

AIM-ALPHA documentation

Agricultural Land-use Partial Equilibrium Model

Ryo Totake, Hiroki Yoshida, Tomoko Hasegawa, Shinichiro Fujimori
Kyoto University

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Abstract

This document describes the model structure and system of equations for AIM-ALPHA. AIM-ALPHA is a one-year step sequential dynamic partial equilibrium model targeting agricultural markets and land use. It performs future projections considering 166 countries on the demand side, 400 production units on the supply side, 23 food commodities, and 5 land use categories. This model is anticipated to be applicable to research including analyses of food security issues, climate change impacts, evaluations of climate change mitigation measures, and assessments of biodiversity impacts related to land use.

Keywords: Integrated assessment model, partial equilibrium, agricultural markets, land use, climate change mitigation

Authors: Ryo Totake, Hiroki Yoshida, Tomoko Hasegawa, Shinichiro Fujimori

Affiliation: Kyoto University

Contact: totake.ryo.85s@st.kyoto-u.ac.jp

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1 Introduction

1.1 About this document

This document describes the model structure and system of equations of AIM-ALPHA (the Asia-Pacific Integrated Model - Agricultural Land-use Partial equilibrium model for Harmonized Analysis), a partial equilibrium model for agriculture and land use. The document is organized as follows:

- 1) Model Structure
- 2) System of Equations
- 3) Data Processing
- 4) Parameter Estimation
- 5) Model Calculation Flow and Execution Method

1.2 Background

Future projections of agriculture and land use play an essential role in understanding global sustainability challenges. Increasing food demand, dietary shifts, and the growing use of bioenergy are intensifying pressures on land resources, while agriculture and land-use activities remain major sources of greenhouse gas (GHG) emissions and biodiversity loss. At the same time, these sectors are highly vulnerable to climate change through altered temperature and precipitation patterns that affect crop yields and food availability. Consequently, designing sustainable pathways for agriculture and land management requires an integrated understanding of the interactions among socioeconomic drivers, land-use dynamics, and environmental outcomes.

Model-based approaches provide a powerful framework for exploring such interlinked systems. A variety of global and regional models have been developed to evaluate the implications of alternative socioeconomic and climate scenarios for food security, mitigation, and ecosystem conservation. However, many existing models operate at aggregated regional scales and provide limited representation of country-specific agricultural systems, land-use competition, and trade linkages. This limits their applicability for detailed policy analysis or assessment of subnational dynamics.

To address these limitations, the AIM-ALPHA model has been developed as a high-resolution partial equilibrium model covering the agriculture and land-use sectors at national and subnational levels. The model is designed to complement the broader AIM (Asia-Pacific Integrated Model) framework by offering

a detailed, bottom-up representation of agricultural markets, land-use allocation, and environmental interactions.

This formulation document provides a comprehensive description of the model structure, mathematical formulation, and computational framework of AIM-ALPHA. It aims to enhance transparency and reproducibility of the model's analytical components, facilitate linkage with other models in the AIM framework, and support further applications in global and national assessments of sustainable land-use transitions.

2 Model Structure

This section provides an overview of the AIM-ALPHA model. AIM-ALPHA is a recursive-dynamic partial equilibrium model focusing on agricultural markets and land use, operating with an annual time step. The model uses 2015 as the base year and projects up to 2100. It is formulated as a nonlinear complementarity problem (NCP) and handles approximately 200,000 variables.

On the spatial dimension, the demand side covers 166 countries and regions globally, while the production side consists of 400 production units. These production units are defined by overlaying the 166 demand regions with FAO's 230 major river basin boundaries. Figure 2 illustrates the geographical coverage of the demand regions and production units.

The basic model structure is shown in Figure 1. Food production is categorized into 13 primary crops, 6 livestock products, and 4 processed goods. Table 1 lists the food commodity classifications used in the model. The production functions are represented by Leontief-type functions, where each good is produced by combining cropland, feed and pasture, and raw materials as inputs. Other factors such as labor, capital, and energy are aggregated into a single production factor.

Primary crops and livestock products that require land are differentiated by production unit, whereas processed goods, which do not require land inputs, are modeled at the level of the 166 demand regions. Land use within each production unit is allocated according to a hierarchical logit function that balances total land area, and land shares are determined by relative land prices.

Food demand is driven by population and GDP, with income elasticity considered for future changes. Food prices are determined endogenously so that supply and demand are balanced in the domestic market. Within each country, the balance between production, domestic demand, and net trade (imports minus exports) is maintained. In the global market, total world imports and exports are also balanced. Furthermore, commodities that were not produced or traded in the base year are assumed to remain inactive in that country or production unit throughout the projection period.

