "subtotals" are related to decomposition.

Box 9. Simulation scenario in the CMF file for SIMPLE-G-Adapt

```
! Shocks based on Haqiqi et al. 2023. ERL.

! The change due to water requirement by crops from WBM
Shock p_AFWATERgl(GRID,"irrigated") = file shf\Userdata.HAR header "afsg";

! The change in surface water availability from WBM
Shock s_QWATSRFgl(GRID,"irrigated") = file shf\Userdata.HAR header "srfw";

! Crop yiled changes due to heat stress from GCWM- emulator
Shock p_AOCROPgl(GRID,"irrigated") = file shf\Userdata.HAR header "yldi";
Shock p_AOCROPgl(GRID,"rainfed") = file shf\Userdata.HAR header "yldr";

! Other changes in yield
Shock p_AOCROPm = file shf\Userdata.HAR header "y15";

! Change in income due to COVID19
Shock p_INC_PC = file shf\Userdata.HAR header "inc";

! Change in the productivity on other inputs due to supply chain disruptions
Shock p_AFNLANDr = file shf\Userdata.HAR header "afp";
```

5 Results

It is possible to run the model by opening the TAB file in "TABmate.exe" and clicking on the "RUN CMF" icon.

5.1 Running the model with a batch file

The "do_simpleg_*.bat" files are batch files that automatically run the model and specific simulations by double-clicking them. They can be called in the command line

or used in other programs like R or Python.

Box 10. List of batch files for SIMPLE-G-Adapt

```
do_simpleg_climCov_adapt.bat
do_simpleg_climCov_nutrition.bat
do_simpleg_climCov_ghg.bat
```

The batch file manages model simulations. This file can be opened with any text editor. The content of this file is similar to box 11:

Box 11. Content of a batch file used for SIMPLE-G-Adapt

```
call simpleg -cmf cmf\simpleg_climCov_adapt.cmf
pause
```

This command means:

- `call`: the command to run the compiled model as executable file (simpleg.exe)
- `simpleg`: the name of the executable file under the same folder, here it refers to "simpleg.exe"
- `-cmf`: it indicates the model should be simulated with command files
- `cmf\simpleg_climCov_adapt.cmf`: this is the relative path of the command file.

The last line, "pause", asks the console window to remain open after all simulations, for the convenience of users to check if simulations are conducted successfully or not. Users can also get the same report from log files (*.log) in the folder "out". For multiple simulations, it is possible to use separate batch files for each simulation or a combined call in one batch file.

5.2 View solution files: SL4 and TXT

After running the simulations, the out folder includes output files, log files, and updated data files for each simulation.

Box 12. List of output files for test simulation for SIMPLE-G-Adapt

```
out\
     simpleg_climCov.log
     simpleg_climCov.sl4
     simpleg_climCov.slc
     simpleg_climCov.upd
     simpleg_climCov-cond.txt
```

The typical output files for each simulation are:

- LOG file: Records the sequence of commands, errors, warnings, and reports from running the simulation. It provides a useful trail for debugging.
- SL4 file: Contains detailed solution results, including percentage changes in variables, pre- and post-simulation values, and subtotals if available.
- SLC/UDC file: Contains the values of the model's coefficients at the pre/post simulation levels.

- UPD file: Updated data file.
- TXT files: User-specified output files or condensation files. The condensation process reduces the size of the original model equations by substituting or eliminating redundant variables and equations (Baldos et al., 2020).

There are two general ways to see the results:

- Double-click to open the solution file with ViewSOL.exe (a tool installed together with GEMPACK), which will list variables and their descriptions for further checking.
- Access the solution file in R using the "HARr" package (Ivanic, 2023), which allows users to save simulation results as data frames with scripts for saving or further analysis.

For the results of each variable in the percentage form (starts with "p_"), the solution file will report the percentage of that variable in the first column (here 10 means 10% increase). If the variable also contains the level form (the quantity at base), the solution file will also report its value before the shock (the second column), after the shock (the third column), and the difference in net values, not percentage change (the fourth column). The easiest way of exporting simulation results is to "Export – Copy" in ViewSOL, which can be pasted to spreadsheets and other editors.

