AIM/Hub 2.3.19 Documentation

Shinichiro Fujimori

September 21, 2023

Authors: Shinichiro Fujimori[1,2*]

[1] Department of Urban and Environmental Engineering, Kyoto University
Postal address: 367, C1-3, Kyoto-daigaku Katsura campus, Nishikyo-ku, Kyoto city, Kyoto, 606-8540, Japan
[2] Center for Social and Environmental Systems Research, National institute for environmental studies
Postal address: National institute for environmental studies, 16-2 Onogawa, Tsukuba, Ibaraki, 305-8506, Japan
*E-mail address: fujimori.shinichiro.8a@kyoto-u.ac.jp (S. Fujimori)

Abstract;
This document describes AIM/Hub V2.3 (formerly named AIM/CGE) model which is widely used in the AIM (Asia-Pacific Integrated Modeling) group assessments. AIM/Hub 2.3 model is recursive dynamic computable general equilibrium model which can simulate energy supply and demand, land-use dyanamics, agricultural goods supply and demand, and emissions with considering whole economic transactions. The basic idea of the model,
model structure, fomula and how to deal with actual programing codes are documented.

Key words;
Computable General Equilibrium model, Social Accounting Matrix, Energy Balance Table

Update history

- Jun, 2010 S. Fujimori Version 0.01
- Jul, 2010 S. Fujimori Version 0.02
  Installing AEEI scenario
- Aug, 2010 S. Fujimori Version 0.03
  (1) Biomass consumption, (2) GHG and air pollutants emissions are installed, (3) Labor and capital growth module, (4) dynamic system (recursive type) and (5) GHG emission cost and its allocation module are installed and (6) power sectors are disaggregated. (The output directory structure is modified because model is changed as recursive dynamic type.)
- Aug, 2010 S. Fujimori Version 0.04
  (1) Installing formulas which make energy commodity satisfy the energy balance. (2) Energy balance table is calculated
- Sep., 2010 S. Fujimori Version 0.05
  (1) Production function is revised
- Sep., 2010 S. Fujimori Version 0.06
  - Fossil fuel extraction cost scenario is installed
  - Renewable energy capacity is installed
  - Capital vintage (two types; old and new) is installed
- Oct., 2010 S. Fujimori Version 0.07
  - CCS technology is available
  - Base year energy balance table comparison tool is introduced
- Oct., 2010 S. Fujimori Version 0.08
  Labor and capital are disaggregated.
- Nov., 2010 S. Fujimori Version 0.10
  - Natural resource is considered for one of the factors
  - Production function is revised
  - Non-CO_2 emission abasement is considered
  - Emission trading is installed
- Jan., 2011 S. Fujimori Version 0.20
  Results output format is revised
- Jan., 2012 S. Fujimori Version 0.50
  AIDADS is added
- Mar., 2012 S. Fujimori Version 0.60
  Transport module Logit function
- May, 2012 S. Fujimori Version 0.61
  Capital allocation
- May, 2012 S. Fujimori Version 0.62
  - Biofuel industry
  - Bio electricity sector's production structure
- Jun., 2012 S. Fujimori Version 0.63

  - Renewable energy cost reduction module
  - Household energy consumption is incorporated in AIDADS

- Aug., 2012 S. Fujimori Version 0.64
  - CCS installation module is revised
  - Program modification tool is implemented.
  - Rest of the Kyoto 6 gases (SF6, CF4, C2F6) and HFC gases become available.
  - Climate tool is implemenated. MAGICC5.3 climate calculation is available.
  - Socioeconomic scenarios are independently treated while previous version could not do it.

- Oct., 2012 S. Fujimori Version 0.65
  - Power selection mechanism is revised
  - Agriculture and land use are disaggregated.
  - Land use module is implemented.
  - Biomass transformation sectors (1^{st}, and 2^{nd} generation) are added.
  - Solar and wind power structure is revised
  - A description about scenario dependent parameter settings is added.

- Nov., 2012 S. Fujimori Version 0.70
  Coupling with Enduse device information

- Jun., 2015 S. Fujimori Version 0.9
  SSP related modification
  Denominate version number

  ... Many revisions

- September, 2020 S. Fujimori Version 2.3

- July, 2021 S. Fujimori Version 2.3.1
  System change in combine 1 and IAMC template generation processes Shell operation system has been checked to be available

- October, 2021 S. Fujimori Version 2.3.2
  Shell files are updated and system management was revised. Batch file is no longer maintained.

- November, 2021 S. Fujimori Version 2.3.3
  CCS bug has been fixed.

- November, 2021 S. Fujimori Version 2.3.4
  IAMC template output directory location has changed

- December, 2021 S. Fujimori Version 2.3.5
  International transport representation has changed. Parameter declaration location has changed and merged into two places

- December, 2021 S. Fujimori Version 2.3.6
  Technoeconomic information has ben updated based on World Energy Outlook 2021 CCS and non-energy related abatement cost treatment has been fixed Specific assumption years are centraliry managed by /inc_prog/SpecYear.gms
- January, 2022 S. Fujimori Version 2.3.7
  DICE emissions has been updated to moderate the lower boundary of negative emissions Cost for non-energy related emissions abatement has been fixed A function to remove output files for specific scenarios has been installed
- January, 2022 S. Fujimori Version 2.3.8
  Input data has been restructured and new repository for input data has been established
- January, 2022 S. Fujimori Version 2.3.9
  Input data is further moved to independent repostiry (FAO, GAINS, SSP and CEDS)
- January, 2022 S. Fujimori Version 2.3.10
  Code cleaning has been done. Operation shell structure has been changed so that base year split1 can be removed.
- March, 2022 S. Fujimori Version 2.3.12
  Data load strucuture in scenario.gms has been updated. Basically, the GDX data is loaded in AIMHub.gms as much as possible. GDX compression for AIMHub.gms and scenario.gms has been revoked
- March, 2022 S. Fujimori Version 2.3.13
  Submodule has been introduced for Data load.
- March, 2022 S. Fujimori Version 2.3.14
  EAT-Lancet assumption has been added to IAV assumption.
- October, 2022 S. Fujimori Version 2.3.15
  A tool to allow multiple thread solution is introduced which helps to get stable solution.
- October, 2022 S. Fujimori Version 2.3.16
  Climate model MAGICC has been updated and MAGICC7 is available in linux system.
- October, 2022 S. Fujimori Version 2.3.17
  Execution log and lst files locations, and execution directries have been revised.
- December, 2022 S. Fujimori Version 2.3.18
  Batch files support has been finished. IAMC template calculation has been revised for the variables using denominators
- April, 2023 S. Fujimori Version 2.3.19
  IEA calibration period is extended to 2019 from 2015
- April, 2023 S. Fujimori Version 2.3.20
  New sector, agricultural residue biomass, has been introduced.

Recommendation for read

- Beginners of this model and to think about learning: Chapter 1,2,3,6,7,11
- For national modelers, it would be better to read chapter 8 as well.
- Intermediate experiences in model operation and get to learn changing the model code: Chapter 5, 9, 10
- Well-experienced model developers: Chapter 4, 5

Directory Structure
|
+—control Control file for national scenario assumptions
+—data A directory for model input data
+—define A directory for set and map files
+—doc Documentation
+—inc_prog A directory for program files included in the main programs
+—individual A directory for storing individual exercises
+—output A directory including results
+—prog Main programs
+—scenario A directory for programs of scenarios
+—shell A directory for shell script
+—batch Batch file to execute the model and some other tools (no longer mentained since Nov. 2021)
\—tools tools (e.g. IAMC template, climate model)

Contents

List of Figures

List of Tables

Chapter 1

Introduction

CGE model is one of the most useful tools for empirical economic analysis. During the last few decades, the CGE (computable general equilibrium) model has been applied to various countries and to the whole world for not only economic analysis but also energy consumption and greenhouse gas emission analysis.

We, the AIM (Asia-pacific Integrated Model) team, have been investigating CGE model for more than twenty years [1]. The CGE model is used for the analysis of global and country CO_2 emissions, mitigation costs or carbon taxes. Recently, we rebuilt the CGE model called as ”AIM/Hub” referring to ”A standard CGE model” which was developed by Lofgren *et al.* (2002) [2]. This document is organized as follows.

(1) Social accounting matrix (used in the model)

(2) Model structure

(3) Mathematical statement of the model

(4) Model dynamics

(5) How to use the model

(6) Results

Chapter 2

Social accounting matrix (used in the model)

2.1 Social accounting matrix framework

A social accounting matrix (SAM) is a comprehensive, economy-wide data framework, typically representing the economy of a nation. In this model we use global SAM so it covers not only nation but also some regions. A SAM is a square matrix in which each account is represented by a row and a column. Each cell shows the payment from the account of its column to the account of its row. Thus, the incomes of an account appear along its row and its expenditures down its column. The underlying principle of double-entry accounting requires that, for each account in the SAM, total revenue (row total) equals total expenditure (column total). Table 2.1 shows an aggregated SAM concept with verbal explanations in the cells instead of numbers. The payments are not permitted in the blank cells of Table2.1.

The typical SAM distinguishes between accounts for ”activities” (the entities that carry out production) and ”commodities”. They are definitely different from general Input-output table framework. The receipts are valued at producer prices in the activity

Table 2.1: Standard social accounting matrix

		Industry			Products			Factor		Corporation	Household	Government	Saving and investment	Property	Current transfer	Import tax	export tax	Value added tax	Taxes on production	Tax on income and wealth	Rest of the world	TOTAL
		Industry1	Industry2	Industry3	Products1	Products2	Products3	Labor	Operating surplus													
	Industry1																					
Industry	Industry2				Prodcution																	
	Industry3																					
	Products1																					
Products	Products2	Intermediate consumption									Household consumption	Government consumption	Gross Capital formation								Exports of goods and services	
	Products3																					
Factor	Labor	Compensation of employees																			compensation from rest of the world	
	Operating surplus	Operating Surplus and mixed income																				
Corporation																						
Household								Resource of compensation	Resource of Operating surplus and mixed income					resource of property income	resource of current transfer							
Government																Receipt of Import tax, Export tax, Value added tax, Taxes on production, and Tax on income and wealth						
Saving and investment										Gross saving												
Property										Use of property income											Property income from rest of the world	
Current transfer										Use of current transfer											Current transfer from rest of the world	
Import tax					Import tax																	
Export tax					Export tax																	
Value added tax					Value added tax																	
Taxes on production		Taxes on prodcution																				
Tax on income and wealth										Tax on income and wealth												
Trade margin					Trade margin																	
Rest of the world					Imports of goods and services			Compensation to rest of the world					Net foreign direct investment	Property income to rest of the world	Current transfer to rest of the world							
TOTAL																						

accounts and at market prices (including value added commodity taxes which is a part of tax on products and production) in the commodity accounts.

Same as the IFPRI's framework [2] the domestic nongovernment institutions in the SAM consist of households and enterprises. The enterprises earn factor incomes (reflecting their ownership of capital and/or land). They may also receive transfers from other institutions. Their incomes are used for direct taxes, savings, and transfers to other institutions. As opposed to households, enterprises do not consume. Technically, the standard CGE model requires that the SAM have at least one household account; enterprise accounts are not necessary.

The property income and current transder are accounted in this SAM as they may be different from other SAM framework. They represent the transaction among institution sectors. They are basically aggregated into one category but optionally can be differentiated as the objectives of the model simulation.

AIM/HUB couples multiple assounting framewok for SAM. Concretely, typical SAM does not include physical volume transaction data and describes as only monetary unit but this CGE model deals with energy commodity with physical unit volume. Therefore, the SAM attaches energy input-output table whose structure is same as the monetary unit SAM.

2.2 Sector classification

The SAM sector classification is shown in Table 2.2. The AIM default column shows the default classification and the original SAM column shows the classification of the original SAM data. The default classification has 14 non-energy sectors and 26 energy sectors. The commodity is coded as "COM_" sector name. The commodity classification is basically same as industrial sectors but there are a few excpetions. One is related to electricity all power supplying sectors produce same commodity as electricity "COM_ELY". The second is biofuel as "COM_BIO". The third is petroreum products and coal transformation products, namely COM_P_P and COM_COP. The fourth is hydrogen "COM_HYG".

Table 2.2: List of sectors

CGE code	Original SAM code	Description	ISIC rev3 code	GTAP
PDR	PDR	Rice	01	PDR
WHT	WHT	Wheat		WHT
GRO	GRO	Other grains		GRO
OSD	OSD	Oil seed crops		OSD
C_B	C_B	Suger crops		C_B
OTH_A	V_F, PFB, OCR	Vegetable, Fruits and Nuts, Fiber crops, Other crops		V_F, PFB, OCR
CTL	CTL	Ruminat livestock		CTL
RMK	RMK	Raw milk		RMK

Continue to next page

Continued from previous page

CGE code	Original SAM code	Description	ISIC rev3 code	GTAP
OTH_L	OAP, WOL, FSH	Non ruminat livestock, other livestock and fishery	05	OAP, WOL, FSH
FRS	FRS	Forestry	02	FRS
COA	COA	Coal mining	101, 102	COA
OIL	OIL	Oil mining	111, 112 (related to oil extraction), 103	OIL
GAS	GAS	Gas mining	111, 112 (related to gas extraction)	GAS
OMN	OMN	Mineral mining and Other quarrying	12, 13, 14	OMN
FPR	OMT, VOL, MIL, SGR, OFD, B_T	Food products		CMT, OMT, VOL, MIL, SGR, OFD, B_T, PCR
LIN	TEX	Textiles and Apparel and Leather	17, 18, 19, 243	TEX, WAP, LEA
LIN	LUM	Wood products	20	LUM
PPP	PPP	Paper, Paper products and Pulp	21, 2211, 2212, 2213, 2219, 222, 223	PPP
CRP	CRP	Chemical, Plastic and Rubber products	241, 242, 25	CRP
PRF	P_C	Petroleum refinery	231, 232, 233	P_C
CTF		Coal transformation		
BTR		Biomass transfromation (1st generation)		
BTR3		Biomass transfromation (2nd generation with solid biomass)		
NMM	NMM	Mineral products nec	26	NMM
I_S	I_S	Iron and Steel	271, 2731	I_S
NFM	NFM	Non Ferrous products	272, 2732	NFM
OMF	FMP, OME, ELE, MVH, OTN, OMF	Other Manufacturing	28, 29, 31, 33, 30, 32, 34, 35, 36, 37	FMP, OME, ELE, MVH, OTN, OMF
E_COL	E_COL	Coal-fired generation without CCS		

Continue to next page

part of 401 ELY

Continued from previous page

CGE code	Original SAM code	Description	ISIC rev3 code	GTAP
E_OIL	E_OIL	Oil-fired generation without CCS		
E_GAS	E_GAS	Gas-fired generation without CCS		
E_NUC	E_NUC	nuclear electric power generation		
E_HYD	E_HYD	hydroelectric power generation		
E_GEO	E_GEO	geothermal power generation		
E_SPV	E_SPV	photovoltaic power generation		
E_WIN	E_WIN	wind-power generation		
E_BIO	E_BIO	waste biomass-power generation		
E_ORN	E_ORN	other renewable energy power generation		
E_BIN	E_BIO	advanced biomass-power generation		
GDT	GDT	Gas manufacture distribution	402, 403	GDT
CNS	CNS	Construction	45	CNS
TRS	TRS	Transport and communications	60, 61, 62, 63, 64	ATP, OTP, WTP, CMN
CSS	WTR, TRD, FIR, CSS	Other service sectors	41, 50,51,52,55, 65, 66, 67, 70, 71, 72, 73, 74, 75, 80, 85, 90, 91, 92, 93, 94, 95, 99	ROS, OSG, WTR, TRD, OFI, ISR, OBS, DWE
CCSN		CCS Service		
NEA		Non energy related emissions atabement service		
RIS		Electricity integration service		
ECR		Energy crop production		
ARE		Agricultural residue collection		
HGG		Hydrogen production using gas		
HGB		Hydrogen production using biomass		
HGE		Hydrogen production using electricity		

Continue to next page

Continued from previous page

CGE code	Original SAM code	Description	ISIC rev3 code	GTAP
HGC		Hydrogen production using coal		
DAC		Direct air capture		
STO		Carbon storoge for DAC		
T_D		Transmission and Distribution		
OHE		Overhead of electricity including administering		

End

2.3 Region classification

The global model 17 regions are classified as below.

Table 2.3: List of regions

Code	Region	Code	Region
JPN	Japan	TUR	Turkey
CHN	China	CAN	Canada
IND	India	USA	United States
XSE	Southeast Asia	BRA	Brazil
XSA	Rest of Asia	XLM	Rest of South America
XOC	Oceania	XME	Middle East
XE25	EU25	XNF	North Africa
XER	Rest of Europe	XAF	Rest of Africa
CIS	Former Soviet Union		

Further regional aggregation mapped with ISO code is shown Table 13.1 Appendix I (List of coutries and mapping with global 17 regions).

Chapter 3

Model Structure

The AIM/Hub model explains all of the payments recorded in the SAM. The energy commodity transaction and GHG emissions are particulary delt with in detail. The model therefore follows the SAM disaggregation of factors, activities, commodities, and institutions. It is written as a set of simultaneous equations without any objective functions. In addition, there are complement variables to solve the problem like the carbon tax attached to carbon emissions constraint. Therefore Mixed Complementary Problem (MCP) is used to solve them. The equations define the behavior of the different actors. In part, this behavior follows simple rules captured by fixed coefficients. For production and consumption decisions, behavior is captured by nonlinear, first-order optimality conditions - that is, production and consumption decisions are driven by the maximization of profits and utility, respectively. The equations also include a set of constraints that have to be satisfied by the system as a whole but are not necessarily considered by any individual actor, namely macro economic banalce and balance of payment and so on. An overview of this structure is shown in Figure 3.1[1].

There are four blocks: production, income distribution, final consumption, and market. The first block, production, represents the structure of the production functions. We apply a nested CES function for production activities with multiple nested CES functions. Secondly, incomes are distributed to three institutional sectors: enterprises, government, and households. The government takes in income by collecting taxes. Thirdly, institutions consume goods as final consumption. Government expenditure and capital formation are defined as a constant coefficient function. The LES (Linear Expenditure System) or AIDADS (An Impricit Direct Additive Demand System) is used for household consumption. Lastly, the CES function is applied to the import of goods and the CET function is applied to the export of goods. A goods-consumption-and-supply equilibrium is achieved for each market.

3.1 Activity production and factor markets

Each producer (represented by an activity) is assumed to maximize profits, defined as the difference between revenue earned and the cost of factors and intermediate inputs. Profits are maximized subject to a production technology, the structure of which is shown in Figure 3.2. At the top level, there is non-energy related GHG emission

[1]The production function excludes emission gases in this figure. Moreover, this production function is applied to only non energy transformation sectors

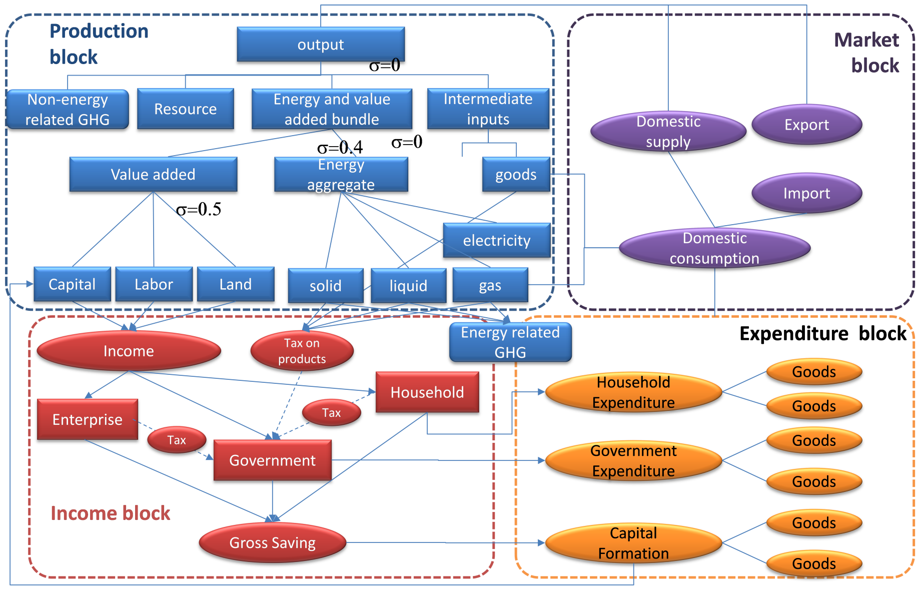

Figure 3.1: Overview of AIM/Hub model structure

and conventional inputs. This GHG emission treatment is described in detailed by Hyman [3]. Conventional inputs technology is specified by a Leontief function of the quantities of energy and value-added bundle, aggregate non-energy intermediate input and resource input. Energy and value added bundle is nested by valued added and energy inputs. Value added is itself a constant elasticity of substitution (CES) function of primary factors. The aggregated energy inputs are specified by a Logit function. The aggregate intermediate input is a Leontief function of disaggregated intermediate inputs. The energy transformation sectors such as the power and petroleum refinery sectors are assumed to be different production functions from the other sectors. The structure is drawn as below. Value added aggregation and energy inputs are speficied by Leontief.

There is an option to specify the each sector's energy consumption by using detailed enduse technology device information. Once the option turned on, the energy consumption is separated from value added nest and determined by device selection Logit function and the devices input energy sources.

Each activity produces one or more commodities according to fixed yield coefficients. A commodity may be produced by more than one activity. In this model, the electricity is produced by many types of power supply technology. The revenue of the activity is defined by the level of the activity, yields, and commodity prices at the producer level.

As part of its profit-maximizing decision, each activity uses a set of factors up to the point where the marginal revenue product of each factor is equal to its factor price. The quantity supplied of each factor is fixed at a certain level. As for the captital, the capital accumulation is taken into account. This level is recursive dynamically decided. An economy-wide wage variable is free to vary to assure that the sum of demands from all activities equals the quantity supplied. New capital is allocated to anywhere. Old capital is assumed to be fixed to each sector, which is named the putty-clay assumption. The rate of return of capital is same for both of old and new capitals. However, if the

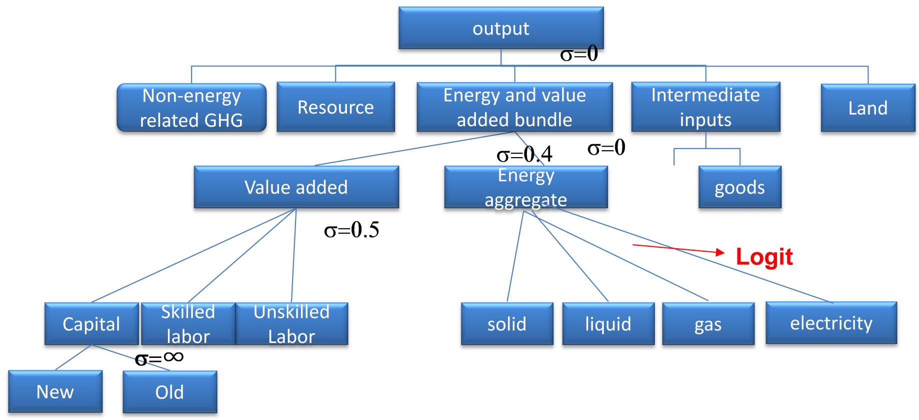

Figure 3.2: Production structure (Non-energy transformation sectors)

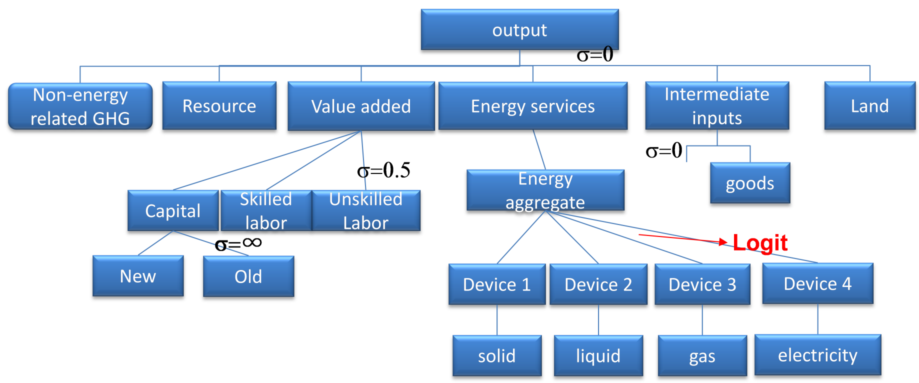

Figure 3.3: Production structure (Non-energy transformation sectors) with enduse option

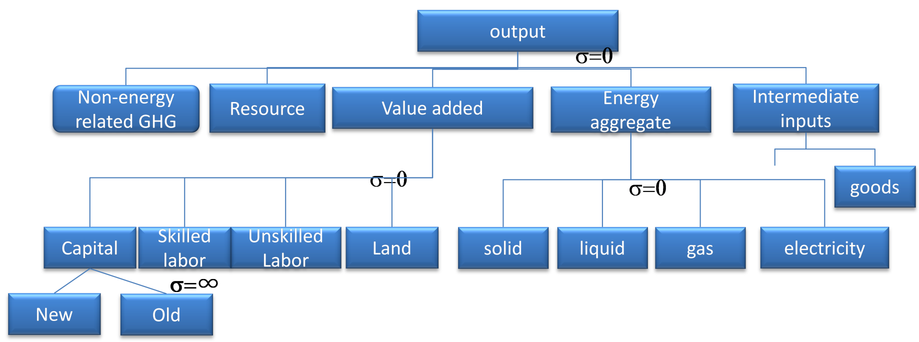

Figure 3.4: Production structure (Energy transformation sectors)

new capital is not allocated, the price of old capital is lower than new one and the operation ratio could be lower than 1.

3.2 Institutions

In the CGE model, institutions are represented by: households, enterprises, the government, and the rest of the world[2]. The households (disaggregated as in the SAM) receive income from the factors of production (directly or indirectly via the enterprises) and transfers from other institutions. The households use their income to pay direct taxes, save, consume, and make transfers to other institutions. In the basic model version, direct taxes and transfers to other domestic institutions are defined as fixed shares of household income whereas the savings share is flexible for selected households. The income that remains after taxes, savings, and transfers to other institutions is spent on consumption. When the economy has to implement carbon tax, all of the revenues are assumed to be receipt by the household.

Household consumption covers marketed commodities, purchased at market prices that include commodity taxes. Household consumption is allocated across different commodities according to linear expenditure system (LES) demand functions, derived from maximization of a Stone-Geary utility function.

Instead of being paid directly to the households, factor incomes may be paid to the enterprise. The Enterprise may also receive transfers from other institutions. Enterprise incomes are allocated to direct taxes, savings, and transfers to other institutions. Enterprises do not consume. Apart from this, the payments to and from enterprises are modeled in the same way as the payments to and from households. The government collects taxes and receives transfers from other institutions. In the basic model version, all taxes are at fixed *ad valorem* rates.

The government uses this income to purchase commodities for its consumption and for transfers to other institutions. Government consumption is fixed in real (quantity) terms whereas government transfers to domestic institutions (households and enterprises) are CPI-indexed. Government savings (the difference between government income and spending) is a flexible residual.

The saving rate made by all institution is fixed coefficient also.

The final institution is the rest of the world. As noted, transfer payments between the rest of the world and domestic institutions and factors are all fixed in foreign currency. Foreign savings (or the current account deficit) is the difference between foreign currency spending and receipts. Commodity trade with the rest of the world is discussed in the next section.

3.3 Commodity market

All commodities (domestic output and imports) enter markets. Domestic output may be sold in the market. For marketed output, the first stage in the chain consists of generating aggregated domestic output from the output of different activities of a given commodity. These outputs are imperfectly substitutable as a result of, for example, differences in timing, quality, and distance between the locations of activities. A CES

[2]This is the default version classification but if the long-term simulation like till 2100 is the objectives, household government and enterprises are treated as one aggregated representative household.

function is used as the aggregation function[3]. The demand for the output of each activity is derived from the problem of minimizing the cost of supplying a given quantity of aggregated output subject to this CES function. Activity-specific commodity prices serve to clear the implicit market for each disaggregated commodity.

In the next, aggregated domestic output is allocated between exports and domestic sales on the assumption that suppliers maximize sales revenue for any given aggregate output level, subject to imperfect transformability between exports and domestic sales, expressed by a constant elasticity of transformation (CET) function. In the international markets, export demands are infinitely elastic at given world prices. The price received by domestic suppliers for exports is expressed in domestic currency and adjusted for export taxes (if any). If the commodity is not exported, total output is passed to the domestic market.

Domestic demand is made up of the sum of demands for household consumption, government consumption, investment (the determination of which is discussed below), and intermediate inputs.

To the extent that a commodity is imported, all domestic market demands are for a composite commodity made up of imports and domestic output, the demands for which are derived on the assumption that domestic demanders minimize cost subject to imperfect substitutability. This is also captured by a CES aggregation function which is so-called Armington assumption. Total market demand is directed to imports for commodities that lack domestic production and to domestic output for non-imported commodities. The derived demands for imported commodities are met by international supplies that are infinitely elastic at given world prices. The import prices paid by domestic demanders also include import tariffs (at fixed *ad valorem* rates) and the cost of a fixed quantity of transactions services per import unit, covering the cost of moving the commodity from the border to the demander. Similarly, the derived demand for domestic output is met by domestic suppliers.

The AIM/HUB model treats the volume of energy commodities[4] as energy units, though usual CGE model do not as well. In the calibration procedure, the energy unit transaction data is used.

Although energy commodities must satisfy the energy balance condition, CES and CET function make the balanced condition. Therefore, we apply specific formulas to the energy and agricultural commodities that are treated as physical volume, which is a sort of Logit function. We determine the share of imported and domestic consumption by the ratio of the current price to previous year's price. The share of exported and domestic consumption, and the share of the same commodity production are determined as well as the import composition. The share is controlled by the ratio of previous year's and calculation year price with an elasticity parameter. For example, if import price is increased over that of domestic products, the share of import commodity would be decreased.

3.4 Land allocation and its market

Land is disaggregated into AEZ (Agro-Ecological Zone) categories, and default version assumes 3 kinds of land type (AEZ1 to AEZ3). The land use sectors; cropping,

[3]Energy commodity has specific treatment. It is discussed below

[4]Coal (COA), crude oil (OIL), natural gas (GAS), petroleum products (P_C), town gas (GDT) and electricity (ELY)

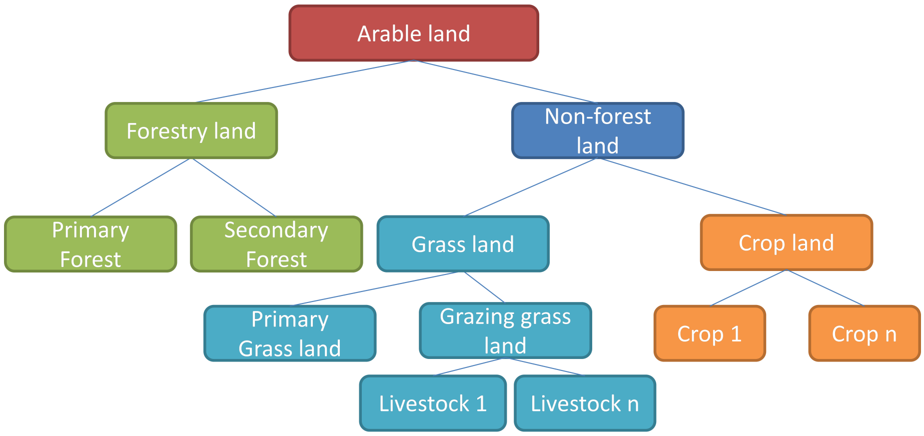

Figure 3.5: Land allocation strucuture

livestock and forestry, input these land categories. The farmers and forestry activities determine the share of the land input according to the land price.

On the other hand, the land owners decide the share of land use according to the land price and there are multiple decisions to allocate the land to each activity. Firstly, agricutlrue and forestry land are identified. Then, forestry is disaggregated into primary and secondary forestry. The other blanch has grass land and crop land disaggregation. Grass land has unused primary area and grazing area. Crop land and grazing area have final disaggregation to each specific commodity production activity. Each decision is based on Logit function. This decision process is illustrated in Figure 3.5.

3.5 Macro economic balances

The CGE model includes three macroeconomic balances: the (current) government balance, the external balance (the current account of the balance of payments, which includes the trade balance), and the Savings-Investment balance.

For the government balance, the closure is that government savings (the difference between current government revenues and current government expenditures) is a flexible residual while all tax rates are fixed.

For the external balance, which is expressed in foreign currency, the closure is that the real exchange rate is flexible while foreign savings (the current account deficit) is fixed. Given that all other items are fixed in the external balance (transfers between the rest of the world and domestic institutions), the trade balance is also fixed.

For the Savings-Investment balance, the closure is investment-driven. Real investment quantities are fixed. In order to generate savings that equal the cost of the investment bundle, the base-year savings rates of selected nongovernment institutions are adjusted by the same number of percentage points. Implicitly, it is assumed that the government is able to implement policies that generate the necessary private savings to finance the fixed real investment quantities.

3.6 Air pollutants and GHG emissions

The CGE model includes air pollutants and GHG emissions module. The emission gases treated in this model are CO, NH_3, NMVOC, NOx, SO_2, BC, OC, CO_2 CH_4 and N_2O. The emission sources are classified into two groups; (1) One is related to fuel combustion and this kind of emission is proportional to the energy consumption. (2) The other is related to the activity level, e.g. CO_2 emission from cement production, and this kind of emission is proportional to the activity level. The emission sources and their groups are shown in Table 3.1. There are other categories that are not classified in IPCC but exist in the model in Table 3.2.