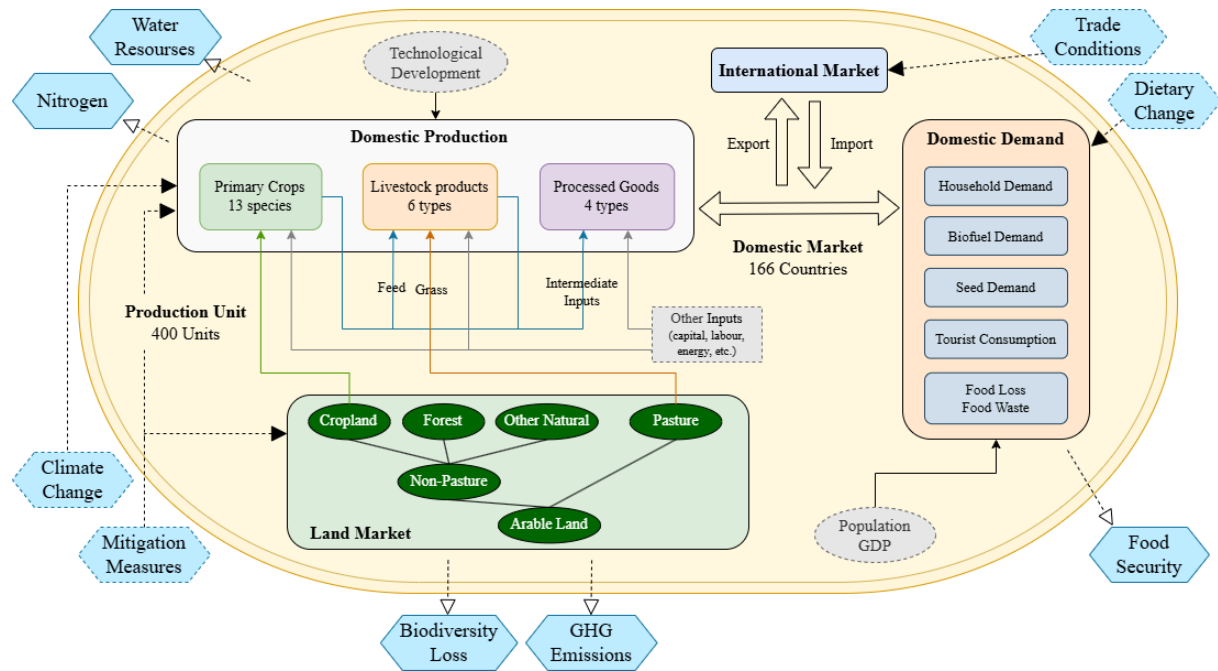


Figure 1: Overview of AIM-ALPHA

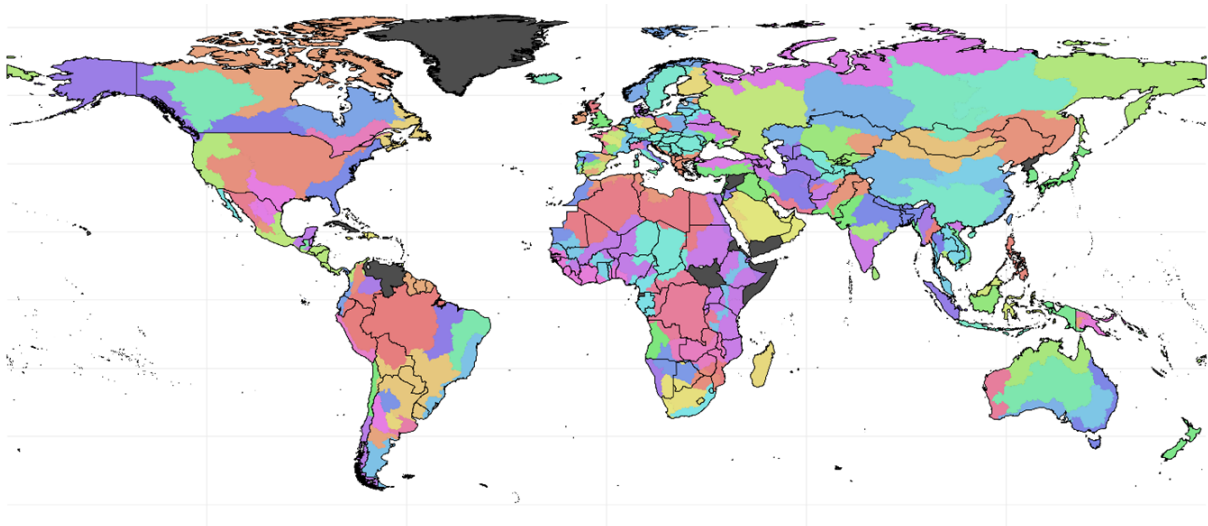


Figure 2: Geographical coverage of demand regions (166) and production units (400).

Table 1: Classification of food commodities

Category	Commodity	Model code
Primary crops	Wheat	wht
	Rice	rce
	Maize	mze
	Other cereals	crl
	Roots and tubers	str
	Sugar crops	sgr
	Pulses	pls
	Nuts	nut
	Oil crops	ocr
	Vegetables	vgt
	Fruits	frt
	Stimulant crops	stm
	Spices	spc
Livestock products	Beef	cmt
	Sheep and goat meat	rmt
	Poultry meat	pmt
	Other meat	omt
	Eggs	egg
	Milk	mlk
Processed products	Sugar products	swt
	Vegetable oils	vol
	Alcoholic beverages	alc
	Dairy products	dai

3 Variables and Parameters

This section describes the variables and parameters used in the model.

3.1 Indices

Table 2 lists the indices used in the model.

Table 2: List of indices

Index	Description	Dimension	Notes
cty	Country / region	166	
bas	River basin	400	
region	Macro region	17	Same as the regional classification in AIM-Hub
c(a)	Food commodities (production activities)	23	See Table 1
acro	Primary crops	13	
aliv	Livestock products	6	
apro	Processed products	4	
cfeed	Feed inputs	10	
cint	Intermediate inputs	8	
cbio	Biofuel crops	3	
water	Crop production technology	2	Irrigated / rainfed
cz	Climate zone	4	Tropical, temperate, arid, hyper-arid
sys	Livestock production system	2	Pasture-based, mixed farming
src	GHG emission sources	13	Enteric fermentation, manure management, rice cultivation, synthetic fertilizer application, organic fertilizer application, manure on pasture, cultivation of organic soils, crop residues, crop residue burning, grassland burning, forests, natural wildfires, deforestation
gas	Gas species	3	CO ₂ , CH ₄ , N ₂ O

3.2 Endogenous Variables

Table 3 lists the endogenous variables used in the model.