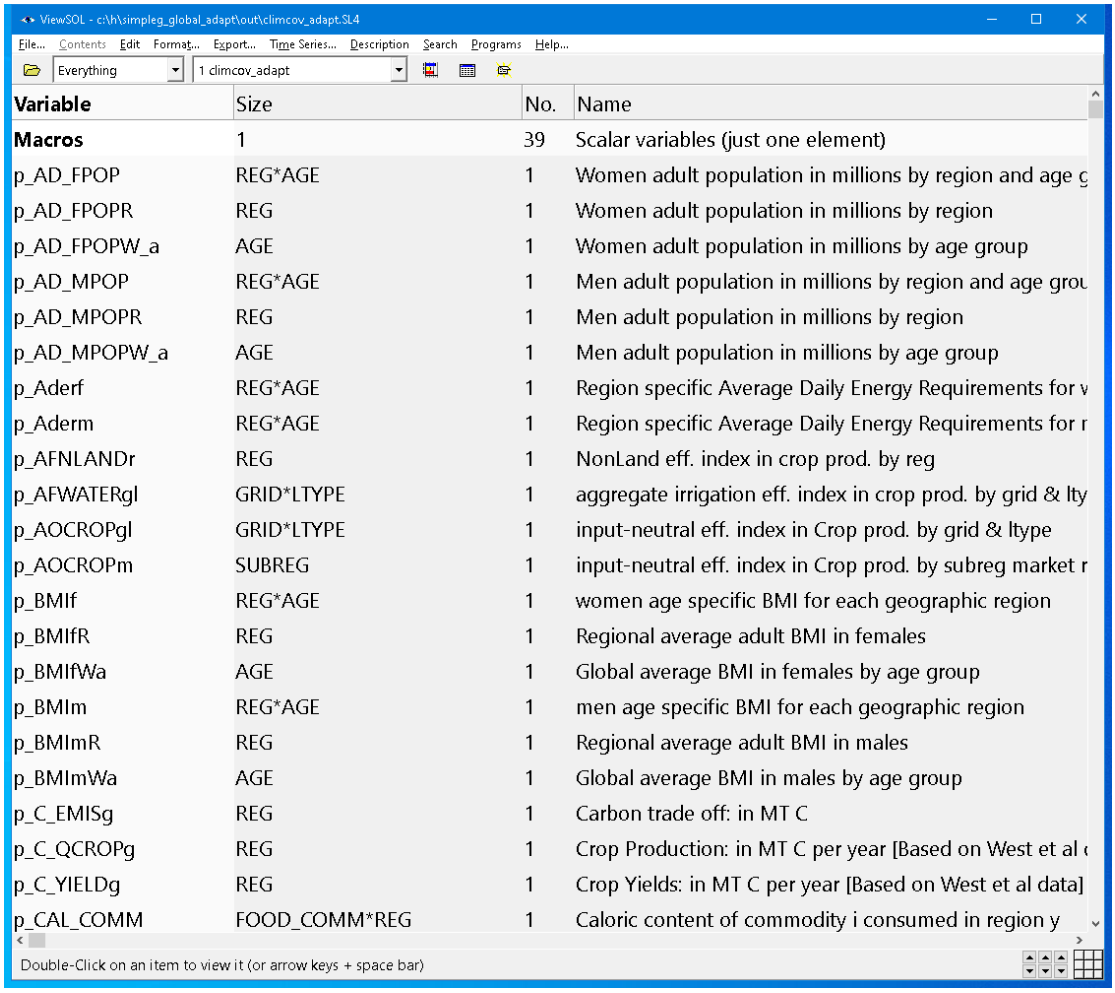


Figure 3. Screenshot of the home screen of the SL4 file in ViewSOL

5.2.1 A note on condensation

The SL4 file will not report the variables if they are substituted out in the condensation process. To report all the variables, the TAB file should be updated using "backsolve" command instead of "substitute".

5.2.2 A note on the coefficients

To see the value of coefficients defined in the model and calculated in the condensation process, users should report the "SLC" file. The options of the CMF file should change so that: `SLC file = yes;`

5.2.3 Simple plots and charts

Right-click on the column label will load "The Charter" for quick visual plots. The chart types are limited to lines, horizontal bar charts, vertical bar charts, and x-y scatter plots. This feature is helpful for quick comparison of variables.

5.3 The pandemic shock

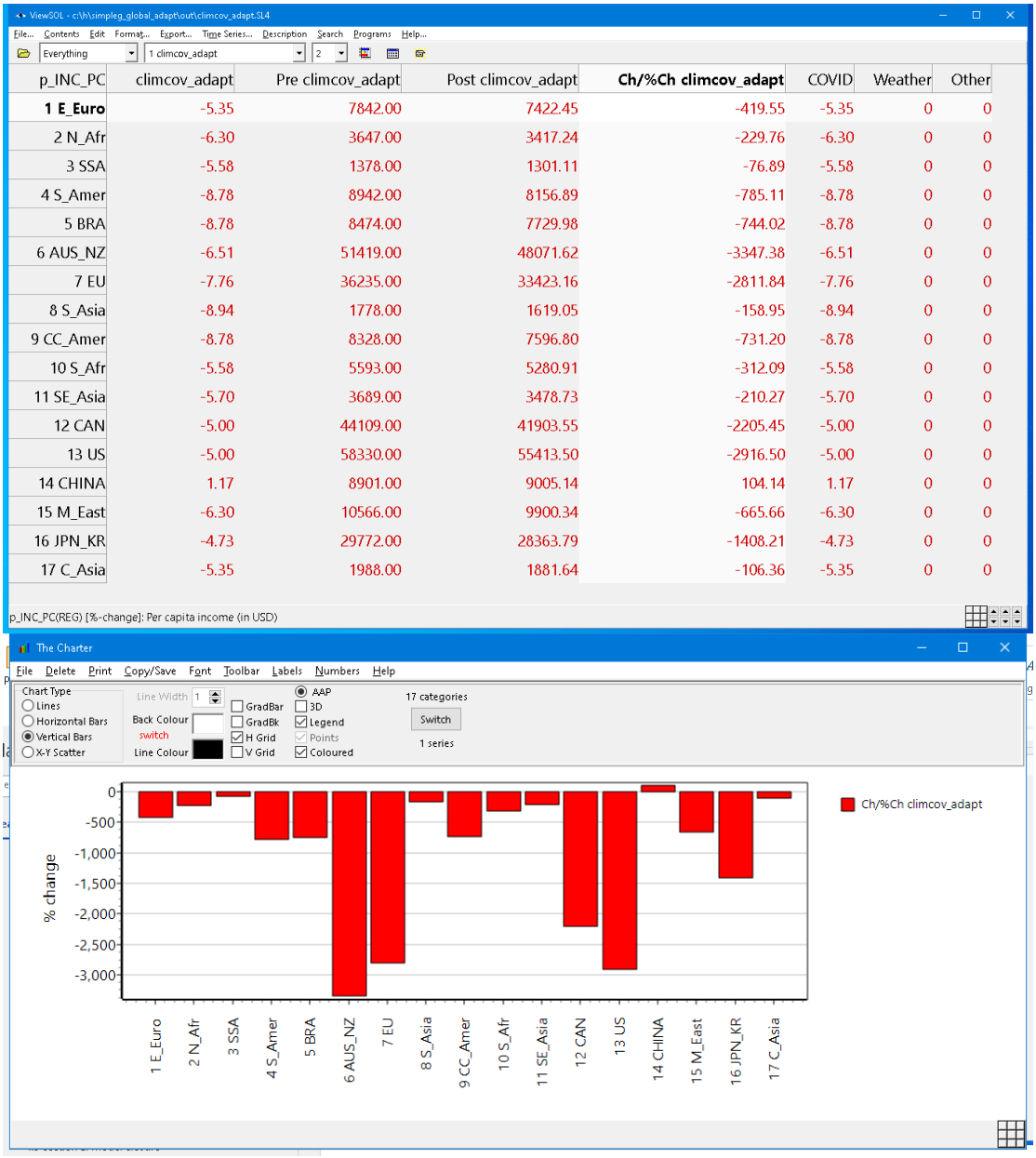
Pandemic shock includes a shock on income and productivity. Figure 4 shows the values related to per capita income. It includes multiple columns such as % change, pre-simulation values, post-simulation values, absolute change, the contribution of COVID to % change, the contribution of weather to % change, and the contribution of other changes in % change of per capita income. The color red for the values here means the variable was an exogenous variable.

5.3.1 Percentage change in income

This scenario shows that income declined by 5.35% in East Europe. It has increased in China by 1.17%. In South Asia the decline in per capita income was 8.94% due to the Covid19 according to the World Bank Reports.

5.3.2 Absolute change in per capita income

These percentage changes are equivalent to a decline of $419.55 a year in per capita income in East Europe and an increase of equivalent to $104.14 a year in China. Note that due to the large baseline income, the absolute changes are most significant in Australia, the European Union, and the United States, showing a decline of $3347.38, $2811.84, and $2916.50, respectively.