Table 3.1: Emission sources

IPCC category	Explanation
1A1a	Public electricity and heat production
1A1bc	Other Energy Industries
1A2	Manufacturing Industries and Construction
1A3a	Domestic aviation
1A3b	Road transportation
1A3c	Rail transportation
1A3d	Inland navigation
1A3e	Other transportation
1A4	Residential and other sectors
2A	Production of minerals
2A1	Cement production
2A2	Lime production
2B	Production of chemicals
2C	Production of metals
2D	Production of pulp/paper/food/drink
2G	Non-energy use of lubricants/waxes (CO2)
3A	Solvent and other product use: paint
3B	Solvent and other product use: degrease
3C	Solvent and other product use: chemicals
3D	Solvent and other product use: other
4A	Enteric fermentation
4B	Manure management
4C	Rice cultivation
4D1	Direct soil emissions
4D2	Manure in pasture/range/paddock
4D3	Indirect N2O from agriculture
4D4	Other direct soil emissions
4E	Savanna burning
4F	Agricultural waste burning
5A	Forest fires
5C	Grassland fires
5F2	Forest Fires-Post burn decay
6A	Solid waste disposal on land
6B	Wastewater handling
6C	Waste incineration
6D	Other waste handling

Table 3.2: Emission sources for non-IPCC categories

Code	Description
5X	Other land use change
5Y	Carbon sink in land
5Z	Wood removal
10X	CCS removal
10Y	Biomass emissions (But net accounted as zero)

Chapter 4

Mathematical statement

This chapter presents the mathematical model statement equation by equation. In its mathematical form, the CGE model is a system of simultaneous, nonlinear equations. The model is square - that is, the number of equations is equal to the number of variables. In this class of models, this is a necessary (but not a sufficient) condition for the existence of a unique solution. The chapter divides the equations into six blocks: prices, production and trade, institutions, international trade[1], energy and CO_2 emissions, and system constraints. New items (sets, parameters, and variables) are defined the first time that they appear in the equations. Table 4.1 summarizes the notational principles. Parameter and variable names are chosen to facilitate interpretation; most importantly, commodity and factor quantities start with q, commodity prices with p, and factor prices with w.

Table 4.1: Notational principles

Item	Notation
Endogenous variables	Upper-case Latin letters without a bar
Exogenous variables	Upper-case Latin letters with a bar
Paramters	Lower-case Latin letters (with or without a bar) or lower-case Greek letters (with or without superscripts)
Set indices	Lower-case Latin letters as subscripts to variables and parameters

The price system of the model is rich, primarily because of the assumed quality differences among commodities of different origins and destinations (exports, imports, and domestic outputs used domestically). The price block consists of equations in which endogenous model prices are linked to other prices (endogenous or exogenous) and to non-price model variables.

Import Price

$$PM_{r,c} = PWMR_{r,c} \cdot (1 + tm_{r,c}) \cdot \overline{EXR_r}, \quad \forall r \in R,\ c \in CM \text{ (PMEDEF)}$$

$r \in R$: a set of regions,

[1] The equations in the "International trade block" are involved only if you chose a global model.

$c \in C$: a set of commodities (also referred to as *c'* and *C'*),
$c \in CM\,(\subset C)$: a set of imported commodities,
$PM_{r,c}$: composite commodity price (including import tax and transaction costs),
$PWMR_{r,c}$: Import price of commodity c in region r,
$tm_{r,c}$: import tariff rate,
EXR_r: exchange rate country r.

The import price is the price paid by domestic users for imported commodities (exclusive of the sales tax). Equation (PMDEF) states that it is a transformation of the world price of these imports, considering the exchange rate and import tariffs plus transaction costs (the cost of trade inputs needed to move the commodity from the border to the demander) per unit of the import. The domain of the equation is the set of imported commodities (a subset of the commodity set). The model includes one equation like (PMDEF) for every imported commodity.

Note that the notational principles make it possible to distinguish between variables (upper-case Latin letters) and parameters (lower-case Latin letters). This means that the exchange rate and the domestic import price are flexible, while the tariff rate and the world import price are fixed. The fixedness of the world import price stems from the "small-country" assumption. That is, for all its imports, the assumed share of world trade for the modeled country is so small that it faces an infinitely elastic supply curve at the prevailing world price.

Export Price

$$PE_{r,c} = PWER_{r,c} \cdot (1 - te_{r,c}) \cdot \overline{EXR_r}, \quad \forall r \in R,\ c \in CE \text{ (PEDEF)}$$

$c \in CE\,(\subset C)$: a set of exported commodities (with domestic production),
$PE_{r,c}$: export price of commodity c,
$PWMR_{r,c}$: Export price of commodity c in region r,
$te_{r,c}$: export tax rate.

The export price is the price received by domestic producers when they sell their output in export markets. This equation is similar in structure to the import price definition. The main difference is that the tax reduces the price received by the domestic producers of exports (instead of adding to the price paid by domestic demanders of imports). The domain of the equation is the set of exported commodities, all of which are produced domestically.

Demand Price of Domestic Non-traded Goods

$$PDD_{r,c} = PDS_{r,c}, \quad \forall r \in R,\ c \in CD \text{ (PDDDEF)}$$

$c \in CD\,(\subset C)$: a set of commodities with domestic sales of domestic output,
$PDD_{r,c}$: demand price for commodity produced and sold domestically,
$PDS_{r,c}$: supply price for commodity produced and sold domestically.

Equation (PDDDEF) defines the demand prices as the supply price.

Absorption

$$PQ_{r,c} \cdot QQ_{r,c} = PDD_{r,c} \cdot QD_{r,c} + PM_{r,c} \cdot QM_{r,c}, \quad \forall r \in R,\ c \in (CD \cup CM) \text{ (PQDDEF)}$$

$PQ_{r,c}$: composite commodity price excluding sales tax,
$QQ_{r,c}$: quantity of goods supplied to domestic market (composite supply),
$QD_{r,c}$: quantity sold domestically of domestic output,
$QM_{r,c}$: quantity of imports of commodity.

Absorption is total domestic spending on a commodity at domestic demander prices. Equation (PQDDEF) defines it exclusive of the sales tax. Absorption is expressed as the sum of spending on domestic output and imports at the demand prices, *PDD* and *PM*. The prices *PDD* and *PM* include the cost of trade inputs but exclude the commodity sales tax.

The equation as a whole applies to all commodities that are imported and/or have domestic sales of domestic output (the union of the sets *CD* and *CM*). It does not apply to commodities for which the entire output volume is exported. Each of the two terms on the right-hand side applies only to its relevant set (*CD* and *CM*, respectively). In the *GAMS* code, *PM* and *QM* are fixed at zero for commodities that are not elements in the set *CM*; similarly *PDD* and *QD* are fixed at zero for commodities that are not elements in the set *CD*. This approach is followed throughout: all variables that should be excluded from the model are fixed at zero.

Commodity market monetary balance

$$PQD_{r,c} \cdot \left(\begin{array}{c} PQ_{r,c} \cdot QQ_{r,c} = \\ \sum_{a \in A} dfpq_{r,c,a} \cdot QINT_{r,c,a} + \sum_{h \in H} pfdq_{r,c,h} \cdot QH_{r,c,h} \\ + pfdq_{r,c,\text{"}gov\text{"}} \cdot QG_{r,c} + pfdq_{r,c,\text{"}s-i\text{"}} \cdot QINV_{r,c} \\ \text{(PQDEF)} \end{array} \right), \quad \forall r \in R,\ c \in CX$$

$PQD_{r,c}$: composite commodity price excluding sales tax,
$dfpq_{r,c,i}$: price differences of commodity price among inputs sectors,
$QINT_{r,c,a}$: quantity of commodity c as intermediate input to activity a,
$QH_{r,c,h}$: quantity of consumption of marketed commodity c for household h,
$QG_{r,c}$: government consumption demand for commodity,
$QINV_{r,c}$: quantity of fixed investment demand for commodity.

Marketed Output with stock change

$$QX2_{r,c} = QX_{r,c} + stch_{r,c}, \quad \forall r \in R,\ c \in CX \text{ (QX2DEF)}$$

$QX_{r,c}$: aggregate marketed quantity of domestic output of commodity,
$QX2_{r,c}$: aggregate marketed quantity of domestic output of commodity including stock change,
$stch_{r,c}$: stock change of commodity c (positive).

Marketed Output Value with stock change

$$PX2_{r,c} \cdot QX2_{r,c} = PX_{r,c} \cdot QX_{r,c}, \quad \forall r \in R,\ c \in CX \text{ (PXDEF)}$$

$PX_{r,c}$: aggregate producer price for commodity,
$PX2_{r,c}$: aggregate producer price for commodity including stock change effects.

The above 2 equations describe the relataionship between output and stock changes, and those of market value.

Marketed Output Value

$$PX2_{r,c} \cdot QX2_{r,c} = PDS_{r,c} \cdot QD_{r,c} + PE_{r,c} \cdot QE_{r,c}, \quad \forall r \in R,\ c \in CX \text{ (PX2DEF)}$$

$c \in CX\,(\subset C)$: a set of commodities with domestic output,
$QE_{r,c}$: quantity of exports.

For each domestically produced commodity, the marketed output value at producer prices is stated as the sum of the values of domestic sales and exports. Domestic sales and exports are valued at the prices received by the suppliers, *PDS* and *PE*, both of which have been adjusted downwards to account for the cost of trade inputs.

The domain limitation to domestically produced commodities (the elements in the set *CX*) has to be stated explicitly given that the model includes a category of imported commodities without domestic production. The domestic part applies only to elements in *CD* whereas the export part applies only to elements in *CE*. *PX* and *QX* are referred to as "aggregate" values since they may apply to an aggregation of output from different domestic producers of the same commodity. By dividing through by *QX2*, this equation could be rewritten as an explicit definition of *PX*.

Consumer Price Index

$$CPI_r = \sum_{c \in C} \left(PQD_{r,c} \cdot dfpq_{r,c,\text{"}hurb\text{"}} \cdot (1 + tqd_{r,c,\text{"}hurb\text{"}})\right) \cdot cwts_{r,c} \;\; \forall r \in R, \forall g \in G \text{ (CPIDEF)}$$

$cwts_{r,c}$: weight of commodity c in the consumer price index,
CPI_r: consumer price index (exogenous variable).

Producer Price Index for Nontraded Market Output

$$DPI_r = \sum_{c \in C} PDS_{r,c} \cdot dwts_{r,c} \quad \forall r \in R \text{ (DPIDEF)}$$

$dwts_{r,c}$: weight of commodity c in the producer price index,
DPI_r: producer price index for domestically marketed output.

Equations (CPIDEF) and (DPIDEF) define the consumer price index and the producer price index for domestically marketed output. The *CPI* is fixed and functions as the numéraire in the basic model version; alternatively, the *DPI* may be fixed. A numéraire is required since the model is homogeneous of degree zero in prices. A doubling of the value of the numéraire would double all prices but leave all real quantities unchanged. All simulated price and income changes should be interpreted as changes vis-á-vis the numéraire price index.

Export Price Index

$$EPI_r = \sum_{c \in C} PE_{r,c} \cdot ewts_{r,c} \quad \forall r \in R \text{ (EPIDEF)}$$

$ewts_{r,c}$: weight of commodity c in the export price index,
EPI_r: export price index.

Import Price Index

$$MPI_r = \sum_{c \in C} PM_{r,c} \cdot mwts_{r,c} \quad \forall r \in R \text{ (MPIDEF)}$$

$mwts_{r,c}$: weight of commodity c in the import price index,
MPI_r: import price index.

Governmental consumption Price Index

$$GPI_r = \sum_{c \in C} PQD_{r,c} \cdot dfpq_{r,c,\text{"}gov\text{"}} \cdot \left(1 + tqd_{r,c,\text{"}gov\text{"}}\right) \cdot gwts_{r,c} \quad \forall r \in R \text{ (GPIDEF)}$$

$gwts_{r,c}$: weight of commodity c in the governement price index,
GPI_r: Governement price index.

Capital Formation Price Index

$$IPI_r = \sum_{c \in C} PQD_{r,c} \cdot dfpq_{r,c,\text{"}S-I\text{"}} \cdot (1 + tqd_{r,c,\text{"}S-I\text{"}}) \cdot iwts_{r,c} \quad \forall r \in R \text{ (IPIDEF)}$$

$iwts_{r,c}$: weight of commodity c in the capital formation price index,
IPI_r: Capital formation price index.

Export, import, governmental consumption and capital formation price indices are defined as aboves.

4.1 Production block

The production and trade block covers four categories: domestic production and input use; the allocation of domestic output to home consumption, the domestic market, and exports; the aggregation of supply to the domestic market (from imports and domestic output sold domestically); and the definition of the demand for trade inputs that is generated by the distribution process.

Production is carried out by activities that are assumed to maximize profits subject to their technology, taking prices (for their outputs, intermediate inputs, and factors) as given. In other words, it acts in a perfectly competitive setting. The CGE model includes the first-order conditions for profit-maximization by producers.

Activity Price

$$PA_{r,a} \cdot QA_{r,a} = \sum_{c \in C} PXAC_{r,a,c} \cdot QXAC_{r,a,c}, \quad \forall r \in R,\ a \in A \text{ (PADEF)}$$

$a \in A$: a set of activities,
$PA_{r,a}$: activity price (gross revenue per activity unit),
$QA_{r,a}$: quantity (level) of activity,
$PXAC_{r,a,c}$: producer price of commodity c for activity a,
$QXAC_{r,a,c}$: marketed output quantity of commodity c from activity a,

The gross revenue per activity unit, the activity price, is the return from selling the output or outputs of the activity, defined as yields per activity unit multiplied by activity-specific commodity prices, summed over all commodities. This allows for the fact that activities may produce multiple commodities.

Aggregate Non-energy Intermediate Input Price

$$QINTA_{r,a} \cdot PINTA_{r,a} = \sum_{c \in CNEN} dfpq_{r,c,a} \cdot PQD_{r,c} \cdot QINT_{r,c,a} \cdot (1 + tqd_{r,c,a}) \ \forall r \in R,\ a \in A,\ c \in CNEN \text{ (PINTADEF)}$$

$c \in CNEN$: a set of non-energy commodities,
$PINTA_{r,a}$: aggregate intermediate input price for activity a,
$QINTA_{r,a}$: quantity of aggregate intermediate input,
$tq_{r,c,ac}$: rate of sales tax (as share of composite price inclusive of sales tax). Suffix ac includes activity a and institution i.

The activity-specific aggregate intermediate input price shows the cost of disaggregated intermediate inputs per unit of aggregate intermediate input. It depends on composite commodity prices and intermediate input coefficients, which show the quantity of input commodity c per unit of aggregate intermediate input (not per unit of output).

Activity Revenue and Costs (Non-energy transformation sector)

$$PA_{r,a}\cdot(1-ta_{r,a})\cdot QA_{r,a} = PVAE_{r,a}\cdot QVAE_{r,a}+PINTA_{r,a}\cdot QINTA_{r,a}+PRES_{r,a}\cdot QRES_{r,a} + GHGCA\_NENE_{r,a} + VRENCAP_{r,a}\cdot QA_{r,a} + \sum_{emcm\in EMCM} QRED_{r,emcm,a}, \quad \forall r \in R,\ a \in ACES \quad \text{(PVADEF)}$$

Activity Revenue and Costs (Energy transformation sector)

$$\begin{aligned} PA_{r,a}\cdot(1-ta_{r,a})\cdot QA_{r,a} = {} & PVA_{r,a}\cdot QVA_{r,a} + PINTA_{r,a}\cdot QINTA_{r,a} + \\ & PENE_{r,a}\cdot QENE_{r,a} + PRES_{r,a}\cdot QRES_{r,a} + \\ & GHGCA\_NENE_{r,a} + VRENCAP_{r,a}\cdot QA_{r,a} + \\ & \sum_{emcm\in EMCM} QRED_{r,emcm,a} + \\ & \sum_{g,emsc} ABTC\_NCS_{r,a,g,emsc} - GHGCAFULL_{R,A}\cdot CarTaxExempt \\ & \forall r \in R,\ a \in ALEO(PVADEF) \end{aligned}$$

$a \in ACES$ ($\subset A$): a set for non-energy transformation,
$a \in ALEO$ ($\subset A$): a set for energy transformation,
$ta_{r,a}$: tax rate for activity,
$PVAE_{r,a}$: price of (aggregate) energy and value-added bundle (non-energy transformation sector),
$QVAE_{r,a}$: quantity of (aggregate) energy and value-added bundle (non-energy transformation sector),
$PVA_{r,a}$: price of (aggregate) value-added,
$QVA_{r,a}$: quantity of (aggregate) value-added,
$PENE_{r,a}$: price of (aggregate) energy input,
$QENE_{r,a}$: quantity of (aggregate) energy input,
$GHGCA\_NENE_{r,a}$: GHG emission cost related biomass burning and CCS negative emissions of activity a in region r,
$VRENCAP_{r,a}$: Rent of electricity capacity activity a in region r,
$PRES_{r,a}$: price of resource input,
$QRES_{r,a}$: quantity of resource input,
$QRED_{r,emcm,a}$: input of counter emission reduction counter measures of activity a and measure $emcm$,
$ABTC\_NCS_{r,a,g,emsc}$: Non-energy related emissions abatement cost for region r, sector a, gases g, and emission sources emsc
$emcm \in EMCM$: a set of emission reduction counter measures (CCS).
$emsc \in EMSC$: a subset of emission reduction counter measures which are for non-energy related emissions.
$GHGCAFULL_{r,ac}$: Carbon tax penalty on residual emissions.
$CarTaxExempt$: Flag parameter for carbon tax penalty exemption.

Activity cost is different between the energy transformation sector and non-energy transformation sector as shown in the previous chapter. The difference is energy and value added treatment. For each activity, total revenue net of taxes is fully exhausted by payments for value-added and intermediate inputs. Given the above definitions of *PA*, *PVA, PENE, PINTA*, *PENE* and *PRES*, equation (PVADEF) implicitly defines the value-added price, *PVA*.

If we had GHG emission constraints, each activity is levied on to its GHG emissions. The GHG emission cost related with biomass burning is represented as *GHGCA_NENE*. GHG cost related to energy consumption is included in energy cost.

Moreover, sometimes, activity level is constrained by political decisions; for example, nuclear power plant construction is not determined only by economic rationality. In such cases, a rent is absorbed by the activity as *VRENCAP*.

The emission reduction countermeasures for CCS technology cost and non-energy related demissions are added up as *ABTC_NoCCS* and *QRED*.

Resource Input Price

$$pres\_base_{r,a} = PRES_{r,a}\,, \quad \forall r \in R,\ a \in A \text{ (PRESDEF)}$$

Resource inputs price is assumed equal as the activity price.

$pres\_base_{r,a}$: resource price (normally 1).

Leontief Technology: Demand for Aggregate Value-Added (energy transformation sector)

$$QVA_{r,a} = iva_{r,a} \cdot QA_{r,a} \cdot \left(1 + H^{iva}_{r,a}\right), \quad \forall r \in R,\ a \in ALEO \text{ (LEOAGGVA)}$$

Leontief Technology: Demand for Aggregate energy Input (energy transformation sector)

$$QENE_{r,a} = iena_{r,a} \cdot QA_{r,a} \cdot (1 + celoss_{r,a})\,, \quad \forall r \in R,\ a \in ALEO \text{ (LEOAGGENE)}$$

Energy and Value added Bundle (non-energy transformation sector)

$$QVAE_{r,a} = ivae_{r,a} \cdot QA_{r,a}, \quad \forall r \in R,\ a \in ACES \text{ (LEOAGGVAE)}$$

Leontief Technology: Demand for Aggregate Non-energy Intermediate Input

$$QINTA_{r,a} = inta_{r,a} \cdot QA_{r,a}, \quad \forall r \in R,\ a \in A \text{ (LEOAGGINT)}$$

Leontief Technology: Demand for Resource Input

$$QRES_{r,a} = ires_{r,a} \cdot QA_{r,a}, \quad \forall r \in R,\ a \in A \text{ (LEOAGGRES)}$$

$iva_{r,a}$: quantity of value-added per activity unit,
$iena_{r,a}$: quantity of aggregate energy input per activity unit,
$ivae_{r,a}$: quantity of value-added energy composite per activity unit,
$inta_{r,a}$: quantity of aggregate non-energy intermediate input per activity unit,
$ires_{r,a}$: quantity of aggregate resource input per activity unit.
$celoss_{r,a}$: CCS energy loss rates
$H^{iva}_{r,a}$: Energy system model investment complementary variable with CGE sector classification (in the code this variable is represented by COMP_FC_TEC3)

As for the energy transformation sectors, a Leontief function at the top of the conventional inputs are equations (LEOAGGVA), (LEOAGGENE), (LEOAGGINT) and (LEOAGGRES) where the demands for value-added, the aggregate intermediate inputs, the aggregate energy input and resource inputs are defined as Leontief functions of the activity level. For the non-energy transformation sectors, the equations (LEOAGGVA) and (LEOAGGENE) are replaced by equation (LEOAGGVAE). $CFT3_{r,a}$ is complementary variable to meet the constraint of additional energy investment which is only applied for the mode using energy system model coupling.

Energy and Value-Added composite

$$QVAE_{r,a} = \alpha^{vae}_{r,a} \cdot \left(\delta^{vae}_{r,a} \cdot QVA_{r,a}{}^{-\rho^{vae}_{r,a}-\Gamma^{vae}_{r,a}} + \left(1-\delta^{vae}_{r,a}\right) \cdot \left(1+H^{vae}_{r,a}\right) \cdot aeeit_{r,a} QENE_{r,a}{}^{-\rho^{vae}_{r,a}-\Gamma^{vae}_{r,a}}\right)^{-\frac{1}{\rho^{vae}_{r,a}+\Gamma^{vae}_{r,a}}}, \quad \forall r \in R,\ a \in ACES \quad \text{(CESVAENE)}$$

Energy and Value-added Input CES Technology: Energy – Value added -Input Ratio

$$QVA_{r,a} = QENE_{r,a} \cdot \left(\frac{\delta^{vae}_{r,a}}{\left(1-\delta^{vae}_{r,a}\right)\cdot\left(1+H^{vae}_{r,a}\right)} \cdot \frac{PENE_{r,a}}{PVA_{r,a}}\right)^{\frac{1}{1+\rho^{vae}_{r,a}+\Gamma^{vae}_{r,a}}}, \quad \forall r \in R,\ a \in ACES \quad \text{(CESVAENEFOC)}$$

$\alpha^{vae}_{r,a}$: efficiency parameter in the CES energy and value-added function,
$\delta^{vae}_{r,a}$: CES energy and value-added function share parameter in activity a,
$\rho^{vae}_{r,a}$: CES energy and value-added function exponent,
$aeeit_{r,a}$: AEEI for energy total consumption,
$\Gamma^{vae}_{r,a}$: Complementary variable for final energy consumption constrain for elasticity for the energy information coupling mode (in the code this variable is represented by SUM(FCAGGA$MapFCCONS(FCAGGA,"TOTAL",A,"COM_ELY"),COMP_FC_TEC_AGG2(R,FCAGGA,"TOTAL")))
$H^{vae}_{r,a}$: Complementary variable for final energy consumption constrain for the energy information coupling mode (in the code this variable is represented by SUM(FCAGGA$MapFCCONS(FCAGGA,"TOTAL",A,"COM_ELY"),COMP_FC_TEC_AGG(R,FCAGGA,"TOTAL")+CompFCTecAgg(R,FCAGGA,"TOTAL"))).
COMP_FC_TEC_AGG is endogenously determined and CompFCTecAgg is exogenous, which is calibrated before 2015 period).

Energy and Value-Added composite balance

$$QVAE_{r,a} \cdot PVAE_{r,a} = QENE_{r,a} \cdot PENE_{r,a} + QVA_{r,a} \cdot PVA_{r,a}, \quad \forall r \in R,\ a \in ACES \quad \text{(PVEDEF)}$$

Non-energy transformation sectors determine their energy and value added inputs as shown previously. CES function is applied to these inputs. If there is an industry using no energy, the value added is defined as below.

Energy and Value-Added composite (Non energy use sector)

$$QVAE_{r,a} = QVA_{r,a}, \quad \forall r \in R,\ a \in ACES \quad \text{(CESVAENE2)}$$

Value-Added and Factor Demands: Non-power Supply Activities

$$QVA_{r,a} = (TFPADJ_{r,a} \cdot tfpact_{R,A} + 1 \cdot (1 - tfpact_{R,A})) \cdot \alpha^{va}_{r,a} \cdot \\ (\sum_{f \in F} \delta^{va}_{r,a} \cdot (fcmult_{r,f,a} \cdot QF_{r,f,a}/(1 + H^{vae}_{r,a}))^{-\rho^{va}_{r,a}})^{-\frac{1}{\rho^{va}_{r,a}}}, \quad \forall r \in R,\ a \in A(CESVAPRD)$$

$tfpact_{R,A}$: A flag parameter to specify the sectors that adapt generic whole economic TFP growth

Value-Added and Factor Demands: Power Supply Activities

$$PVA_{r,a} \cdot (1 - tva_{r,a}) \cdot QVA_{r,a} = \sum_{f \in F} WFA_{r,f,a}, \quad \forall r \in R,\ a \in A \text{ (CESVAFOC2)}$$

Factor Demand: Non-power Supply Activities

$$WFA_{r,f,a} = \\ PVA_{r,a} \cdot (1 - tva_{r,a}) \cdot QVA_{r,a} \cdot \left(\sum_{f \in F'} \delta^{va}_{r,a} \cdot \left(fcmult_{r,f,a} \cdot QF_{f,r,a}/\left(1 + H^{vae}_{r,a}\right)\right)^{-\rho^{va}_{r,a}}\right)^{-1} \cdot \\ \delta^{va}_{r,a} \cdot \left\{fcmult_{r,f,a}/\left(1 + H^{vae}_{r,a}\right)\right\}^{-\rho^{va}_{r,a}} \cdot QF_{r,f,a}{}^{-\rho^{va}_{r,a}-1}, \forall r \in R,\ a \in A,\ f \in F \text{ (CESVAFOC)}$$

Factor Demand: Power Supply Activities

$$QF_{r,f,a} = ivfa_{r,f,a} \cdot QVA_{r,a}, \quad \forall r \in R,\ a \in A,\ f \in F \text{ (FCTLEO)}$$

Factor cost: Power Supply Activities

$$\sum_f WFA_{r,f,a} \cdot QF_{r,f,a} = PVA_{r,a} \cdot (1 - tva_{r,a}) \cdot QVA_{r,a}, \quad \forall r \in R,\ a \in A \text{ (FCTLEO2)}$$

$f \in F\ (= F')$: a set of factors,
$tva_{r,a}$: rate of value-added tax for activity a,
$\alpha^{va}_{r,a}$: efficiency parameter in the CES value-added function,
$\delta^{va}_{r,a}$: CES value-added function share parameter for factor f in activity a,
$\rho^{va}_{r,a}$: CES value-added function exponent,
$ivfa_{r,f,a}$: input coefficient of factors for Leontief inputs,
$fcmult_{r,f,a}$: productivity shifter of factor f in activity a,
$QF_{r,f,a}$: quantity demanded of factor f from activity a,
$WFA_{r,f,a}$: factor price for factor f in activity a.
$TFPADJ_{r,a}$: TFP adjustment variable which is only applied as endogenous variable in BaU_NoCC (no climate policy and no climate change impacts) scenario which calibrates the GDP assumptions. In other scenarios, the value is taken from BaU_NoCC scenario.

Equation (CESVAPRD) states that, for each activity, the quantity of value-added is a CES function of disaggregated factor quantities. According to equation (CESVAFOC), activities demand factors at the point where the marginal cost of each factor (defined on the left-hand side as the activity-specific factor price) is equal to the marginal revenue product (net of intermediate input costs) of the factor. In the GAMS code, the domain of equation (CESVAFOC) is limited to the factor-activity combinations that appear in the base-year SAM. Similar domain restrictions apply to other equations that are defined over mappings between multiple indices. The exponent ρ^{va} is a transformation of the elasticity of factor substitution: the higher this elasticity, the smaller the value of ρ^{va} and the larger the optimal change in the ratios between different factor quantities in response to changes in relative factor prices. The fact that the average factor price is an endogenous variable while the activity-specific "wage-distortion" factor is exogenous reflects the treatment of factor markets.

Regarding with power sectors, we assume the Leontief type of factor input function, so they are slightly different equations as (FCTLEO) and (FCTLEO2).

Capital aggregation: Perfect substitution

$$QF_{r,\text{"ccap"},a} = QF_{r,\text{"ncap"},a} + QF_{r,\text{"cap"},a} \cdot COPR_{r,a}, \quad \forall r \in R,\ a \in A \text{ (CAPAGG5\_PS)}$$

Capital aggregation: New industry

$$QF_{r,\text{"ccap"},a} = QF_{r,\text{"ncap"},a}, \quad \forall r \in R,\ a \in A \text{ (CAPAGG4)}$$

Capital aggregation: Base year

$$QF_{r,\text{"ccap"},a} = QF_{r,\text{"cap"},a}, \quad \forall r \in R,\ a \in A \text{ (CAPAGG1)}$$

Capital cost balance

$$QF_{r,f,a} \cdot WFA_{r,f,a} = QF_{r,\text{"ncap"},a} \cdot WFA_{r,\text{"ncap"},a} + QF_{r,\text{"cap"},a} \cdot COPR_{r,a} \cdot WFA_{r,\text{"cap"},a} \forall r \in R,\ a \in A,\ f \in FCCAP \text{ (CAPAGG2)}$$

Capital rate of return for new and old

$$WFA_{r,\text{"ncap"},a} \geq WFA_{r,\text{"cap"},a} \ \perp \ QF_{r,\text{"ncap"},a} \geq 0, \quad \forall r \in R,\ a \in A \text{ (CAPAGG3\_PS)}$$

Capital Operation ratio

$$COPR_{r,a} = \left(\frac{WFAT_{r,\text{"cap"},a}}{(WFA_{r,\text{"ncap"},a} + WFA\_FIX_{r,\text{"ncap"},a})}\right)^{\varsigma_{r,a}}, \quad \forall r \in R,\ a \in A \text{ (CAPOPR)}$$

$f \in FCAP\,(= F)$: a set of capital (new and old; "ncap" and "cap"), $WFA\_FIX_{r,\text{"ncap"},a}$: Fixed WFA for NEA and CCSN sectors.

$COPR_{r,a}$: operation ratio,
$\varsigma_{r,a}$: a parameter for operation ratio (assumed 1 as default).

Capital vintage is taken into account and the old and new capitals are aggregated. The first equation represents quantity of operated capital "ccap" is sum of new and old capital quantity. The old capital has operation rate COPR. COPR works only if the rate of return of a sector is less than country average rate of return. In other word the sector does not require any new capital. This is described in the second equation. The third equation defines operation rate which is a function of a ratio of old and new capital's rate of return. .

Disaggregated Intermediate Input Demand

$$QINT_{r,c,a} = ica_{r,c,a} \cdot QINTA_{r,a}, \quad \forall r \in R,\ a \in A,\ c \in CNEN \text{ (INTDEM)}$$

$ica_{r,c,a}$: quantity of c per unit of aggregate intermediate input a,

Emission reduction counter measures (CCS is a good example) are installable when the emission is constrained. The emission reduction inputs is $QRED$ and their cost (\$/tonCO_2eq) is η.

capital consumption for CCS and non-energy related emissions reduction

$$QF_{r,f,a} \cdot WFA_{r,f,a} = \sum_{ap,emcm \in EMCM} QRED_{r,emcm,ap} + \sum_{g,emsc,ap} ABTC\_NCS_{r,ap,g,emsc} \;\; \forall r \in R,\ a \in A\_CCSNorA\_NEA,\ f \in FCCAP \quad \text{(ABTCCAP)}$$

$a \in A\_CCSN$: a sector subset of CCS service
$a \in A\_NEA$: a sector subset of non-energy related emission abatement service

Reduction measures (for non-energy related GHG emissions)

$$QRED_{r,emcm,a} = \xi_{emcm,a}^{max_{emcm,a}} \cdot TSCT_{r,a,\text{"}ccs\text{"}} \sum_{g \in G} gwp_g \cdot EMALI_{r,a,g}$$
$$\forall r \in R,\ a \in A,\ emcm \in EMCM0 (GHG\_ABATEMENT)$$

$QRED_{r,emcm,a}$: input of counter emission reduction counter measures of activity a and measure $emcm$,
$emcm \in EMCM0\,(\subset EMCM)$: a subset of emission reduction counter measures which are for non-energy related emissions.
$tc \in TC$: a set of technology,
$TSCT_{r,a,tc}$: technology tc's share in sector a and region r,
$\xi_{emcm,a}^{max_{emcm,a}}$: Unit cost of CCS in sector a.

Reduction measures (for Energy related GHG emissions)

$$QRED_{r,emcm,a} = \xi_{emcm,a}^{max_{emcm,a}} \cdot TSCT_{r,a,\text{"}ccs\text{"}} \sum_{c \in ENE} \sum_{g \in G} gwp_g \cdot QINT_{r,c,a} \cdot enur_{r,c,a} \cdot efffc_{r,c,a,g}$$
$$\forall r \in R,\ a \in A,\ emcm \in EMCM1 (GHG\_ABATEMENT2)$$

$emcm \in EMCM1\,(\subset EMCM)$: a subset of emission reduction counter measures which are for energy related emissions.

Reduction measures (for biomass power plant GHG absorption)

$$QRED_{r,emcm,a} = \xi_{emcm,a}^{max_{emcm,a}} \cdot TSCT_{r,a,\text{"}ccs\text{"}} \sum_{g \in G} gwp_g \cdot EMBII_{r,a,g}$$
$$\forall r \in R,\ a \in A,\ emcm \in EMCM2 (GHG\_ABATEMENT3)$$

$emcm \in EMCM2\,(\subset EMCM)$: a subset of emission reduction counter measures which are for biomass power plant absorption.

CCS installation rate is determined by the following equation.

CCS equipped share

$$TSCT_{r,a,tc} = exp\left(\left(PGHG_r - \xi_{emcm,a}^{max_{emcm,a}}\right)/(\xi_{emcm,a}^{max_{emcm,a}} \cdot \beta_{r,a,tc})\right) \cdot$$
$$\left(1 + exp\left(\left(PGHG_r - \xi_{emcm,a}^{max_{emcm,a}}\right)/(\xi_{emcm,a}^{max_{emcm,a}} \cdot \beta_{r,a,tc})\right)\right)^{-1}, \forall r \in R,\ a \in A,\ tc \in TC$$
(TECHTOTSHARECCS)

$\alpha_{a,tc}^{tech}$: share parameter for technology Logit selection function,
$\beta_{r,a,tc}^{tech}$: exponent of technology Logit selection.