Table 3: List of endogenous variables

Variable	Description	Unit
QDEM	Domestic demand	1000t
QH	Household consumption demand	1000t
QF	Feed demand	1000t
QI	Intermediate input demand for processed goods	1000t
QBIO	Biofuel demand	1000t
QSEED	Seed demand	1000t
QTOUR	Tourist consumption demand	1000t
QLOSS	Food loss amount	1000t
QWASTE	Food waste amount	1000t
QOTH	Other demand	1000t
QFEED	Feed input	1000t
QINT	Raw material input	1000t
QSUP	Domestic production	1000t
QS	Production by river basin	1000t
QSWAT	Crop production by technology	1000t
QSSYS	Livestock production by system	1000t
QM	Imports	1000t
QE	Exports	1000t
NT	Net trade	1000t
PP	Producer price	\$/t
PC	Consumer price	\$/t
PB	Border price	\$/t
PM	Import price	\$/t
PE	Export price	\$/t
PW	World price	\$/t
YLD	Crop yield	t/ha
SYSSHARE	Livestock system share	-
QGRASS	Grass utilization	1000t
ANIMALYLD	Livestock yield per hectare	t/ha
ICL	Feed input coefficient	t/t
ANIMAL	Number of livestock	1000 head
PO	Price of other production factors	\$/t
QLVEG	Vegetation area	1000ha
QLPAS	Pasture area	1000ha
QLPASN	Non-pasture grassland area	1000ha

Continued on next page

Table 3: List of endogenous variables (continued)

Variable	Description	Unit
QLCRO	Cropland area	1000ha
QLFRS	Forest area	1000ha
QLGRA	Other natural land area	1000ha
QLCROCLT	Harvested cropland area	1000ha
QLCROFAL	Fallow cropland area	1000ha
QL	Total production area	1000ha
PLPAS	Pasture land price	\$/ha
PLPASN	Non-pasture land price	\$/ha
PLCRO	Cropland price	\$/ha
PLCROCLT	Harvested cropland price	\$/ha
PL	Land price	\$/ha
PENE	Energy crop land price	\$/ha
GHG	GHG emissions from agriculture sector	ktCO ₂ -eq/yr
GHGLU	GHG emissions from land-use sector	ktCO ₂ -eq/yr
RR	Emission reduction rate	-
AC	Abatement cost	\$/t
PCB	Carbon price on residual emissions	\$/t
PPCOMP	Complementary variable for production	-
TMCOMP	Complementary variable for imports	-
PLCOMP	Complementary variable for land price	-

3.3 Exogenous Variables

Table 4 lists the exogenous variables used in the model.

Table 4: List of exogenous variables

Variable	Description	Data Source
QHBASE	Household consumption demand in the base year	FAOSTAT
QBIOBASE	Biofuel demand in the base year	FAOSTAT
QSEEDBASE	Seed demand in the base year	FAOSTAT
QTOURBASE	Tourist consumption demand in the base year	FAOSTAT
QLOSSBASE	Food loss in the base year	FAOSTAT
QOTHBASE	Other demand in the base year	FAOSTAT
QSUPPRE	Domestic production in the previous year	FAOSTAT
QSPRE	Production by river basin in the previous year	GAEZ v4
QENE	Demand for dedicated energy crops	AIM-Hub

Continued on next page

Table 4: List of exogenous variables (continued)

Variable	Description	Data Source
QST	Change in stock	FAOSTAT
QRES	Residual of international trade balance	FAOSTAT
LOSSRATE	Food loss rate	FAOSTAT
WASTERATE	Food waste rate	FAO (2011)
GDPPC	GDP per capita	SSP 3.0
GDPPCBASE	GDP per capita in the base year	World Bank
POP	Population	SSP 3.0
POPBASE	Population in the base year	World Bank
MMJ	Market margin	GTAP 10
PSE	Producer Support Estimate (PSE)	GTAP 10
CSE	Consumer Support Estimate (CSE)	GTAP 10
CSEBASE	CSE in the base year	GTAP 10
TM	Import tariff rate	GTAP 10
MMM	Import margin rate	GTAP 10
TE	Export tariff rate	GTAP 10
MME	Export margin rate	GTAP 10
YLDBASE	Crop yield in the base year	FAOSTAT, GAEZ v4
YLDGR	Yield change rate due to technological progress	IMPACT
YLDCHAN	Yield change rate due to climate change impacts	GAEZ v4
CROPINTENSITY	Cropping intensity	MAPSPAM
GRASSYLD	Grass yield	GAEZ v4
ANIMALPRODRATE	Slaughtering / milking rate	FAOSTAT
FEDEFFICIENCY	Feed conversion efficiency	Herrero & Acosta et al. (2018)
FEEDSHARE	Share of concentrate feed	Herrero & Acosta et al. (2018)
GRAINSHARE	Share of grain feed	FAOSTAT
ANIMALWEIGHT	Livestock body weight	FAOSTAT
ANIMALRES	Number of non-productive livestock	FAOSTAT
QLRES	Pasture area not used for livestock production	FAOSTAT, LUH2
POBASE	Price of other production factors in the base year	FAOSTAT, GTAP 10
QLTOT	Total land area	LUH2
QLVEGN	Non-vegetated land area	LUH2
QLAFR	Afforested area	AIM-PLUM
PLFRS	Forest land price	LUH2, GTAP 10
PLGRA	Price of other natural land	LUH2, GTAP 10
PLCROFAL	Fallow land price	LUH2, GTAP 10
EF	GHG emission factor in agriculture sector	FAOSTAT
EFLU	GHG emission factor in land-use sector	FAOSTAT
PRCCAR	Carbon price	AIM-Hub

Continued on next page

Table 4: List of exogenous variables (continued)

Variable	Description	Data Source
MRP	Maximum reduction potential of abatement technologies	Harmsen et al. (2019)

3.4 Parameters

Table 5 lists the parameters used in the model.