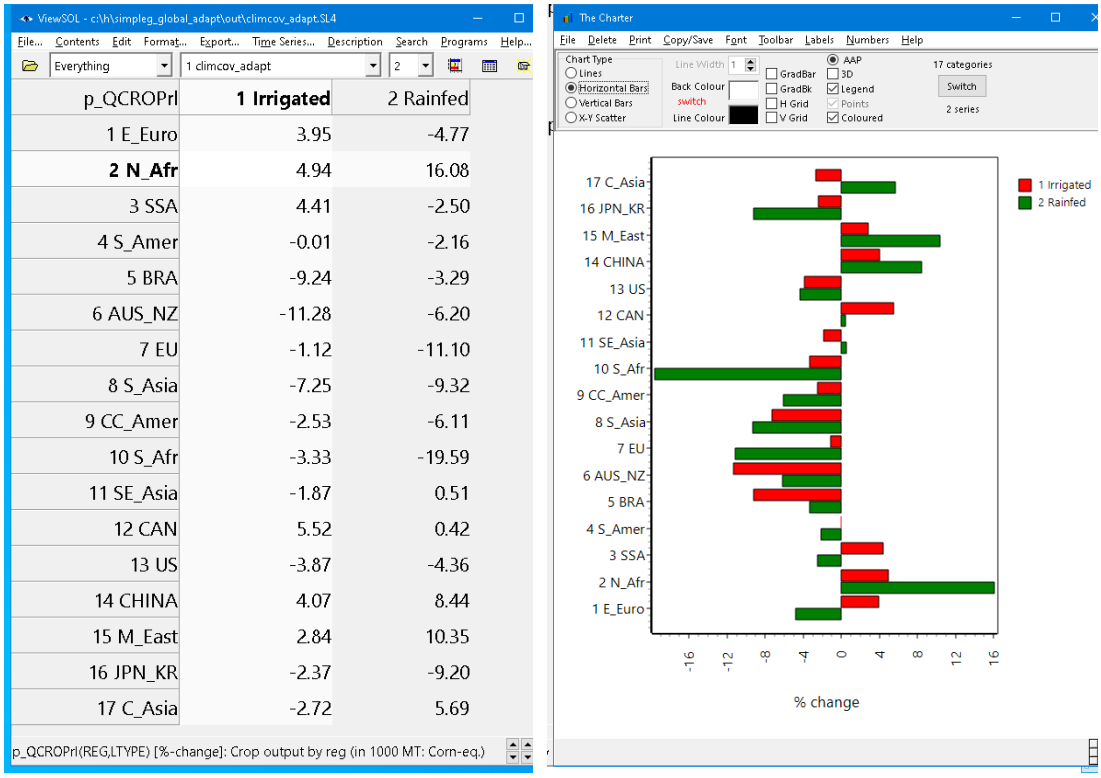


p_INC_PC	climcov_adapt	Pre climcov_adapt	Post climcov_adapt	Ch/%Ch climcov_adapt	COVID	Weather	Other
1 E_Euro	-5.35	7842.00	7422.45	-419.55	-5.35	0	0
2 N_Afr	-6.30	3647.00	3417.24	-229.76	-6.30	0	0
3 SSA	-5.58	1378.00	1301.11	-76.89	-5.58	0	0
4 S_Amer	-8.78	8942.00	8156.89	-785.11	-8.78	0	0
5 BRA	-8.78	8474.00	7729.98	-744.02	-8.78	0	0
6 AUS_NZ	-6.51	51419.00	48071.62	-3347.38	-6.51	0	0
7 EU	-7.76	36235.00	33423.16	-2811.84	-7.76	0	0
8 S_Asia	-8.94	1778.00	1619.05	-158.95	-8.94	0	0
9 CC_Amer	-8.78	8328.00	7596.80	-731.20	-8.78	0	0
10 S_Afr	-5.58	5593.00	5280.91	-312.09	-5.58	0	0
11 SE_Asia	-5.70	3689.00	3478.73	-210.27	-5.70	0	0
12 CAN	-5.00	44109.00	41903.55	-2205.45	-5.00	0	0
13 US	-5.00	58330.00	55413.50	-2916.50	-5.00	0	0
14 CHINA	1.17	8901.00	9005.14	104.14	1.17	0	0
15 M_East	-6.30	10566.00	9900.34	-665.66	-6.30	0	0
16 JPN_KR	-4.73	29772.00	28363.79	-1408.21	-4.73	0	0
17 C_Asia	-5.35	1988.00	1881.64	-106.36	-5.35	0	0

Figure 4. Changes in per capita income assumed in the climCov scenario

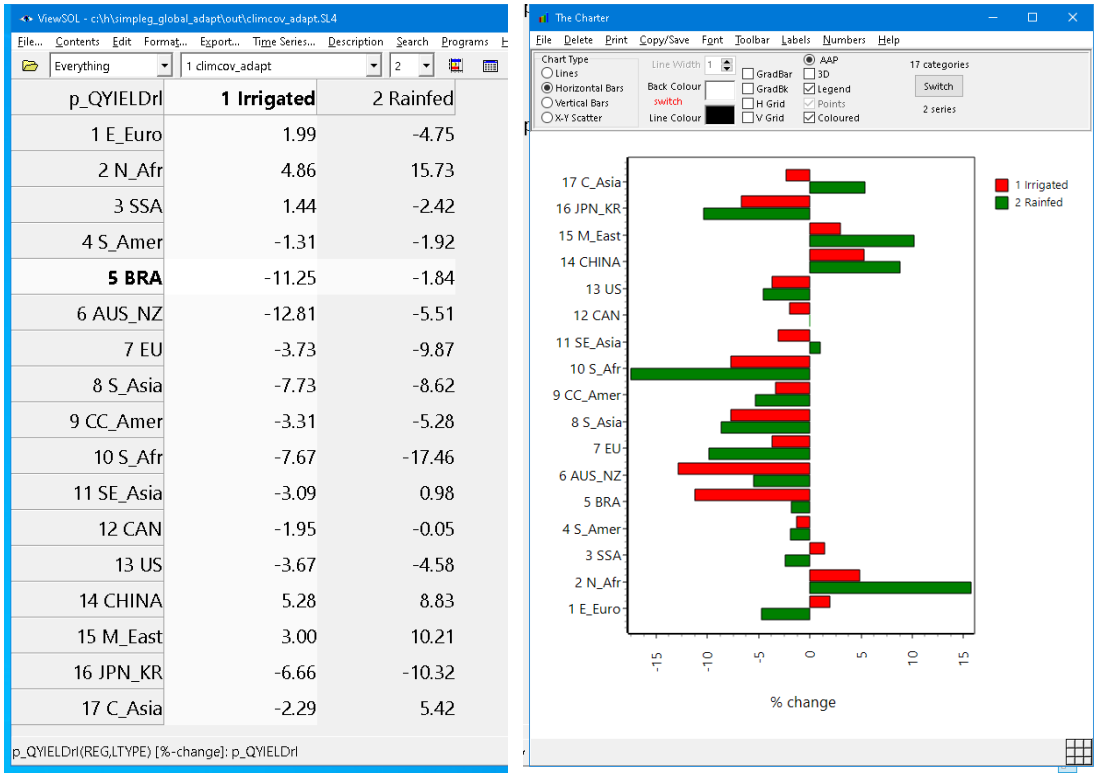
5.4 The impacts on crop production

Figures 5 and 6 show the results of the climCov scenario on % change in crop production (p_QCROPrl) and crop yield (p_QYIELDrl). For example, it shows that the climCov scenario will lead to a 3.95% increase in irrigated crop production and a 4.77% reduction in rainfed production in the East Europe region. In terms of yield, the crop yield increased by 1.99% for irrigated crops and declined by -4.75% for rainfed crops.