Energy Input Technology Share:

$$\begin{aligned} QINT_{r,c,a} = {} & QENE_{r,a} \cdot \left(1 + H_{r,c,a}^{ene}\right) \cdot \beta_{r,c,a}^{inden} \cdot \{PQD_{r,c} \cdot (1 + tqd_{r,c,a}) + \\ & PGHG_r \cdot \sum_{g \in G} gwp_g \cdot enur_{r,c,a} \cdot efffc_{r,c,a,g}\}^{el_{r,c,a}^{inden}} \cdot [\sum_{cp \in ENE} \left(1 + H_{r,cp,a}^{ene}\right) \\ & \beta_{r,cp,a}^{inden} \cdot \{PQD_{r,cp} \cdot \left(1 + tqd_{r,cp,a}\right) + \\ & PGHG_r \cdot \sum_{g \in G} gwp_g \cdot enur_{r,cp,a} \cdot efffc_{r,cp,a,g}\}^{el_{r,cp,a}^{inden}}]^{-1} \\ & \forall r \in R,\ c \in ENE,\ a \in A \end{aligned}$$

(ENELOGIT)

Energy Input Costs

$$PENE_{r,a} \cdot QENE_{r,a} =$$
$$\textstyle\sum_{c \in C\_ENE} \left\{PQD_{r,c,a} \cdot (1 + tqd_{r,c,a}) + PGHG_r \cdot \sum_{g \in G} gwp_g \cdot enur_{r,c,a} \cdot efffc_{r,c,a,g}\right\} \cdot$$
$$QINT_{r,c,a}, \quad \forall r \in R,\ a \in A \text{ (PENEDEF)}$$

$PGHG_r$: GHG emission price in region r (US$/t$CO_2$),

$a \in ACES\_ENE\ (\subset A)$: a set of activities with a CES function at energy nest,
$\beta_{r,c,a}^{inden}$: share parameter of Logit function for industrial activity energy source selection,
$el_{r,c,a}^{inden}$: Price elasticity parameter of Logit function for industrial activity energy source selection,
$efffc_{r,c,ac,g}$: emission factors for emissions fossil fuel combustion by sector ac consuming of goods c,
$enur_{r,c,ac}$: energy-used ratio (1-non-energy-use ratio),
gwp_g: global warming potential of gas g.
$H_{r,c,a}^{ene}$: Complementary variable for final energy consumption by fuel constrainy for the energy information coupling mode (in the code this variable is represented by `COMP_FC_TEC(R,A,C)+CompFCTec(R,A,C))`

COMP_FC_TEC is endogenously determined and CompFCTec is exogenous, which is calibrated before 2015 period).

Activities excluding energy transformation sector, which is specified by a set of *ACES_ENE*, have CES energy input technology. Transport sector is an exception for this energy specification and it will be explained later. The energy input is disaggregated into each energy source. The energy source share is determined by Logit function as equation (ENELOGIT). This equation has two parameters one determines base share and the other represents price elasticity. Price includes tax and carbon emission tax which is formulated as multiplying energy use ratio, emission coefficient and GWP (Global Warming Potential) associated with carbon tax rate. These parameters are explained later in detail.

Energy Consumption of Energy Transformation sector

$QINT_{r,c,a} = QENE_{r,a} \cdot iene_{r,c,a}, \quad \forall r \in R,\ a \in ALEO\_ENE,\ c \in ENE$ (LEOENEELY)

$a \in ALEO\_ENE\ (\subset A)$: a set of activities with a CES function at energy nest,

$iene_{r,c,a}$: energy commodity consumption ratio.

Commodity Production and Allocation

$$QXAC_{r,a,c} = \theta_{r,a,c} \cdot QA_{r,a} \cdot (1 - CURRATIO_{r,a}), \quad \forall r \in R,\ a \in A,\ c \in CX \quad \text{(COMPRDFN)}$$

$\theta_{r,a,c}$: yield of output c per unit of activity a.
$CURRATIO_{r,a}$: Curtailement ratio which will be explained later

On the right-hand side, production quantities, disaggregated by activity, are defined as yields times activity levels. On the left-hand side, these quantities are allocated to market sales. Note that this equation permits (i) any commodity to be produced by one or more activities and (ii) any activity to produce one or more commodities.

Energy storage service inputs

$$QINT_{r,c,a} = \theta_{r,a,c} \cdot QA_{r,a} \cdot STORRATIO_{r,a} \cdot strcost_{r,c,a}, \quad \forall r \in R,\ a \in ALEO\_ENE,\ c \in C\_RIS \quad \text{(RENINTEGRATE)}$$

$c \in C\_RIS$: energy storage service
$strcost_{r,c,a}$: Storage cost conversion factor (in the programing which incorporates conversions from capacity to energy amount and MWh to ktoe)

Commodity Production and Allocation (non-energy commodities)

$$QX_{r,c} = \alpha^{ac}_{r,c} \cdot \left(\sum_{a \in A} \delta^{ac}_{r,a,c} \cdot QXAC_{r,a,c}{}^{-\rho^{ac}_{r,c}}\right)^{-\frac{1}{\rho^{ac}_{r,c}}}, \quad \forall r \in R,\ c \in (CX - ENE) \quad \text{(OUTAGGFN)}$$

$\alpha^{ac}_{r,c}$: shift parameter for domestic commodity aggregation function,
$\delta^{ac}_{r,a,c}$: shift parameter for domestic commodity aggregation function,
$\rho^{ac}_{r,c}$: domestic commodity aggregation function exponent,
$c \in ENE$: a set of energy commodities (COM_COA, COM_OIL, COM_GAS, COM_P_P, COM_COP, COM_ELY, COM_GDT).

First-Order Condition for Output Aggregation Function (non-energy commodities)

$$PXAC_{r,a,c} = PX_{r,c} \cdot QX_{r,c} \cdot \left(\sum_{ap \in A} \delta^{ac}_{r,ap,c} \cdot QXAC_{r,ap,c}{}^{-\rho^{ac}_{r,ap}}\right)^{-1} \cdot \delta^{ac}_{r,a,c} \cdot QXAC_{r,a,c}{}^{-\rho^{ac}_{r,a}-1}, \quad \forall r \in R,\ a \in A,\ c \in (CX - ENE) \quad \text{(OUTAGGFOC)}$$

Aggregate marketed production of any commodity excluding energy commodity is defined as a CES aggregate of the marketed output levels of the different activities producing the commodity (equation (OUTAGGFN)). The optimal quantity of the commodity from each activity source is inversely related to the activity-specific price (equation (OUTAGGFOC)). *QX* appears as the output, sold at the price, *PX*, and produced with the inputs, *QXAC*, that are purchased at the prices, *PXAC*.

More specifically, the choice between commodities from different sources is cast as an optimization problem. Equations (OUTAGGFN) and (OUTAGGFOC) are the first-order conditions for maximizing profits from selling the aggregate output, *QX*, at the price, *PX*, subject to the aggregation function and the disaggregated commodity prices, *PXAC*. A decline in the price, *PXAC*, of one activity relative to others would shift demand in its favor without totally eliminating demand for other, higher-priced sources. The degree of substitutability between different producers depends on the value of ρ_a^{ac} which is a transformation of the elasticity of substitution.

It should be noted that, for the case where there is a single producer of a given commodity, the value of the share parameter, δ_a^{ac} would be unity and, as a result, *QXAC* = *QX* and *PXAC* = *PX*, irrespective of the values for the elasticity and the exponent. Or if we assume perfect substitution among the production sectors, equation (OUTAGGFN) is substituted by (OUTAGG_PERFECT_SUB2).

Single sector commodity source

$$PXAC_{r,a,c} = PX_{r,c}, \quad \forall r \in R,\ a \in A,\ c \in (CX - ENE) \text{ (OUTAGGFOC2)}$$

Perfect substitution commodity sources

$$\textstyle\sum_{a \in A} QXAC_{r,a,c} = QX_{r,c}, \quad \forall r \in R,\ a \in A \text{ (OUTAGG\_PERFECT\_SUB2)}$$

Share of Commodity Production and Allocation (energy commodities)

$$SHAC_{r,a,c} = \frac{(1+\Lambda_{r,a,c})\psi^{ac}_{r,a,c} PXAC_{r,a,c}^{\eta^{ac}_{r,a,c}}}{\sum_{ap \in A}(1+\Lambda_{r,ap,c})\psi^{ac}_{r,ap,c} PXAC_{r,ap,c}^{\eta^{ac}_{r,ap,c}}}, \quad \forall r \in R,\ c \in (CX \cap ENE)$$
(PRD_MATERIAL_BAL_SH)

$SHAC_{r,a,c}$: share of the commodity c produced by activity a,
$\psi^{ac}_{r,a,c}$: share parameter of the commodity c produced by activity a,
$\eta^{ac}_{r,a,c}$: Elasticity of domestic commodity aggregation.
$\Lambda_{r,a,c}$: complementary variable for energy system information which is appeared in (EQ_PW_SH_CONS)

Alternatively, considering the capital turn-over, the following equation can be applied,

$$\begin{aligned} SHAC_{r,a,c} = {} & (1 - depr_r - depmult_{r,c}) \cdot (1 + \Lambda_{r,a,c}) \cdot SHAC^{pre}_{r,a,c}/(1 + VRENCAP_{r,c}) + \\ & (depr_r + depmult_{r,c}) \cdot \frac{(1 + \Lambda_{r,a,c})\,\psi 2^{ac}_{r,a,c} PXAC_{r,a,c}^{\eta^{ac}_{r,a,c}}}{\sum_{ap \in A}\left(1 + \Lambda_{r,ap,c}\right)\psi 2^{ac}_{r,ap,c} PXAC_{r,ap,c}^{\eta 2^{ac}_{r,ap,c}}}, \\ & \forall r \in R,\ c \in (CX \cap ENE) \end{aligned}$$

(PRD_MATERIAL_BAL_SH2)

$SHAC^{pre}_{r,a,c}$: previous year's share of the commodity c produced by activity a,
$\psi 2^{ac}_{r,a,c}$: share parameter for new capital of the commodity c produced by activity a,
$\eta 2^{ac}_{r,a,c}$: Elasticity of domestic commodity aggregation for new capital,
$\Lambda_{r,a,c}$: complementary variable for energy system information which is appeared in (EQ_PW_SH_CONS),
$depr_r$: capital depreciation (4%),
$depmult_{r,c}$: additional capital turnover rate by commodity c.

Commodity Production and Allocation (energy commodities)

$$QXAC_{r,a,c} = QX_{r,c} \cdot SHAC_{r,a,c}, \quad \forall r \in R,\ a \in A,\ c \in (CX \cap ENE)$$
(PRD_MATERIAL_BAL)

Aggregate marketed production of the energy commodity is defined as a share function. The share is determined by Logit function. The volume is calculated by multiplying the share and the total produced commodity volume.

Balance of the output and commodity aggregate (energy commodities)

$$\textstyle\sum_{a \in A} QXAC_{r,a,c} \cdot PXAC_{r,a,c} = QX_{r,c}PX_{r,c}, \quad \forall r \in R,\ c \in (CX \cap ENE)$$
(PRDSUM_MATERIAL_BAL)

Energy supply capacity

$$\begin{aligned}\sum_{c \in \{\theta_{r,a,c} > 0\}} QXAC_{r,a,c} = & \sum_{c \in \{\theta_{r,a,c} > 0\}} QC_{r,f,a} \cdot MW2ktoe \\ & \cdot COPR_{r,a} \cdot (CapFac_{r,a} - \sum_{(ap,c) \in AVRE} SHAC_{r,a,c} \cdot 0.5) \\ & ,\ \forall r \in R,\ a \in AESUP\end{aligned}$$

(ENESUPCAP)

$a \in AESUP$: Energy supply sectors
$a \in AVRE$: Variable renewable energy sectors (Solar and wind)
$CapFac_{r,a}$: Capacity factor
$MW2ktoe$: Conversion factor from MW to ktoe/year

Energy supply capacity and capital cost

$$QF_{r,f,a} = QC_{r,f,a} \cdot CostEneSup_{r,f,a}\ ,\ \forall r \in R,\ a \in A,\ f \in Fcap \text{ (ENESUPCAPITAL)}$$

$CostEneSup_{r,f,a}$: cost parameter for capacity

Energy supply capacity and factor prices

$$\begin{aligned}QF_{r,f,a} \cdot WFA_{r,f,a} = & QC_{r,f,a} \cdot COPR_{r,a} \cdot AnnuCostEneSup_{r,f,a} \\ & \cdot CapFac_{r,a} \cdot (1 + CapReturn_{r,f,a}),\ f \in FCAP, \\ & \forall r \in R,\ a \in AESUP\end{aligned}$$

$$\begin{aligned}QF_{r,f,a} \cdot WFA_{r,f,a} = & QC_{r,f,a} \cdot COPR_{r,a} \cdot AnnuCostEneSup_{r,f,a} \\ & \cdot CapFac_{r,a} \cdot (1 + CapReturn_{r,f,a}),\ f \in FCAP, \\ & \forall r \in R,\ a \in AESUP\end{aligned}$$

(ENESUPFACPRI)

$AnnuCostEneSup_{r,f,a}$: annualized unit cost of factor input per capcity of energy supply

4.2 Trade block

Output Transformation (CET) Function (Non-energy commodities)

$$QX2_{r,c} = \alpha^t_{r,c} \cdot \left(\delta^t_{r,c} \cdot QE_{r,c}{}^{\rho^t_{r,c}} + \left(1 - \delta^t_{r,c}\right) \cdot QD_{r,c}{}^{\rho^t_{r,c}}\right)^{\frac{1}{\rho^t_{r,c}}}, \quad \forall r \in R,\ c \in (CE \cap CD - ENE) \text{ (CET)}$$

$\alpha^t_{r,c}$: a CET function shift parameter,
$\delta^t_{r,c}$: a CET function share parameter,
$\rho^t_{r,c}$: a CET function exponent,
$qe\_up_{r,c}$: export constraint.

Equations (CET) address the allocation of marketed domestic output, defined in equation (OUTAGGFN), to two alternative destinations: domestic sales and exports for non-energy commodities. Equation (CET) reflects the assumption of imperfect transformability between these two destinations. The CET function, which applies to commodities that are both exported and sold domestically, is identical to a CES function except for negative elasticities of substitution. The elasticity of transformation between the two destinations is a transformation ofρ^t, for which the lower limit is one. The values are restricted to assure that the isoquant corresponding to the output transformation function is concave to the origin.

Export-Domestic Supply Ratio (Non-energy commodities)

$$\frac{QE_{r,c}}{QD_{r,c}} = \left(\frac{PE_{r,c}}{PDS_{r,c}} \cdot \frac{1-\delta^t_{r,c}}{\delta^t_{r,c}}\right)^{\frac{1}{\rho^t_{r,c}-1}}, \quad \forall r \in R,\ c \in (CE \cap CD - ENE) \text{ (ESUPPLY)}$$

Equation (ESUPPLY) defines the optimal mix between exports and domestic sales. Equations (PX2DEF), (CET), and (ESUPPLY) constitute the first-order conditions for maximization of producer revenues given the two prices and subject to the CET function and a fixed quantity of domestic output. Note that equation (ESUPPLY) assures that an increase in the export-domestic price ratio generates an increase in the export-domestic supply ratio (i.e. a shift toward the destination that offers the higher return).

Output Transformation for Domestically Sold Outputs Without Exports and for Exports Without Domestic Sales

$$QX2_{r,c} = QD_{r,c} + QE_{r,c}, \quad \forall r \in R,\ c \in (CE \cap CEN) \cup (CD \cap CDN) \text{ (CET2, CET3)}$$

$c \in CEN\,(\subset C)$: non-exported commodities (complement of CE),
$c \in CDN\,(\subset C)$: commodities without domestic market sales of domestic output (complement of CD).

This equation replaces the CET function for domestically produced commodities that do not have both exports and domestic sales. It allocates the entire output volume to one of these two destinations.

Share of the Domestically Sold and Export (energy commodities)

$$SHQE_{r,c} = \frac{\psi^t_{r,c} PE_{r,c}{}^{\eta^t_{r,c}}}{\psi^t_{r,c} PE_{r,c}{}^{\eta^t_{r,c}} + \psi 2^t_{r,c} PDS_{r,c}{}^{\eta^t_{r,c}}}, \quad \forall r \in R,\ c \in (CE \cap CD \cap ENE) \text{ (EXP\_MATERIAL\_BAL\_SH)}$$

$SHQE_{r,c}$: share of domestically sold and export commodity c,
$\psi^t_{r,c}$: scale parameter for export share of commodity c,
$\psi 2^t_{r,c}$: scale parameter for domestically produced share of commodity c,
$\eta^t_{r,c}$: elasticity of domestic produced commodity aggregation.

Exported Energy Commodities

$$QE_{r,c} = QX2_{r,c} \cdot SHQE_{r,c}, \quad \forall r \in R,\ c \in (CE \cap CD \cap ENE)$$
(EXP_MATERIAL_BAL)

Domestically Sold Energy Commodities

$$QD_{r,c} = QX2_{r,c} \cdot (1 - SHQE_{r,c}), \quad \forall r \in R,\ c \in (CE \cap CD \cap ENE)$$
(DOME_MATERIAL_BAL)

The allocation of the domestically produced energy commodities is determined with the price change comparing with the previous year. The share of the export to produced commodities is described as the above equation. The volume is calculated by multiplying the share and the total produced commodity volume.

Composite Supply (Armington) Function (Non-energy commodities)

$$QQ_{r,c} = \alpha^q_{r,c} \cdot \left(\delta^q_{r,c} \cdot QM_{r,c}{}^{-\rho^q_{r,c}} + \left(1 - \delta^q_{r,c}\right) \cdot QD_{r,c}{}^{-\rho^q_{r,c}}\right)^{-\frac{1}{\rho^q_{r,c}}}, \quad \forall r \in R,\ c \in (CM \cap CD - ENE) \text{ (ARMINGTON)}$$

$\alpha^q_{r,c}$: an Armington function shift parameter,
$\delta^q_{r,c}$: an Armington function share parameter,
$\rho^q_{r,c}$: an Armington function exponent.

Imperfect substitutability between imports and domestic output sold domestically is captured by a CES aggregation function in which the composite commodity that is supplied domestically is ”produced” by domestic and imported commodities entering this function as ”inputs”. When the domain of this function is limited to commodities that are both imported and produced domestically, it is often called an ”Armington” function, named after the originator of the idea of using a CES function for this purpose. The elasticity of substitution between commodities from these two sources is a transformation of for which the lower limit is minus one.

Import-Domestic Demand Ratio (non-energy commodities)

$$\frac{QM_{r,c}}{QD_{r,c}} = \left(\frac{PDD_{r,c}}{PM_{r,c}} \cdot \frac{\delta^q_{r,c}}{1-\delta^q_{r,c}}\right)^{\frac{1}{\rho^q_{r,c}+1}}, \quad \forall r \in R,\ c \in (CM \cap CD - ENE) \text{ (COSTMIN)}$$

Equation (COSTMIN) defines the optimal mix between imports and domestic output. Its domain is thus limited to imports with domestic production. Note that the equation assures that an increase in the domestic-import price ratio generates an increase in the import-domestic demand ratio (that is, a shift away from the source that becomes more expensive). Together, equations (PQDDEF), (ARMINGTON) and (COSTMIN) constitute the first-order conditions for cost-minimization given the two prices and subject to the Armington function and a fixed quantity of the composite commodity.

Composite Supply for Non-imported Outputs and Non-produced Imports

$$QQ_{r,c} = QD_{r,c} + QM_{r,c}, \quad \forall r \in R,\ c \in (CD \cap CMN) \cup (CM \cap CDN)$$

(ARMINGTON2, ARMINGTON3)

$c \in CMN\,(\subset C)$: a set of non-imported commodities.

The Armington function is replaced by equation (ARMINGTON2, ARMINGTON3) for the union of commodities that have either imports or domestic sales of domestic output but not both. For any commodity in this category, it imposes equality between ”composite supply” and one of the variables on the right-hand side.

Share of the domestically sold and imported (energy commodities)

$$SHQM_{r,c} = \frac{\psi^m_{r,c} {PM_{r,c}}^{\eta^m_{r,c}}}{\psi^m_{r,c} {PM_{r,c}}^{\eta^m_{r,c}} + \psi 2^m_{r,c} {PDD_{r,c}}^{\eta^m_{r,c}}}, \quad \forall r \in R,\ c \in (CM \cap CD \cap ENE)$$

(IMP_MATERIAL_BAL_SH)

$SHQM_{r,c}$: share of domestically sold and imported commodity c,
$\psi^m_{r,c}$: scale parameter for import share of commodity c,
$\psi 2^m_{r,c}$: scale parameter for domestically produced goods share of commodity c,
$\eta^m_{r,c}$: elasticity of domestic consumption commodity aggregation.

Imported energy commodities

$$QM_{r,c} = QQ_{r,c} \cdot SHQM_{r,c}, \quad \forall r \in R,\ c \in (CM \cap CD \cap ENE)$$

(IMP_MATERIAL_BAL)

Domestically sold energy commodities

$$QD_{r,c} = QQ_{r,c} \cdot (1 - SHQM_{r,c}), \quad \forall r \in R,\ c \in (CM \cap CD \cap ENE)$$

(DOMI_MATERIAL_BAL)

The aggregation of imported and domestically produced energy commodities is determined with the price change compared to the previous year being the same as the export share determination.

4.3 Land block

The land producitity is exogenously determined if you switch on the land disggragation (which is specified as LANDAGG in program).

Land input of activity

$$QF_{r,f,a} \cdot Crop\_intensity_{r,a} = landeff_{r,f,a} \cdot fcmult_{r,f,a} \cdot \textstyle\sum_c QXAC_{r,a,c}, \quad \forall r \in R,\ f \in FLND, a \in A$$

(LANDINPUT)

$landeff_{r,f,a}$: land productivity coefficient.
$Crop\_intensity_{r,a}$: Crop intensity

Enodogenous yield change for activity a

$$ENDYILC_{r,a} = (WFA_{r,\text{"}LND\text{"},a} / WFA\_base_{r,\text{"}LND\text{"},a})^{\varphi yi_{r,a}}, \quad \forall r \in R,\ a \in A$$

(ENDYILCEQU)

$\varphi yi_{r,a}$: Endogenous yield exponent
$WFA\_base_{r,f,a}$: *WFA* price in base year

The land cost is equal to the summation of all AEZ cost.

AEZ aggregation for activity a

$$QF_{r,f,a} \cdot WFA_{r,f,a} = \sum_{fl \in FL} PLAND_{r,fl,a} \cdot QLAND_{r,fl,a}, \quad \forall r \in R,\ f \in FLND, a \in A$$

(LANDAGGAEZ)

$PLAND_{r,fl,a}$: land price of activity a and AEZ *fl*,
$QLAND_{r,fl,a}$: land quantity of activity a and AEZ *fl*.

The agrictultural activities determine the share of AEZ based on Logit function and the land price.

AEZ selection for activity a

$$QLAND_{r,fl,a} = QF_{r,\text{"lnd"},a} \cdot \frac{\delta^{ls}_{r,fl,a} \cdot PLAND_{r,fl,a}{}^{\rho^{ls}_{r,a}}}{\sum_{flp \in FL} \delta^{ls}_{r,flp,a} \cdot PLAND_{r,flp,a}{}^{\rho^{ls}_{r,a}}}, \quad \forall r \in R,\ fl \in FL, a \in A$$

(LANDAEZSEL)

$\delta^{ls}_{r,fl,a}$: share parameter of AEZ input,
$\rho^{ls}_{r,a}$: exponent parameter of aez input function.

Crop field aggregated price is as follows.

Crop land price

$$QCROP_{r,fl} \cdot PCROP_{r,fl} = \sum_{a \in AAGR} PLAND_{r,fl,a} \cdot QLAND_{r,fl,a}, \quad \forall r \in R,\ fl \in FL$$

(CROPLANDPRICE)

$PCROP_{r,fl}$: crop field AEZ aggregated land price,
$QCROP_{r,fl}$: crop field AEZ aggregated land use.

Crop land selection is detemined by the Logit as specified followings.

AEZ land crop selection

$$QLAND_{r,fl,a} = QCROP_{r,fl} \cdot \frac{\delta^{ltc}_{r,fl,a} \cdot PLAND_{r,fl,a}{}^{\rho^{ltc}_{r,fl}}}{\sum_{ap \in AAGR} \delta^{ltc}_{r,fl,ap} \cdot PLAND_{r,fl,ap}{}^{\rho^{ltc}_{r,fl}}}, \quad \forall r \in R,\ fl \in FL,\ a \in AAGR$$

(CROPSEL)

$\delta^{ltc}_{r,fl}$: share parameter of crop AEZ input,
$\rho^{ltc}_{r,a}$: exponent parameter crop input.

Grazing field aggregated price is as follows.

Grazing land price

$$QGRZ_{r,fl} \cdot PGRZ_{r,fl} = \sum_{a \in ALIV} PLAND_{r,fl,a} \cdot QLAND_{r,fl,a}, \quad \forall r \in R,\ fl \in FL$$
(GRAZPRICE)

$PGRZ_{r,fl}$: grazing AEZ aggregated land price,
$QGRZ_{r,fl}$: grazing AEZ aggregated land use.

Grazing land selection is detemined by the Logit as specified followings.

AEZ land grazing selection

$$QLAND_{r,fl,a} = QGRZ_{r,fl} \cdot \frac{\delta^{ltc}_{r,fl,a} \cdot PLAND_{r,fl,a}^{\rho^{ltc}_{r,fl}}}{\sum_{ap \in ALIV} \delta^{ltc}_{r,fl,ap} \cdot PLAND_{r,fl,ap}^{\rho^{ltc}_{r,fl}}}, \quad \forall r \in R,\ fl \in FL,\ a \in ALIV$$
(GRAZSEL)

$\delta^{ltc}_{r,fl}$: share parameter of grazing AEZ input,
$\rho^{ltc}_{r,fl}$: exponent parameter grazing input.

Crop and grazing land use decision is made by the following equations.

Crop and grazing selection for AEZ (crop)

$$QCROP_{r,fl} = QAGRT_{r,fl} \cdot \frac{\delta^{ltt}_{r,fl,\text{"CROP"}} \cdot PCROP_{r,fl}^{\rho^{ltt}_{r,fl}}}{\delta^{ltt}_{r,fl,\text{"CROP"}} \cdot PCROP_{r,fl}^{\rho^{ltt}_{r,fl}} + \delta^{ltt}_{r,fl,\text{"GRZ"}} \cdot PGRZ_{r,fl}^{\rho^{ltt}_{r,fl}}}, \quad \forall r \in R,\ fl \in FL$$
(CROPGRAZSEL)

$QAGRT_{r,fl}$: agriculture AEZ aggregated land use,
$\delta^{ltt}_{r,fl}$: share parameter of crop and grazing input,
$\rho^{ltt}_{r,fl}$: exponent parameter crop and grazing input.

Crop and grazing selection for AEZ (grazing)

$$QGRZ_{r,fl} = QAGRT_{r,fl} \cdot \frac{\delta^{ltt}_{r,fl,\text{"GRZ"}} \cdot PGRZ_{r,fl}^{\rho^{ltt}_{r,fl}}}{\delta^{ltt}_{r,fl,\text{"CROP"}} \cdot PCROP_{r,fl}^{\rho^{ltt}_{r,fl}} + \delta^{ltt}_{r,fl,\text{"GRZ"}} \cdot PGRZ_{r,fl}^{\rho^{ltt}_{r,fl}}}, \quad \forall r \in R,\ fl \in FL$$
(CROPGRAZSEL2)

Aggregation of agriculture (in case missing either crop or graze)

$$QAGRT_{r,fl} = QCROP_{r,fl} + QGRZ_{r,fl}, \quad \forall r \in R,\ fl \in FL \text{ (AGRAGGNON)}$$

Aggregated agriculture land price is derived from the next equation.

Aggregated agricultural price

$$QAGR_{r,fl} \cdot PAGRT_{r,fl} = QCROP_{r,fl} \cdot PCROP_{r,fl} + QGRZ_{r,fl} \cdot PGRZ_{r,fl}, \quad \forall r \in R,\ fl \in FL$$
(AGRLANDPRICE)

$PAGRT_{r,fl}$: agriculture AEZ aggregated land price.

Forestry or agricultural use is determined by following equations.

Agriculture and forestry selection for AEZ (agriculture)

$$QAGRT_{r,fl} = QLANT_{r,fl} \cdot \frac{\delta^{ltf}_{r,fl,\text{"AGR"}} \cdot PAGRT_{r,fl}^{\rho^{ltf}_{r,fl}}}{\delta^{ltf}_{r,fl,\text{"AGR"}} \cdot PAGRT_{r,fl}^{\rho^{ltf}_{r,fl}} + \delta^{ltf}_{r,fl,\text{"FRS"}} \cdot PLAND_{r,fl,\text{"FRS"}}^{\rho^{ltf}_{r,fl}}}, \quad \forall r \in R,\ fl \in FL$$
(AGRFRSSEL)

$QLANT_{r,fl}$: total AEZ aggregated land use,
$\delta^{ltf}_{r,fl}$: share parameter of agriculture and forestry input,
$\rho^{ltf}_{r,fl}$: exponent parameter agriculture and forestry input.

Agriculture and forestry selection for AEZ (forestry)

$$QLAND_{r,fl,a} = QLANDT_{r,fl} \cdot \frac{\delta^{ltf}_{r,fl,\text{"AGR"}} \cdot PLAND_{r,fl,\text{"FRS"}}^{\rho^{ltf}_{r,fl}}}{\delta^{ltf}_{r,fl,\text{"AGR"}} \cdot PAGRT_{r,fl}^{\rho^{ltf}_{r,fl}} + \delta^{ltf}_{r,fl,\text{"FRS"}} \cdot PLAND_{r,fl,\text{"FRS"}}^{\rho^{ltf}_{r,fl}}}, \quad \forall r \in R,\ fl \in FL, A \in AFRS$$
(AGRFRSSEL2)

Aggregation of agriculture (in case missing agriculture)

$$QLANDT_{r,fl} = QLAND_{r,fl,\text{"FRS"}}, \quad \forall r \in R,\ fl \in FL \text{ (AGGLAND\_NON)}$$

Aggregation of agriculture (in case missing forestry)

$$QLANDT_{r,fl} = QAGRT_{r,fl}, \quad \forall r \in R,\ fl \in FL \text{ (AGGLAND\_NON2)}$$

Total land use price is expressed by the following.

Aggregated total land price

$$QLANDT_{r,fl} \cdot PLANDT_{r,fl} = QAGRT_{r,fl} \cdot PAGRT_{r,fl} + QLAND_{r,fl,\text{"FRS"}} \cdot PLAND_{r,fl,\text{"FRS"}}, \quad \forall r \in R,\ fl \in FL$$
(AGGLANDPRICE)

$PLANDT_{r,fl}$: total AEZ aggregated land price.

Total land use is determined by the following equation.

Total land

$$QLANDT_{r,fl} = qlandtotara_{r,fl} \cdot \frac{\delta^{ara}_{r,fl,\text{"USE"}} \cdot PLANDT_{r,fl}^{\rho^{ara}_{r,fl}}}{\delta^{ara}_{r,fl,\text{"USE"}} \cdot PLANDT_{r,fl}^{\rho^{ara}_{r,fl}} + \delta^{ara}_{r,fl,\text{"NUS"}} \cdot plandt\_ini_{r,fl}^{\rho^{ara}_{r,fl}}}, \quad \forall r \in R,\ fl \in FL$$
(TOTLAND)

$qlandtotara_{r,fl}$: total AEZ arable land,
$plandt\_ini_{,r,fl}$: total unused land price,
$\delta^{ara}_{r,fl,*}$: share parameter of arable land input,
$\rho^{ara}_{r,fl}$: exponent parameter of arable land input.

Land use change emissions by AEZ

$$LUCHEM_{r,fl} = LUCHEM\_P_{r,fl} + LUCHEM\_N_{r,fl}, \quad \forall r \in R,\ fl \in FL$$
(EQ_LUCHEM)

$LUCHEM_{r,fl}$:Land use change emissions in AEZ fl region r
$LUCHEM\_P_{r,fl}$: Land use change emissions (positive) in AEZ fl region r
$LUCHEM\_N_{r,fl}$: Land use change emissions (negative) in AEZ fl region r

Positive Land use change emissions

$$LUCHEM\_P_{r,fl} = \max\left[0, \left(qfrspre_{r,fl} - QPRMLANDT_{r,fl,\text{"}frs\text{"}}\right) \cdot ecoefluc_{r,fl,\text{"}frs\text{"}}\right], \quad \forall r \in R,\ fl \in FL$$
(EQ_LUCHEM_P)

$QPRMLANDT_{r,fl}$: Primary land area AEZ *fl*, region *r*
$qfrspre_{r,fl,sprl}$: Previous year's primary land area AEZ *fl*, region *r*, land classification *sprl*
$ecoefluc_{,fl,sprl}$: Landuse chage emission coefficient AEZ *fl*, region *r*, land classification *sprl*

Negative Land use change emissions

$$\begin{aligned} LUCHEM\_N_{r,fl} = &-\sum_{y \in Yold} prluch_{y,r,fl} \cdot cf\_v2t \cdot cdst\_wd \cdot 11/3 \cdot \\ &[\exp[\alpha^{bms}_{fl} - \frac{30}{(Pyear - baseyear + 1) - Year_y}] - \\ &\exp[\alpha^{bms}_{fl} - \frac{30}{(Pyear - baseyear) - Year_y}]] \quad \forall r \in R,\ fl \in FL \end{aligned}$$

(EQ_LUCHEM_N)

Pyear: the calculation year
Baseyear: base year
$Year_y$: Year order (ex; base year is 1)
$prluch_{y,r,fl}$: Prior year's land use change
cf_v2t: conversion factor from volume to ton
$cdst\_wd$: conversion factor for Carbon density
α^{bms}_{fl}: a parameter of biomass stock

4.4 Institution block

Factor price

$$WFA_{r,f,a} = WF_{r,f} \cdot WFDIST_{r,f,a} - GHGCOST_r / \textstyle\sum_{(ap,fp) \in A,FLAB} QF_{r,fp,a}, \forall r \in R,\ a \in A,\ f \in F$$ (FACPRICEDEF)

$WF_{r,f}$: average price of factor,
$WFDIST_{r,f,a}$: factor price distortion factor for factor f in activity *a*.
$GHGTCOST_r$: Carbon tax revenue

Factor Income

$$YF_{r,f} = \textstyle\sum_{a \in A} WF_{r,f} \cdot WFDIST_{r,f,a} \cdot QF_{r,f,a} + transfr\_f_{r,f,\text{"}ROW\text{"}} \cdot EXR_r, \forall r \in R,\ f \in F$$ (YFDEF)

$YF_{r,f}$: income of factor *f*,
$transfr\_f_{r,f}$: factor transfer from abroad.