Table 5: List of parameters

Parameter	Description	Notes
elhg	Income elasticity of consumption	Estimated from the food demand model
elhp	Price elasticity of consumption	Estimated by regression based on Muhammad et al. (2011)
ica	Intermediate input coefficient	
elop	Elasticity of other production factors	
δ	Coefficient parameter of the logit function	
ρ	Exponent parameter of the logit function	For land use, adopted from GCAM; for production systems, estimated by regression based on Herrero Acosta et al. (2018)
res	Residual parameter	
watshare	Share of primary-crop production technologies	
czshare	Climate zone share	
grassusagerate	Grass (pasture) utilization rate	
pintcoef	Price coefficient for intermediate inputs	
pfeedcoef	Price coefficient for feed inputs	
pbres	Residual between consumer price and border price	
pmres	Residual between import price and world price	
peres	Residual between export price and world price	
exr	Exchange rate	
σ	Elasticity of adoption of abatement technologies	Estimated by regression based on Harmsen et al. (2019)

4 System of Equations

This section presents the mathematical formulation of the model and its explanation. In the following, **endogenous variables** are denoted by uppercase letters, **exogenous variables** by uppercase letters with an overline, and **parameters** by lowercase or Greek letters.

4.1 Demand Block

This block describes the equations related to demand determination. In the demand block, food demand is determined by factors such as prices, population, and GDP.

Total Demand

$$QDEM_{c,cty} = QH_{c,cty} + QF_{c,cty} + QI_{c,cty} + QBIO_{c,cty} + QSEED_{c,cty} + QTOUR_{c,cty} + QLOSS_{c,cty} + QWASTE_{c,cty} + QOTH_{c,cty} \quad (QDEMEQ)$$

Household Consumption Demand

$$QH_{c,cty} = \overline{QHBASE}_{c,cty} \cdot \left(\frac{\overline{GDPPC}_{cty}}{\overline{GDPPCBASE}_{cty}} \right)^{elhgc,cty} \cdot \prod_{cc} \left(\frac{(1 - \overline{CSE}_{cc,cty}) \cdot PC_{cc,cty}}{(1 - \overline{CSEBASE}_{cc,cty}) \cdot \overline{PCBASE}_{cc,cty}} \right)^{elhpc,cc,cty} \cdot \frac{\overline{POP}_{cty}}{\overline{POPBASE}_{cty}} \quad (QHEQ)$$

Feed Demand

$$QF_{cfeed,cty} = \sum_{bas} \sum_{aliv} QFEED_{aliv,cfeed,cty} \quad (QFEEDEQ)$$

Intermediate Input Demand for Processing

$$QI_{cint,cty} = \sum_{apro} QINT_{apro,cint,bas,cty} \quad (QINTEQ)$$

Biofuel Demand

$$QBIO_{c,cty} = \overline{QBIOBASE}_{c,cty} \cdot \prod_{cc} \left(\frac{(1 - \overline{CSE}_{cc,cty}) \cdot PC_{cc,cty}}{(1 - \overline{CSEBASE}_{cc,cty}) \cdot \overline{PCBASE}_{cc,cty}} \right)^{elhp_{c,cc,cty}} \quad (QBIOEQ)$$

Seed Demand

$$QSEED_{c,cty} = \overline{QSEEDBASE}_{c,cty} \cdot \frac{\overline{POP}_{cty}}{\overline{POPBASE}_{cty}} \cdot \prod_{cc} \left(\frac{(1 - \overline{CSE}_{cc,cty}) \cdot PC_{cc,cty}}{(1 - \overline{CSEBASE}_{cc,cty}) \cdot \overline{PCBASE}_{cc,cty}} \right)^{elhp_{c,cc,cty}} \quad (QSEEDQ)$$

Tourist Consumption Demand

$$QTOUR_{c,cty} = \overline{QTOURBASE}_{c,cty} \cdot \prod_{cc} \left(\frac{(1 - \overline{CSE}_{cc,cty}) \cdot PC_{cc,cty}}{(1 - \overline{CSEBASE}_{cc,cty}) \cdot \overline{PCBASE}_{cc,cty}} \right)^{elhp_{c,cc,cty}} \quad (QTOUREQ)$$

Loss and Waste

$$QLOSS_{c,cty} = QDEM_{c,cty} \cdot \overline{LOSSRATE}_{c,cty} \quad (QLOSSEQ)$$

$$QWASTE_{c,cty} = QH_{c,cty} \cdot \overline{WASTERATE}_{c,cty} \quad (QWASTEQ)$$

Other Demand

$$QOTH_{c,cty} = \overline{QOTHBASE}_{c,cty} \cdot \prod_{cc} \left(\frac{(1 - \overline{CSE}_{cc,cty}) \cdot PC_{cc,cty}}{(1 - \overline{CSEBASE}_{cc,cty}) \cdot \overline{PCBASE}_{cc,cty}} \right)^{elhp_{c,cc,cty}} \quad (QOTHEQ)$$

4.2 Production Block

The production block describes the equations determining the production quantities of each food commodity, the input of intermediate goods and production factors, and the producer prices. Primary crops are differentiated by production technologies (irrigated and rainfed), while livestock products are distinguished by climate zones and production systems (pasture-based or mixed). Yield improvements due to technological progress and climate impacts are considered for crops, and productivity changes in livestock are captured through feed requirements and feed share. For energy crops, production quantities by year and macro-region are given exogenously from AIM-Hub, and allocated to production units according to price and yield.