p_QCROPrl	1 Irrigated	2 Rainfed
1 E_Euro	3.95	-4.77
2 N_Afr	4.94	16.08
3 SSA	4.41	-2.50
4 S_Amer	-0.01	-2.16
5 BRA	-9.24	-3.29
6 AUS_NZ	-11.28	-6.20
7 EU	-1.12	-11.10
8 S_Asia	-7.25	-9.32
9 CC_Amer	-2.53	-6.11
10 S_Afr	-3.33	-19.59
11 SE_Asia	-1.87	0.51
12 CAN	5.52	0.42
13 US	-3.87	-4.36
14 CHINA	4.07	8.44
15 M_East	2.84	10.35
16 JPN_KR	-2.37	-9.20
17 C_Asia	-2.72	5.69

Figure 5. Changes in crop production



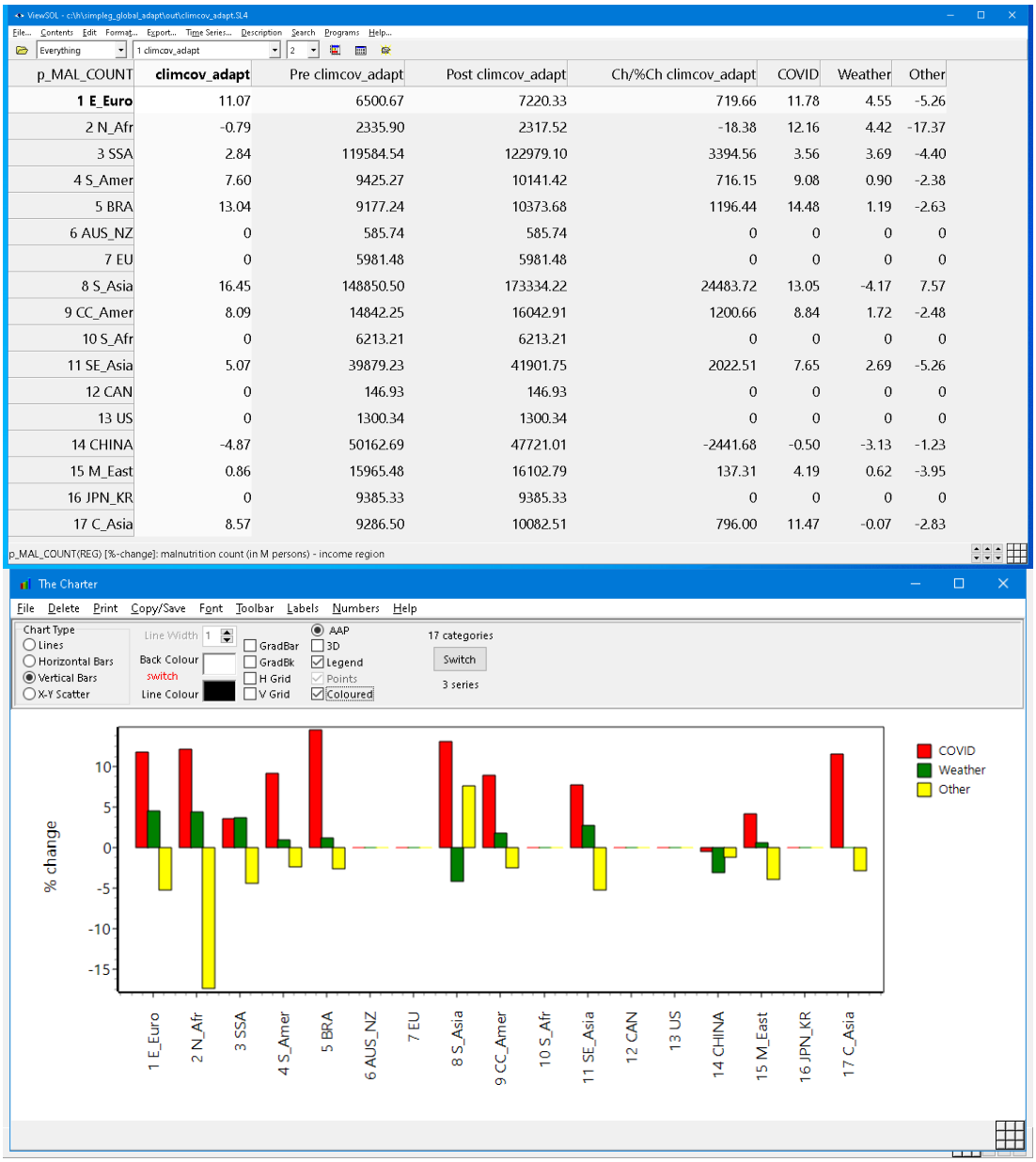
p_QYIELDrl	1 Irrigated	2 Rainfed
1 E_Euro	1.99	-4.75
2 N_Afr	4.86	15.73
3 SSA	1.44	-2.42
4 S_Amer	-1.31	-1.92
5 BRA	-11.25	-1.84
6 AUS_NZ	-12.81	-5.51
7 EU	-3.73	-9.87
8 S_Asia	-7.73	-8.62
9 CC_Amer	-3.31	-5.28
10 S_Afr	-7.67	-17.46
11 SE_Asia	-3.09	0.98
12 CAN	-1.95	-0.05
13 US	-3.67	-4.58
14 CHINA	5.28	8.83
15 M_East	3.00	10.21
16 JPN_KR	-6.66	-10.32
17 C_Asia	-2.29	5.42

Figure 6. Changes in crop yields

5.5 Changes in malnutrition

Figure 7 shows the results of the climCov scenario on malnutrition count (p_MAL_COUNT). This information was used to create Figures 17.3 and 17.4 of the

SIMPLE-G Book. Users can see the results of decomposition using the decomposition method in GEMPACK (Harrison et al., 2000). This is based on subtotal definitions on the CMF file.