Institutional Factor Incomes

$$YIF_{r,i,f} = shif_{r,i,f} \cdot \left(\left(1 - tf_{r,f}\right) \cdot YF_{r,f} - transfr_{r,\text{"}ROW\text{"},f} \cdot EXR_r\right), \forall r \in R,\ i \in INSD, f \in F \text{ (YIFDEF)}$$

$i \in INS$: a set of institutions (domestic and rest of the world),
$i \in INSD\,(\subset INS)$: a set of institutions (domestic and rest of the world),
$YIF_{r,i,f}$: income to domestic institution *i* from factor *f*,
$shif_{r,i,f}$: share of domestic institution *i* in income of factor *f*,
$tf_{r,f}$: direct tax rate for factor *f*,
$transfr_{r,f}$: factor transfer to abroad.

Equation (YFDEF) defines the total income of each factor. In equation (YIFDEF), this income is splited among domestic institutions in fixed shares after payment of direct factor taxes and transfers to the rest of the world. The latter are fixed in foreign currency and transformed into domestic currency by multiplying by the exchange rate. This equation makes reference to the set of domestic institutions (households, enterprises, and the government), a subset of the set of institutions, which also includes the rest of world.

Income of non-governmental domestic Institution

$$\begin{aligned} YI_{r,i} = & \sum_{f \in F} YIF_{r,i,f} + TRII\_Resource_{r,i} \\ & + shincome_{r,i} \cdot (GHGTCOST_r - \sum_{ac \in AC} CarTaxExempt \cdot GHGCAFULL_{r,ac}) + VRENCAPTOT_{r,i} \\ & - (PGHG\_G + PGHG\_IMP\_QUO_r - PGHG\_EXP\_QUO_r) \\ & \cdot GHG\_IMP_r \cdot EXR_r \cdot shincome_{r,i} \\ & + shres_{r,i} \cdot \sum_{a \in A} PRES_{r,a} \cdot QRES_{r,a} + shincome_{r,i} \cdot \\ & \sum_{a \in A} QENE_{r,a} \cdot PENE_{r,a} \cdot (\frac{1}{1 - ADEEI_{r,a}} - 1) \\ & + shincome_{r,i} \cdot \sum_{a \in A} RQUOQA_{r,a} \cdot QA_{r,a} \cdot PA_{r,a} \forall r \in R,\ i \in I \end{aligned}$$

$$\text{(YIDEF)}$$

$i \in INSDNG\,(\subset INSD)$: a set of domestic nongovernment institutions,
$YI_{r,i}$: income of institution i (in the set INSDNG),
$TRII\_Resource_{r,i}$: transfers to institution *i,*
$GHGTCOST_r$: GHG emission cost,
$VRENCAPTOT_r$: rent related to electricity capacity,
$shincome_{r,i}$: total income share of GHG emission cost for institution *i,*
$shres_{r,i}$: resource income share of institution *i,*
GHG_IMP_r: GHG emission credit import (net),
$PGHG\_G_r$: global GHG emission price,
$PGHG\_IMP\_QUO_r$: GHG emission price generated by import quota,
$PGHG\_EXP\_QUO_r$: GHG emission price generated by export quota.
$RQUOQA_{r,a}$: shadow subsidies of the fixed activity level (If the acticity level is fixed, the complementary subsidies are generated as $RQUOQA$).

Domestic nongovernment institutions form a subset of the set of domestic institutions. The total income of any domestic nongovernment institution is the sum of factor incomes (defined in equation (YIDEF), transfers from other domestic nongovernment institutions, the balance of payment of GHG emission trading, CCS installation cost, rent generated by the quota of the activity level and electricity generation capacity rent. This rent total is defined below (only for enterprise).

Total rent of electricity capacity

$$VRENCAPTOT_{r,\text{"}ent\text{"}} = \sum_{a \in A} VRENCAP_{r,a} \forall r \in R \quad \text{(VRENCAPIN)}$$

Household Consumption Expenditures

$$\begin{aligned} EH_{r,h} = {} & (1 - shii\_use_{r,h})(1 - MPS_{r,h}) \cdot (1 - TINS_{r,h}) \cdot YI_{r,h} - PGHG_r \\ & \cdot \sum_{g \in G} gwp_{r,g} \cdot (EMALH_{r,h,g} + EMBIH_{r,h,g}) \\ & + CarTaxExempt \cdot GHGCAFULL_{r,h} \forall r \in R,\ h \in H \end{aligned}$$

(EHDEF)

$h \in H\,(\subset INSDNG)$: a set of households,

$EH_{r,h}$: household consumption expenditures,

$shii\_use_{r,i}$: share of net income of i,

$MPS_{r,i}$: marginal propensity to save for domestic nongovernment institution (exogenous variable),

$TINS_{r,i}$: direct tax rate for institution i.

Government Revenue

$$
\begin{aligned}
YG_r = & \sum_{i \in INSDNG} TINS_{r,i} \cdot YI_{r,i} + \sum_{f \in F} tf_{r,f} \cdot YF_{r,f} \\
& + \sum_{a \in A} ta_{r,a} \cdot PA_{r,a} \cdot QA_{r,a} + \sum_{a \in A} tva_{r,a} \cdot PVA_{r,a} \cdot QVA_{r,a} \\
& + \sum_{c \in CM} tm_{r,c} \cdot PWM_c \cdot dis\_imp_{r,c} \cdot QM_{r,c} \cdot \overline{EXR}_r \\
& + \sum_{c \in CE} te_{r,c} \cdot PWE_c \cdot dis\_exp_{r,c} \cdot QE_{r,c} \cdot \overline{EXR}_r \\
& + \sum_{c \in C} \sum_{a \in A} tqd_{r,c,a} \cdot dfpq_{r,c,a} \cdot PQD_{r,c} \cdot QINT_{r,c,a} \\
& + \sum_{c \in C} \sum_{h \in H} tqd_{r,c,h} \cdot dfpq_{r,c,h} \cdot PQD_{r,c} \cdot QH_{r,c,h} \\
& + \sum_{c \in C} tqd_{r,c,\text{"}gov\text{"}} \cdot dfpq_{r,c,\text{"}gov\text{"}} \cdot PQD_{r,c} \cdot QG_{r,c} \\
& + \sum_{c \in C} tqd_{r,c,\text{"}S-I\text{"}} \cdot dfpq_{r,c,\text{"}S-I\text{"}} \cdot PQD_{r,c} \cdot QINV_{r,c} \\
& + \sum_{f \in F} YIF_{r,\text{"}gov\text{"},f} + TRII\_Resource_{r,\text{"}gov\text{"}} - TRII\_Use_{r,\text{"}gov\text{"}} \\
& + GHGTCOST_r \cdot shincome_{r,\text{"}gov\text{"}} \\
& + GHG_{IMP_r} \cdot EXR_r \cdot \left(PGHG_{IMP_{QUO_r}} - PGHG_{EXP_{QUO_r}}\right) \\
& + shres_{r,\text{"}gov\text{"}} \cdot \sum_{a \in A} PRES_{r,a} \cdot QRES_{r,a} \forall r \in R
\end{aligned}
$$

(YGDEF)

YG_r: government revenue.

Total government revenue is the sum of revenues from taxes, factors, and transfers from the rest of the world. Emission trade cost is paid by government.

Government Expenditure

$$EG_r = \textstyle\sum_{c \in C} PQD_{r,c} \cdot dfpq_{r,c,\text{"}gov\text{"}} \cdot \left(1 + tqd_{r,c,\text{"}gov\text{"}}\right) \cdot QG_{r,c} \quad \forall r \in R \text{ (EGDEF)}$$

EG_r: government expenditures,
$TRII\_Use_{r,i}$: transfers from institution i.

Total government spending is the sum of government spending on consumption and transfers.

Transfer use

$$TRII\_Use_{r,i} = shii\_use_{r,i} \cdot (1 - MPS_{r,i}) \cdot (1 - TINS_{r,i}) \cdot YI_{r,i}, \forall r \in R,\ i \in INSDNG$$

(TRIIDEF2_H, TRIIDEF2_E)

Transfers between domestic nongovernment institutions are paid as fixed shares of the total institutional incomes net of direct taxes and savings. The values of *MPS* and *TINS* are defined in separate equations.

Government transfer use

$$TRII\_Use_{r,"gov"} = \overline{trnsfr\_CRT_{r,"gov"}} \cdot CPI_r \quad \forall r \in R \text{ (TRIIDEF2\_G)}$$

$\overline{trnsfr\_CRT_{r,"gov"}}$: governmental transfer in base year.

Governmental transfer is production of CPI and that of base year.

Transfer resource

$$TRII\_Resource_{r,i} = shii\_resource_{r,i} \cdot \left(crt\_in_r \cdot \overline{EXR_r} - crt\_out_r \cdot \overline{EXR_r} + \sum_{i'} TRII\_Use_{r,i'}\right), \forall r \in R,\ i \in INSD$$
(TRIIDEF3)

$shii\_resource_{r,i}$: a ratio of transfer to institution i of total transfer in a country,
crt_in_r: transfer from rest of the world,
crt_out_r: transfer to rest of the world.

4.5 Expenditure block

Among the domestic nongovernment institutions, only households demand commodities. Household expenditure is divided into two sources, one is energy and the other is non-energy commodities. Non-energy commodity expenditure is determined by LES or alternatively by AIDADS. The energy expenditure has two classifications. One is car fuel use expenditure and the other is other energy service demand such as space heating, space cooling, cooking and so on.

The passenger car made by household is formulated by the income level and its elasticity.

Household Consumption Spending (LES)

$$PQH_{r,ch} \cdot QCH_{r,ch,h} = PQH_{r,ch} \cdot \gamma^m_{r,ch,h} + \beta^m_{r,ch,h} \cdot \left(EH_{r,h} - \sum_{c' \in C} PQH_{r,ch'} \cdot \gamma^m_{r,c'h,h}\right)$$
$$forall r \in R,\ c \in C, h \in H$$

(HMDEM2)

$\gamma^m_{r,ch,h}$: subsistence consumption of marketed commodity c for household h,
$\beta^m_{r,ch,h}$: marginal share of consumption spending on marketed commodity c for household h.

If the enduse device selection is considered, the above equation is slightly chaged. The concept of the following equation is energy device selection is made outside of the utility function.

$$
\begin{aligned}
PQH_{r,ch} \cdot QCH_{r,ch,h} = PQH_{r,ch} \cdot \gamma^{m}_{r,ch,h} + \beta^{m}_{r,ch,h} \cdot (EH_{r,h} - \sum_{c' \in C} PQH_{r,ch'} \cdot \gamma^{m}_{r,c'h,h} \\
- \sum_{c' \in C\_ENE} (PQD_{r,c'} \cdot dfpq_{r,c',h} \cdot (1 + tqd_{r,c',h}) \\
+ \sum_{g \in G} PGHG_r \cdot gwp_g \cdot efffc_{r,c',h,g}) \cdot QH_{r,c',h}) \\
\forall r \in R,\ c \in C, h \in H
\end{aligned}
$$

(HMDEM2)

Household goods price

$$
\begin{aligned}
QCH_{r,ch,h} \cdot PQH_{r,ch,h} = \sum_{c \in wch_{r,ch,c,h}} QH_{r,c,h} \cdot (PQD_{r,c} \cdot dfpq_{r,c,h} \cdot (1 + tqd_{r,c,h}) \\
+ \sum_{g \in G} PGHG_r \cdot gwp_g \cdot efffc_{r,c,h,g}) \forall r \in R,\ ch \in CH, h \in H
\end{aligned}
$$

(HPMAP)

Household goods consumption mapping

$QH_{r,c,h} \cdot AgrWstc_{r,c,h} = \sum_{ch \in wch_{r,ch,c,h}} QCH_{r,ch,h} \quad , \forall r \in R,\ c \in C, h \in H$ (HMMAP)

$PQH_{r,ch,h}$: price of household category commodity ch,
$QCH_{r,ch,h}$: household consumption of household commodity category ch,
$AgrWstc_{r,c,h}$: a coefficient for food waste generated in household sector
$ch \in CH$: household commodity category ch.

It is assumed that each household maximizes a ”Stone-Geary” utility function subject to a consumption expenditure constraint. The resulting first-order conditions, equations (HMDEM2), are referred to as LES (linear expenditure system) functions since spending on individual commodities is a linear function of total consumption spending, EH. Note that the energy commodity price includes GHG emission price and additional energy efficiency improvement is also considered.

One thing that should be noted here is househould commodity category ch. This is same as c except for energy commodity. Energy commodity is aggregated as one ”energy”. Therefore, this function determines total energy consumption rather than that of each fuel type. Fuel share is determined by Logit function.

The energy related consumption is a sum of car energy consumption, non-car energy consumption and machineary (COM_OMF) as follows. Basically, CES substitution is assumed for them which divides the consumption into energy, and machineary part. Energy consumption is further disaggregated by fuels by logit function which are same as the industrial activities.

Household energy source consumption

$QH_{r,c,h} = QCARENE_{r,c,h} + QHENEGE_{r,c,h} + \sum_{ch \in CHtoCOMF} QENESMCH_{r,ch,h},\ \forall r \in R,\ h \in H,\ c \in ENEorOMF$ (HMDEM_ENE_FL)

$ch \in CHtoCOMF$: mapping set from ch to C only for (COM_OMF)
$QHENEGE_{r,c,h}$: Energy consumption for non-car usage in the household sector
$QCARENE_{r,c,h}$: Energy consumption for car usage in the household sector
$QENESMCH_{r,ch,h}$: machienary consumption in the household sector

Energy and Value-Added composite for household energy consumption

$$QCH_{r,ch,h} = \alpha^{hene}_{r,ch,h} \cdot (\delta^{hene}_{r,ch,h} \cdot QENESMCH_{r,ch,h}{}^{-\rho^{hene}_{r,ch,h} - \Gamma^{hene}_{r,ch,h}} + (1 - \delta^{hene}_{r,ch,h}) \cdot (1 + H^{hene}_{r,ch,h}) \cdot aeeit_{r,h} QENESENET_{r,ch,h}^{-\rho^{hene}_{r,ch,h} - \Gamma^{hene}_{r,ch,h}})^{-\frac{1}{\rho^{hene}_{r,ch,h} + \Gamma^{hene}_{r,ch,h}}} \forall r \in R,\ h \in \mathrm{H},\ ch \in CHENE$$

(HENECES)

Energy and Value-added Input CES Technology: Energy – Value added -Input Ratio for household energy consumption

$$QENESMCH_{r,ch,h} = QENESENET_{r,ch,h} \cdot \left(\frac{\delta^{hene}_{r,ch,h}}{\left(1-\delta^{hene}_{r,ch,h}\right) \cdot \left(1+H^{vae}_{r,a}\right)} \cdot \frac{PENESENET_{r,ch,h}}{PQD_{r,\text{"}com\_OMF\text{"}} \cdot dfpq_{r\text{"}com\_OMF\text{"},h} \cdot \left(1+tqd_{r,\text{"}com\_OMF\text{"},h}\right)} \right)^{\frac{1}{1+\rho^{hene}_{r,ch,h}+\Gamma^{hene}_{r,ch,h}}}, \quad \forall r \in R,\ h \in H,\ ch \in CHENE \text{ (HENEFOC)}$$

$ch \in$ CHENE: household consumption classification for energy consumption (car-usage or non-car)
$\alpha^{hene}_{r,a}$: efficiency parameter in the CES energy and value-added function,
$\delta^{hene}_{r,ch,h}$: CES energy and value-added function share parameter in household,
$\rho^{hene}_{r,ch,h}$: CES energy and value-added function exponent,
$\Gamma^{hene}_{r,ch,h}$: Complementary variable for final energy consumption constrain for elasticity for the energy information coupling mode
$PENESENET_{r,ch,h}$: Parice of energy for houseld energy consumption
$QENESENET_{r,ch,h}$: total energy consumption for each houseld consumption category (car, non-car usage)

Energy and mechineary consumption aggregation in household

$$PCH_{r,ch,h} \cdot QCH_{r,ch,h} = PENESENET_{r,ch,h} \cdot QENESENET_{r,ch,h} + PQD_{r,\text{"}com\_OMF\text{"}} \cdot dfpq_{r,\text{"}com\_OMF\text{"},h} \cdot (1 + tqd_{r,\text{"}com\_OMF\text{"},h}) \cdot QENESMCH_{r,ch,h}, \quad \forall r \in R,\ h \in \mathrm{H},\ ch \in CHENE \text{ (PHENEDEF)}$$

Energy consumption price aggregation in household

$$\begin{aligned} PENESENET_{r,ch,h} \cdot QENESENET_{r,ch,h} = & \sum_{c \in C\_ENE} (PQD_{r,c} \cdot dfpq_{r,c,h} \cdot (1 + tqd_{r,c,h}) \\ & + \sum_{g \in G} PGHG_r \cdot gwp_g \cdot efffc_{r,c,h,g}) \cdot (QCARENE_{r,c,h} \\ & + QHENEG_{r,c,h}) \\ & \forall r \in R,\ h \in \mathrm{H},\ ch \in CHENE \end{aligned}$$

(PENESENETDEF)

Energy Input Technology Share of car usage in the household :

$$
\begin{aligned}
QCARENE_{r,c,h} = {} & QENESENET_{r,\text{"}COM\_CAR\text{"},h} \cdot (1 + H^{carh}_{r,c,h}) \cdot \beta^{carh}_{r,c,h} \cdot \\
& \{PQD_{r,c} \cdot (1 + tqd_{r,c,h}) + PGHG_r \cdot \sum_{g \in G} gwp_g \cdot enur_{r,c,h} \cdot efffc_{r,c,h,g}\}^{el^{carh}_{r,c,h}} \\
& \cdot [\sum_{cp \in ENE} (1 + H^{carh}_{r,cp,h}) \cdot \beta^{carh}_{r,cp,h} \cdot \{PQD_{r,cp} \cdot (1 + tqd_{r,cp,h}) \\
& + PGHG_r \cdot \sum_{g \in G} gwp_g \cdot enur_{r,cp,h} \cdot efffc_{r,cp,h,g}\}^{el^{carh}_{r,cp,h}}]^{-1} \\
& \forall r \in R,\ c \in ENE,\ h \in H
\end{aligned}
$$

(QCARENEDEF)

$\beta^{carh}_{r,c,h}$: share parameter of Logit function for for car usage in the household energy source selection,
$el^{carh}_{r,c,h}$: Price elasticity parameter of Logit function for for car usage in the household energy source selection (for car usage in the household),
$H^{carh}_{r,c,a}$: Complementary variable for car-usage energy consumption in the household consumption by fuel constrainy for the energy information coupling mode (in the code this variable is represented by `COMP_FC_TEC(R,H,C)+CompFCTec(R,H,C)`)

COMP_FC_TEC is endogenously determined and CompFCTec is exogenous, which is calibrated before 2015 period).

Energy Input Technology Share of non-car usage in the household :

$$
\begin{aligned}
QHENEG_{r,c,h} = {} & QENESENET_{r,\text{"}COM\_ENE\text{"},h} \cdot (1 + H^{enec}_{r,c,h}) \cdot \\
& \beta^{enec}_{r,c,h} \cdot \{PQD_{r,c} \cdot (1 + tqd_{r,c,h}) + PGHG_r \cdot \sum_{g \in G} gwp_g \cdot enur_{r,c,h} \cdot efffc_{r,c,h,g}\}^{el^{enec}_{r,c,h}} \cdot \\
& [\sum_{cp \in ENE} (1 + H^{enec}_{r,cp,h}) \cdot \beta^{enec}_{r,cp,h} \cdot \{PQD_{r,cp} \cdot (1 + tqd_{r,cp,h}) \\
& + PGHG_r \cdot \sum_{g \in G} gwp_g \cdot enur_{r,cp,h} \cdot efffc_{r,cp,h,g}\}^{el^{enec}_{r,cp,h}}]^{-1}, \\
& \forall r \in R,\ c \in ENE,\ h \in H
\end{aligned}
$$

(HMDEM_ENE_G)

$\beta^{carh}_{r,c,h}$: share parameter of Logit function for non-car usage in the household energy source selection ,
$el^{carh}_{r,c,h}$: Price elasticity parameter of Logit function for non-car usage in the household source selection,
$H^{carh}_{r,c,a}$: Complementary variable for non-car energy usage in the household consumption by fuel constrainy for the energy information coupling mode (in the code this variable is represented by `COMP_FC_TEC(R,H,C)+CompFCTec(R,H,C)`)

COMP_FC_TEC is endogenously determined and CompFCTec is exogenous, which is calibrated before 2015 period).

Similarly, cereal consumption is nexted by logit function as below.

Cereal consumption share in the household :

$$QH_{r,c,h} \cdot (1 + AgrWstc_{r,c,h}) = QCH_{r,\text{"}COM\_CEL\text{"},h} \cdot \beta^{rlc}_{r,c,h} \cdot \{PQD_{r,c} \cdot (1 + tqd_{r,c,h})\}^{el^{rlc}_{r,c,h}} \cdot \left[\sum_{cp \in CCER} \beta^{rlc}_{r,cp,h} \cdot \left\{PQD_{r,cp} \cdot \left(1 + tqd_{r,cp,h}\right)\right\}^{el^{rlc}_{r,cp,h}}\right]^{-1} \quad \forall r \in R,\ c \in ENE,\ h \in H$$

(LOGITQH_AGGCR)

$\beta^{rlc}_{r,c,h}$: share parameter of Logit function for cereal consumption in the household,
$el^{rlc}_{r,c,h}$: Price elasticity parameter of Logit function for for cereal consumption in the household,
$AgrWstc_{r,c,h}$: Food waste ratio in the household

As mentioned, the consumption function can be switched from LES to AIDADS in order to better performe the change of household expenditure behabvior once their income increase. The AIDADS function is described in equations AIDADS_UTI, AIDADS_MCS, and AIDADS_CNS for utility, budget share parameter, and the consumption demand, respectively.

Household Utility (AIDADS)

$$Vu_{r,ch} = \sum_{ch} V\mu_{r,ch,h} \cdot \ln\left(\frac{QCH_{r,ch,c}}{poph_{r,h}} - \theta h_{r,ch,h}\right) - (\ln A + 1)\ \ ,\forall r \in R,\ h \in H$$

(AIDADS_UTI)

Household marginal share (AIDADS)

$$V\mu_{r,ch,h} = \frac{\left[\alpha h_{r,ch,h} + \beta h_{r,ch,h} \cdot e^{uh_{r,h}}\right]}{\left[1 + e^{uh_{r,h}}\right]}, \forall r \in R,\ ch \in CH,\ h \in H \text{ (AIDADS\_MCS)}$$

Household Consumption Spending (AIDADS)

$$\begin{aligned} QCH_{r,ch,h} \cdot PQH_{r,ch,h} = poph_{r,h} \cdot [\theta h_{r,ch,h} \cdot PQH_{r,ch,h} + V\mu_{r,ch,h} \cdot \\ (EH_h - \sum_{c' \in C\_ENE} (PQD_{r,c'} \cdot dfpq_{r,c',h} \cdot (1 + tqd_{r,c',h}) \\ + \sum_{g \in G} PGHG_r \cdot gwp_g \cdot efffc_{r,c',h,g}) \cdot QCARENE_{r,c',h} \\ - \sum_{chp \in CH} PQH_{r,chp,h} \cdot \theta h_{r,chp,h})] \forall r \in R,\ ch \in CH, h \in H \end{aligned}$$

(AIDADS_CNS)

$Vu_{r,h}$: utility of household h defined by AIDADS,
$V\mu_{r,ch,h}$: marginal share of consumption spending on household commodity category ch for household h,
$\theta h_{r,ch,h}$: subsistence consumption of household commodity category ch for household h,
$\alpha h_{r,ch,h}$: a parameter for AIDADS,
$\beta h_{r,ch,h}$: a parameter for AIDADS,
$poph_{r,h}$: population of household h.

Investment Demand

$$QINV_{r,c} = IADJ_r \cdot \overline{qinv_{r,c}}, \forall r \in R,\ c \in C \text{ (INVDEM)}$$

$\underline{IADJ_r}$: investment adjustment factor (exogenous variable),
$qinv_{r,c}$: base-year quantity of fixed investment demand.

Fixed investment demand is defined as the base-year quantity multiplied by an adjustment factor. For the basic model version, the adjustment factor is exogenous, in effect also making the investment quantity exogenous. Inventory investment is also included in the model, but is treated as an exogenous demand.

Government Consumption Demand

$$QG_{r,c} = \overline{GADJ_r} \cdot \overline{qg_{r,c}}, \forall r \in R,\ c \in C \text{ (GOVDEM)}$$

$\overline{GADJ_r}$: government consumption adjustment factor (exogenous variable),
$\overline{qg_{r,c}}$: government consumption adjustment factor (exogenous variable).

Similarly, government consumption demand, in which the main component tends to be the services provided by the government labor force, is also defined as the base-year quantity multiplied by an adjustment factor. This factor is also exogenous and, hence, the quantity of government consumption is fixed.

4.6 International trade block

Imported commodity

$$QWM_{r,c} = QM_{r,c}, \forall r \in R,\ c \in CM \text{ (QWMDEF)}$$

$QWM_{r,c}$: quantity of imports of commodity.

Internationally traded commodity equals to each country's imports.

Exported commodity

$$QWE_{r,c} = QE_{r,c}, \forall r \in R,\ c \in CE \text{ (QWEDEF)}$$

$QWE_{r,c}$: quantity of exports of commodity.

Quantity of domestic export is the sum of commodity export and international trade service (it is only for transport sector).

World trade nominal balance

$$\sum_{r \in R} (PWMR_{r,c} - tw_{r,c}) \cdot QWM_{r,c} =$$
$$\sum_{r \in R} PWER_{r,c} \cdot QWE_{r,c} - \sum_{c \in C_{TRS}} PTRS_c \cdot QTRS_c, \forall c \in (CM \cap CE) \text{ (WMEQ)}$$

$tw_{r,c}$: international trade cost ratio,
$PTRS_c$: price of international trade service,
$QTRS_c$: quantity of international trade service.

World nominal trade balance is shown in equation (WMEQ).

World trade volume balance

$$\sum_{r\in R} QWM_{r,c} = (1-\lambda^w_c)\cdot\left(\sum_{r\in R} QWE_{r,c} - QTRS_c\right), \forall c \in (CM \cap CE) \text{ (WMQB)}$$

λ^w_c: depreciation rate of traded commodity c.

Total imported commodity in the world is equal to that of exported excluding depreciation.

Transport service demand

$$PTRS_c \cdot \sum_r QWE_{r,c} = \sum_r PWER_{r,c} \cdot QWE_{r,c}, \quad \forall c \in C\_TRS \text{ (WTTR)}$$

CIF and FOB relationship

$$PTRS_c \cdot QTRS_c = \sum_{r'} tw_{r',c} \cdot PWM_c \cdot QWM_{r',c}, \quad \forall c \in C\_TRS \text{ (PTRSDEF)}$$

tsh_c: share of international trade service to world total international trade service,
$c \in C\_TRS$: a set of transport service.

The transport service is assumed to be proportional to the world total export of transport. The nominal international trade service provided by a country r is assumed to produce a constant share ratio and world total international trade service.

The world trade share of each region is determined by the following equations by logit selection

$$QWE_{r,c} = \sum_{r'} QWE_{r',c} \cdot \frac{\alpha^{ie}_{r,c}\cdot PWER_{r,c}{}^{\beta^{ie}_{r,c}}}{\sum_{r'\in R}\alpha^{ie}_{r',c}\cdot PWER_{r',c}{}^{\beta^{ie}_{r',c}}}, \quad \forall r \in R,\ c \in C \text{ (QWESHARE)}$$

$$QWM_{r,c} = \sum_{r'} QWM_{r',c} \cdot \frac{\alpha^{im}_{r,c}\cdot PWMR_{r,c}{}^{\beta^{im}_{r,c}}}{\sum_{r'\in R}\alpha^{ie}_{r',c}\cdot PWMR_{r',c}{}^{\beta^{im}_{r',c}}}, \quad \forall r \in R,\ c \in C \text{ (QWMSHARE)}$$

$\alpha^{ie}_{r,c}$: share parameter of world export share,
$\beta^{ie}_{r,c}$: exponent parameter of world export share
$\alpha^{im}_{r,c}$: share parameter of world import share,
$\beta^{im}_{r,c}$: exponent parameter of world import share

4.7 Biomass consumption as fuel combustion

The biomass is still the main energy source in some developing countries and they are a main factor of air pollutants emission. The biomass consumption is calculated as below.

Biomass consumption (Household)

$$TBH_{r,h} = \left(1 + H^{trd}_{r,h}\right)\cdot poph_{r,h}\cdot bioc_{r,h}\cdot biod_{r,h} \quad \forall r \in R,\ h \in H$$
(TRDBIO_CONS_HOU)

Biomass consumption (Industry)

$$TBI_{r,a} = \left(1 + H^{trd}_{r,a}\right)\cdot QA_{r,a}\cdot bioc_{r,a}\cdot biod_{r,a} \quad \forall r \in R,\ a \in A \text{ (TRDBIO\_CONS\_IND)}$$

$TBH_{r,h}$: biomass consumption by household h,
$TBI_{r,a}$: biomass consumption by activity a,
$bioc_{r,ac}$: biomass consumption coefficient to the activity level of sector ac,
$biod_{r,ac}$: decreasing rate of biomass consumption of sector ac.
$H^{trd}_{r,ac}$: Complementary variable for traditional biomass consumption constraint for the energy information coupling mode (in the code this variable is represented by the following statement)

```
SUM(FCAGGA$TrdBioMap(FCAGGA,"TrdBio",H),
COMP_FC_TEC_AGG(R,FCAGGA,"TrdBio")+
CompFCTecAgg(R,FCAGGA,"TrdBio"))
```

COMP_FC_TEC_AGG is endogenously determined and CompFCTecAgg is exogenous, which is calibrated before 2015 period).

The biomass consumption is defined as activity level multiplied by two coefficients. One is the base year calibrated coefficient *bioc* and the other is decreasing rate of its use *biod*. Equation (TRDBIO_CONS_HOU) represents household biomass consumption and the activity level is defined as number of population. The industrial biomass consumption is shown in equations (TRDBIO_CONS_IND).

4.8 Air pollutants and GHG emissions

As is mentioned already in section 3.6, the air pollutants and GHG emissions are classified into two groups (related to activity level and fuel combustion). We are going to formulate these two groups separately.

Emissions related to activity level (Industrial activity)

$$EMALI_{r,a,g,emsc} = DRV\_EMIPRO_{r,a,g,emsc} \cdot efacl_{r,a,g,emsc}\left(1 - NERED_{r,a,g,emsc}\right) - \sum_{emcm \in EMCM}\left(\frac{QRED_{r,emsc,a}}{\eta_{emsc,a}}\right),$$
$$\forall r \in R,\ a \in A,\ g \in G,\ emsc \in EMSC$$

(EMI_FROM_IND_PRO, EMI_FROM_IND_PRO2, EMI_FROM_IND_PRO3)

$g \in G$: a set of emission gases,
$emsc \in EMSC$; a set of emission sources
$EMALI_{r,a,g,emsc}$: emissions non-energy related emission by industrial activity a, energy source *emsc*,
$efacl_{r,ac,g,emsc}$: emission factors for emissions related to activity level by sector ac, energy source *emsc*,
$NERED_{r,a,g,emsc}$: emission reduction caused by the GHG emission price, energy source *emsc*
$DRV\_EMIPRO_{r,a,g,emsc}$: Driving force of emissions which is represented by acticity levels for each industry a.

Emissions driving forces

$$DRV\_EMIPRO_{r,a,g,emsc} = \left\{\begin{array}{c} {QA_{r,a}}^{proemiela_{r,a,g}} \cdot {QA\_base_{r,a}}^{1-proemiela_{r,a,g}} \\ \frac{QF_{r,\text{"LND"},a}}{Crop_intensity_{r,a}} \\ \\ popchange_r \cdot \left(\frac{GDP_r}{gdp\_base_r}\right)^{proemiela_{r,a,g}} \\ \sum_{fl \in FL} QPRMLANDT_{r,fl,\text{"liv"}} \\ \sum_{fl \in FL} QPRMLANDT_{r,fl,\text{"frs"}} \end{array}\right\} \quad \forall r \in R, a \in A, g \in G, a \in EMSC,$$ (EQ_DRV_EMIPRO)

$proemiela_{r,a,g}$: income or production level elasticity to the emissions driving force
GDP_r: GDP of region r.
gdp_base_r: base year GDP of region r.

Additional emission reductions related to activity level (Industrial activity)

$$NERED_{r,a,g,emsc} = 1 - (PGHG_r + 1)^{-\sigma^{ghg}_{r,a,g,emsc}}, \quad \forall r \in R,\ a \in A,\ g \in G,\ emsc \in EMSC$$
(EFFIMPR_PRICE_CONS)

$\sigma^{ghg}_{r,a,g,emsc}$: elasticity of the additional emission reductions of non-energy related emissions.

The abatement cost is the integral of the reduction cost for baseline emissions are ($\int_0^{PGHG} NERED_{r,a,g,emsc} dPGHG$). Hence, actual marginal abatement cost is multipying emissions in baseline ($EMIAL \cdot /(1 - NERED)$) to that.

Abatement cost for non-energy related emissions but not for CCS

$$\begin{aligned} ABTC\_NCS_{r,a,g,emsc} = & \\ & \sum_{emsc \in EMSC} \sum_{g \in G} gwp_g \cdot EMALI_{r,a,g,emsc} \cdot frac11 - NERED_{r,a,g,emsc} \\ & \left(\frac{\sigma^{ghg}_{r,a,g,emsc}}{1 - \sigma^{ghg}_{r,a,g,emsc}}\right)\left(1 - NERED_{r,a,g,emsc}\right)^{\left(\frac{\sigma^{ghg}_{r,a,g,emsc}-1}{\sigma^{ghg}_{r,a,g,emsc}}\right)} \\ & - NERED_{r,a,g,emsc} - \frac{\sigma^{ghg}_{r,a,g,emsc}}{1 - \sigma^{ghg}_{r,a,g,emsc}} \\ & \forall r \in R,\ a \in A,\ a \in G,\ emsc \in EMSC \end{aligned}$$

(EQABTC_NCS)

$Scale$: scaling parameter for carbon parice (=1000\$/tCO_2)

Emissions related to activity level (household)

$$EMALH_{r,h,g,emsc} = poph_{r,h} \cdot efacl_{r,h,g,emsc} \quad \forall r \in R,\ h \in H,\ g \in G,\ emsc \in EMSC$$
(EMI_FROM_HOU_TOT)

$EMALH_{r,h,g.emsc}$: emissions related to activity level by household h, emission source $emsc$.