4.2.1 Crop Production

The livestock production block describes equations for determining livestock output, production systems, feed requirements, and associated prices. Livestock products are distinguished by climate zones and production systems (pasture-based or mixed). Feed use and production efficiency depend on feed composition, feed efficiency, and animal productivity.

Domestic Production

$$QSUP_{a,cty} = \sum_{bas} QS_{a,bas,cty} \quad (QSUPEQ)$$

Crop Production by Technology

$$QSWAT_{acro,bas,cty,water} = QS_{acro,bas,cty} \cdot watshare_{acro,bas,cty,water} \quad (CROWATEREQ)$$

Producer Price of Crops

$$PP_{acro,cty} = \left(PL_{acro,bas,cty} \cdot \sum_{water} \frac{watshare_{acro,bas,cty,water}}{YLD_{acro,bas,cty,water} \cdot \overline{CROPINTENSITY}_{acro,bas,cty,water}} + PO_{acro,bas,cty} \right) / (1 + PPCOMP_{acro,bas,cty}) \quad (PPCROEQ)$$

Land Input for Crop Production

$$QL_{acro,bas,cty} = QS_{acro,bas,cty} \cdot \sum_{water} \frac{watshare_{acro,bas,cty,water}}{YLD_{acro,bas,cty,water} \cdot \overline{CROPINTENSITY}_{acro,bas,cty,water}} \quad (QLCROINPUTEQ)$$

Crop Yield

$$YLD_{acro,bas,cty,water} = \overline{YLD_{BASE}}_{acro,bas,cty,water} \cdot \overline{YLD_{GR}}_{acro,bas,cty,water} \cdot \overline{YLD_{CHAN}}_{acro,bas,cty,water} \quad (YLDEQ)$$

Other Production Factor Price

$$PO_{acro,bas,cty} = \overline{PO_{BASE}}_{acro,bas,cty} \cdot \left(\frac{QS_{acro,bas,cty}}{\overline{QSPRE}_{acro,bas,cty}} \right)^{elop_{acro,cty}} \quad (POCROEQ)$$

4.2.2 Livestock Production

The livestock production block describes equations for determining livestock output, production systems, feed requirements, and associated prices. Livestock products are distinguished by climate zones and production systems (pasture-based or mixed). Feed use and production efficiency depend on feed composition, feed efficiency, and animal productivity.

Livestock Production by System

$$QSSYS_{aliv,bas,cty,cz,sys} = QS_{aliv,bas,cty} \cdot czshare_{aliv,bas,cty,cz} \cdot SYSSHARE_{aliv,bas,cty,cz,sys} \quad (\text{LIVSYSEQ})$$

Livestock System Share Function

$$SYSSHARE_{aliv,bas,cty,cz,sys} = \frac{1}{1 + \delta_{aliv,cz,sys}^{sys} \cdot \overline{GDPPC}_{cty}^{\rho_{aliv,sys}^{sys}}} + res_{aliv,bas,cty,cz,sys} \quad (\text{SYSSHAREEQ})$$

Producer Price of Livestock

$$PP_{aliv,cty} = \left(PL_{aliv,bas,cty} / ANIMALYLD_{aliv,bas,cty} + pfeedcoef_{aliv,cty} \cdot \sum_{cfeed} (1 - \overline{CSE}_{cfeed,cty}) \cdot PC_{cfeed,cty} \cdot \sum_{cz,sys} \left(czshare_{aliv,bas,cty,cz} \cdot SYSSHARE_{aliv,bas,cty,cz,sys} \cdot ICL_{aliv,cfeed,bas,cty,cz,sys} \right) + PO_{aliv,bas,cty} \right) / (1 + PPCOMP_{aliv,bas,cty}) \quad (\text{PPLIVEQ})$$

Grass Input Calculation

$$Qgrass_{aliv,bas,cty} = \frac{QS_{aliv,bas,cty}}{ANIMALPRODRA_{aliv,cty}} \cdot \sum_{cz,sys} \left(czshare_{aliv,bas,cty,cz} \cdot SYSSHARE_{aliv,bas,cty,cz,sys} \cdot \overline{FEDEFFICIENCY}_{aliv,bas,cty,cz,sys} \cdot (1 - \overline{FEEDSHARE}_{aliv,bas,cty,cz,sys}) \right) \quad (\text{QGRASSINPUTEQ})$$

Available Grassland Area

$$Qgrass_{aliv,bas,cty} = \left(QL_{aliv,bas,cty} - \overline{QLRES}_{aliv,bas,cty} \right) \cdot \overline{GRASSYLD}_{bas,cty} \cdot grassusagerate_{bas,cty} \quad (\text{QLLIVINPUTEQ})$$

Livestock Yield

$$ANIMALYLD_{aliv,bas,cty} = \frac{QS_{aliv,bas,cty}}{QL_{aliv,bas,cty} - \overline{QLRES}_{aliv,bas,cty}} \quad (ANIMALYLDEQ)$$

Feed Input Calculation

$$QFEED_{aliv,cfeed,bas,cty} = \frac{QS_{aliv,bas,cty}}{\overline{ANIMALPRODRATE}_{aliv,cty}} \cdot \sum_{cz,sys} (czshare_{aliv,bas,cty,cz} \cdot SYSSHARE_{aliv,bas,cty,cz,sys} \cdot ICL_{aliv,cfeed,bas,cty,cz,sys}) \quad (QFEEDINPUTEQ)$$