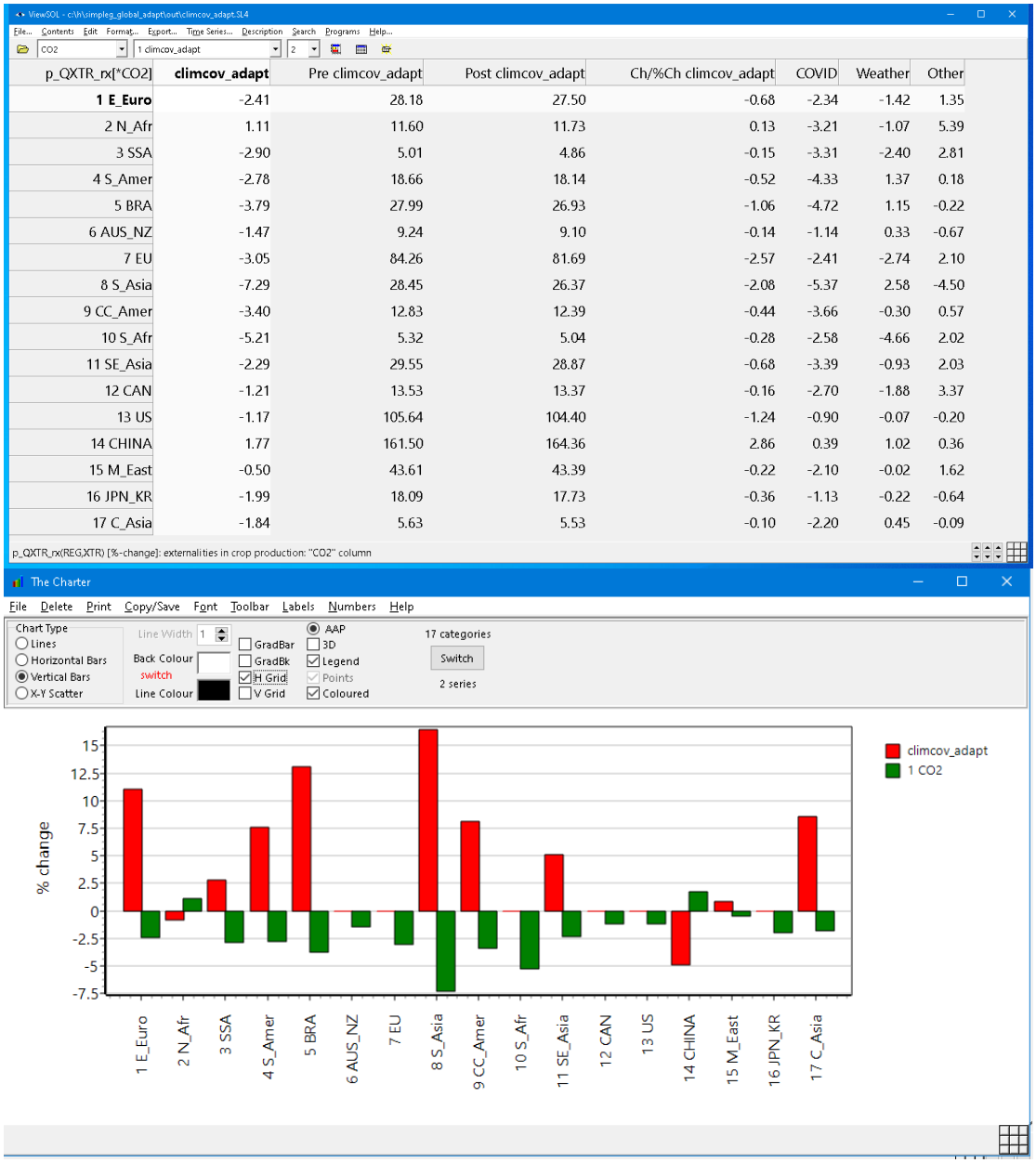


p_MAL_COUNT	climcov_adapt	Pre climcov_adapt	Post climcov_adapt	Ch/%Ch climcov_adapt	COVID	Weather	Other
1 E_Euro	11.07	6500.67	7220.33	719.66	11.78	4.55	-5.26
2 N_Afr	-0.79	2335.90	2317.52	-18.38	12.16	4.42	-17.37
3 SSA	2.84	119584.54	122979.10	3394.56	3.56	3.69	-4.40
4 S_Amer	7.60	9425.27	10141.42	716.15	9.08	0.90	-2.38
5 BRA	13.04	9177.24	10373.68	1196.44	14.48	1.19	-2.63
6 AUS_NZ	0	585.74	585.74	0	0	0	0
7 EU	0	5981.48	5981.48	0	0	0	0
8 S_Asia	16.45	148850.50	173334.22	24483.72	13.05	-4.17	7.57
9 CC_Amer	8.09	14842.25	16042.91	1200.66	8.84	1.72	-2.48
10 S_Afr	0	6213.21	6213.21	0	0	0	0
11 SE_Asia	5.07	39879.23	41901.75	2022.51	7.65	2.69	-5.26
12 CAN	0	146.93	146.93	0	0	0	0
13 US	0	1300.34	1300.34	0	0	0	0
14 CHINA	-4.87	50162.69	47721.01	-2441.68	-0.50	-3.13	-1.23
15 M_East	0.86	15965.48	16102.79	137.31	4.19	0.62	-3.95
16 JPN_KR	0	9385.33	9385.33	0	0	0	0
17 C_Asia	8.57	9286.50	10082.51	796.00	11.47	-0.07	-2.83

Figure 7. Changes in malnutrition count

5.6 Changes in GHG

Figure 8 shows the results of the climCov scenario on CO2 emissions. This information was used to create Figures 17.3 and 17.4 of the SIMPLE-G Book. Note that in the bar chart, the green colors are the % change in CO2 emissions from the food system, and the red colors are the % change in malnutrition count. Overall, undernourishment has increased for most regions while emissions have declined.