The emissions related to activity level such as CO_2 emission from cement production is calculated by multiplying the activity level by the emission factor *efacl*. However, non-energy related GHG emission related to activity levels such as CH_4 emission from rice fields and CO_2 emission from the cement industry is defined at the top nest of the production function.

If an industrial sector can install CCS technology, it reduces the emission. In addition, there is additional emission reduction in mitigation case as *NERED*.

Emissions related to fossil fuel combustion (Industrial activity)

$$EMFFI_{r,c,a,g} = QINT_{r,c,a} \cdot enur_{r,c,a} \cdot efffc_{r,c,a,g} \quad \forall r \in R,\ c \in ENE,\ a \in A\ ,\ g \in G$$
(EMI_FROM_FF_IND)

$EMFFI_{r,c,a,g}$: emissions related to fossil fuel combustion emitted by industrial activity a consuming of goods c.

Emissions related to fossil fuel combustion associated with car usage (household)

$$EMFFCH_{r,c,h,g} = QCARENE_{r,c,h} \cdot efffc_{r,c,\text{"}trs\text{"},g} \quad \forall r \in R,\ c \in ENE,\ h \in H\ ,\ g \in G$$
(EMI_FROM_FF_HOUCAR)

$EMFFCH_{r,c,h,g}$: emissions related to fossil fuel combustion associated with car usage emitted by household h consumption of goods c.

Emissions related to fossil fuel combustion associated with non-car usage (household)

$$EMFFH_{r,c,h,g} = QHENEG_{r,c,h} \cdot efffc_{r,c,h,g} \quad \forall r \in R,\ c \in ENE,\ h \in H\ ,\ g \in G$$
(EMI_FROM_FF_HOU)

$EMFFH_{r,c,h,g}$: emissions related to fossil fuel combustion emitted by household h consumption of goods c.

The CO_2 emitted by industrial activity is calculated in equation (EMI_FROM_FF_IND). The energy commodity inputs are multiplied by emission factor *efffc* and "energy-used ratio" *enur* represents the ratio of combustion to intermediate input of the energy commodity. Only the chemical industry is the only sector assumed to use fossil fuel as non-energy.

The emission factor *efffc* of CO_2 is multiplied by three kinds of parameters which are "flag of fossil fuel transformation", "carbon fraction" and "CO_2 emission coefficient".

The emission factor *efffc* of non-CO_2 is calibrated by EDGAR 4.1 emission inventory data [4] and Bond *et al.* [5] and IPCC guideline [6].

Emissions related to biomass combustion (Industrial activity)

$$EMBII_{r,a,g} = TBI_{r,a} \cdot efbio_{r,a,g} \quad \forall r \in R,\ a \in A\ ,g \in G \text{ (TRDBIO\_EMI\_IND)}$$

$EMBII_{r,a,g}$: emissions related to biomass combustion emitted by industrial activity a, $efbio_{r,ac,g}$: emission factors for emissions fossil fuel combustion by sector ac.

Emissions related to biomass combustion (household activity)

$$EMBIH_{r,h,g} = TBH_{r,h} \cdot efbio_{r,h,g} \quad \forall r \in R,\ h \in H\ ,\ g \in G \text{ (TRDBIO\_EMI\_HOU)}$$

$EMBIH_{r,h,g}$: emissions related to biomass combustion emitted by household h.

The emission from biomass combustion is estimated to multiply biomass consumption (*EMBII* and *EMBIH*) by emission factor *efbio*.

Non-energy related gas emissions

$$EMNEG_{r,g} = ecfneng_{r,g} \cdot \left(\frac{GDP_r}{gdp\_base_r}\right)^{ecf\_gdpelas_{r,g}} \cdot PGHG_r^{-\sigma ghg\_hfc_{r,g}} \text{ (EMNEGDEF)}$$

$EMNEG_{r,g}$: non-energy related emissions C2F6, SF6, CF4 and HFCs,
$ecfneng_{r,g}$: emission coefficient of Non-energy related emissions,
$ecf\_gdpela_{r,r}$: elasticity of Fgas to GDP increase in region r, gas g.
$\sigma^{ghg\_hfc}_{r,g}$; Parameter for a MAC curve of international transport CO2 reduction

GHG emission related to the international aviation and marine bankers are calculated by following equation.

GHG Emission Related to the International Transport

$$EMFFINT_{tr,g} = \sum_{(c,,r)\in C,R} TRS\_ENE\_EMI_{r,tr,c,g} \text{ (GAS\_FROM\_FF\_INT)}$$

The energy use in international transport is as follows.

International transport energy demand

$$INTTRSENE_{tr,c} = \sum_r TRS\_ENE\_FL_{r,tr,c} \text{ (INTTRSENEDEF)}$$

GHG emission total in a region

$$\begin{aligned}
GHGT_r = & \sum_{g\in G} gwp_g \cdot \{\sum_{h\in H}\sum_{c\in C} QH_{r,c,h} \cdot enur_{r,c,h} \cdot efffc_{r,c,h,g} \\
& + \sum_{h\in H}\sum_{c\in C} EMFFHC_{r,c,h,g} + \sum_{a\in A(notA_TRS)}\sum_{c\in C} QINT_{r,c,a} \cdot enur_{r,c,a} \cdot efffc_{r,c,a,g} \\
& + \sum_{tr\in TR_DM}\sum_{c\in C} TRS_ENE_EMI_{r,tr,c,g} + \sum_{emsc\in EMSC} (\sum_{h\in H} EMALH_{r,h,g,emsc} \\
& + \sum_{a\in A} EMALI_{r,a,g,emsc}) + (\sum_{h\in H} EMBIH_{r,h,g} + \sum_{a\in A} EMBII_{r,a,g}) + \sum_{fl\in FL} LUCHEM_{r,fl}\} \\
& \forall r \in R
\end{aligned}$$

(GHG_FROM_TOT)

$GHGT_r$: GHG emission from region r (CO_2 equivalent).
$tr \in TR\_DM$: A subset of tranaport mode for domestic transportation

Region total GHG emission (CO_2 equivalent) is the summation of industry and household emissions weighted by gwp_g (CO_2=1, CH_4=25, N_2O=298, C2F6, SF6, CF4). Currently, GHG coverage is Kyoto gases.

Gas total emissions in a region

$$\begin{aligned}
GAST_{r,g} = & \sum_{h\in H}\sum_{c\in C} QH_{r,c,h} \cdot enur_{r,c,h} \cdot efffc_{r,c,h,g} + \\
& \sum_{h\in H}\sum_{c\in C} EMFFHC_{r,c,h,g} + \sum_{a\in A(notA_TRS)}\sum_{c\in C} QINT_{r,c,a} \cdot enur_{r,c,a} \cdot efffc_{r,c,a,g} + \\
& \sum_{tr\in TR_DM}\sum_{c\in C} TRS_ENE_EMI_{r,tr,c,g} + \sum_{emsc\in EMSC} (\sum_{h\in H} EMALH_{r,h,g,emsc} + \\
& \sum_{a\in A} EMALI_{r,a,g,emsc})(\sum_{h\in H} EMBIH_{r,h,g} + \\
& \sum_{a\in A} EMBII_{r,a,g}) + EMNEG_{r,g} + \sum_{fl\in FL} LUCHEM_{r,fl} \quad \forall r \in R
\end{aligned}$$

(GAS_TOT)

$GAST_{r,g}$: gas g's emissions from region r.

Energy related CO_2 emissions in a region

$$\begin{aligned} CO2FFIND_r = & \sum_{g \in GCO2} \{ \sum_{h \in H} \sum_{c \in C} QH_{r,c,h} \cdot enur_{r,c,h} \cdot efffc_{r,c,h,g} \\ & + \sum_{h \in H} \sum_{c \in C} EMFFHC_{r,c,h,g} \\ & + \sum_{a \in A(notA\_TRS)} \sum_{c \in C} QINT_{r,c,a} \cdot enur_{r,c,a} \cdot efffc_{r,c,a,g} \\ & + \sum_{tr \in TR\_DM} \sum_{c \in C} TRS\_ENE\_EMI_{r,tr,c,g} \\ & + \sum_{emsc \in EMSCIND} (\sum_{h \in H} EMALH_{r,h,g,emsc} + \sum_{a \in A} EMALI_{r,a,g,emsc}) \} \; \forall r \in R \end{aligned}$$

(EQCO2FFIND)

$CO2FFIND_r$: energy related CO_2 emissions from region r.
$emsc \in EMSCIND$: emissions sources for energy related emissions

Global energy related CO_2 emissions

$$CO2FFINDGLOBAL = \textstyle\sum_{r \in R} CO2FFIND_r + \sum_{tr \in TR} EMFFINT_{tr,"CO2"}$$
(EQCO2FFINDGLOBAL)

$CO2FFINDGLOBAL$: global energy related CO_2 emissions.
$EMFFINTt_{r,g}$: gas g's emissions from international transport.

Global CO2 emissions

$$CO2GLOBAL = \textstyle\sum_{r \in R} GAST_{r,"CO2"} + \sum_{tr \in TR} EMFFINT_{tr,"CO2"}$$
(EQCO2FFINDGLOBAL)

$CO2GLOBAL$: global energy related CO_2 emissions.

GHG emission includes emission trading

$$GHGT\_CT_r = GHGT_r - GHGT\_IMP_r \cdot \quad \forall r \in R \quad \text{(GHG\_TOT\_CT)}$$

$GHGT\_CT_r$: GHG emission from region r (CO_2 equivalent) includes emission permit import.

GHG emission permits can be imported from foreign countries. In reality, the amount of emission trading is constrained to a certain level which can be treated as an import or export quota. In addition, these import and export quota make the emission price higher or lower considering global and domestic emission prices as below.

GHG emission importing trading upper limit

$$\overline{ghgt\_imp\_cap_r} - GHGT\_IMP_r \geq 0 \; \perp PGHG\_IMP\_QUO_r \geq 0 \;\; \forall r \in R$$

(GHGT_IMPDEF)

GHG emission exporting trading upper limit

$$GHGT\_IMP_r - \overline{ghgt\_exp\_cap_r} \geq 0 \perp PGHG\_EXP\_QUO_r \geq 0 \;\; \forall r \in R$$
(GHGT_EXPDEF)

GHG emission price and international price

$$PGHG_r = EXR_r \cdot (PGHG\_G + PGHG\_IMP\_QUO_r - PGHG\_EXP\_QUO_r) \;\; \forall r \in R$$
(GHGT_IMPDEF2)

$\overline{ghgt\_imp\_cap_r}$: GHG emission trading (import) limit,
$\overline{ghgt\_exp\_cap_r}$: GHG emission trading (export) limit.

If emission trade is equal to the limit, the domestic GHG emission price (*PGHG*) will be different from global price (*PGHG_G*).

GHG emission constraint

$$\overline{ghgc_r} - GHGT\_CT_r \geq 0 \perp PGHG_r \geq 0 \;\; \forall r \in R \text{ (GHG\_CONSTRAINT\_REGION)}$$

$\overline{ghgc_r}$: GHG emission constraint.

If the regional total GHG emission is constrained by $\overline{ghgc_r}$, the GHG emission price is complementary variable of this equation. In the model, *ghgc* can be capped on CO_2 or energy related CO_2 emissions and in such case, *GHGT_CT* would be replaced by *GAST* or *CO2FFIND*.

GHG emission cost of non-energy (Industry)

$$\begin{aligned} GHGCA\_NENE_{r,a} = {} & PGHG_r \cdot \sum_{g \in G} gwp_g \cdot (EMBII_{r,a,g} + \sum_{emsc \in EMSC} EMALI_{r,a,g,emsc}) / \\ & (1 + COMGHGCA\_NE_{r,a})/(1 + COMGHGCA\_NE2_{r,a}) \\ & \forall r \in R,\ a \in A \end{aligned}$$

(GHG_NENE_COST_A)

$COMGHGCA\_NE_{r,a}$: Complementary variable to constraint the carbon tax penalty (upper limit).
$COMGHGCA\_NE2_{r,a}$: Complementary variable to constraint the carbon tax penalty (lower limit).

To compute and model carbon tax imposition penalty, the following two equatiosn are defined.

Carbon tax penalty on residual emissions in activities

$$GHGCAFULLr, a = PGHG_r \cdot \sum_{g \in G} pghgprg_g \cdot gwp_g \cdot \\ (\sum_{a \in A, c \in C} (QINT_{r,c,a} \cdot enur_{r,c,a} \cdot efffc_{r,c,a,g}) \\ + \sum_{c \in C, tr \in TR} TRS\_ENE\_EMI_{r,tr,c,g}) + GHGCA\_NENE_{r,c,a} \\ \forall r \in R,\ a \in A$$

(EQGHGCAFULLA)

Carbon tax penalty on residual emissions in household

$$GHGCAFULLr, h = PGHG_r \cdot \sum_{g \in G} pghgprg_g \cdot gwp_g \cdot \\ (\sum_{a \in H, c \in C} (QHENEG_{r,c,h} \cdot enur_{r,c,h} \cdot efffc_{r,c,h,g}) \\ + \sum_{c \in C, h \in H} EMFFHC_{r,c,h,g}) \forall r \in R,\ a \in A$$

(EQGHGCAFULLH)

GHG emission cost constraint lower boundary

$$GHGCA\_NENE_{r,a} > \\ QA_{r,a} \cdot PA_{r,a} \cdot (1 + ta_{r,a}) \cdot bghgca\_nene_{r,a} \perp COMGHGCA\_NE2_{r,a} > 0 \ \forall r \in R,\ a \in A$$

(GHG_NENE_COST_A_CONS)

$bghgca\_nene_{r,a}$: lower counstraint for the GHG emission tax penalty. (this is assumed mainly for sectors that can implement BECCS)

GHG emission cost constraint upper boundary

$$GHGCA\_NENE_{r,a} < \\ QA_{r,a} \cdot PA_{r,a} \cdot (1 + ta_{r,a}) \cdot ughgca\_nene_{r,a} \perp COMGHGCA\_NE_{r,a} > 0 \forall r \in R,\ a \in A$$

(GHG_NENE_COST_A_CONS2)

$ughgca\_nene_{r,a}$: upper counstraint for the GHG emission tax penalty. (this is assumed mainly for sectors that can implement BECCS)

GHG total cost

$$GHGTCOST_r = \sum_{a \in A} \left(QINT_{r,c,a} \cdot enur_{r,c,a} \cdot efffc_{r,c,a,g} \right) + GHGCA\_NENE_{r,c,a} \\ + \sum_{h \in H} PGHG_r \cdot \sum_{g \in G} gwp_g \cdot \\ \left(\sum_{c \in C} QH_{r,c,h} \cdot efffc_{r,c,h,g} + EMALH_{r,h,g} + EMBIH_{r,h,g} \right) \quad \forall r \in R \text{ (GHGCOSTDEF)}$$

GHG cost consists of those of activity and household.

When the GHG constrained on only global total emissions, the following equations are introduced instaid of the above.

Global GHG emission constraint

$$\overline{ghgtot\_c} - \sum_{r\in R} GHGT\_CT_r \geq 0 \perp PGHG\_G \geq 0 \text{ (GHG\_CONSTRAINT\_TOTAL)}$$

$\overline{ghgtot\_c}$: global GHG emission constraint,
$PGHG\_G$: GHG emission price corresponding to the global emission constraint.
$\sum_{r\in R} GHGT\_CT_r$ part can be altered dependent on the ghgtot_c. if that is for CO2 emissions, then it becomes CO2.

Global GHG emission constraint price

$$PGHG\_G \cdot EXR_r = PGHG_r, \quad \forall r \in R \text{ (GHG\_CONSTRAINT\_PRICE)}$$

Global GHG emission trading total

$$\sum_{r\in R} GHG\_IMP_r = 0 \text{ (GHG\_WORLD\_TR)}$$

Net GHG emission trading should be zero globally.

4.9 System constraint block

Factor Markets

$$\sum_{a\in A} QF_{r,f,a} = \overline{QFS}_{r,f} \cdot \left(WF_{r,f}/WFBase_{r,f}\right)^{\theta^{sp}_{r,f}}, \forall r \in R,\ f \in F \text{ (FACEQUIL)}$$

$\overline{QFS}_{r,f}$: quantity supplied of factor (exogenous variable).
$\theta^{sp}_{r,f}$: labor market unemployment elasticity
$WFBase_{r,f}$: baseline's WF

Unemployment

$$UNEMPLOYR_r = UNEMPLOYRBase_r \cdot \sum_{f\in F} \left(WF_{r,f}/WFBase_{r,f}\right)^{\theta^{sp}_{r,f}}, \forall r \in R,\ f \in F \text{ (DEFUNEMPLOYR)}$$

$UNEMPLOYR_r$: Unemployment rate in region r
$UNEMPLOYRBase_r$: Unemployment rate in region r for the base year,

Equation (FACEQUIL) imposes equality between the total quantity demanded and the total quantity supplied for each factor other than capital. In the basic model version, all demand variables are flexible while the supply variable is fixed. The factor wage, *WF*, is the equilibrating variable that assures that this equation is satisfied: an increase in *WF* raises the wage paid by each activity, *WF WFDIST*, which is inversely related to the quantities of factor demand, *QF*. All factors other than old capital are mobile between the demand activities. For the labor market, we assumed unemployment price elasticity.

Composite Commodity Markets

$$QQ_{r,c} - (QX2_{r,c} + QM_{r,c}) \cdot loss_{r,c} + stch2_{r,c}$$
$$= \sum_{a\in A} QINT_{r,c,a} + \sum_{h\in H} QH_{r,c,h} + QG_{r,c} + QINV_{r,c}, \forall r \in R,\ c \in C \text{ (COMEQUIL)}$$

$loss_{r,c}$: distribution loss rate,
$stch2_{r,c}$: Stock change of commodity c (negative).

Equation (COMEQUIL) imposes equality between quantities supplied (from equations (ARMINGTON), (COSTMIN) and (ARMINGTON2, ARMINGTON3)) and demanded of the composite commodity. The demand side includes endogenous terms (from equations (INTDEM)), (HMMAP), (INVDEM) and (GOVDEM)) and a new exogenous term for stock change. Among the endogenous terms, *QG* and *QINV* are fixed in the basic model version (compare with equations (INVDEM) and (GOVDEM)). The composite commodity supply, *QQ*, drives demands for domestic marketed output, *QD*, and imports, *QM*. The market-clearing variables are the quantities of import supply, for the import side, and the two interrelated domestic prices, *PDD* and *PDS*, for domestic market output.

Current-Account Balance for the Rest of the World, in Foreign Currency

$$\sum_{c \in CM} PWMR_{r,c} \cdot QM_{r,c} + transfr\_crt\_out_r + GHG\_IMP_r \cdot PGHG_r + \sum_{f \in F} transfr_{r,\text{"}ROW\text{"},f}$$
$$= \sum_{c \in CE} PWER_{r,c} \cdot QE_{r,c} + transfr\_crt\_in_r + \overline{FSAV_r} + \sum_{f \in F} transfr\_f_{r,f,\text{"}ROW\text{"}} \quad \forall r \in R, f \in F \text{ (CURACCBAL)}$$

$\overline{FSAV_r}$: foreign savings (FCU) (exogenous variable),
$transfr\_crt\_out_r$: current transfer to rest of the world,
$transfr\_crt\_in_r$: current transfer from rest of the world.

The current-account balance, which is expressed in foreign currency, imposes equality between the country's spending and its earning of foreign exchange. For the basic model version, foreign savings is fixed; the (real) exchange rate (*EXR*) serves the role of equilibrating variable to the current-account balance. The fact that all items except imports and exports are fixed means that, the trade deficit also is fixed. Alternatively, the exchange rate may be fixed and foreign savings unfixed. In this case, the trade deficit is free to vary.

Government Balance

$$YG_r = EG_r + GSAV_r \quad \forall r \in R \text{ (GOVBAL)}$$

$GSAV_r$: government savings.

The government balance imposes equality between current government revenue and the sum of current government expenditures (not including government investment) and savings. Savings may be negative. The alternative mechanisms for maintaining this balance are associated with equation (TINSDEF).

Direct Tax Rate

$$TINS_{r,i} = \overline{tins_{r,i}} \cdot \left(1 + \overline{TINSADJ_r} \cdot tins01_{r,i}\right) + \overline{DTINS_{r,i}} \cdot tins01_{r,i}, \forall r \in R,\ i \in INSDNG \text{ (TINSDEF)}$$

$\overline{tins_{r,i}}$: rate of direct tax on domestic institutions i,
$\overline{TINSADJ_r}$: direct tax scaling factor (= 0 for base; exogenous variable),
$tins01_{r,i}$: 0.1 parameter with 1 for institutions with potentially flexed direct tax rates,
$\overline{DTINS_{r,i}}$: change in domestic institution tax share (= 0 for base; exogenous variable).

Equation (TINSDEF) defines the direct tax rates of domestic nongovernment institutions. For the basic model version, all variables on the right-hand side are fixed, in effect fixing the values for the direct tax rate variable for all institutions. In this setting, government savings is the endogenous variable that clears the government balance.

In the GAMS implementation of the standard model, two alternative closure rules are coded for the government balance. For both alternatives, government savings is fixed. In the first case, *DTINS* is the flexible variable that clears the government balance by scaling the base-year tax rates of each tax-paying institution. In this setting, the rates will change by a uniform number of (percentage) points for all institutions with a value of 1 for the parameter *tins*01 (that is, for all institutions with potentially flexed direct tax rates). Hence, the initial tax rate has no impact on the rate change. In the second case, *TINSADJ* becomes a variable while *DTINS* is fixed. For this closure, the changes in *TINS* are relatively large for institutions with relatively large base-year rates (if they have a value of 1 for *tins*01).

Institutional Savings Rates

$$MPS_{r,i} = \overline{mps_{r,i}} \cdot \left(1 + \overline{MPSADJ_r} \cdot mps01_{r,i}\right) + DMPS_r \cdot mps01_{r,i}, \forall r \in R,\ i \in INSDNG \tag{MPSDEF}$$

$\overline{mps_{r,i}}$: base savings rate for domestic institution i,
$\overline{MPSADJ_r}$: savings rate scaling factor (= 0 for base),
$mps01_{r,i}$: 0-1 parameter with 1 for institutions with potentially flexed direct tax rates,
$DMPS_r$: 0-1 parameter with 1 for institutions with potentially flexed direct tax rates.

Equation (MPSDEF) defines the savings rates of domestic nongovernment institutions. Its structure is the same as that of equation (TINSDEF). Whether one or none of the variables *MPSADJ* and *DMPS* is flexible depends on the closure rule for the Savings-Investment balance. For the basic model version, *DMPS* is flexible, permitting *MPS* to be adjusted by a uniform rate for selected (one or more) nongovernment institutions.

Savings–Investment Balance

$$\begin{aligned}&\textstyle\sum_{i \in INSDNG} MPS_{r,i} \cdot (1 - TINS_{r,i}) \cdot YI_{r,i} + GSAV_r + \overline{FSAV_r} \cdot \overline{EXR_r} \\ &= \textstyle\sum_{c \in C} PQ_{r,c} \cdot dfpq_{r,c,\text{"}S-I\text{"}} \cdot (1 + tq_{r,c,\text{"}S-I\text{"}}) \cdot QINV_{r,i} + WALRAS_r \quad \forall r \in R\end{aligned} \tag{SAVINVBAL}$$

Equation (SAVINVBAL) states that total savings and total investment have to be equal. Total savings is the sum of savings from domestic nongovernment institutions, the government, and the rest of the world, with the last item converted into domestic currency. Total investment is the sum of the values of fixed investment (gross fixed capital formation) and stock changes.

In the basic model version, the flexible variable, *DMPS*, performs the task of clearing this balance (compare with equation (MPSDEF)). None of the other items in the Savings-Investment balance is free to vary to assure that the balance holds. Given that the balancing role is performed by the savings side, this closure represents a case of ”investment-driven” savings. In the GAMS code, additional Savings-Investment closures have also been programmed.

Global Investment Balance

$$\sum_{r \in R} FSAV_r = 0 \quad \text{(GLOBALINVBAL)}$$

Global invenstment should be balanced.

Up to this point, the matrix of this model as stated is not square; the number of equations exceeds the number of variables by one. However, the model satisfies Walras' law: one equation is functionally dependent on the others and can be dropped. The Savings-Investment balance or the current-account balance is commonly eliminated. After eliminating one equation, the model becomes square and, in the absence of errors in formulation, a unique solution typically exists. Instead of dropping one equation, it is also possible to add one variable to the macroeconomic balance equations. The solution value of this variable should be zero. If not, one or more equations are not satisfied and a general equilibrium solution has not been found. This is the approach followed in the GAMS version of the model. A variable called *WALRAS* is added to the Savings-Investment balance. No equation is dropped.

After this adjustment, the model presented is complete and self-contained. In the basic model version, three more equations (and three new variables that appear in them) are added. The reason for including these is that they permit the formulation of balanced Savings-Investment closures 4 and 5. We will return to the closure issue later, after presenting the new equations and their notation.

4.10 Activity constraint block

4.10.1 Power generation

Climate policy analysis requires us to simulate power sectors activities in detail; however, their activity levels are decided not only by economic rationality but also political decision. Therefore, the power share or activity level should be constrained exogenously.

Activity constraint (Upper boundary)

$$renew\_up_{r,a} - QA_{r,a} \cdot \theta_{r,a,\text{"}COM\_ELY\text{"}} \geq 0 \perp VRENCAP_{r,a} \geq 0$$
$$\forall r \in R,\ a \in A = \{renew\_up_{r,a} > 0\}$$

(RENEWABLE_CAP)

$renew\_up_{r,a}$: capacity of the activity level a (for power sector energy).

Alternatively, we could have the constraints for power generation share.

$$sh\_ely\_up_{r,a} \cdot \sum_{ap \in A} (\theta_{r,ap,\text{"}ely\text{"}} \cdot QA_{r,ap}) - \theta_{r,a,\text{"}ely\text{"}} \cdot QA_{r,a} \geq 0 \perp VRENCAP_{r,a} \geq 0,$$
$$\forall r \in R,\ a \in A = \{sh\_ely\_up_{r,a} > 0\}$$

(POWER_SHARE_CAP)

$sh\_ely\_up_{r,a}$: power generation share of activity a.

Activity constraint (QUOTA for aggregated region and activity)

$$quotaqa_{ragg,aagg} = \sum_{r \in Map\_Ragg(r,ragg)} \sum_{a \in Map\_aagg(a,aagg)} \sum_{c \in C} QA_{r,a} \cdot \theta_{r,a,c} \geq 0$$
$$\perp RQUOQA\_agg_{ragg,aagg} \geq 0, \forall ragg \in Ragg,\ aagg \in Aagg$$

(QUOQA_agg)

Activity constraint (QUOTA shadow price)

$$RQUOQA_{r,a} = \sum_{ragg \in Map\_Ragg(r,ragg)} \sum_{aagg \in Map\_aagg(a,aagg)} RQUOQA\_agg_{ragg,aagg} \geq 0,$$
$$\forall r \in R,\ a \in A \text{ (QUOQA)}$$

$aagg \in Aagg$: a set of aggregated activity,
$ragg \in Ragg$: a set of aggregated regions,
$quotaqa_{ragg,aagg}$: quota of aggregated ragion $ragg$ and aggregated activity $aagg$.

In some cases, activities output can be constrained by a quota.

4.10.2 Energy system information

Some may want to incorporate energy system information more explicitly into the model either by using exisiting energy statistics or energy system model outputs. Here we show those constraints which have complementary variable that would change the energy inputs or outputs.

Energy consumption constraint

$$FCCons_{r,aagg,cagg} = \sum_{c,a,h \in ESM} QINT_{r,c,a} +$$
$$QCARENE_{r,c,h} + QHENEG_{r,c,h} + TBI_{r,a} + TBH_{r,h},$$
$$\forall r \in R,\ aagg \in Aagg,\ cagg \in Cagg$$

(EQ_FCCONSTRAIN, EQ_FCCONSTRAIN2)

$FCCons_{r,aagg,cagg}$: energy consumption constraint for aggregated sector and goods.
$ESM_{c,a,h}$: mapping of energy system information from CGE original sectoral and goods classifications. This mapping is divided into several pieces in the actual code.

EQ_FCCONSTRAIN and EQ_FCCONSTRAIN 2 are distinguished as whether it is applied to change the AEEI or substitution elasticity. The complementary variable for this equation is H, which is mapped in the equation (EQ_FCCONSCOMP or EQ_FCCONSCOMP2) that are not described in this document but just equal statment.

For the mitigation scenarios and incorporating the energy system model information, the additional investment in the energy demand side is available which is fed into as following equation

Additional investment constraint

$$AddEneInv_{r,aagg} = \sum_{a \in MapFCINV} QF_{r,\text{"}ccap\text{"},a} \frac{qabau_{r,a}}{QA_{r,a}} - qfccapbau_{r,a} + \sum_{ch,h \in FCAGGACHMap} QENESMCH_{r,ch,h} \frac{qchbau_{r,ch,h}}{QCH_{r,ch,h}} - QENESMCH\_BaU_{r,ch,h}) \quad \forall r \in R,\ aagg \in Aagg$$

(EQ_ FCCONSINVEST)

$AddEneInv_{r,aagg}$: additional energy invesntment.
$qfccapbau_{r,a}$: baseline's $QF_{r,''ccap'',a}$
$qabau_{r,a}$: baseline's $QA_{r,a}$
$ehbau_{r,h}$: baseline's EH
$QENESMCH\_BaU_{r,ch,h}$: baseline's $QENESMCH$
$FCAGGACHMap_{fcagga,ch}$: mapping from energy system model goods category to CGE
$MapFCINV_{fcagga,a}$: mapping from energy system model sector category to CGE

Similar to the energy consumption, the output share can be constrained by exogenous assumptions taken from energy system model or energy sitatistics. Mostly used for the power generation. The complementary variables are $\Lambda_{r,a,c}$.

Output share constraints

$$SHAC_{r,a,c} = OutputShareCons_{r,a,c}, \quad \forall r \in R,\ a \in A, c \in C \text{ (EQ\_PW\_SH\_CONS)}$$

$OutputShareCons_{r,a,c}$: Output share of goods c production

4.10.3 Variable renewable energy treatment and curtailment and storages

The curtailment happens when variable renewable energy has a certain share and similarly electricity storage is needed. These are formulated as follows. They are basically documented in Dai et al.(2017) [7]

Curtailement rate

$$CURSHARE_r = adjust\_curshr_r \cdot \textstyle\sum_a acurtail_{r,a} \cdot SHAC_{r,a}{}^{bcurtail_{r,a}}, \quad \forall r \in R,\ a \in A, c \in C \text{ (CURTAILMENT)}$$

$CURSHARE_r$: Share of curtailement in total power generation.
$acurtial_{r,a}$, $bcurtial_{r,a}$, $adjust\_curshr_r$: parameters determining the curtailament share which is calibrated from the power dispatch model results.

Storage rate

$$STORSH_r = adjust\_strshr_r \cdot \textstyle\sum_a astrg_{r,a} \cdot SHAC_{r,a}{}^{bstrg_{r,a}}, \quad \forall r \in R \text{ (STORAGESH)}$$

$STORSH_r$: Share of storage in total power generation.
$astrg_{r,a}$, $bstrg_{r,a}$, $adjust\_strshr_r$: parameters determining the stroge share which is calibrated from the power dispatch model results.

Mapping curtailment rate from region total to sector

$$CURRATIO_{r,a} = CURSHARE_r \cdot QX_{r,\text{"}COM\_Ely\text{"}} / \sum_{ap} QXAC_{r,ap,\text{"}COM\_Ely\text{"}}, \quad \forall r \in R,\ a \in A \text{ (CURTAILMENTRATE)}$$

Mapping storage rate from region total to sector

$$STORRATIO_{r,a} = STORSH_r \cdot QX_{r,\text{"}COM\_Ely\text{"}} / \sum_{ap} QXAC_{r,ap,\text{"}COM\_Ely\text{"}}, \quad \forall r \in R,\ a \in A \text{ (STORAGERATE)}$$

4.11 Transport block

Transport sector is treated as single sector as an industrial acticity while it would be better to represent more in details from the perspective of mode-wise differences in energy and emissions. Here we have a disaggregation method for the transport sector.

Transport energy consumption by mode

$$TRS\_ENE_{r,tr} = QDTRST_{r,tr} \cdot trseneeffi_{r,tr} \cdot (PENE\_TR_{r,tr}/PENE\_TR\_base_{r,tr})^{prtrsrel_{r,tr}}, \quad \forall r \in R,\ tr \in TR \text{ (TRSENEEQ)}$$

$tr \in TR$: a set of transport mode in industry
$TRS\_ENE_{r,tr}$: Transport energy consumption by mode tr
$QDTRST_{r,tr}$: Transport demand,
$PENE\_TR_{r,tr}$: Price of transport,
$PENE\_TR\_base_{r,tr}$: Price of transport in the base year
$prtrsrel_{r,tr}$: Price elasticity of transport,

Passenger and Freight transport by mode computed by the transport sector activity

$$QDTRST_{r,tr} = QA_{r,\text{"TRS"}} \cdot trscef_{r,tr}, \quad \forall r \in R,\ tr \in TRPSS \text{ (TRSPSSEQ)}$$

$$QDTRST_{r,tr} = QA_{r,\text{"TRS"}} \cdot trscef_{r,tr}, \quad \forall r \in R,\ tr \in TRFRT \text{ (TRSFRTEQ)}$$

$trscef_{r,tr}$: Transport demand coefficient to transport sectro' activity level.
$tr \in TR\_PSS$: a set of passenger modes
$tr \in TR\_FRT$: a set of freight modes

Household passenger car conversion from monetary to physical unit

$$QCARU_{r,h} = QCH_{r,\text{COM\_CAR},h} \cdot pcaru_{r,h}, \quad \forall r \in R,\ tr \in TR,\ h \in H \text{ (HCARPAS)}$$

$QCARU_{r,tr}$: passenger car demand in household
$pcaru_{r,tr}$: conversion factor from monetary to physical unit for passenger car in household

Transport energy price by mode

$$PENE\_TR_{r,tr} = \sum_{c' \in ENE} \{(PQD_{r,c'} \cdot dfpq_{r,c',h} \cdot (1 + tqd_{r,c',h}) + \sum_{g \in G} PGHG_r \cdot gwp_g \cdot efffc_{r,c',h,g}) \cdot TRS\_ENE\_FL_{r,tr,c}\} \sum_{c' \in ENE} TRS\_ENE\_FL_{r,tr,c} \; \forall r \in R,\; tr \in TR$$

(PENE_TR_DEF)

$TRS\_ENE\_FL_{r,tr,c}$: Transport energy consumption by mode *tr* by fuel *c*.