Feed Input Coefficient

$$ICL_{aliv,cfeed,bas,cty,cz,sys} = \frac{\overline{FEEDEFFICIENCY}_{aliv,bas,cty,cz,sys}}{\overline{FEEDSHARE}_{aliv,bas,cty,cz,sys} \cdot \overline{GRAINSHARE}_{aliv,cfeed,bas,cty,cz,sys}} \quad (ICLEQ)$$

Other Production Factor Price (Livestock)

$$PO_{aliv,bas,cty} = \overline{POBASE}_{aliv,bas,cty} \cdot \left(\frac{QS_{aliv,bas,cty}}{\overline{QSPRE}_{aliv,bas,cty}} \right)^{elop_{aliv,cty}} \quad (POLIVEQ)$$

Livestock Production Quantity

$$QS_{aliv,bas,cty} = \frac{\overline{ANIMALWEIGHT}_{aliv,cty} \cdot (ANIMAL_{aliv,bas,cty} - \overline{ANIMALRES}_{aliv,bas,cty})}{\overline{ANIMALPRODRATE}_{aliv,cty}} \quad (ANIMALEQ)$$

4.2.3 Processed Goods production

This section describes the production equations for processed agricultural products. Processed products are produced using intermediate inputs and other production factors.

Producer Price of Processed Products

$$PP_{apro,cty} = pintcoef_{apro,cty} \cdot \sum_{cint} \left((1 - \overline{CSE}_{cint,cty}) \cdot PC_{cint,cty} \cdot ica_{apro,cint,cty} \right) + PO_{apro,cty} \quad (PPPROEQ)$$

Intermediate Input Demand for Processed Products

$$QINT_{apro,cint,cty} = QSUP_{apro,cty} \cdot ica_{apro,cint,cty} \quad (QINTINPUTEQ)$$

Other Production Factor Price (Processed Products)

$$PO_{apro,cty} = \overline{POBASE}_{apro,cty} \cdot \left(\frac{QSUP_{apro,cty}}{QSUPRE_{apro,cty}} \right)^{elop_{apro,cty}} \quad (\text{POPROEQ})$$

4.2.4 Energy Crop Production

Energy crop production is determined from regional totals provided exogenously by the AIM-Hub model.

Regional Energy Crop Supply Balance

$$\overline{QENE}_{region} = \sum_{bas,cty \in region} QS_{ecr,bas,cty} \quad (\text{QSENEEQ})$$

Land Input for Energy Crops

$$QL_{ecr,bas,cty} = \frac{QS_{ecr,bas,cty}}{YLD_{ecr,bas,cty}} \quad (\text{QLENEINPUTEQ})$$

Land Price for Energy Crops

$$PL_{ecr,bas,cty} = PENE_{region} \quad (\text{PLENEEQ})$$

4.3 Land Use Block

The land-use block allocates available land among different uses through a Logit function. Prices for non-human-used land (forest, other natural land, and fallow land) are fixed at their baseline values. A constraint is imposed to ensure that total agricultural land does not exceed the physically available land area due to slope and soil limitations. Afforestation areas are given exogenously from AIM-PLUM results.

Vegetation Area

$$QLVEG_{bas,cty} = \overline{QLTOT}_{bas,cty} - \overline{QLVEGN}_{bas,cty} - \overline{QLAFR}_{bas,cty} \quad (\text{QLVEGEQ})$$

Pasture Area Allocation

$$QLPAS_{bas,cty} = QLVEG_{bas,cty} \cdot \frac{\delta_{pas,bas,cty} \cdot PLPAS_{bas,cty}^{\rho_{pas,bas,cty}}}{\delta_{pas,bas,cty} \cdot PLPAS_{bas,cty}^{\rho_{pas,bas,cty}} + \delta_{pasn,bas,cty} \cdot PLPASn_{bas,cty}^{\rho_{pasn,bas,cty}}} \quad (\text{QLPASEQ})$$

Non-pasture Grassland Area

$$QLPASN_{bas,cty} = QLVEG_{bas,cty} \cdot \frac{\delta_{pasn,bas,cty} \cdot PLPASN_{bas,cty}^{\rho_{pasn,bas,cty}}}{\delta_{pas,bas,cty} \cdot PLPAS_{bas,cty}^{\rho_{pas,bas,cty}} + \delta_{pasn,bas,cty} \cdot PLPASN_{bas,cty}^{\rho_{pasn,bas,cty}}} \quad (QLPASNEQ)$$

Cropland Area

$$QLCRO_{bas,cty} = QLPASN_{bas,cty} \cdot \frac{\delta_{cro,bas,cty} \cdot PLCRO_{bas,cty}^{\rho_{cro,bas,cty}}}{\delta_{cro,bas,cty} \cdot PLCRO_{bas,cty}^{\rho_{cro,bas,cty}} + \delta_{frs,bas,cty} \cdot \overline{PLFRS}_{bas,cty}^{\rho_{frs,bas,cty}} + \delta_{gra,bas,cty} \cdot \overline{PLGRA}_{bas,cty}^{\rho_{gra,bas,cty}}} \quad (QLCROEQ)$$

Forest Area

$$QLFRS_{bas,cty} = QLPASN_{bas,cty} \cdot \frac{\delta_{frs,bas,cty} \cdot \overline{PLFRS}_{bas,cty}^{\rho_{frs,bas,cty}}}{\delta_{cro,bas,cty} \cdot PLCRO_{bas,cty}^{\rho_{cro,bas,cty}} + \delta_{frs,bas,cty} \cdot \overline{PLFRS}_{bas,cty}^{\rho_{frs,bas,cty}} + \delta_{gra,bas,cty} \cdot \overline{PLGRA}_{bas,cty}^{\rho_{gra,bas,cty}}} \quad (QLFRSEQ)$$