p_QXTR_rx[*CO2]	climcov_adapt	Pre climcov_adapt	Post climcov_adapt	Ch/%Ch climcov_adapt	COVID	Weather	Other
1 E_Euro	-2.41	28.18	27.50	-0.68	-2.34	-1.42	1.35
2 N_Afr	1.11	11.60	11.73	0.13	-3.21	-1.07	5.39
3 SSA	-2.90	5.01	4.86	-0.15	-3.31	-2.40	2.81
4 S_Amer	-2.78	18.66	18.14	-0.52	-4.33	1.37	0.18
5 BRA	-3.79	27.99	26.93	-1.06	-4.72	1.15	-0.22
6 AUS_NZ	-1.47	9.24	9.10	-0.14	-1.14	0.33	-0.67
7 EU	-3.05	84.26	81.69	-2.57	-2.41	-2.74	2.10
8 S_Asia	-7.29	28.45	26.37	-2.08	-5.37	2.58	-4.50
9 CC_Amer	-3.40	12.83	12.39	-0.44	-3.66	-0.30	0.57
10 S_Afr	-5.21	5.32	5.04	-0.28	-2.58	-4.66	2.02
11 SE_Asia	-2.29	29.55	28.87	-0.68	-3.39	-0.93	2.03
12 CAN	-1.21	13.53	13.37	-0.16	-2.70	-1.88	3.37
13 US	-1.17	105.64	104.40	-1.24	-0.90	-0.07	-0.20
14 CHINA	1.77	161.50	164.36	2.86	0.39	1.02	0.36
15 M_East	-0.50	43.61	43.39	-0.22	-2.10	-0.02	1.62
16 JPN_KR	-1.99	18.09	17.73	-0.36	-1.13	-0.22	-0.64
17 C_Asia	-1.84	5.63	5.53	-0.10	-2.20	0.45	-0.09

Figure 8. Changes in CO2 emissions

5.7 Changes in exports and imports

Figure 9 shows the impact on exports and imports. Here, p_QSCROPr("global") shows the exports, while p_QDCROPr(*, "global") shows imports by final use. The final users include direct crop consumption, use as feed in livestock production, or use as input in processed food production.

The results show that China's exports increased by 77.68%, and its imports declined by 40.31%, 34.62%, and 40.06% for direct consumption, feed, and processed food inputs, respectively.

% change in the supply of crops to local or global markets

ViewSOL - c:\h\simpleg_global_adapt\out\climcov_adapt.SL4

File... Contents Edit Format... Export... Time Series... Description Search Programs Help...

Everything | 1 climcov_adapt | 2

p_QSCROPr	1 local	2 global
1 E_Euro	-4.14	-5.49
2 N_Afr	3.22	60.25
3 SSA	-2.50	2.58
4 S_Amer	-3.03	0.52
5 BRA	-4.67	-6.62
6 AUS_NZ	-5.50	-10.76
7 EU	-6.56	-14.69
8 S_Asia	-7.87	-20.77
9 CC_Amer	-4.37	-6.07
10 S_Afr	-9.40	-18.49
11 SE_Asia	-1.70	14.68
12 CAN	-1.87	1.95
13 US	-3.08	-7.74
14 CHINA	4.42	77.68
15 M_East	2.01	37.17
16 JPN_KR	-5.60	-32.00
17 C_Asia	-1.46	10.65

p_QSCROPr(REG,MKT) [%-change]: regional crop supply and by source

% change in the demand for crop imports from international markets by use

ViewSOL - c:\h\simpleg_global_adapt\out\climcov_adapt.SL4

File... Contents Edit Format... Export... Time Series... Description Search Programs Help...

global | 1 climcov_adapt | 2

p_QDCROPr[**global]	1 Crops	2 Livestock	3 Proc_Food
1 E_Euro	-0.06	-9.54	-1.10
2 N_Afr	-33.58	-31.69	-34.79
3 SSA	-7.21	-13.93	-7.84
4 S_Amer	-3.30	-12.50	-5.46
5 BRA	0.35	-10.41	-2.12
6 AUS_NZ	3.91	-8.17	1.95
7 EU	6.56	-6.90	4.22
8 S_Asia	10.44	-3.49	7.14
9 CC_Amer	0.03	-10.41	-1.83
10 S_Afr	3.82	-7.57	3.34
11 SE_Asia	-14.12	-18.30	-15.49
12 CAN	-0.60	-10.36	-2.08
13 US	3.27	-8.10	1.63
14 CHINA	-40.31	-34.62	-40.06
15 M_East	-23.83	-24.60	-25.24
16 JPN_KR	37.40	9.97	35.22
17 C_Asia	-11.62	-16.50	-12.40

p_QDCROPr(*,*,global) [%-change]: regional crop demand by use and by source

Figure 9. Changes in exports and imports due to the climCov scenario

5.8 Decomposing the drivers of change in exports

Figure 9 shows the decomposition of the drivers of change in exports from pandemic, weather, or other changes. This shows that weather impact is a more prominent contributor to change and volatility in exports.

ViewSOL - c:\h\simpleg_global_adapt\out\climcov_adapt.SL4

File... Contents Edit Format... Export... Time Series... Description Search Programs Help...

global | 1 climcov_adapt | 2

p_QSCROPr[*global]	climcov_adapt	Pre climcov_adapt	Post climcov_adapt	Ch/%Ch climcov_adapt	COVID	Weather	Other
1 E_Euro	-5.49	147515.80	139418.47	-8097.33	-2.49	-11.24	8.24
2 N_Afr	60.25	24381.98	39073.18	14691.20	8.56	-1.17	52.76
3 SSA	2.58	81514.38	83620.66	2106.27	-1.96	-42.59	47.13
4 S_Amer	0.52	183955.50	184909.94	954.44	-8.01	13.81	-5.28
5 BRA	-6.62	261957.08	244623.58	-17333.50	-11.43	12.46	-7.64
6 AUS_NZ	-10.76	74533.95	66514.58	-8019.38	-5.30	6.48	-11.95
7 EU	-14.69	447830.75	382024.41	-65806.34	-7.85	-20.24	13.40
8 S_Asia	-20.77	88284.36	69948.84	-18335.52	-0.62	31.06	-51.21
9 CC_Amer	-6.07	149363.81	140299.28	-9064.53	-6.56	1.18	-0.69
10 S_Afr	-18.49	37946.78	30931.11	-7015.68	-1.49	-25.03	8.04
11 SE_Asia	14.68	134123.03	153814.58	19691.55	3.86	-1.51	12.33
12 CAN	1.95	109800.76	111944.42	2143.66	-3.99	-5.91	11.85
13 US	-7.74	420501.59	387941.03	-32560.56	-2.28	2.10	-7.56
14 CHINA	77.68	45818.94	81409.77	35590.82	44.53	47.51	-14.36
15 M_East	37.17	49169.60	67445.88	18276.27	1.23	10.07	25.85
16 JPN_KR	-32.00	3415.14	2322.18	-1092.96	4.48	2.20	-38.68
17 C_Asia	10.65	13219.60	14628.00	1408.40	5.64	17.37	-12.35

p_QSCROPr(REG,MKT) [%-change]: regional crop supply and by source: "global" column

Figure 10. Drivers of change in exports

5.9 Changes in prices by region

Figure 11 shows changes in food prices by category due to the climCov scenario, highlighting the most significant % change in price increase in Japan and South Korea.