The transport sector's energyconsumption is constrainted by QINT which is adjusted in the next equations

Transport energy aggregation

$$QINT_{r,c,a} = \sum_{tr \in TR\_DM} TRS\_ENE\_FL_{r,tr,c}, \quad \forall r \in R,\; a \in ATRS, c \in ENE$$

(QENEFUEL_TRS)

Transport energy consutmpion by fuel and by mode:

$$TRS\_ENE\_FL_{r,tr,c} = TRS\_ENE_{r,tr} \cdot (1 + CETRSFUEL_{r,c,\text{"}trs\text{"}}) \cdot \beta^{trsene}_{r,tr,c} \cdot \{PQD_{r,c} \cdot (1 + tqd_{r,c,\text{"}trs\text{"}}) + PGHG_r \cdot \sum_{g \in G} gwp_g \cdot enur_{r,c,\text{"}trs\text{"}} \cdot efffc_{r,c,\text{"}trs\text{"},g}\}^{el^{trsene}_{r,tr,c}} \cdot [\sum_{cp \in ENE} \beta^{trsene}_{r,tr,cp} \cdot \{PQD_{r,cp} \cdot (1 + tqd_{r,cp,\text{"}trs\text{"}}) + PGHG_r \cdot \sum_{g \in G} gwp_g \cdot enur_{r,cp,\text{"}trs\text{"}} \cdot efffc_{r,cp,\text{"}trs\text{"},g}\}^{el^{trsene}_{r,tr,cp}}]^{-1} \forall r \in R,\; c \in ENE,\; h \in H$$

(TRSENEFLEQ)

$\beta^{trsene}_{r,tr,c}$: share parameter of Logit function for transport by mode energy source selection ,

$el^{trsene}_{r,tr,c}$: Price elasticity parameter of Logit function for transport by mode energy source selection,

$CETRSFUEL_{r,c,\text{"}trs\text{"}}$: complementary variable to meet energy consumption from QENEFUEL_TRS

The emissions can be computed by the emission factors.

Emissions associated with transport energy consutmpion by fuel and by mode:

$$TRS\_ENE\_EMI_{r,tr,c,g} = TRS\_ENE\_FL_{r,tr,c} \cdot enur_{r,c,\text{"}trs\text{"}} \cdot eff\_tr_{r,tr,c,g} \quad \forall r \in R,\; c \in ENE,\; tr \in TR$$ (TRS_EMIS)

$TRS\_ENE\_EMI_{r,tr,c,g}$: transport related gas emissions
$eff\_tr_{r,tr,c,g}$: transport related gas emissions factor

4.12 Water use block

The industrial water is associated with the acticity levels with the consideration of sea water usage and CCS technology as follows.

Industrial water withdrawal

$$\begin{aligned} WATWTH_{r,a} = & \sum_{c \in C} QXAC_{r,a,c} \cdot (1 - seawater_{r,a}) \cdot \\ & \sum_{ctech} (watwithcoef_{r,a,\text{"}No\text{"},ctech} \cdot (1 - TSCT_{r,a,\text{"}ccs\text{"}}) \\ & - watwithcoef_{r,a,\text{"}CCS\text{"},ctech} \cdot TSCT_{r,a,\text{"}ccs\text{"}}) \forall r \in R,\ a \in ANCROP \end{aligned}$$

(INDWATWITH)

Industrial water consumption

$$\begin{aligned} WATCNS_{r,a} = & \sum_{c \in C} QXAC_{r,a,c} \cdot (1 - seawater_{r,a}) \cdot \\ & \sum_{ctech} (watcnscoef_{r,a,\text{"}No\text{"},ctech} \cdot (1 - TSCT_{r,a,\text{"}ccs\text{"}}) \\ & - watcnscoef_{r,a,\text{"}CCS\text{"},ctech} \cdot TSCT_{r,a,\text{"}ccs\text{"}}) \forall r \in R,\ a \in ANCROP \end{aligned}$$

(INDWATCNS)

$a \in ANCROP$: Non-crop production activities
$WATWTH_{r,a}$: water withdrawal in activity a
$WATCNS_{r,a}$: water consumption in activity a
$seawater_{r,a}$: Sea water usage ratio in acticity a
$watwithcoef_{r,a,ccs,ctech}$: Water withdrawal coefficient depending on CCS usage
$watcnscoef_{r,a,ccs,ctech}$: Water consumption coefficient depending on CCS usage

The water consumption estimated by land inputs or livestock products outputs multiplying water consumption coefficients that are calibrated based on the above historical water data.

The water withdrawal is computed by irrigation rates and irrigation efficiency as follows.

Irrigation water withdrawal

$$WATWTH_{r,a} = WATCNS_{r,a} \cdot IrrigationRate_{r,a} \cdot IrrigationEff_{r,a} \quad \forall r \in R,\ a \in ACROP$$ (AGRWATWITH)

$IrrigationRate_{r,a}$: Irrigation rate to the total agricultural area
$IrrigationEff_{r,a}$: Irrigation efficiency

Irrigation water consumption

$$WATCNS_{r,a} = WATCNS_{r,a} \cdot QF_{r,"LND",a} \cdot Crop\_intensity_{r,a} \cdot \sum_{ctech} (watcnscoef_{r,a,"No",ctech}) \quad \forall r \in R,\ a \in ACROP \text{ (AGRWATWITH)}$$

we adopt Bijl's approach [8] using global panel data to estimate historical water withdrawal in municipal sector. We assume that water intensity is primarily explained by income level, i.e. GDP per capita. The following regression function is used:

Domestic water withdrawal

$$WATWTH_{r,h} = \left(\sigma_r^{MunWat} + \mu^{MunWat} + \eta^{MunWat} \cdot lnGDP\_cap_r\right) \cdot Pop_r/1000 \quad \forall r \in R,\ h \in H \text{ (MUNWATWITH)}$$

σ_r^{MunWat}: country fixed effects for the domestic water consumption
μ^{MunWat}: a parameter for the domestic water consumption
η^{MunWat}: income elasticity of domestic water consumption

Domestic water consumption

$$WATWTH_{r,h} = WATCNS_{r,h} \quad \forall r \in R,\ h \in H \text{ (MUNWATWITH)}$$

4.13 Enduse energy device module

This model has an option to determine final energy demand based on detailed energy device specification. Basically the devices are selected by Logit function with each device's cost. The cost consists of investment cost and operation cost, and the former cost is annualized by using discount rate and life time of individual devices. The latter is energy, carbon emission cost and other operation cost like labor wages. The above device selection is assumed to be made only for new investment devices. The current year's old device stock is passed from previous year.

Enduse device stock

Enduse device stock is defined as the sum of stock remained from previous year and new investment. The stock of previous year is depleted by inverse of the life time and discounted by rate of not working devices.

$$END\_STK_{r,ac,l} = \left(\left(1 - \frac{1}{\tau_l}\right) \cdot stka\_pre_{r,ac,l} \cdot \left(1 - \sum_{i \in LI(l,i)} END\_QEOR_{r,ac,i}\right) + END\_QR_{r,ac,l}\right) \text{ (EQ\_END\_STK)}$$

$END\_STK_{r,ac,l}$: enduse device stock,
τ_l: life time of device l,
$END\_QEOR_{r,ac,i}$: enduse device (not working),
$stka\_pre_{r,ac,l}$: previous year's stock of combination of device l in sector ac,
$END\_QR_{r,ac,l}$: enduse device new investment,
$i \in I$: energy service i,
$l \in L$: enduse device l,
$LI(l,i)$: mapping device l and energy service i,

Enduse device stock operation

Enduse device stock operation is derived from working stock and operation ratio.

$$\left(1+\lambda^{d}_{r,ac,l}\right)\cdot END\_STK_{r,ac,l} = END\_QXD_{r,ac,l} \quad \text{(EQ\_END\_OPE)}$$

$\lambda^{d}_{r,ac,l}$: operating rate of device l in sector ac,
$END\_QXD_{r,ac,l}$: enduse device stock operation.

Enduse device service supply

Service demand is equal to the product of enduse device stock operation and supply output per operation unit considering service efficiency.

$$(1+\varphi_{r,ac,i})\cdot \sum_{l\in LI(l,i)} (ad_{r,ac,l,i}\cdot END\_QXD_{r,ac,l}) = QSD_{r,ac,i} \quad \text{(EQ\_END\_SRD)}$$

$\varphi_{r,ac,i}$: a measure of service efficiency of service type i in sector ac,
$ad_{r,ac,l,i}$: supply output of service i per operating unit of device l in sector ac (same as specific service output),
$QSD_{r,ac,i}$: service demand.

Industry Service demand

The industrial service demand is derived based on base year's service demand and the change of quantity of activity compared with base year. *indserincel* is the elasticity determining the effects from the change of quantity of activity to service demand.

$$QSD_{r,a,i} = sd\_base_{r,a,i}\cdot\left(\frac{QA_{r,a}}{QA\_base_{r,a}}\right)^{indserincel_{r,a}} \forall a\notin A\_TRS \quad \text{(EQ\_END\_SRD\_IND)}$$

$sd\_base_{r,a,i}$: base service demand coefficient of industry,
$indserincel_{r,a}$: output elasticity of energy service demand of industry.

Residential Service demand

The residential service demand is derived based on base year's service demand and the changes of household income and consumer price index compared with base year. Similarly to *indeserincel* in industrial service demand, *resserincel* is the elasticity parameter.

$$QSD_{r,h,i} = sd\_base_{r,h,i}\cdot\left(\frac{EH_{r,h}}{EH\_base_{r,h}}\cdot\frac{CPI\_base_{r}}{CPI_{r}}\right)^{resserincel_{r,h}} \quad \text{(EQ\_END\_SRD\_RSD)}$$

$sd\_base_{r,h,i}$: base service demand coefficient of household,
$resserincel_{r,h}$: income elasticity of energy service demand of household.

Transport Service demand

The transport service demand is derived based on base year's service demand.

$$QSD_{r,a,i} = sd\_base_{r,a,i}\cdot\frac{\sum_{tr\in MTR(tr,i)} QDTRST_{r,tr}}{\sum_{tr\in MTR(tr,i)} QDTRST\_base_{r,tr}} \forall a\in A\_TRS \quad \text{(EQ\_END\_SRD\_TRS)}$$

Enduse device new investment selection

Enduse device as new investment is selected based on device's price by Logit function. The device selection is made for each energy service demand.

$$\sum_{i\in LI(l,i)}\left((1+\phi_{r,ac,i})\cdot ad_{r,ac,l,i}\cdot\left(1+\lambda^{d}_{r,ac,l}\right)\cdot END\_QR_{r,ac,l}\right)$$
$$=\sum_{i\in LI(l,i)}\left(\frac{\mu_{r,ac,l}\cdot\left(END\_PCOST_{r,ac,l}\right)^{\eta^{end}_{r,ac,l}}}{\sum_{ll\in LI(ll,i)}\left(\mu_{r,ac,ll}\cdot\left(END\_PCOST_{r,ac,ll}\right)^{\eta^{end}_{r,ac,ll}}\right)}\cdot END\_QRT_{r,ac,i}\right) \quad \text{(EQ\_END\_LOGIT)}$$

$END\_PCOST_{r,ac,l}$: enduse device price,
$\eta^{end}_{r,ac,l}$: exponent of Logit function,
$END\_QRT_{r,ac,i}$: enduse total new investment for service.

Enduse device price

Enduse divece price is the sum of annualized investment cost, operation cost and enegy cost. The energy cost is calculated as the product of energy use by device and energy price including carbon tax. Note that emissions from biomass fuel are not considered as GHG.

$$\begin{aligned}END\_PCOST_{r,ac,l} = {} & invc_{r,ac,l}+ \\ & (oped_{r,ac,l} + \sum_{K\_END}(ied_{r,ac,l}K\_END \cdot (END\_PED_{r,K\_END,ac}+ \\ & (1 - \sum_{i\in LI(l,i)} BFRATIO_{r,ac,i})\cdot \\ & PGHG_r \cdot \sum_{g\in G}(gwp_{r,g} \cdot emcoef\_end_{r,ac,K\_END,g})))) \cdot (1 + \lambda^{d}_{r,ac,l})\end{aligned}$$

(EQ_END_PRICE)

$invc_{r,ac,l}$: annualized investment cost per unit of combination of device l in sector ac and region r,
$oped_{r,ac,l}$: operating cost except for energy per unit of combination of device l in sector ac and region r,
ied_{r,ac,l,K_END}: energy use of energy kind k per operating unit (or specific energy input) of device l in sector ac region r,
$END\_PED_{r,K\_END,ac}$: enduse energy price,
$BFRATIO_{r,ac,i}$: enduse biofuel ratio,
$emcoef\_end_{r,ac,K\_END,g}$: emission coefficient for enduse device,
$k \in K\_END$: energy kind for endues device.

Enduse total new investment for service

The new investment for each energy service should be greater than 0. Once it reaches zero, the old stock would not work and ENDQEOR has value. This mechanism is formulated with MCP.

$END\_QRT_{r,ac,i} \geq 0 \quad \perp \quad END\_QEOR_{r,ac,i} \geq 0$ (EQ_END_OPR)

Enduse energy price

$END\_PED_{r,K\_END,ac} = end\_ped\_base_{r,K\_END,ac}\cdot\sum_{c\in ENEENDMAP(c,K\_END)}\left(\frac{PQD_{r,c}}{PQD\_base_{r,c}}\right)$ (EQ_END_ENEPRI)

$end\_ped\_base_{r,K\_END,ac}$: base energy price of enduse stock,
$c \in ENEENDMAP_{c,K\_END}$:...

Energy use of service *i* in enduse energy

$END\_ENE_{r,ac,i,K\_END} = \sum_{l\in LI(l,i)} ied_{r,ac,l,K\_END}\cdot END\_QXD_{r,ac,l}$ (EQ_END_ENERGY)

END_ENE_{r,ac,i,K_END}: energy use of service i in enduse energy.

Energy use of service *i* in CGE energy

The energy kinds used for enduse device are more aggregated than CGE's original commodity classification. For example, the coal in enduse device consists of crude coal and coal producst (COM_COA and COM_COP). Thus, the energy consumption specified by enduse devices should be disaggregated. In this model, that disaggregation is made by Logit function as below.

$$\begin{aligned}
QEND_ENE_{r,c,ac,i} = & \sum_{KAGG_END} \Big(\sum_{K_END} END_ENE_{r,ac,i,K_END} \cdot \mu^{ea}_{r,c,ac,i} \\
& \cdot (dfpq_{r,c,ac} \cdot PQD_{r,c} \cdot (1 + tqd_{r,c,ac}) \\
& + PGHG_r \cdot \sum_{g \in G} (gwp_{r,g} \cdot enur_{r,c,ac} \cdot efffc_{r,c,ac,g}))^{\eta^{ea}_{r,c,ac}} / \\
& \sum_{cp \in MKAGGC} \mu^{ea}_{r,cp,ac,i} \cdot (dfpq_{r,cp,ac} \cdot PQD_{r,cp} \cdot \\
& (1 + tqd_{r,cp,ac}) + PGHG_r \cdot \sum_{g \in G} (gwp_{r,g} \cdot enur_{r,cp,ac} \cdot efffc_{r,cp,ac,g}))^{\eta^{ea}_{r,cp,ac}} \Big)
\end{aligned}$$

(EQ_END_ENERGY_MAP)

$QEND\_ENE_{r,c,ac,i}$: energy use of service i in CGE energy.

Industry Enduse energy mapping

The energy consumption specified by enduse devices are mapped to intermediate inputs and total energy consumption of each industrial and transport sectors.

$QINT_{r,c,a} = \sum_i QEND\_ENE_{r,c,a,i}$ (EQ_END_ENERGY_INDMAP)

Industry Enduse energy total

$QENE_{r,a} = \sum_{c \in C\_ENE(c)} QINT_{r,c,a}$ (EQ_END_ENERGY_INDTOT)

Transport Enduse energy mapping

$TRS\_ENE\_FL_{r,tr,c} = \sum_{i \in MTR\_I(tr,i)} QEND\_ENE_{r,c,"TRS",i} \forall tr \in TR$ (EQ_END_ENERGY_TRSMAP)

Transport Enduse energy total

$TRS\_ENE_{r,tr} = \sum_c TRS\_ENE\_FL_{r,tr,c}$ (EQ_END_ENERGY_TRSTOT)

Residential Enduse energy mapping

$QH_{r,c,h} - QCARENE_{r,h,c} = \sum_i QEND\_ENE_{r,c,h,i}$ (EQ_END_ENERGY_RSDMAP)

Residential Car Enduse energy mapping

The energy consumption for passenger car owned by household is allocated from transport to household consumption.
$QCARENE_{r,h,c} = \sum_{i \in MTR\_I("PC",i)} QEND\_ENE_{r,c,"TRS",i}$ (EQ_END_ENERGY_CARMAP)

$trspc\_enecoef_{r,h,c}$: passenger transport industry and residential efficiency difference.

Residential Car Enduse energy total

$QCARENET_{r,h} = \sum_c QCARENE_{r,h,c}$ (EQ_END_ENERGY_CARTOT)

Enduse biofuel ratio

The biofuel ratio is defined as below.
$BFRATIO_{r,ac,i} \cdot \sum_{c \in MKaggc("OIL",c)} QEND\_ENE_{r,c,ac,i} = QEND\_ENE_{r,"COM\_BIO",ac,i}$ (EQ_END_BIORATIO)

4.14 Additional equations

GDP

$$\begin{aligned} GDP_r = & \sum_{c \in C} (\sum_{h \in H} PQD\_base_{r,c} \cdot dfpq_{r,c,h} \cdot (1 + tqd_{r,c,h}) \cdot QH_{r,c,h} + \\ & PQD\_base_{r,c} \cdot dfpq_{r,c,"gov"} \cdot (1 + tqd_{r,c,"gov"}) \cdot QG_{r,c} + \\ & PQD\_base_{r,c} \cdot dfpq_{r,c,"S-I"} \cdot (1 + tqd_{r,c,"S-I"}) \cdot QINV_{r,c} + \\ & PE\_base_{r,c} \cdot QE_{r,c} + PM\_base_{r,c} \cdot QM_{r,c}), \forall r \in R \end{aligned}$$

(GDP)

$PQD\_base_{r,c}$; base year's PQD,
$PE\_base_{r,c}$; base year's PE,
$PM\_base_{r,c}$; base year's PM.

Primary factor to GDP ratio calculation

$QFS_{r,f} \cdot FCPROD\_base_{r,f} \cdot FCPROD_{r,f} = GDP_r \; \forall r \in R, c \in C$ (EQFACPROD)

$FCPROD_{r,f}$: Factor productivity change compared with base year
$FCPROD\_base_{r,f}$: Factor productivity in the base year

Base freight transport by mode in industry

$QDTRS_{r,tr,a} = QINT_{r,\mathrm{COM\_TRS},a} \cdot trscvf_{r,tr,a}, \quad \forall r \in R,\ tr \in TR,\ a \in A$ (INTTRNS)

$QDTRS_{r,tr,ac}$: Freight transport demand associated with each industrial acticity,
$trscvf_{r,tr,ac}$: Freight transport demand coefficient to intermeidaite or household transport goods consumption

Base freight transport by mode in household

$QDTRS_{r,tr,h} = QH_{r,\mathrm{COM\_TRS},h} \cdot trscvf_{r,tr,h}, \quad \forall r \in R,\ tr \in TR,\ h \in H$ (HOUTRNS)

Chapter 5

Model dynamics

This section describes the feature of model dynamics[1].

5.1 Capital

AIM/Hub is categorized as a recursive dynamic model. The capital stock is determined by the previous year's capital stock, capital formation and capital depreciation.

$$QF^{t}_{r,\text{"}cap\text{"},a} = QF^{t-1}_{r,\text{"}cap\text{"},a} \cdot \left(1 - dep^{t-1}_{r}\right) \quad \forall r \in R,\ t \in T \tag{5.1}$$

$t \in T$: a set of time series,

dep^{t}_{r}: capital depreciation rate in time t and region r.

As is mentioned in the previous chapter the old capital is fixed to each sector exogenously. The current year's new capital is determined as previous year's capital formation.

$$\overline{QFS^{t}_{r,\text{"}NCAP\text{"}}} = \sum_{c} QINV^{t-1}_{r,c} \quad \forall r \in R,\ t \in T \tag{5.2}$$

In this framework, the capital stock is calculated except for the base year. The base year capital stock is prepared by using the World Bank's physical capital stock database[2].

5.2 Labor

The population and labor is dynamically determined.

$$labor\_stock^{t}_{r} = labor\_stock^{t-1}_{r} \cdot lab\_gr^{t}_{r} \quad \forall r \in R,\ t \in T \tag{5.3}$$

$labor\_stock^{t}_{r}$: labor stock in time t and region r,
$lab\_gr^{t}_{r}$: labor stock (annual) growth rate in time t and region r.

The labor stock calculated in the upper equation will be the factor quantity.

$$QFS^{t}_{r,f} = labor\_stock^{t}_{r} \quad \forall r \in R,\ t \in T,\ f \in F_{lab} \tag{5.4}$$

[1] The programs which are described in this chapter are from [../scenario/BaU.gms]

[2] http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/0,contentMDK:20699846~pagePK:64214825~piPK:64214943~theSitePK:469382,00.html

$f \in F_{lab}$: labor (skilled and unskilled labor).

The current version assumes the growth rate is as the data from SSP database [9].

5.3 TFP (Total Factor Productivity)

We are aiming to simulate the future scenarios using this model and usually we assume the target GDP exogenously. The TFP (total factor productivity) should be determined on the assumption that labor stock and capital stock in a region are already estimated as shown in equation 5.1 and 5.2. The efficiency parameter $\alpha^{va}_{r,a}$ stands for TFP in this model, thus the $\alpha^{va}_{r,a}$ (appeared in equation (CESVAPRD)) is calculated with GDP growth target.

$$= \frac{QVA^{t-1}_{r,a} \cdot (1 + gdp\_gr^{t*}_{r})}{\left(\sum_{f \in F} \delta^{va}_{r,a} \cdot \left(QF^{t-1}_{r,f,a} \cdot \left(1 + fac\_gr^{t}_{r,f}\right)\right)^{-\rho^{va}_{r,a}}\right)^{-\frac{1}{\rho^{va}_{r,a}}}}, \quad \forall r \in R,\ a \in A \tag{5.5}$$

$\alpha^{va*}_{r,a}$: adjusted efficiency parameter in the CES value-added function,
$gdp\_gr^{t*}_{r}$: expected GDP growth target (annual growth rate),
$fac\_gr^{t}_{r,f}$: expected factor input growth rate (calculated by equation 5.4 and 5.2).

5.4 AEEI (Autonomous Energy Efficiency Improvement)

The energy demand is controlled by calibration of the Autonomous Energy Efficiency Improvements (named AEEIs). We set the annually AEEI improvement rate and revise the intermediate input coefficients and household energy commodity consumption rate as:

$$ene^{t}_{r,c,a} = iene^{"base\_year"}_{r,c,a} \cdot aeei^{t}_{r,c,a}, \quad \forall r \in R,\ c \in ENE,\ a \in A \tag{5.6}$$

$$iena^{t}_{r,ca} = iene^{"base\_year"}_{r,c,a} \cdot \sum_{c \in ENE} iene^{"base\_year"}_{r,c,a} \cdot aeei^{t}_{r,c,a}, \quad \forall r \in R,\ a \in ACES\_ENE \tag{5.7}$$

$${\gamma^{m}_{r,c,h}}^{t} = {\gamma^{m}_{r,c,h}}^{t-1} \cdot aeei^{t}_{r,c,h}, \quad \forall r \in R,\ c \in ENE,\ h \in H \tag{5.8}$$

$aeei^{t}_{r,c,ac}$: annual AEEI rate of energy commodity c, sector ac, time t and region r.

CES parameters determining energy consumption is also dynamically calibrated.

Chapter 6

How to use the model

6.1 System preparation

6.1.1 Installation software

- GAMS (`http://www.gams.com/`) (license is needed, please contact Fujimori). Version 26.0.0 or newer is needed. CONOPT and PATH are needed for the solver licences

- Git application software, (e.g. Source Tree (`https://www.sourcetreeapp.com/`) and TortoiseGit (`https://tortoisegit.org/`)) (open source)

- R (`http://www.r-project.org/`) (open source); this is not necessity but highly recommended to use for analysis and visualization.

- RStudio (`http://www.rstudio.com/`) (open source) is recommended to use R.

6.1.2 GitHub and download the CGE model

Additionally, tex building software is recommended for the advanced users who would change the model codes significantly (e.g., Texlive: https://www.tug.org/texlive/acquire-netinstall.html).

- Make one directory for working space of the latest AIM/CGE (e.g. AIM_CGE1.0) and clone the model from Github or get the code from Fujimori.

- Right click in the folder and Github checkout

  – You would be asked the repository and then put the repository name `https://github.com/KUAtmos/AIMCGE`. Using branches would be preferable and for the beginner, it would be better to make a branch from ”master”. For the developer, new branch is better to be made by ”develop”.

  – If you don’t have access to the repository please contact Fujimori

  – Then you have several folders under aimcge such as shown below

AIM_CGE1.0
|control
|data
|define
|doc
|

6.1.3 Environmental variables

The following directory paths should be added to "Path"

- GAMS exe file location
- Cygwin exe file location (Cygwin/bin)
- R exe file location (R/bin)

Note that you need to reboot the system in order to reflect the changes of the environmental variables. It should be English instead of font of Chinese or other languages.

How can you check whether you have added the directory paths to 'Path' correctly? First, open command prompt. Then type 'bash' to see if Cygwin works fine. Then type 'R' to see if R works fine. When you run the model and find something is wrong with plotting graphs, please try install R library. First, open R studio, click 'tools', then 'install package', type 'ggplot2' in the blank line and click 'install'. After it is finished, do it similarly for 'RColorBrewer' and 'reshape2'.

Note for WSL or linux users

- MAGICC6 uses exe file which required windows basis execution. cygiwn is supposed to use MAGICC6. (updated)
- MAGICC7 uses a binary file that is only aviabel for pure linux os system.

6.2 Basic flow

There are two stages to use this AIM/Hub model (as shown in Figure 6.1). The first stage prepares basic scenario parameters, emission data. In the second stage, the model is run.

At the first stage, [emission.gms], [AEEI_mod.gms] and [scenario_parameter.gms] in the [/prog] directory should be run. This is basically already done when you download the latest version of the model.

AIM/HUB model is started by running [execution.bat] in the [/batch] directory. This batch file (explained later) controlstwo main programs [AIMHub.gms] and [scenario.gms] for the model runs. Firstly, it runs [AIMHub.gms] which carries out 4 things, "data loading", "parameter calibration", "model describing" and "base year simulating". Then, this program saves the results temporarily. Secondly, [scenario.gms] is run. [scenario.gms] consists of scenario setting and simulation. This process can be carried out iteratively, for example if you want to have several scenarios or multiple years, you can set them. Moreover, there are post-processes after running AIMHub.gms and scenario.gms which will be explained in the next section. [AIMHub.gms] consists of mainly 7 parts (without declaration of sets, parameters, variables and so on).

The structure of [AIMHub.gms] is drawn in 6.2. Left-side boxes represent the 7 procedures and some program files are included in each procedure, so the program

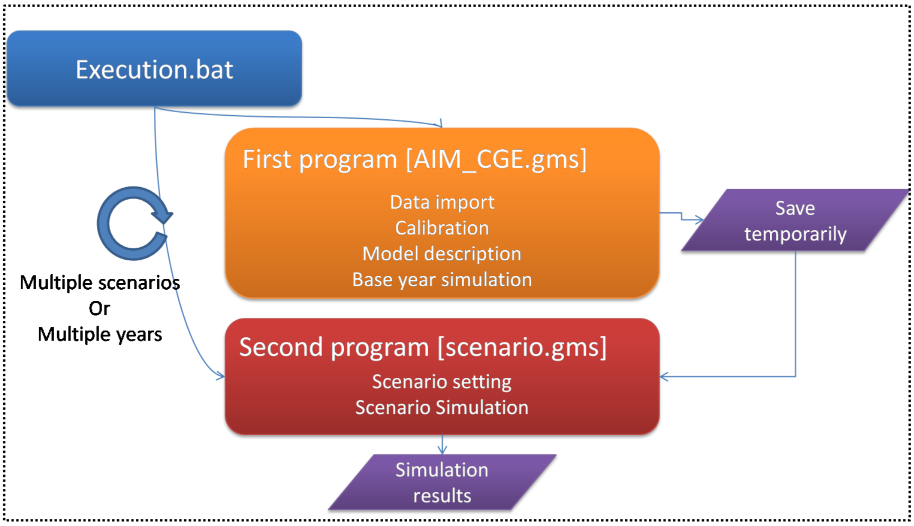

Figure 6.1: Overview of the program structure

names are shown in right side of that figure. The list of the components and their contents are described 6.2[1].[scenario.gms] includes following assumptions shown in 6.6.

6.3 How to run the model

There are two ways to run. One is using batch file and the other is shell. From Oct 2021, batch file operation is no longer updated and using shell is highly recommened.

For shell users, the execution of the model is done by execute a shell file /shell/ execution_global.sh. This execution batch file includes setting file shell/settings/ex ecution01.sh which specifies several model execution parameters. For users, please copy execution01.sh and execution_global.sh into same directories respectively and use them so that they are kept as default settings of shell configuration. The execution parameters can be classified into two. One is about the process parameters and the other is model settings.

For batch users, these two corresponding files are batch/execution_global.bat and batch/settings/execution01.bat.

Warning: During the running procedure, when multiple windows are open and one window request you to press any key to continue, be careful not to push it at the wrong time. When only one window is open, it is OK to push any key to continue.

6.4 Process parameters

The execution process can be divided into eight as shown in Figure 6.3. It starts from base year balancing and parameter declaration (1). Then, calibration and base year

[1]This list includes the declaration of sets, parameters and so on. The number of the sections shown in second column corresponds to that of in the actual program.

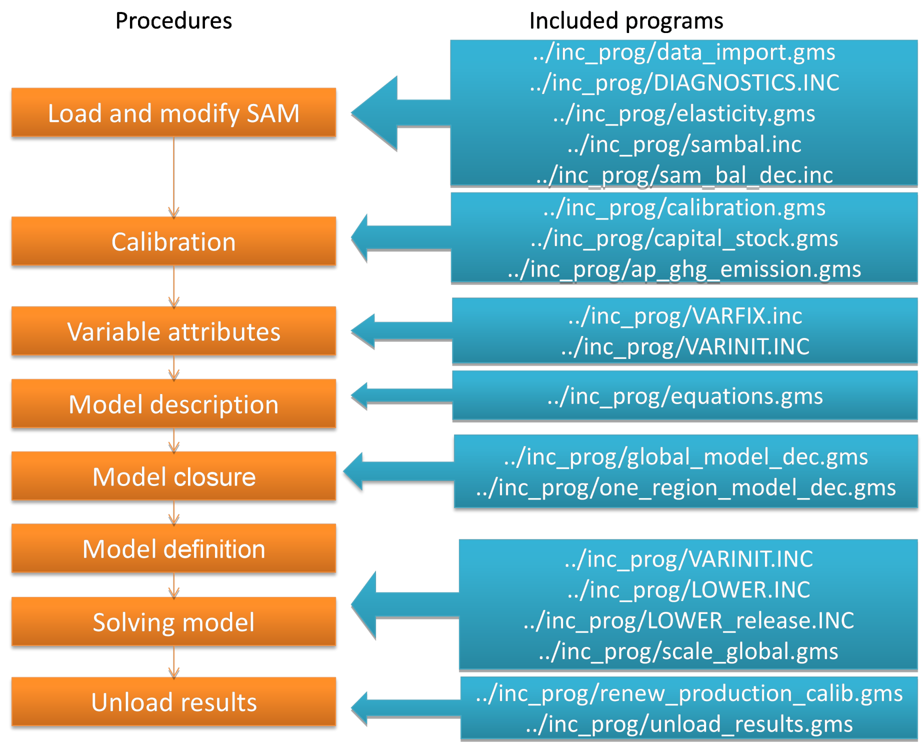

Figure 6.2: AIMHub.gms structure

Table 6.1: List of AIMHub.gms components

Program	Section	Section Name	Description	Included file
AIM_CGE.gms	**1-1**	**Set declarations**	**All sets are declared. (No sets are defined here).**	
	1-2	Load and modify SAM	SAM parameter is declared. Include file with data for a selected country is read in. In this file, the SAM structure is adjusted to fit the model structure. Error messages alert the user to missing data. The user has the option	../inc_prog/data_import.gms ../inc_prog/DIAGNOSTICS.INC ../inc_prog/elasticity.gms ../inc_prog/sambal.inc ../inc_prog/sam_bal_dec.inc
	1-3	**Parameter declarations**	**All model parameters (including those used to initialize variables) are DECLARED.**	
	1-4	Calibration	All model parameters (including those used to initialize variables) are DEFINED.	../inc_prog/calibration.gms ../inc_prog/capital_stock.gms ../inc_prog/ap_ghg_emission.gms
	1-5	**Variable declarations**	**All model variables are declared.**	
	1-6	Variable attributions	All model variables are initialized. In addition, variables not included in the model are fixed.	../inc_prog/VARINIT.INC
	1-7	**Equation declarations**	**The model equations are declared. They are divided into the following four blocks: "Price block", "Production and trade block", "Institution**	
	1-8	Model description	The model equations are defined. They are divided into the same four	../inc_prog/equations.gms
	1-9	**Display of model parameters and variables**	**All model parameters and variables (initial levels) are displayed in alphabetical order.**	
	1-10	Model closure	Macro and micro closure rules are selected by fixing selected	
	1-11	Model definition	The model (a set of equations most of which are linked to variables)	../inc_prog/global_model_dec.gms ../inc_prog/one_region_model_dec.gms
	1-12	Solving model	The model is solved for the base with some optional tests of robustness	../inc_prog/VARINIT.INC ../inc_prog/LOWER.INC ../inc_prog/LOWER_release.INC ../inc_prog/scale_global.gms
	1-13	Unload results	Unload base year simulation results	../inc_prog/renew_production_calib.gms ../inc_prog/unload_results.gms

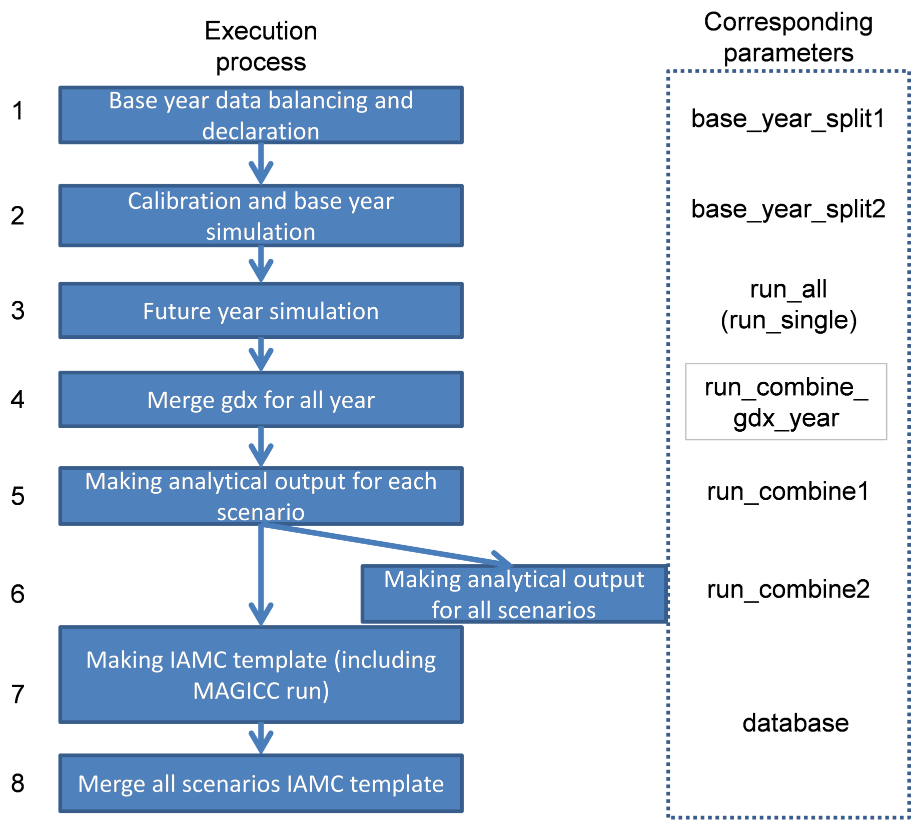

Figure 6.3: Process flow of the AIM/CGE model execution and corresponding parameters

simulation is made (2). After that, future year simulation is preceded (3). Latter processes are the translation of CGE model variables into analytical indicators. Merge gdx for all years is done for each scenario (4) and next is making analytical output for each scenario (5). These 4 and 5 proceudres keep annual information as they are computed. Then, all scenario results are combined (6) which limits the information to every 5 year step. This process (6) is no longer main stream of results synthesizing as of July 2021. Process (7) is done for making IAMC template which is required to submit any scenarios to IIASA database. This process (7) is run for each scenario keeping annual information. Also, MAGICC run is carried out within this process. Finally, IAMC template of all scenarios are merged into single GDX file in (8). From version 2.3.2, the users can specify CPU threads numbers that the users would like to use. Then, the shell script automatically allocates the jobs to threads. There are other several remarks as below.