Other Natural Land

$$QLGRA_{bas,cty} = QLPASN_{bas,cty} \cdot \frac{\delta_{gra,bas,cty} \cdot \overline{PLGRA}_{bas,cty}^{\rho_{gra,bas,cty}}}{\delta_{cro,bas,cty} \cdot PLCRO_{bas,cty}^{\rho_{cro,bas,cty}} + \delta_{frs,bas,cty} \cdot \overline{PLFRS}_{bas,cty}^{\rho_{frs,bas,cty}} + \delta_{gra,bas,cty} \cdot \overline{PLGRA}_{bas,cty}^{\rho_{gra,bas,cty}}} \quad (QLGRAEQ)$$

Harvested Cropland Area

$$QLCROCLT_{bas,cty} = QLCRO_{bas,cty} \cdot \frac{\delta_{croclt,bas,cty} \cdot PLCROCLT_{bas,cty}^{\rho_{croclt,bas,cty}}}{\delta_{croclt,bas,cty} \cdot PLCROCLT_{bas,cty}^{\rho_{croclt,bas,cty}} + \delta_{crofal,bas,cty} \cdot \overline{PLCROFAL}_{bas,cty}^{\rho_{crofal,bas,cty}}} \quad (QLCROCLTEQ)$$

Fallow Cropland Area

$$QLCROFAL_{bas,cty} = QLCRO_{bas,cty} \cdot \frac{\delta_{crofal,bas,cty} \cdot \overline{PLCROFAL}_{bas,cty}^{\rho_{crofal,bas,cty}}}{\delta_{croclt,bas,cty} \cdot \overline{PLCROCLT}_{bas,cty}^{\rho_{croclt,bas,cty}} + \delta_{crofal,bas,cty} \cdot \overline{PLCROFAL}_{bas,cty}^{\rho_{crofal,bas,cty}}} \quad (QLCROFALEQ)$$

Cropland Allocation

$$QL_{acro,bas,cty} = QLCROCLT_{bas,cty} \cdot \frac{\delta_{acro,bas,cty} \cdot \overline{PL}_{acro,bas,cty}^{\rho_{acro,bas,cty}}}{\sum_{acro} \delta_{acro,bas,cty} \cdot \overline{PL}_{acro,bas,cty}^{\rho_{acro,bas,cty}}} \quad (QLCRODISTEQ)$$

Pasture Allocation

$$QL_{aliv,bas,cty} = QLPAS_{bas,cty} \cdot \frac{\delta_{aliv,bas,cty} \cdot \overline{PL}_{aliv,bas,cty}^{\rho_{aliv,bas,cty}}}{\sum_{aliv} \delta_{aliv,bas,cty} \cdot \overline{PL}_{aliv,bas,cty}^{\rho_{aliv,bas,cty}}} \quad (QLLIVDISTEQ)$$

Land Prices

$$\overline{PLCROCLT}_{bas,cty} \cdot QLCROCLT_{bas,cty} = \sum_{acro} \overline{PL}_{acro,bas,cty} \cdot QL_{acro,bas,cty} \quad (PLCROCLTEQ)$$

$$\begin{aligned} PLCRO_{bas,cty} \cdot QLCRO_{bas,cty} &= (\overline{PLCROCLT}_{bas,cty} \cdot QLCROCLT_{bas,cty} \\ &\quad + \overline{PLCROFAL}_{bas,cty} \cdot QLCROFAL_{bas,cty}) \\ &\quad / (1 + \overline{PLCOMP}_{bas,cty}) \end{aligned} \quad (PLCROEQ)$$

$$\begin{aligned} PLPASN_{bas,cty} \cdot QLPASN_{bas,cty} &= PLCRO_{bas,cty} \cdot QLCRO_{bas,cty} \\ &\quad + \overline{PLFRS}_{bas,cty} \cdot QLFRS_{bas,cty} \\ &\quad + \overline{PLGRA}_{bas,cty} \cdot QLGRA_{bas,cty} \end{aligned} \quad (PLPASNEQ)$$

$$PLPAS_{bas,cty} \cdot QLPAS_{bas,cty} = \frac{\sum_{aliv} \overline{PL}_{aliv,bas,cty} \cdot QL_{aliv,bas,cty}}{1 + \overline{PLCOMP}_{bas,cty}} \quad (PLPASEQ)$$

Agricultural Land Constraint

$$\overline{QLLIM}_{cty} \geq QLCRO_{bas,cty} + QLPAS_{bas,cty} \quad \perp \quad \overline{PLCOMP}_{bas,cty} \geq 0 \quad (QLLIMEQ)$$

4.4 Market Block

This subsection describes the equations in the market block, where consistency between food demand and supply is ensured. Trade of food commodities is represented as a complementarity problem. When the

import price is higher than the border price, the import quantity becomes zero. Once the import price decreases to equal the border price, imports begin. Similarly, when the border price is higher than the export price, exports become zero, and once the export price rises to match the border price, exports take place.

Domestic Trade Balance

$$NT_{c,cty} = QSUP_{c,cty} - QDEM_{c,cty} - \overline{QST}_{c,cty} \quad (\text{NTEQ})$$

$$NT_{c,cty} = QE_{c,cty} - QM_{c,cty} \quad (\text{QEQMEQ})$$

International Trade Balance

$$\sum_{cty} NT_{c,cty} - \overline{QRES}_c = 0 \quad (\text{NT0EQ})$$

Import and Export Conditions

$$PM_{c,cty} \geq PB_{c,cty} \quad \perp \quad QM_{c,cty} \geq 0 \quad (\text{PBPMEQ})$$

$$PB_{c,cty} \geq PE_{c,cty} \quad \perp \quad QE_{c,cty} \geq 0 \quad (\text{PBPEEQ})$$

4.5 GHG Emission Block

This subsection describes the equations in the GHG emission block. GHG emissions are calculated based on the production quantities of each food commodity. When carbon prices are considered, the amount of mitigation technology adoption and its cost are computed from the MAC (Marginal Abatement Cost) curve. Emissions from the land-use sector are calculated according to each land area.