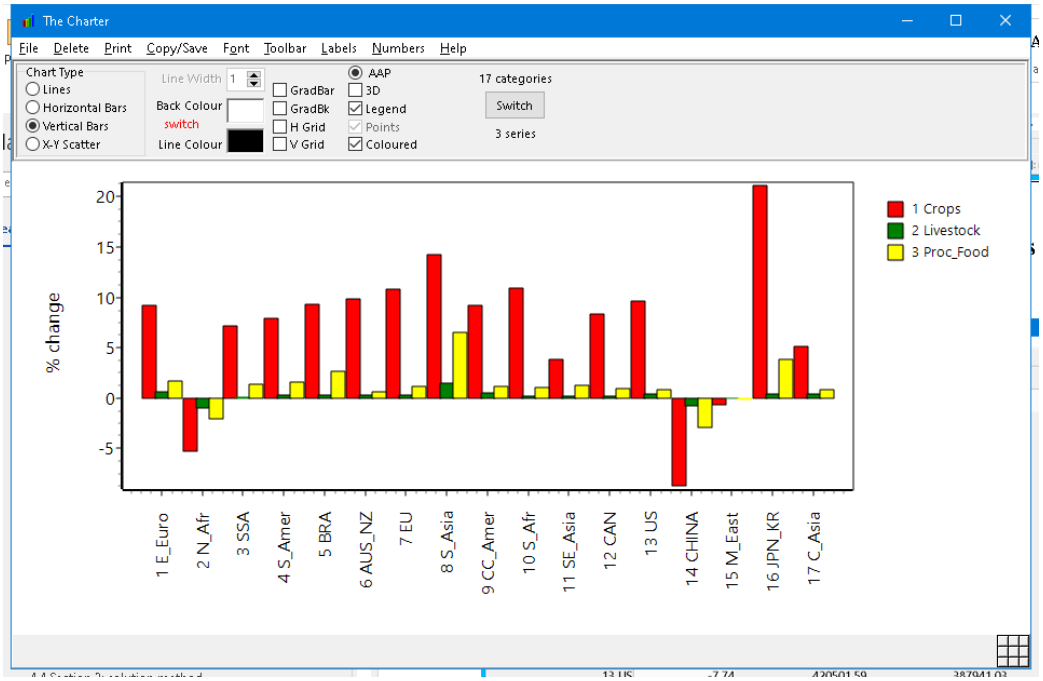


Figure 11. Changes in prices (p_P) due to the climCov scenario

5.10 Changes in per capita consumption

Figure 12 shows the resulting % changes in consumption of commodities due to the climCov scenario. This shows a higher reduction in non-food consumption as they are more sensitive to income changes. The increase in crop consumption despite the reduction in income is associated with the changes in diet and food basket.

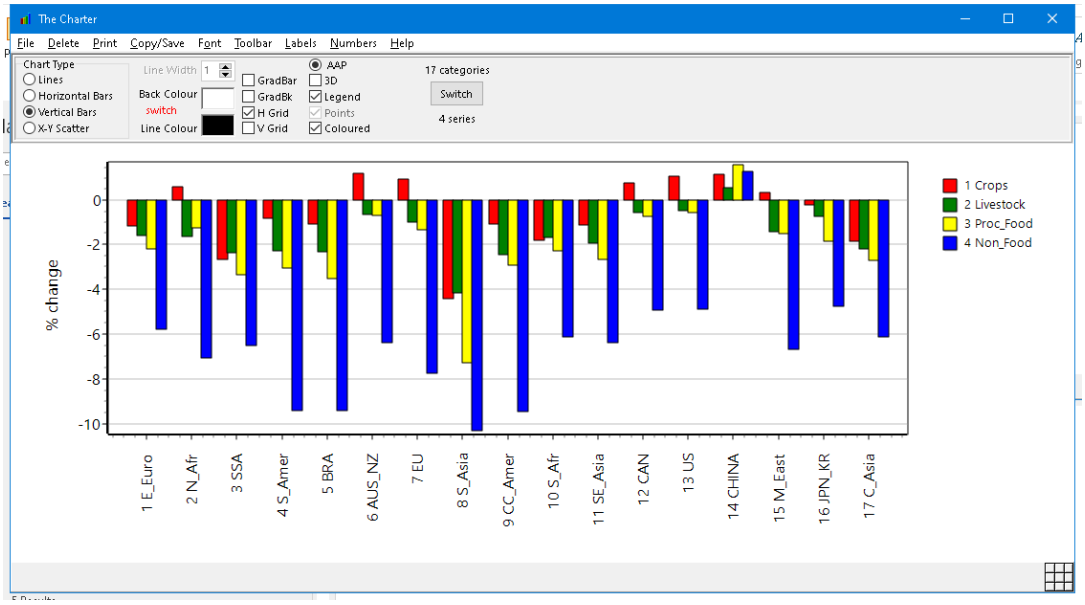


Figure 12. Changes in consumption (p_QCONS) due to the climCov scenario

5.11 Body Mass Index by age and gender

The food security module provides information about the impacts of scenarios on different metrics by age and gender. Figure 13 shows the BMI by age groups. Note that the label on the vertical axis is generated automatically, the actual unit of the axis is BMI for this figure here.