Some notes:

- XXX_BaU_NoCC should be run at the first time regardless of socioeconomic assumptions. After getting combine1 process for XXX_BaU_NoCC, you can run mitigation or impacts cases changing the ”BaU” and ”NoCC” terms. This is because under BaU_NoCC scenario, some parameters such as TFP and household consumption preferences are calibrated.

- If you run base_year, usually you don't need to run anymore. Only when you have revisions of original data or basic structure of models, you need to rerun .
- Run_single is usually used for debugging the year where you find solution errors. This option allows you to run the year which you want to run and stop the simulation at that year.
- Run_combine_gdx_year is merging gdx process so that it cannot be paralleled even if you had many scenarios.
- For mulple scenario parallel runs, you should turn off "run_all" and "run_single".

set rmScenarioDataAll=on remove GDX output files.

set base_yearōff base year run (loading and balancing SAM, base year calibration and base year run) ("on" for the first operation when you first receive the model)

set run_all=on future years' run (all years) (no longer used from October 2021)

set run_single=off future year's run but each year the "pause" command is used

set run_combine1=on making analytical gdx for one scenario

set run_combine2=on combining all results across scenarios and make results files.

set run_all_parallel=off future years' run (all years) with multi-process parallel run

set database=off running climate model and making a csv file for IIASA database template model results (This function is outdated from July 2021)

set NCPU=8 Specifying number of cores that are used for the pararell process

set pausemode=off If you would like to pause each process, turn on this switch

set MultiSol=3 If you would like to use multi-threds, specify the number and 1,3, or 5 are currently available. Becareful number of NCPU, scenarios and this MultiSol. $scenarios*$MultiSol will be parallelly used.

set SceNameSpe=off If you would like to specify IAMC template scenario names, turn on this switch and specify the scenario mapping ../tools/iiasa_database/define/scenario.map.

on/off are options for all parameters

6.5 Model setting parameters

Table 6.2 shows list of model setting parameters. CLP and scenario_name can have multiple codes (e.g. SSP2 and SSP3 for scenario_name) and if you choose parallel process parameters on, the scenarios run in parallel. However, to run climate policy scenarios (not BaU) you have to finish BaU running process (for "combine_gdx_year" and "combine_gdx1" in advance since climate policy cases use BaU results. In shell files, if you would like to multiple parameters for a particular set below, you should double quote with space seprates (e.g. CLP="BaU CM").

If you define new scenarios or climate policy cases, you have to change settings in tools as follows.

Table 6.2: model setting parameters

parameters	Default value	Alternative options	Description
global	on	Off	Specification of global model or single country model
Sr	JPN	106 regions	Code of country if the model is used as single country model. Regional codes are listed in the manual.
base_year	2005	None	Base year
target_year	2050	2100	Last year of target period
Start_year	2006	Any from base to target year	The starting year of scenario run. Basically 2006 is preferable but for when the users check the model results and conditions in case the users encounter errors
CLP	BaU	CTAX, 26W, 37W, 45W, 60W etc.	Specification of climate policy. BaU does not have any constraint on emissions nor emission price while the others have. The strength of the constraint depends on the scenarios. The emissions cap or emission price is described in the prog /scenario/emission/***.gms
IAV_ass	NoCC	CC1 etc.	For the IAV analysis, climate change condition can be specified by this switch.
Scenario_name	SSP2	SSP1-SSP5 and any	Scenario name that specifies socioeconomic assumptions. The name is freely available. Corresponding socioeconomic scenario should be specified in the prog/scenario/socioeconomic/***.gms
Enduse	on	Off	If detailed Enduse technological information is used, then turn on. It increases computational burden almost double.

6.5.1 Socioeconomic assumptions list

”scenario_name” specifies the socioeconomic assumptions. Currently a list of default scenarios is shown in the table in Table 6.3.

Table 6.3: Socioeconomic assumptions list

Scenario_name	Description
SSP1-SSP5	Shared Socioeconomic Pathways (SSPs) default five scenarios. Details are in Fujimori et al. (2017) [10]
SSP2_hindcast	For hindcasting simulation of which details are shown in Fujimori et al. (2016) [11]

SSP2i	Basic assumptiosn are SSP2 but currently planed policies are reflected. Details are shonw in Roelfsema et al. [12]. Currently (July, 2020), this would have very little impacts since IEA Energy balance is reflected until 2015.
SSP2_AIMEInv	AIM/Enduse energy system information is reflected which is only avaialbe for Japan (July, 2020). Details are shown in Fujimori et al. (2019) [13].
SSP2_CGEG	CGE global results are again fed into the simulation so that carbon tax effects to change price conditions are isolated.

6.5.2 Climate policy assumption list

"CLP" specifies the climate policy assumptions. Currently a list of default assumtpions is shown in table 6.4.

Table 6.4: Climate policy assumptions list

Scenario_name	Global/ National	Description
BaU	Global/ National	Without any climate policy. This scenario should be run firstly to calibrate TFP.
20W, 26W, 34W, 45W, 60W	Global	Stabilizing radiative forcing at 2100 roughly corresponding values. The global uniform carbon price for all sectors and GHGs start from 2015.
_SPA# (can be the radiative forcing, # can be 1-5)	Global	Stabilizing radiative forcing at 2100 roughly corresponding values. The sectoral coverage of GHG pricing imposition, the regional variation of timing of climate policy is dependent on SPA which is described in Fujimori et al. [10].
_SPA1 (can be the radiative forcing)	Global	Stabilizing radiative forcing at 2100 roughly corresponding values. The global uniform carbon price for all sectors and GHGs starts from 2020.
_SPA1CO2 (can be the radiative forcing)	Global	Stabilizing radiative forcing at 2100 roughly corresponding values but the actual implementation is based on cumulative carbon budget (20W=400, 26W=1000, 34W=1600). The global uniform carbon price for all sectors and GHGs starts from 2020.
_INDCCO2 (can be the radiative forcing)	Global	Stabilizing radiative forcing at 2100 roughly corresponding values but the actual implementation is based on cumulative carbon budget (20W=400, 26W=1000, 34W=1600). The global uniform carbon price for all sectors and GHGs starts from 2030. And 2020-2030 are under NDC assumption
INDC _CONT3	Global	2020-2030 the NDC assumtpions are applied and the same carbon price is applied thereafter.

Table 6.5: Country code list

Code	Name	Code	Name	Code	Name
58	Belgium-Luxembourg	HUN	Hungary	SDN	Sudan
890	Fmr Yugoslavia	IDN	Indonesia	SGP	Singapore
ARE	United Arab Emirates	IND	India	SLV	El Salvador
ARG	Argentina	IRL	Ireland	SUHH	Fmr USSR
AUS	Australia	IRN	Iran	SVK	Slovakia
AUT	Austria	IRQ	Iraq	SVN	Slovenia
BGD	Bangladesh	ISR	Israel	SWE	Sweden
BGR	Bulgaria	ITA	Italy	SYR	Syria
BLR	Belarus	JPN	Japan	THA	Thailand
BRA	Brazil	KAZ	Kazakhstan	TUN	Tunisia
BRN	Brunei Darussalam	KEN	Kenya	TUR	Turkey
CAN	Canada	KOR	Rep. of Korea	TWN	Chinese Taipei
CHE	Switzerland	KWT	Kuwait	UKR	Ukraine
CHL	Chile	LBN	Lebanon	URY	Uruguay
CHN	China	LBY	Libya	USA	USA
CIV	Cote d'Ivoire	LKA	Sri Lanka	UZB	Uzbekistan
COL	Colombia	MAR	Morocco	VEN	Venezuela
CRI	Costa Rica	MEX	Mexico	VNM	Viet Nam
CSHH	Czechoslovakia	MNG	Mongolia	XBT	Baltic countries
CSXX	Serbia and Montenegro	MYS	Malaysia	XCA	Rest of Central America
CUB	Cuba	NGA	Nigeria	XCI	Rest of CIS countries
CZE	Czech Rep.	NLD	Netherlands	XCS	Rest of Centeral Asia
DEU	Germany	NOR	Norway	XE10	Rest of EU10
DNK	Denmark	NZL	New Zealand	XENI	Rest of Annex I
DOM	Dominican Rep.	OMN	Oman	XER	Rest of Europe
DZA	Algeria	PAK	Pakistan	XME	Rest of East Middle
ECU	Ecuador	PAN	Panama	XOC	Rest of Oceania
EGY	Egypt	PER	Peru	XSA	Rest of South Asia
ESP	Spain	PHL	Philippines	XSE	Rest of Southeast Asia
FIN	Finland	POL	Poland	XSM	Rest of South America
FRA	France	PRK	Dem. People's Rep. of Korea	XSS	Rest of Africa
GBR	United Kingdom	PRT	Portugal	XYU	Rest of former Yugoslavia
GRC	Greece	QAT	Qatar	YEM	Yemen
GTM	Guatemala	ROU	Romania	ZAF	South Africa
HKG	China, Hong Kong SAR	RUS	Russian Federation		
HRV	Croatia	SAU	Saudi Arabia		

INDC _CONT2	Global	2020-2030 the NDC assumtpions are applied and the same carbon price is applied thereafter. During the NDC period from 2021 to 2030, the emissions trading is available. [10]
CTAX100, CTAX1000	Global/ National	Carbon price path starting from 2021 and linearly connect to 2100 by 100 or 1000$/tCO2.
****INDC (*** is numbers)	Global	2020-2030 the NDC assumtpions are applied and then the global uniform carbon price starts to meet cumulative carbon budget from 2011 to 2100 specified by **** GtCO2. The emissions pathways from DICE model.
****CACN (*** is numbers)	Global	The global uniform carbon price starts from 2020 to meet cumulative carbon budget from 2011 to 2100 specified by **** GtCO2. The emissions pathways from DICE model.
Global26WEne	Global	Global energy system model is fed into the simulation but mitigation cases.

Table 6.6: List of key assumptions in scenario.gms

Flag	file name	Assumption name	Contents
Assumption001	scenario.gms inc_prog/030_close_act2.gms inc_prog/030_parameter_in.gms inc_prog/030_close_act.gms	Closing small sectors Closing sectors that have small activity levels	Closing sectors that have small activity levels. This treatment is needed to avoid infeasible solution due to the small numbers
Assumption002	scenario.gms	Specifying emissions gases that are exempted from emissions tax	Some sectors could cause infeasibility due to very high emissions penalty associated with emissions tax and to avoid this situation, some non-energy related emissions are exempted. The default sectors are as below. • Coal mining, oil extraction and gas extraction • Forestry

contibue to the next page

conrtinued from previous page

Flag	file name	Assumption name	Contents
Assumption003	scenario.gms	Power generation cost calibration	The base year power cost information may have some issues and make 2006-2010 as calibration period. The basic idea is to assume following standard technological information. • Investment cost • Life time • Operation and Management cost • Capacity factor • Cost share of transmission and distribution The actual assumptions are in /data/TechnoEconomic.gdx. From 2006 to 2009, the production function input coefficients are adjusted to match with the data shown in Table 11.1 to Table 11.6. The cost decreases and capacity factor changes for the further period are assumed as shown in the tables. This treatment without forcing the energy consumption to IEA Energy Balance Table, the power price changes happen, which actually show something strange behavior in electricity consumption. Thus, IEA Energy Balance calibration option for this period should also be implemented simultaneously.

contibue to the next page

conrtinued from previous page

Flag	file name	Assumption name	Contents
Assumption004	scenario.gms	Power generation and biomass nesting share parameter shift	The logit share parameter (psiac) is controlled by this assumption but it should be noted that here the assumptions are quite strong. Power sector; The logit share parameter (psiac) is basically calibrated IEA Energy balance table until 2015. For BaU scenario, they are kept as they are afterwards. For mitigation scenario, after carbon price occurs, the bias currently existing in the renewable energy is diminished and it is assumed that the share parameter has equal value in fossil and renewable (win, spv and bio) in 2050 (sum of renewable = sum of fossil). Biomass; For second generation (residue and energy crops) bioenergy, the shift parameter is to be equal in 10 years. The first generation bioenergy is to decrease by 1 %.
Assumption005	scenario.gms inc_prog/030_PopGDPScenario.gms	GDP and population assumptions	GDP and population are assumed as indicated in the socioeconomic assumption files.
Assumption005-1	scenario.gms	Hindcast capital formation and price assumptions	Capital formation and price assumptions for hindcasting mode
Assumption006	scenario.gms inc_prog/030_aeei_adjustment.gms	AEEI assumptions	AEEI assumptions that are described in Fujimori et al. [10]. For the total energy consumption, the AEEI is associated with GDP growth. For the energy carrier-wise AEEI, basically shift from the dirty (coal) to cleaner (electricity) is assumed.

contibue to the next page

conrtinued from previous page

Flag	file name	Assumption name	Contents
Assumption007	scenario.gms	Energy service demand parameter	For default mode, transport service is the main parameters to be changed. However, current model does not determine the energy consumption in transport sector is determined by the CES function and disaggregation of the mode specific energy consumptions are derived from the base energy service which can be controlled by this parameter assumption.
Assumption009	scenario.gms	Change saving ratio	The saving ratio assumptions but it is usually unused because the investment is exogenous and saving rates are endogenous variables.
Assumption010	scenario.gms inc_prog/020_biopotential.gms	Biomass fuel potential for wood and agricultural residue	Agricultural residue are computed by previous year's crop production with coefficient which is computed by base year FAO information. Wood residue is also associated with forestry sector's activity level. 50% of both technical potential can be used for the energy purpose.
Assumption011	scenario.gms	Nonenergy use rate (this is only for the detailed Enduse technology representation mode)	Non energy use assumptions but it is only for the Enduse technology on mode which is rarely used now (July, 2020)

contibue to the next page

conrtinued from previous page

Flag	file name	Assumption name	Contents
Assumption012-1	scenario.gms	Plantation rotation assumption	The assumptions related to plantation rotation. Basically base year Co2 sequestration. This is closely related to the description at "*Wood removal for wood production" in ap_ghg_emission.gms The base year assumption is that 90% of wood removal (industrial and fuel wood) in high countries are well managed so that the trees are planted after wood is removed. 50% and 10% are assumed for middle- and low-income countries. The income classifications are made by 12616, and 3323$/cap, respectively. For the future, in 2050 all countries' planation situation catch up with the high income countries' assumptions.
Assumption012-3	scenario.gms	VRE Curtailment and storage	Assumptions related to VRE curtailment and storage. The parameters are shown in Dai et al. [14]. Basically storage is needed if the share of solar exceeds 5%.
Assumption012-5	scenario.gms inc_prog/030_EneModelload.gms	Energy model loading assumption	The energy system model (energy statistics information) is incorporated. The method is fully described in Fujimori et al.(2019) [13]. For the IEA Energy balance table implementation, from 2007 to 2019 are used. 2006 is the special year which has new stock and many model parameters can change and thus to avoid too much jump in 2006, the IEA Energy Balance starts from 2007. Currently, the CCS rates are not fully taken into account (July, 2020).
Assumption013	scenario.gms /inc_prog/030_basescenario.gms	TFP and other related assumptions	Labor force and capital stock assignment to parameters and TFC assumptions.

contibue to the next page

conrtinued from previous page

Flag	file name	Assumption name	Contents
Assumption013-1	scenario.gms ../inc_prog/ ResourceAssumptionVRE.gms	Variable renewable energy supply cost and capacity	VRE renewable energy potential and cost curve is assumed. Basically, there are 5 grades to cut the supply curves and we compare the previous year's production level with these curves and determine the production cost. The curve information is from Silva et al. (2016) [15].
Assumption013-2	scenario.gms /inc_prog/030_renewable_prodcut.gms	Install renewable energy (not existing in the previous year)	Renewable energy, nuclear, storage industry installation that do not exist in the previous year's calculation.
Assumption013-3	scenario.gms /inc_prog/030_CCS_industry.gms	Install CCS plant	Installation of CCS technology industry
Assumption013-4	scenario.gms /inc_prog/030_BaU.gms /inc_prog/030_NonBaU.gms	BaU or NonBaU specific assumptions	BaU or non BaU scenario specific assunmptions (see assumptions inside of the file as below assumptions 1XX)
Assumption013-5	/scenario/BaU.gms	Renewable energy capacity constraints in BaU scenario	Bioenergy, geothermal, other renewable have 2% growth limit. For nuclear, if the country has more than5% of nuclear in power generation, the maximum increase rate is GDP growth rates. Otherwise, 20% is the maximum increase rate.
Assumption013-6	scenario.gms inc_prog/030_EneModelload2.gms	Energy model loading assumption second	This second specification is mainly for the scenarios having carbon price and thus this part is located later than the inclusion of NonBauU.gms.

contibue to the next page

conrtinued from previous page

Flag	file name	Assumption name	Contents
Assumption014	scenario.gms	Power generation constraints (If the quota is finished but there are some years)	If power generation constraint is applied in earlier years, the computed complementary variable for that constraint which is interpreted as part of share parameter of logit function is applied to the later period. Parameters ”Prenew_up” and ”power_share_up” are cancelled if quota is assumed.
Assumption015	scenario.gms	Energy substitution	Energy substitution for the transport electricity and biofuel are adjusted.
Assumption016	scenario.gms	Transport energy efficiency	Transport mode-wise energy efficiency parameter changes. The total energy consumption is determined by the CES aggregates and this can be effective only look at disaggregated transport mode-wise energy consumption.
Assumption016-5	scenario.gms individual/degreedays/ climatechange_impact2 energydemand_scenario.gms	Climate change impacts on heating and cooling	The service demand changes are assumed as Hasegawa et al. [16]. This assumption can only be used for the enduse technology detailed mode.
Assumption017	scenario.gms	Enduse device scenarios	The assumptions of the energy service and technological availability for the enduse detailed mode (but rarely used).
Assumption017-1	scenario.gms	Biopotential supply curve	The biomass energy crop potential supply curve information is loaded. The original data is AIM/PLUM model output [17] [18]. The original gridded data is classified into 8 grades for each region and the bioenergy supply volume in the previous year is compared with that supply curve.
Assumption017-2	scenario.gms inc_prog/030_biofuel.gms	Bioenergy industry assumptions	Bioenergy industry assumptions. Details are described in Fujimori et al. [19]

contibue to the next page

conrtinued from previous page

Flag	file name	Assumption name	Contents
Assumption017-4	scenario.gms	F-gas emissions	F-gas emissions reduction assumptions which is described in SSP paper [10]. The original assumption comes from IMAGE team.
Assumption017-3	scenario.gms inc_prog/030_air_pollutant_scenario.gms	Air pollutant scenario	Assumptions on the air pollutant emissions which is described in SSP papers [10] [20]. The original data comes from GAINS team. There are some critical own assumptions to the baseline. • For agricultural emissions, 0.125, 0.25 and 0.5% annual decrease rates in the emission factors are applied for weak , central and strong air pollution policies respectively. • For forest related emissions, 0.25, 0. 5 and 1.0% annual decrease rates in the emission factors are applied for weak , central and strong air pollution policies respectively. • For waste related emissions, 0.25, 0. 5 and 1.0% annual decrease rates in the emission factors are applied for weak , central and strong air pollution policies respectively. • For the energy-related emissions but missing in GAINS in some species, we assume 2% per annual improvement in the emission factors. For the biofuel which does not exist in base year, we adopt petro emissions factors.

contibue to the next page

conrtinued from previous page

Flag	file name	Assumption name	Contents
Assumption018	scenario.gms	Fossil fuel extraction	Coal, oil and natural gas extraction cost assumptions. The original data is from Rogner et al. [21] which has 5 grades. The volume of cumulative extraction is considered to mark-up the production cost. 5 grades are linearly interpolated to avoid the sudden cost increase at some point.
Assumption018-5	scenario.gms	Electricity distribution loss improvement	The electricity distribution loss rate is assume to have 1% annual improvement (for example, if the distribution loss is 10% in the base year, next year will be 9.9%=0.1*0.99), but the minimum value is set to 4.5% which is current Japan's rates.
Assumption019	scenario.gms	Agriculture yield scenario	For crops, there are two types of yield assumptions; namely default and shock cases. The former is the default technological change assumptions described in Hasegawa et al. [22] which has SSP variations. The latter is mainly for the climate change yield shock and incorporates the crop model yield shock data. For pasture land productivity, we assume that the productivity is improved by the expected livestock demand changes which are computed by GDP growth with income elasticity and population changes.
Assumption020	scenario.gms	Land use change long term shifter	For the land allocation logit function, the share parameter of the energy crop is assumed to shift to the average value of individual crop.

contibue to the next page

conrtinued from previous page

Flag	file name	Assumption name	Contents
Assumption021	scenario.gms	Intermediate input coefficient change	Steel intermediate inputs coefficients changes based on Fujimori et al 2011 [23]. These improvement rates come from Japan's numerical evidence from Committee on iron and steel statistics(Committee on iron and steel statistics, 2006) [24] and STAN Database [25] [25]. The Committee on iron and steel statistics [4] contain steel order volume for each sector and the STAN Database (OECD [13]) has industrial output indexes. The steel consumption per unit production was then plotted as in the Figure 3.5 (Fujimori et al. 2011 [23]). Each industry experienced improvement in steel consumption intensity over the past three decades. This decrease is probably due to the substitution of steel with other materials such as plastics. However, we could not confirm that substitution with the evidence so far. Thus, we assume that the decrease in steel use would be homogenously replaced by the other material inputs. Based on the assessment, we assume 4.7% (average of machinery and transport equipment) and 2.1% for other manufacturing and construction sectors' input respectively. For the other heavy material goods, we don't so far solid evidence how the intermediate inputs changes over time and tentatively 2% per annual are assumed. Those change rates, however, not directly applied to all countries uniformly because the countries which have relatively modest economic growth such as current high-income countries would have such rapid intensity of material use increase and thus, 80, 60 and 50% of these improvement rates are adopted for the countries which GDP growth rates are 1-3, 0-1 and less than 0% respectively.

contibue to the next page

conrtinued from previous page

Flag	file name	Assumption name	Contents
Assumption021-1	scenario.gms	Long-term trade share changes	There are three main assumptions on long-term trade function shift. - For biofuel and raw biomass, the trade and domestic share for both of import and export are eventually equal (determined by price) and thus 30 years later after trade occurs, the parameter shifted.
Assumption021-2	scenario.gms	Trade tariff and export tax assumption change	Trade tariff and export tax rates changes. These are coming from socioeconomic assumptions.
Assumption022	scenario.gms inc_prog/030_CGEBoundary Assumption.gms	CGE boundary conditions	Specification of total primary factor inputs, foreign direct investment, CPI, exchange rates, governmental consumption, governmental saving. Some of them are initial value and rest are fixed values for the model.
Assumption023	scenario.gms	World trade price for national model	World trade price for national model, if there are global scenario named %SCENAME%_%Global4National%, the corresponding world price is used for national model.
Assumption024	scenario.gms	Transfer	Income (property and labor compensation) transfer assumptions of which increases are in line with GDP growth.
Assumption024-3	scenario.gms /inc_prog/020_foodwaste.gms	Food waste assumption	The food waste assumption is made. As stated in the socioeconomic_assumptiong.gms there are two options whether the scenario considers SDG target to halve the food waste generated from consumption process.
Assumption025	scenario.gms /inc_prog/030_hydrogen.gms	Hydrogen implementation	Hydrogen implementation. The way how hydrogen related industries are occurred is similar to bioenergy related industries.

contibue to the next page

conrtinued from previous page

Flag	file name	Assumption name	Contents
Assumption026	scenario.gms	GHG emission price initial value	Initial value for the GHG emissions price. This setting is critical to get solution in the year which firstly implement carbon price. The initial value should be sufficiently small to smoothly find solution.
Assumption027	scenario.gms	Stock change decreasing	The stock change was assigned to some goods treated as physical volume in the model due to the inconsistency in the base year information. The calibrated stock change is assumed to decrease over the time period.
Assumption028	scenario.gms	Non-energy related emissions abatement assumptions	Non-energy related emissions abatement assumptions. The exponential function is used. A similar method is already discussed by Hyman et al. (2003). The parameter is taken from Lucas et al. (2007) [26]
Assumption029	scenario.gms	International emission trading initial value and quota	10-folds of BaU emissions are assumed to be the maximum export and import volume of emissions trading for global model. For national models, R_EM_TR(R) determines the ratios to the total emissions. Either way, CAP_TRADE needs to be turned on.
Assumption029-1	scenario.gms	International emission trading for kyoto protocol period	Emissions trading historical record (price and volume) for the Kyoto Protocol period taken from the World Bank report [27].

contibue to the next page

conrtinued from previous page

Flag	file name	Assumption name	Contents
Assumption030	scenario.gms	Landuse related emissions and their cost	There are two major assumptions related to land-use change emissions. First, if the afforestation option is off, the forest increases in mitigation scenarios should be lower than those in baseline. Second, we assume lower boundary for forest area if carbon tax is sufficiently high (>50$) to avoid large deforestation. The actual assumption is that the previous year's forest area is lower boundary.
Assumption031	scenario.gms	Constraint for GHG cost of activity level (this is mainly for BioCCS)	BECCS related production activities (such as biomass power generation (E_BIN) and biofuel refinery (BTR3) can get too much subsidy (negative carbon tax) under high carbon price, which makes negative production cost. This situation causes trouble in CGE solution and thus here the ceiling of the BECCS subsidy is assumed. The default (SSP2) maximum subsidy level is 66% of production cost but varied among socioeconomic assumptions differentiated by BIOCCP.
Assumption032	scenario.gms /inc_prog/030_biohygtrade.gms	Bioenergy and hydrogen trade assumption on/off	Bioenergy (liquids: COM_BIO, primary energy crop: COM_ECR) and hydrogen trade are assumed. /inc_prog/030_biohygtrade.gms is parameter specification for the initial year to implement these trades. The initial shares of import to the domestic consumption and export to the domestic supply are assumed to be 0.1%.

contibue to the next page

conrtinued from previous page

Flag	file name	Assumption name	Contents
Assumption033	scenario.gms	Water consumption assumptions	Water consumption and withdrawal intensity coefficients are changed overtime. The improvement rates are differentiated by SSP assumptions where basically SSP1 and SSP5 have larger technological progress than SSP3 and SSP4, which leads double and half of the intensity improvement compared to SSP2. Irrigation efficiency is improved by 0.2% as default. All assumptions are described in Fujimori et al. (2017, 2020 [28] [29]) in detail.
Assumption034	scenario.gms	Consumption tax changes	For the cases which national models would like to change the consumption tax rate, it can be used.
Assumption102	/scenario/BaU.gms	Power supply constraints from other literature (currently unused)	This part can implement exogenous power supply constraint for the individual technology but currently unused.
Assumption103	/scenario/BaU.gms	Household preference parameter changes	LES parameters are changed based on income elasticity and income. This is mainly for the food consumption.
Assumption111	/scenario/NonBaU.gms	GHG emissions constraints	Emissions constraint or carbon price path is adopted.
Assumption112	/scenario/NonBaU.gms	Power supply constraints from other literature (currently unused)	This part can implement exogenous power supply constraint for the individual technology but currently unused.
Assumption113	/scenario/NonBaU.gms	BaU's Productivity	BaU's TFP values is adopted.
Assumption114	/scenario/NonBaU.gms	Trade elasticity changes	Change trade elasticity dynamically in non-BaU cases.

contibue to the next page

conrtinued from previous page

Flag	file name	Assumption name	Contents
Assumption121	/inc_prog/030_basescenario.gms	Labor force	Assignment of labor supply to the factor input parameter.
Assumption122	/inc_prog/030_basescenario.gms	Capital stock	Total capital stock
Assumption125	/inc_prog/030_basescenario.gms	TFP growth assumption	TFP assumptions for the scenarios that don't fix GDP in BaU (currently unused in July 2020)
Assumption131	/inc_prog/030_aeei_adjustment.gms	Fuel-wise energy efficiency improvement	Fuel-wise energy efficiency improvements are described. The traditional biomass, modern energy, coal use in building are differentiated.
Assumption132	/inc_prog/030_aeei_adjustment.gms	Total energy consumption efficiency improvement	Total energy consumption efficiency improvement assumptions. The improvement rates are dependent on the GDP growth which reflect the development phases. Detailed assumptions are described in Fujimori et al. [10]

finish

6.6 Specific years assumed in the model

The model assumes some years that change the conditions such as new biofuel and hydrogen industries appear and so on. Here is a list of such year (Table 6.7) and these are specified in "/inc_prog/030_SpecYear.gms".

Table 6.7: List of specific assumptions years

Years	Switch	Contents
2006	WINstart	Onshore wind power starts
2007	SPVstart	Solar PV starts
2010	WIFstart	Offshore wind power starts
2008	EBIOstart	Conventional bioenergy power starts
2008	biostartyear	1st generation biofuel starts
2012	RISstart	Curtailement and storage start (but there is another condition to be implemented, which is VRE share)
2015	PowCalYear	Power generation technoeconomic asssumptions are adopted exogenously from this year (before this year, parameters are interpolated from original SAM)
2015	TDCalYear	Power generation transmission and distribution cost are adopted exogenously from this year (before this year, parameters are interpolated from original SAM)
2013	secondbiostart	2nd generation biofuel and advanced bioenergy power plants start
2020	SocEcoChanStart	SSP-wise socioeconomic assumptions start to be assumed (before 2020, SSP2 is assumed)
2020	absstyr	energy service demand change starts
2020	CCSstart	CCS technology starts to be available
2025	hydrogenstart	Hydrogen industry starts
2023	BioTraStr	Biofuel trade starts
2030	HygTraStr	Hydrogen trade starts
2007	YIEAEBstart	IEA energy balance prameter calibration starts
2019	YIEAEBend	IEA energy balance prameter calibration ends

2017	YEneSysModstart	Energy system model prameter calibration starts
2100	YEneSysModend	Energy system model prameter calibration ends

6.7 Input data

Most input data that are related to future scenario assumtpions are availabe in the AIMHub ripository but some licenced files are separated stored in another repository (such as energy statistics, SAM, and so on). This repository can be downloaded automatically which is executed by the main shell file if you have an access. The corresponding data is downloaded in data/AIMHubData/. Currently (2022, March), the latest available data version is 1.1.0 and the submodule is used for the data download. Thus, if you use fork AIMCGE main repository, you should also fork data repository AIMHubData. Some of the above data can be prepared by "AIMHubSubdata" repository.

Chapter 7

Main results

7.1 Output files

All output files are located at /output. There should be following directories in Table 7.1 when you execute the batch.

Country and global directories store direct model outputs for national and global models respectively. iiasa_database stores IAMC template which file is most important outputs for beginners. Log and lst directories store gams exection log and lst files which can be used for debugging. lst and log directories include subdirectories of which contents are also described as below.

- base: base year calibration process
- scenario: Future scenario simulations
- combine1: merge results among scenarios 1
- combine2: merge results among scenarios 2
- climate: climate model results
- db: IAMC template related process

Temp stores temp.gdx and temp2.gdx. The former takes all information on AIM-CGE.gms execution (base year calibration) and the latter does scenario.gms (future scenario simulation). The latter only appear or overwritten when single run model is turned on. Other files are basically no needed to be seen.