GHG Emissions

$$GHG_{a,src,gas,cty} = QSUP_{a,cty} \cdot \overline{EF}_{a,src,gas,cty} \cdot (1 - RR_{a,src,gas,cty}) \quad (\text{GHGEQ})$$

Land-Use Emissions

$$\begin{aligned} GHGLU_{src,gas,bas,cty} = & \overline{EF_LU}_{src,gas,cty} \cdot QLFRS_{bas,cty} + \overline{EF_LU}_{src,gas,cty} \cdot QLGRA_{bas,cty} \\ & + \overline{EF_LU}_{src,gas,cty} \cdot QLCRO_{bas,cty} + \overline{EF_LU}_{src,gas,cty} \cdot QLPAS_{bas,cty} \end{aligned} \quad (\text{GHGLUEQ})$$

Emission Reduction Rate

$$RR_{a,src,gas,cty} = \overline{MRP}_{src,gas,cty} \cdot \left(1 - \left[1 / (1 + \overline{PRCCAR}_{cty}) \right]^{\sigma_{src,gas,cty}} \right) \quad (\text{RREQ})$$

Abatement Cost

$$AC_{a,cty} = \sum_{src,gas} \overline{EF}_{a,src,gas,cty} \cdot \left[\frac{\sigma_{src,gas,cty}}{(\sigma_{src,gas,cty} - 1)} \cdot \overline{MRP}_{src,gas,cty} \cdot \left(1 - \left(1 - RR_{a,src,gas,cty} / \overline{MRP}_{src,gas,cty} \right)^{(1-1/\sigma_{src,gas,cty})} \right) - RR_{a,src,gas,cty} \right] \quad (ACEQ)$$

Carbon Cost on Remaining Emissions

$$PCB_{a,cty} = \sum_{src,gas} \overline{PRCCAR}_{cty} \cdot \overline{EF}_{a,src,gas,cty} \cdot (1 - RR_{a,src,gas,cty}) \quad (PCBEQ)$$

4.6 Complementarity Conditions

This subsection describes the complementarity conditions introduced to avoid numerical errors in the Logit function when production quantities in specific production units become zero. If the production of a unit becomes zero, its land-use area would also become zero, leading to instability. Therefore, a minimum positive value is imposed to ensure that production quantities do not fall to zero.

Minimum Production Share for Trade

$$\frac{QSUP_{c,cty}}{QM_{c,cty}} \geq 0.01 \quad \perp \quad TMCOMP_{c,cty} \geq 0 \quad (DEPQMEQ)$$

Minimum Production Share for Supply

$$\frac{QS_{a,bas,cty}}{QSUP_{a,cty}} \geq 0.01 \quad \perp \quad PPCOMP_{a,bas,cty} \geq 0 \quad (QSBOUEQ)$$

5 Data and Preprocessing

This section explains the calibration and processing of data used in the model. Exogenous variables and parameters were estimated using multiple datasets, adjusted to obtain equilibrium in the base year, and parameters were estimated by regression analysis.

5.1 Data Sources

Table 6 lists the datasets used in the model.

Table 6: List of data sources

Data Source	Dataset Name	URL
FAOSTAT	Food Balances	https://www.fao.org/faostat/en/#data/FBS
FAOSTAT	Production	https://www.fao.org/faostat/en/#data/QCL
FAOSTAT	Trade	https://www.fao.org/faostat/en/#data/TCL
FAOSTAT	Producer Prices	https://www.fao.org/faostat/en/#data/PP
FAOSTAT	Land Use	https://www.fao.org/faostat/en/#data/RL
FAOSTAT	Emissions	https://www.fao.org/faostat/en/#data/GCE
AQUASTAT	Major hydrological basins of the world	https://data.apps.fao.org/catalog/iso/7707086d-af3c-41cc-8aa5-323d8609b2d1
FAO and IIASA	GAEZ v4	https://gaez.fao.org/
IIASA	SSP 3.0	https://data.ece.iiasa.ac.at/ssp/#/about
GTAP	GTAP 10	https://jgea.org/ojs/index.php/jgea/article/view/77

Continued on next page

Table 6: List of data sources (continued)

Data Source	Dataset Name	URL
IFPRI	MAPSPAM	https://doi.org/10.7910/DVN/SWPENT
World Bank	World Bank Open Data	https://data.worldbank.org/
EDGAR	EDGAR v8.0	https://edgar.jrc.ec.europa.eu/dataset_ghg80
Herrero Acosta et al. (2018)	Livestock production systems	https://doi.org/10.4225/08/5aa068b33fe06
Muhammad et al. (2011)	International Evidence on Food Consumption Patterns	http://199.135.94.241/publications/pub-details/?pubid=47581
T. P. Robinson et al. (2018)	Global distribution of ruminant livestock production systems V5	https://doi.org/10.7910/DVN/WPDSZE
Harmsen et al. (2019)	CH ₄ and N ₂ O MAC curves	https://doi.org/10.1016/j.envsci.2019.05.013
Hurt et al. (2019)	Land Use Harmonization 2	https://luh.umd.edu/index.shtml

6 Parameter Estimation

Parameter estimation

7 Model Calculation Flow and Execution

8 Update History

2025-10-25 R. Totake v1.0
Initial release of AIM-ALPHA documentation.