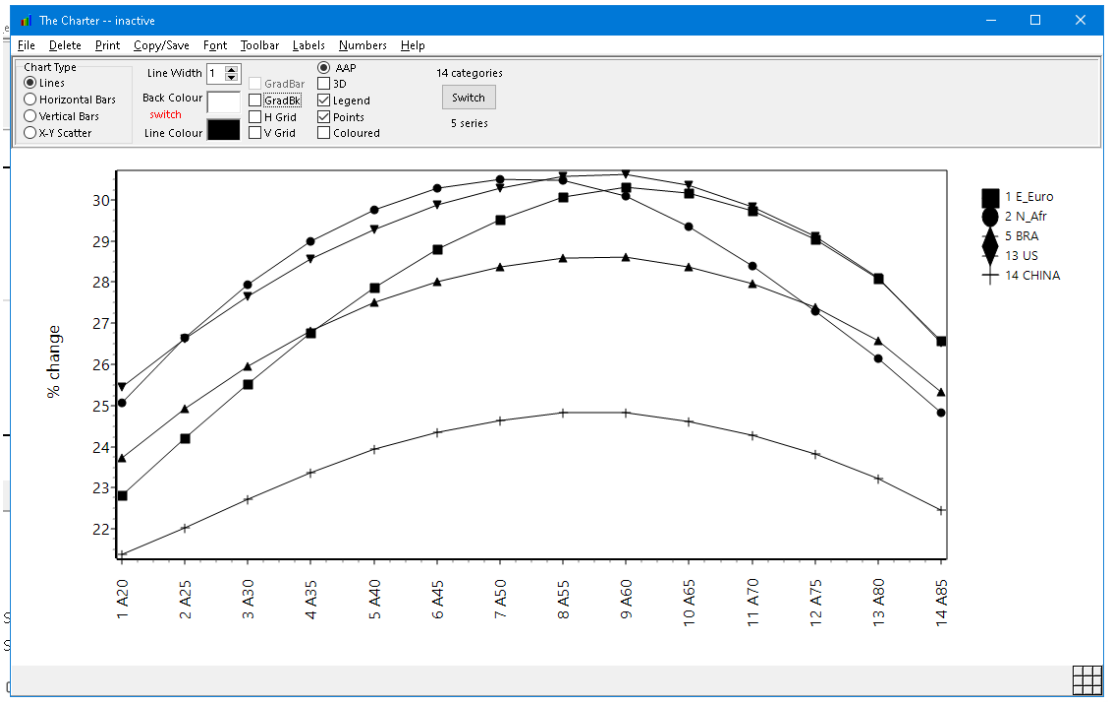


Figure 13. BMI by age (A20-A85) for selected regions

6 Conclusions

This document described the model and databases related to the SIMPLE-G-Global model for the 2017 reference year, incorporating food security and emission modules. This is a global gridded economic model of water and land use, designed for "what-if" policy analysis or evaluating the impacts of environmental and climate shocks. Modified SIMPLE-G models, which exclude market price effects, were also introduced. The information provided encompasses the data files, command files, model codes, and solution files necessary for users to effectively utilize the model. By enabling users to run global change scenarios at the grid cell level, this document facilitates a detailed analysis of complex interactions between water and land use and their implications for food security and greenhouse gas emissions.

This manuscript serves as a valuable resource for researchers seeking to leverage the SIMPLE-G model in their assessments. With its structured file organization and instructions, users can confidently explore various scenarios, contributing to informed decision-making in the context of global environmental challenges. The current model can provide insights into equity concerns as it provides the impacts on food security metrics by gender, age, and region, considering food demand. However, future research requires a comprehensive labor module to provide a more accurate picture of labor

wages and employment (Ray et al., 2023).

Comparing adaptation and no-adaptation scenarios provides essential insights into the value of adaptation channels in buffering the impacts of climate change and pandemics. Previous studies have evaluated the significance of individual adaptation channels (Haqiqi et al., 2022). The likely channels are groundwater substitution, irrigation conversion, relocation, and international trade. This study introduces a more extreme approach by removing all the market prices from the model. This approach generated demand-pull and supply-push models with linear quantity relationships.

In addition, the analysis was based on preliminary versions of food security module with a focus on caloric content of the food. incorporating other important dimensions of malnutrition is important for providing a comprehensive health impact assessments and policy recommendations.

The SIMPLE-G team is continuously working on developing new models and enhancing the existing models and datasets with innovative tools for computation and visualization. This ongoing effort is integral to the Global-to-Local-to-Global framework, which underscores the significance of market-mediated effects on sustainability and food security—an aspect often overlooked in global studies. By incorporating these dynamics, the SIMPLE-G model not only offers a more accurate understanding of local conditions but also facilitates more effective policy interventions. Advanced research and refined methodologies will provide robust analytical capabilities that empower users to address the pressing challenges of our time.

7 Reference

Aguiar, A., Chepeliev, M., Corong, E., Van Der Mensbrugghe, D., 2022. The Global Trade Analysis Project (GTAP) Data Base: Version 11. JGEA 7, 1–37. https://doi.org/10.21642/JGEA.070201AF

Baldos, U.L.C., Haqiqi, I., Hertel, T.W., Horridge, M., Liu, J., 2020. SIMPLE-G: A multiscale framework for integration of economic and biophysical determinants of sustainability. Environmental Modelling & Software 133, 104805. https://doi.org/10.1016/j.envsoft.2020.104805

Baldos, U.L.C., Hertel, T.W., 2014. Global food security in 2050: the role of agricultural productivity and climate change. Australian Journal of Agricultural and Resource Economics 58, 554–570. https://doi.org/10.1111/1467-8489.12048

Haqiqi, I., 2025. SIMPLE-G Model Specification: Mathematical Equations in a Multiscale Market Equilibrium Model, in: Haqiqi, I., Hertel, T.W. (Eds.), SIMPLE-G. Springer Nature Switzerland, Cham, pp. 51–79. https://doi.org/10.1007/978-3-031-68054-0_5

Haqiqi, I., Grogan, D.S., Bahalou Horeh, M., Liu, J., Baldos, U.L.C., Lammers, R., Hertel, T.W., 2023. Local, regional, and global adaptations to a compound pandemic-weather stress event. Environ. Res. Lett. 18, 035005. https://doi.org/10.1088/1748-9326/acbbe3

Haqiqi, I., Hertel, T.W. (Eds.), 2024. SIMPLE-G: A Gridded Economic Approach to Sustainability Analysis of the Earth's Land and Water Resources, 2025th

edition. ed. Springer.
Haqiqi, I., Perry, C.J., Hertel, T.W., 2022. When the virtual water runs out: local and global responses to addressing unsustainable groundwater consumption. Water International 47, 1060–1084. https://doi.org/10.1080/02508060.2023.2131272
Harrison, W.J., Horridge, J.M., Pearson, K.R., 2000. Decomposing Simulation Results with Respect to Exogenous Shocks. Computational Economics, Computational Economics 15, 227–249. https://doi.org/10.1023/A:1008739609685
Hertel, T.W., Baldos, U.L.C., 2016. Global Change and the Challenges of Sustainably Feeding a Growing Planet. Springer International Publishing, New York.
Horridge, J.M., Jerie, M., Mustakinov, D., Schiffmann, F., 2018. GEMPACK manual. Victoria University, Centre of Policy Studies/IMPACT Centre.
Ivanic, M., 2023. GEMPACK simulations in R: Ademonstration of running the GTAP modeland processing its results entirely in R using packages HARr and tabloToR. JGEA 8, 1–20. https://doi.org/10.21642/JGEA.080101AF
Liu, J., Hertel, T.W., Lammers, R.B., Prusevich, A., Baldos, U.L.C., Grogan, D.S., Frolking, S., 2017. Achieving sustainable irrigation water withdrawals: global impacts on food security and land use. Environ. Res. Lett. 12, 104009. https://doi.org/10.1088/1748-9326/aa88db
Ray, S., Haqiqi, I., Hill, A.E., Taylor, J.E., Hertel, T.W., 2023. Labor markets: A critical link between global-local shocks and their impact on agriculture. Environmental Research Letters 18, 035007. https://doi.org/10.1088/1748-9326/acb1c9