Table 7.1: list of directories in ”output”

Name	Main contents	Guideline for users
country	National model direct outputs	Intermediate
global	Global model direct outputs	Intermediate
iiasa_database	IAMC format results	Beginners
log	log file for gams execution	For expert users to debug
lst	lst file for gams execution	For expert users to debug
magicc	Climate model outputs	No need to check

save	Save files	No need to check
temp	Store gdx files for debugging	For expert users to debug
txt	Text files for controling batch	No need to check

7.2 IAMC template outputs for general results

If you run all processes appropriately, the final results appeared in ”output/iiasa_database/txt/global_17_IAMC.csv” or ”output/iiasa_database/gdx/global_17_IAMC.gdx” for the global model (not that global_17_merged.gdx includes all annual information). For the country models, the similar files but the file names have country code appear in the same directory as global files. These files include 5 dimensions; namely model (only AIM/CGE), regions, scenarios, variables, units and years. The variables are defined in sheet ”map” of file ”/doc/variable_list_IAMC.xlsx”. Currently, energy, emissions, economy, land-use and climate information has been stored. For agricultural and land-use data, the detailed information can be found in AgMIP template which is explained in the section of AgMIP template.

Please refer to section 9.7.3 for further explanation.

7.3 AgMIP template outputs for agricultural and land-use

For agricultural and land-use data, the detailed information is stored as so-called AgMIP template which is parameter as ”Pagmipout” in output/global/global_17/gdx/analysis_agr.gdx. For national models, the file location is output/country/%region%/ gdx/analysis_agr.gdx. The parameter consists of four dimensions, namely; scenario, year, region, items, and indicators. The more detailed definition and explanation for each dimension is shown in ”/doc/Reporting_template_AGMIP_2020_02_24.xlsx”

7.4 Other intermediate output files

(1) How are output files made?

- The model solution itself is stored in variables and these solutions are put into parameters and they are saved in GDX files. This ”GDX files” means individual years under scenario folders like ”output/globa/global_17/SSP2_BaU/2020.gdx”. These files are made every ”scenario.gms” running.
  - Generally, the variable names and corresponding parameters are named with ”_load”. For example, the variable of output output is ”PA” and the corresponding parameter saved in GDX file is ”PA_load”
  - PSAM_Value, PSAM_volume and PSAM_price are most important output parameters. They are SAM accounting matrices accounted as value, volume and price.
- Some of the above GDX file information are extracted and translated into some format. This procedure is made under ’combine_gdx.gms’ and the results of this procedure are named as scenario name gdx under the directory ’output/global/global_17/cbnal/’.

- Then, they are combined into one file and combine_gdx2.gms processes the data and create analysis.gdx

(2) All results file

All results from AIM/CGE model are located in /output/global/***/gdx. Some main gdx files are:

analysis.gdx

final_results.gdx

enduse_analysis.gdx

(1) [../output/country/"country_code"/gdx/final_results.gdx] combines (2)'s scenario files. It has several key parameters. The definition of each parameter is described as below[1].

[1] PSAM_value (5 dimensions; scenario, year, country, row and column)

Nominal SAM

[2] PSAM_tax (4 dimensions; scenario, year, country, row and column)

Sales Tax

[3] PSAM_price (4 dimensions; scenario, year, country, row and column)

Price of each cell in SAM

[4] PSAM_volume (4 dimensions; scenario, year, country, row and column)

Volume of SAM

[5] PEMI (4 dimensions; scenario, year, country, fuel and sectors)

Air pollutants and GHG emissions from each sector and fuel consumption

[6] PGHG (2 dimensions; scenario, year, country)

GHG emission price

[7] Psol_stat (3 dimensions; scenario, "solvestat or modelstat", "NLP or MCP")

Solution and model status

[8] Pworld_price (3 dimensions; scenario, year, commodities, "Import or export")

World price

[9] Penergy_b (4 dimensions; scenario, year, country, flow, energy sources)

Energy balance table

[10] Penergy_b_iea (4 dimensions; scenario, year, country, flow, energy sources)

Energy balance table (sector definition is same as IEA's energy balance table)

[1] There are other parameters but ignore them in this case. They are just temporal parameters.

Table 7.2: Cell numbers of energy balance table

	Coal	Crude oil	Natural gas	Oil products	Hydropower	Nuclear	Solar	Wind	Geothermal	Other reneable	Traditional Biomass	Modern Biomass fuel	Electricity and Heat	Total
	EB_F_COL	EB_F_CRU	EB_F_NGS	EB_F_OIL	EB_F_HYD	EB_F_NUC	EB_F_SPV	EB_F_WIN	EB_F_GEO	EB_F_ORN	EB_F_BIO	EB_F_BIE	EB_F_ELY	
PRD	1				2						3	25		
IMP	4												4	
EXP	5												5	
STC	6													
TPES	7													
EB_PWR	8				9								10	
EB_CCS	11										12		13	
EB_PEN												26	14	
EB_P_C	15			16										
EB_GWK	17		18	17									17	
EB_EMN	19												19	
EB_LOSS	20												20	
EB_TFC														
EB_TIN														
EB_I_S														
EB_NFM														
EB_CRP														
EB_NMM	21										21			
EB_OMN														
EB_FPR														
EB_LIN														
EB_PPP														
EB_CNS														
EB_XIN														
EB_TRS	22											27	22	
EB_RSD	23										23		23	
EB_SER														
EB_AGR	21										21			
EB_BTR														
EB_NEU	24													

The 9th parameter, Penergy_b, represents energy balance table made from the estimated SAM. Classifications of the rows and columns are shown below[2]. The default version of this system inputs this energy balance table (BaU case year 2005) into [../output/country/xls/"country code".xls] of sheet "2005 BaU". An example is shown below.

The last parameter is similar to the previous one but the sector definition is different. A detailed explanation is shown in the next section.

The way to convert CGE model variables to an energy balance table is shown below. In Table 7.2, the numbers are written for each cell and the number corresponds to Table 7.3 which shows correspondence from CGE variables to the energy balance table. Sectors and energy sources mapping are show in Table 7.5 and Table 7.4.

Table 7.3: List of correspondence for energy balance table and CGE model variables

Cell	Equation (Variable)	Memo
1	$= QX_{r,c}$	domestic output of commodity, (Only crude fossil fuel)
2	$= QXAC_{r,a''com\_ely''} * ele\_factor_a$	output quantity of electricity of activity a. "ele_factor_a" is conversion factor; nuclear=3, geothermal=10, biomass=3
3	$= QXAC_{r,"bio","com\_ely"} + \sum_h TBH_{r,h} + \sum_a TBI_{r,a}$	Biomass and biomass electricity generation
4	$= QM_{r,c}$	Import quantity of tradable commodity
5	$=- QE_{r,c}$	Export quantity of tradable commodity (negative)

Continue to next page

[2]Primary supply of hydro and nuclear power has different definition from that of IEA's energy balance table. Transport includes industrial internal fuel use by transport equipment. The definition is the same as IEA's energy balance table. Non-energy use is included.

Continued from previous page

Cell	Equation (Variable)	Memo
6	$= stck_{r,c}$	Stock change (exogenous)
7	=PRD+IMP-EXP+STC	(1+2+3+4+5+6)
8	$= QINT_{r,c,a}$	Intermediate inputs of the fossil fuel (only fired- power plants without CCS)
9	$= QXAC_{r,a,''com\_ely''} * ele\_factor_a$	Output quantity of electricity of activity a. "ele_factor_a" is conversion factor; nuclear=3, geothermal=10, biomass=3
10	$= \sum_a QXAC_{r,a,"com\_ely"}$	Summation of electricity output (without CCS)
11	$= QINT_{r,c,a}$	Intermediate inputs of the fossil fuel (only fired- power plants with CCS)
12	$= QXAC_{r,a,''com\_ely''} * ele\_factor_a$	Output quantity of electricity of activity a (only biomass). "ele_factor_a" is conversion factor; biomass=3
13	$= \sum_a QXAC_{r,a,"com\_ely"}$	Summation of electricity output (with CCS)
14	$= -\sum_a QINT_{r,"com\_ely",a}$	Electricity consumption by power sectors
15	= -$QINT_{r,c,''p\_c''}$	Intermediate inputs of the fossil fuel into petroleum refinery "P_C"
16	= -$QINT_{r,''com\_p\_c'',''p\_c''}$ +$QXAC_{r,''p\_c'',''com\_p\_c''}$	Output of "P_C" minus input of oil products "COM_P_C"
17	=- $QINT_{r,c,''p\_c''}$	Intermediate inputs of the fossil fuel of petroleum refinery "GDT"
18	$= QINT_{r,''com\_gas'',''gdt''} + QXAC_{r,''gdt'',''com\_gdt''}$	Output of "COM_GDT" minus input of natural gas "COM_GAS"
19	= -$QINT_{r,c,a}$	Intermediate inputs of the energy products into fossil fuel mining sector "COA", "OIL", "GAS"
20	$= -loss_{r,c}(\sum_a QXAC_{r,c,a} + QM_{r,c})$	(Production + import) multiplied by loss rate
21	$= QINT_{r,c,a} \cdot (1 - non\_energy\_rate_{r,c,a})$	Intermediate inputs of the energy products (excluding non-energy use)
22	$= QH_{r,c,h} + QINT_{r,c,''trs''} \cdot road\_rate_{r,c}$	Transport sector's energy use + household fuel use by car
23	$= QH_{r,c,h} - QINT_{r,c,''trs''} \cdot road\_rate_{r,c}$	household fuel use by car
24	$= QINT r,c,a \cdot non\_energy\_rate_{r,c,a}$	Intermediate inputs of the energy products multiplied by non-energy use rate

End

Note:

1. Export includes international marine and aviation bunkers

2. Oil products includes petroleum products and coal products

Table 7.4: Energy source mapping

energy balance table	energy sources	CGE commodity
EB_F_COL	Coa l	COM_COA
EB_F_CRU	Crude oil	COM_OIL
EB_F_NGS	Natural gas	COM_GAS
EB_F_OIL	Oil products	COM_P_C
EB_F_ELY	Electricity and Heat	COM_ELY
EB_F_BIO	Modern biofuel	COM_BIO

Table 7.5: Sector mapping table

	energy balance table sector		CGE activity
Transformation	EB_PWR	Power plants without CCS	E_COL
			E_OIL
			E_GAS
			E_NUC
			E_HYD
			E_GEO
			E_SPV
			E_ORN
			E_WIN
			E_BIO
			E_BIN
			E_ORN
	EB_CCS	Power plants with CCS	EC_COL
			EC_OIL
			EC_GAS
			EC_BIO
	EB_PEN	Power plant energy use	power
	EB_CTF	Coal transformation	CTF
	EB_BTR	Biomass transformation	BTR
	EB_PRF	Petroleum refinary	PRF
	EB_GWK	Gaswork	GDT
	EB_EMN	Fossil fuel mining	COA
			OIL
			GAS
Industry	EB_I_S	Iron and Steel	I_S
	EB_NFM	Non-ferous metal	NFM
	EB_CRP	Chemical	CRP
	EB_NMM	Non-mineral and non-metaric	NMM
	EB_OMN	Other mining	OMN
	EB_FPR	Food processing	FPR
	EB_LIN	Light industry	LIN
	EB_PPP	Paper, pulp and printing	PPP
	EB_CNS	Construction	CNS
	EB_XIN	Other industry	OMF
Transport	EB_TRS	Transport	TRS
Commercial	EB_SER	Commercial	CSS
			WTR
Agriculture	EB_AGR	Agriculture	AGR
			FRS
Residential	EB_RSD	Residential	HURB
Non energy use	EB_NEU	Non -energy use	

Chapter 8

Change control excel in controldata

There is a excel file named as ”excel_control_***” under control folder in in /control/data/. *** should be replaced by the country code. How to use this excel file is described in the readme sheet. Basically, input the scenarios according to the sample data which are already input in this excel file. Then, run the gams file named ”excel_control.gms”. Finally run the CGE model. Automatically these sceneario assumptions are loaded.

- If already the excel exists
  - Add sheet
  - Basically socioeconomic name should be specified as NS1 NS2 and so on. (refer to other sheets)
  - Put explanation and values in it
- If not the excel exists
  - Copy other regions file and name it as the region name

8.1 Read the excel in control program

- Modify control/prog/ excel_control_new.gms and read the new sheets.
  - Unload the parameter into the gdx which declared in the bottom of the program
  - Add that region code into the loop in control/prog/control_bat.bat
  - Execute control/prog/control_bat.bat

8.2 Read the national information

- Change /inc_prog/030_national_scenario.gms
  - In order to read the national information, the parameter should be loaded from the control gdx. You can just follow the other examples how they are read.

8.3 Mapping the read information

Socioeconomic changes are needed to be configured.

- /inc_prog/030_socioeconomic_assumption.gms

Add following sentence if the regions are not specified (here is US example)

*—– USA

* National scenarios for United States

* The options are [No, NS1, NS2, NS3 and so on which are defined in the national scenario assumptions]

* The scenarios are specified in cotrol directory.

$setglobal NS_USA No

- /scenario/socioeconomic/%%%.gms

The socioeconomic scenario should include following statement

$setglobal NS_USA NS1

- /inc_prog/030_national_scenario.gms

Add following lines around 150 if the regions are not specified (here is US example)

$ifnot%NS_USA%==No$batinclude%prog_dir%\inc_prog\national_scenario_map.gmsUSA%NS_USA%

Chapter 9

Guideline for updating the model

9.1 Rules for working on the model programing

Users are classified into three levels.

- Beginner: can run the model and however, cannot change the code in detail. For example, national model run is made by control sheet shown in section Chapter 6.
- Code contributor: can run the model, can understand the codes roughly and can modify GAMS codes.
- Developer: full understanding of the model and can change model equations and variables.
- Owner: developer + controls merge branches

9.1.1 Git guidelines

- Every new work should be done under a new branch.
- The branch name should be easy to understand but not too long.
  - If the work is under specific project ”Project code”_”work name”_”Version name” (e.g. For suisinhi 2-2002 core scenario work is named as ERF2_2002_Core_V1.0)
  - The project code could be omitted if the work is not under any project.
  - Similarly the work name could be omitted if the work is obviously only one (like international model inter-comparison project)
- There are three kinds of branches; namely ”master”, ”develop” and others.
  - ”master” is stable and can be used for every project and work. For most of beginners and code contributors are supposed to use this branch as a starting point.

  - ”develop” is stable and if new model development is needed start from that branch

- Step-by-step guide
  - Create a new branch (see the guide below for how to name your branch)
  - Make your changes
  - Commit your changes (see the advice below for commits)
  - Push your changes (see the advice below for how often to push)
  - When your development is complete, open a pull request.

- General Advice
  - Smaller changes are easier to review. Consider breaking a very large development into several smaller incremental pull requests.
  - Pushing your changes is a way of backing up your work. More frequent pushing is recommended.

9.1.2 Work rule

- Beginners are supposed to change socioeconomic, climate policy and impact assumptions.
- If new assumptions are needed, it is encouraged to add such changes into individual assumptions location.
- If new assumptions are needed, add lines in the specific location which can be found by searching ”Individual Assumption X” in prog/scenario.gms.
- If the assumptions exceeds 30 lines in prog/scenario.gms, it would be recommended to add new sub-program using individual folder.
- The program owner will consider whether that change should be merged into ”develop” or ”master” branches.

9.2 Code rules

- Every equation changes should be noted in this document. The update history also needed to be added.
- Encouraged to add code notes as much as possible with the reason and purpose of the corresponding changes

9.2.1 Test scenario run after code revision (for ”develop” branch)

After code has been revised and merged into ”develop”, it would be better to test the code for global and national models with default set. To do this, batch/revions_validation.bat enables to do so. There are three kinds of test

- Global climate policy variation test under SSP2

  - This process runs BaU, 2.6W 2.0W stabilization and carobn price paths scenarios (in Kriegler et al. [30]) and INDC_CONT3 and INDC_26WCO2.

- Global socioeconomic assumptions variation
  - SSP1, SSP3, SSP4, and SSP5 are run by 26W_SPA1_CO2 and 34W_SPA1_CO2 of climate policy assumptions

- National model
  - Japan and China BaU, carbon price paths as mentioned above and 50% and 70% GHG emissions reduction compared to 2020.

9.2.2 Parameter declaration (soft) rule

Parameter declaration would be better to be ruled in general although there can be many exceptional cases. In /prog/AIMHub.gms process, there is a place where parameters are defined flagged as ”1-3. PARAMETER DECLARATIONS”. There are six classifications on parameter definitions namely;

a. Parameters appearing in model equations (/inc_prog/010_equations.gms)
b. Parameters used for model calibration and scenario assumptions
c. Parameters for variable initialization
d. Parameters for future socioeconomic specifications
e. Results unload parameters
f. Base (year) parameters that are used in the scenarios assumptions but not in the equations

In /prog/scenario.gms, there is a location flagged as ”2-1. MODEL PARAMETERS AND SETS” where parameters and sets are defined.

The modelers are encouraged to use above-mentioned spaced to declare the parameters. Note that there are some sub-programs in inc_prog including parameter declaration. If the parameters are used in the specific file and the number of them are not so large (e.g. less than five), it would be OK to define in those files.

9.2.3 Set declaration (soft) rule

Set is recommended to declared in inc_prog/010_setdefine.gms in general. However, if you would like to add a specific procedure with new inc_prog files and the usage of the corresponding set is limited to that file, it would be also good to declare in that inc_prog file.

9.3 directory Inc_prog

In directory ./inc_prog, file names begin with numbers from 010 to XXX. These numbers indicate as follows:

- 010: included in ./prog/AIMHub.gms process
- 020: included in both ./prog/AIMHub.gms and ./prog/scenario.gms processes
- 030: included in ./prog/scenario.gms process
- 040: included in ./prog/coombine_gdx1.gms process

- 050: included in ./prog/coombine_gdx2.gms process
- 060: included in other programs

9.4 Debug

9.4.1 General instruction

If you can see the ”Normal completion” in the last part of the window black box or log file (output/log/*), and all the relevant results files are updated, it means you succeeded to run the model. However, if there are any error messages in the window black box or log file (output/log/*), please refer to the .lst file(s) in the .../output/lst directory. Please search for error message or ”****” in these lst file(s) and solve the problem(s).

There are two types of errors; 1)Error without optimization and 2) Optimization is carried out but solution is not found.

- Optimization is carried out but solution is not found
- solutionIteration.gms
  - This option cut a year into several pieces by changing the input coefficients changes. Change "maxite".
  - Moreover, if the scenario implements emissions cap but the emissions constraint is too strict to find solution, then this option might solve this problem. This option is to solve the problem tentatively using the same carbon price and then go to the normal solution. Turn on "NoConsSolvFlag2" and change "maxite3".
- Check PA0 (industrial activity price index) which should be normally around 1 but if it is over 10 or less than 0.1, you should suspect very strong constraint forces the corresponding sector.
- If the log shows like below. The previous iteration results show some inconsistency and check .lst file by searching *****.

— Restarting execution
— scenario.gms(30722) 289 Mb
— Reading solution for model STANDCGE
— scenario.gms(30738) 291 Mb
— Generating MCP model STANDCGE
— scenario.gms(30740) 319 Mb 17 Errors
— LOOPS FOR/WHILE = 1
— 68,919 rows 68,742 columns 341,074 non-zeroes
— 818,836 nl-code 185,365 nl-non-zeroes
— scenario.gms(30740) 313 Mb
*** SOLVE aborted
— scenario.gms(30740) 313 Mb 17 Errors
*** Status: Execution error(s)
— Job scenario.gms Stop 01/22/21 13:58:00 elapsed 0

Parameter checks

- Check the parameters used in the model by turning on the single option on in batch file. Then, check /output/temp/temp2.gdx

- The base year parameter can be also checked by /output/temp/temp.gdx

3) Error without optimization

- GAMS code error

  This can be detected by "single" option to stop the simulation at a year

- GAMS code has no error but the solution does not start

  If zero division or equivalent mathematical rule violation, "single" option to stop the simulation at a year would help to detect

- Number of variables and equation differences

  - This would be because wrong assignment and fix or boundary condition of varialbes.
  - If you don't add any equations or variables but see this error, previous year's simulation may have some issue.

- Some examples of errors and notes

  - At the year when new industries or technologies appear, there are high chgance to occur errors. For example, CCS technologies are going into the system (at certain carbon price), advanced biofuel industry gets in 2021, battery technologies are needed at certain share of variable renewable energies.
  - If the equation residuals seem to be difficult to make WMEQ(C) zero, it might be related to the international transport fuel usages.
  -

9.4.2 Some specific error examapls

1) Unsolved with iteration in residual of WMEQ("COM_P_P")}

The international trade fuel consumption exceeds the potential export of "COM_P_P". Review the assumptions on international transport energy consumption.

(Update in Nov., 2021)

This repsentation has changed and no longer related.

2) CCS related equations residual

Carbon price goes down and then some variables related to CCS reached to zero and cause errors.

9.5 Add new equations and variables

This section describes the procedure how to add new equations and variables into the CGE model. Since the model is on the MCP basis and initial, lower boundary, upper bounary values, or fixing conditions are needed to be specified and several steps are required. To do this, Cygwin must be installed.

Table 9.1: Procedures to add new equations and variables

Num.	Procedure	Descritpion
(1)	Write the equations	/inc_prog/010_euqations.gms POWER_SHARE_AGG_LOW(Ragg,Aagg)$(power_share_agg_lo(Ragg,Aagg)).. 0 =G= (power_share_agg_lo(Ragg,Agg)*SUM(AP$(theta(R,AP,"COM_ELY")), theta(R,AP,"COM_ELY")*QA(R,AP))-SUM(R$Map_Ragg(R,Ragg), SUM(A$Map_Aagg(A,Aagg), theta(R,A,"COM_ELY")*QA(R,A))));
(2)	Declaration of variable and equation, related parameters and specification of attribution of variables, load and unload results. This procedure automatically made by the program modification tool.	Execute /tool/prog_mod/prog/var_add.sh (1) Variable and equation name, elements and description should be specified in /tool/prog_mod/data/varset.data and /tool/prog_mod/data/equset.data. The orders are name, elements and description. Then execute bash copy_mod.sh (2) POWER_SHARE_AGG_LOW Ragg,Aagg Lower boundary of renewable energy group VRENSHR_AGG Ragg,Aagg Dummy variable for renewable power generation group share
(3)	If you need complementary condition, add the complementary variables to equations.	/inc_prog/010_model_dec.gms ”POWER_SHARE_LOW.VRENSHR ” POWER_SHARE_AGG_LOW.VRENSHR_AGG

Continue to next page

Continued from previous page

Num.	Procedure	Descritpion
(4)	Define and take differences of each equation. The equation name is already written in the program after you execute procedure (2). Thus find the location by searching ”add_equ_loc_2” and specify the difference.	/inc_prog/030_check_infes.gms POWER_SHARE_LOW0(R,A)$(ACT0(R,A) AND power_share_lo(R,A)) (power_share_lo(R,A)*SUM(AP$(theta(R,AP,"COM_ELY")), theta(R,AP,"COM_ELY")*QA0(R,AP)) - theta(R,A,"COM_ELY")*QA0(R,A))= 0; POWER_SHARE_AGG_LOW0(Ragg,Aagg)$(power_share_agg_lo(Ragg,Aagg)) = (power_share_agg_lo(Ragg,Agg) * SUM(AP$(theta(R,AP,"COM_ELY")), theta(R,AP,"COM_ELY") * QA00(R,AP))- SUM(R$Map_Ragg(R,Ragg), SUM(A$Map_Aagg(A,Aagg), theta(R,A,"COM_ELY") * QA00(R,A))));
(5)	Scale the equations. The equation name is already written in the program after you execute procedure (2). Thus find the location by searching ”add_equ_loc_1” and specify the scaling parameter.	/inc_prog/020_scale_global.gms POWER_SHARE_LO.SCALE(R,A)$(ACT(R,A) AND power_share_lo(R,A) AND theta(R,A,"COM_ELY")*QA.L(R,A)) = SQRT(ABS(theta(R,A,"COM_ELY")*QA.L(R,A))); POWER_SHARE_AGG_LOW.SCALE(Ragg,Aagg)$(power_share_agg_lo(Ragg,Aagg) AND (SUM(R$Map_Ragg(R,Ragg), SUM(A$Map_Aagg(A,Aagg), theta(R,A,"COM_ELY") * QA.L(R,A)))))= SQRT(ABS(SUM(R$Map_Ragg(R,Ragg), SUM(A$Map_Aagg(A,Aagg), theta(R,A,"COM_ELY") * QA.L(R,A)))));
(6)	If you need lower boundaries, put them.	/inc_prog/BaseScenarioBoth/lower.inc VRENSHR.LO(R,A)$(power_share_lo(R,A)) = 0 ; VRENSHR_AGG.LO(Ragg,Aagg)$(power_share_agg_lo(Ragg,Aagg))= 0 ;
(7)	Through the calibration procedure you need to specify the initial parameters like (VARNAME0)	/inc_prog/010_calibration.gms power_share_lo(R,A) = 0 ; VRENSHR0(R,A) = 0 ; power_share_agg_lo(Ragg,Aagg)=0; VRENSHR_AGG0(Ragg,Aagg) = 0 ;

Continue to next page

Continued from previous page

Num.	Procedure	Descritpion
(8)	Set the parameters for new renewable energy and CCS technology	/inc_prog/030_CCS_industry.gms /inc_prog/030_renew_production_calib.gms /inc_prog/030_renew_prodcution.gms
(9)	VARFIX.gms	VRENCAP.FX(R,A)$(NOT (QA.l(R,A) AND (Prenew_up(R,A) OR power_share_up(R,A) OR prodscenario(R,A))))=0; VRENSHR_AGG.FX(Ragg,Aagg)$(NOT (power_share_agg_lo(Ragg,Aagg) AND SUM(R$(Map_Ragg(R,Ragg)),SUM(A$(Map_Aagg(A,Aagg)),QA00(R,A)))))=0;
(10)	Declare parameter	AIMHub.gms power_share_lo(R,A) Power share lower boundary power_share_agg_lo(Ragg,Aagg) Power group share lower boundary
(11)	Modify income equation	Equations.gms -QA(R,A)*VRENSHR(R,A) VRENCAPTOT(R,INSDNG) =E= SUM(A,QA(R,A)*(VRENCAP(R,A)-VRENSHR(R,A)))*shincome(R,INSDNG); VRENCAPTOT(R,INSDNG) =E= SUM(A,QA(R,A)*(VRENCAP(R,A)-VRENSHR(R,A)-SUM(Ragg$Map_Ragg(R,Ragg),SUM(Aagg$Map_Aagg(A,Aagg), VRENSHR_AGG(Ragg,Aagg)))))*shincome(R,INSDNG);

End

9.6 How to add sectors

This section describes how to add hydrogen production sectors.

9.6.1 Essential procedure

- If the sector is existing in the base year, it should be mapped to EDGAR emissions
  - Using excel file
  - Modification of mapping in Data/edgar/emission.xls
  - Execution of emission.gms
- Execution of elasticity_set.gms
- Execution of AIDADS_para.gms

9.6.2 Procedure for non-elecrticity sector

Assume that now hydrogen sector is to be added.

HGC 1) Set map file change or add

(a) /Define/activity.set

HGC Hydrogen by coal

HGG Hydrogen by gas

HGB Hydrogen by biomass

HGE Hydrogen by electricity
/Define/commodity.set

COM_HYG

- /Define/ household_commodity.set
- /Define/ householdc.map

COM_ENE . COM_HYG
COM_CAR . COM_HYG

1) New program for generating the sectors

- Copy from biofuel.gms to hydrogen.gms

- Need to be declared
  - A_HYG(A)
  - C_HYG(C)
  - Hyginirate(R,A)
  - Hyginidemand(R,A)
  - hydinirate(R)

9.6.3 Electricity sector case

Assume that E_WIF is to be added to an electricity sectory.

- Search from all ”E_WIN”
- Inc_prog/Combine_gdx.gms
  - Add ”E_WIF” to a Set DUM
  - Newly declare A_WIF(A) to /inc_prog/010_data_import.gms.
  - Add A_WIF to gdx/set.gdx
- prog/Combine_gdx2.gms
  - Add ”E_WIF” to a Set DUM
  - Search WIN and add W_WIF where WIN is found.
  - Add WIF in a set of ”Fuel”
- Calibration.gms, Data_import.gms, Ene_bal_make.gms
  - Search Win and add WIF where Win is found.
- Renew_production.gms
  - Supply curve and potential is set in scenario_parameter.gms.
  - Input coefficient is assumed same as E_WIN.

9.7 How to add analytical variables to the final results or figures

- This section describes how to add analytical variables to the final results or figures.
- The main task is interpretation of CGE variables to the final indicator format

9.7.1 Combine_gdx1.gms

- This program combines all years information for a particular scenario. You should add one parameter in combine_gdx1.gdx. Let us assume parameter XXX is supposed to be added.
  - XXX is corresponding to CGE model results.
- Extract CGE model results
  - Find the words ”LOAD CGE DIRECT RESULTS” and then you see the list of parameter declaration and GDX loading.
  - You should declare parameter which you want to include for XXX
  - Then, write that parameter after $gdxin’%output_dir%/%file_loc%/cbnal0 /%region%_%SCENAME%_%CLP%.gdx
- Regional aggregation

  - It is normally 17 regions information, thus to extract regionally aggregated results we put aggregation equation.
  - Find "REGIONAL AGGREGATION", then you find the examples how to aggregate them.

- Compute indicators
  - Find "COMPUTE INDICATORS"
  - After that write down the equation

- Store the results into GDX file
  - Find "UNLOAD COMPUTED INDICATORS", then you see the GDX unload command and indicators are stored into %output_dir%/%file_loc%/cbnal /%SCENAME%_%CLP%.gdx
  - Put your indicator parameter name into that.

9.7.2 Combine_gdx2.gms

- This program combines all scenario results as one database. You should add again the parameter.

- Load indicators which you have stored in combine_gdx1.gms
  - Find "LOAD INDICATORS" and then put the parameter which you have stored. Before that, you also need to declare the parameter.
  - Be cautious that the parameter needs to have scenario dimensions (see other examples)

9.7.3 IAMC template system

This procedure is supposed to follow the document which is in the tools/iiasa_database To participate international model inter-comparison projects like EMF, the data submission form is mostly harmonized to IAMC data template system. This tool aims to make such data submission form by using AIM/Hub results.
Mapping the results of AIM/CGE. Regions, variables, scenario names and units. The input data is main indicators of AIM/Hub results which include emissions, energy, agriculture and land use. Through the process simplified climate model MAGICC is run. In linux system including WSL, MAGICC7 is run and in cygwin system, MAGICC6 is run. This procedure is run if the swtich of "database" is turned on in the main shell control file.
When you want to add scenario names and mapping with them, use /define/scenario.set and /define/scenario.map. The former file is for declaration of scenario name and the latter is for the mapping. For instance, suppose that you are asked to submit a scenario named "SSP2_Ref_SPA0" which corresponds to the scenario "SSP2_BaU_NoCC" in your model running, and then, /define/scenario.set should have "SSP2_Ref_SPA0" and /define/scenario.map should have the following maping.
SSP2_BaU . SSP2_Ref_SPA0

For each exercise, variable list can change, and in such cases, we must specify the variables which should be eliminated from this data submissions. First, you copy the variable list from the shared variable list and paste into the excel sheet "template_sheet" in "variable_list_IAMC.xlsx" (column B). Then you have a list of code which should be included in the output column C (rest of them are excluded from the list). Copy the list into /data/include_parameter.txt

The file location of the output is /output/iiasa_database/gdx/global_17_IAMC.gdx or /output/iiasa_database/txt/global_17_IAMC.csv. Individual scenario gdx files are also located in /output/iiasa_database/scenario.

How to add variables?

- update and get latest IAMC template repository (`https://github.com/KUAtmos/IAMCVariableChange`) and see IAMCTemplate.txt
- Add variable names, codes, units and relevant information
- This IAMCTemplate.txt should be fully copied into the spread sheet of /doc/Variable_List_IAMC.xlsx TemplateRepo (column A to N)
- Copy the contents of sheet "foralllist" to data/all_list.map
- Add weighting variables for regional aggregatoin in the sheet "master" column J.
- List up variables which have aggregation relationships and write down in "aggregation" sheet in /doc/Variable_List_IAMC.xlsx. The column B should have aggregated variables and the column C should have disaggregated variables.
- Copy the contents of column E to G to define/aggregation.map.
- Write programing codes in prog/iiasa_database_ind.gms to speciffy the variables. In this process, the output results of CGE are allocated to the parameter named EMFtemp1. In this program, aggregated variables which are already specified in the previous steps don't need to be written.
- if the corresponding vairiables are economic indicators that should be deflated by price index (mainly for 2005 to 2010US dollar), add the varialbe into tools/iiasa_database/define/Economic or EconomicInd_Price.set

9.8 Note of tools directories - analytical tools management

This section summarizes how to manage analytical tools for CGE model results. CGE analytical tools are managed by subversion in ./tools. There are for example simplified climate model, IIASA database submission form tool and so on.

9.8.1 Basic idea

- The analysis using AIM/CGE should be made under /tools directory. It is beneficial for all CGE users since we can share the analytical tool and treat them separately from CGE main body.
- Creating directory under /tools and put programs, maps and data files.

- The output or temporary files of the analytical tools should be stored in /output which is same hierarchical directory as /tools. Basically making directory for that analysis is recommended.
  - For example, output/iiasa_database is made under the process of IIASA database submissions tool.
- The execution of the analysis should be managed under bat or shell files. The example can be seen under tools/iiasa_database/prog.
  - The batch or shell file should include making directory also.
- GAMS execution of this analysis is highly encouraged to do under /exe directory which is located same hierarchical directory as /tools. It is because GAMS execution creates many dump files and to keep the directory clean.
- The user must remain a ”read me” file for the analysis under the folder (see example in /iiasa_data_submission/readne.docx.) or directly describe in this documentation.

9.8.2 Read me example

Table 9.2: readme example for IAMC database template

Name	A tool for IIASA Database submission form
Introduction	Participating international model inter-comparison projects like EMF and SSP, the data submission form is mostly harmonized to IIASA data system. This tool aims to make such data submission form by using AIM/CGE results.
Method	Mapping the results of AIM/CGE. Regions, variables, scenario names and units. The input data is main indicators of AIM/CGE results which include emissions, energy, agriculture and land use. The output is data submission form. Through the process simplified climate model MAGICC is run.
Main program directory	/Tools/iiasa_data_submission
Execution file	/Tools/iiasa_data_submission/prog/iiasa_database.bat
Input file	combine_gdx2 process which is temporarily saved by SAVE command is restarted. Therefore, all information created by /prog/prog/combine_gdx2.gms process is the input.

Table 9.3: readme example for MAGICC

Name	MAGICC (simplified climate model

Introduction	We are sometimes required to submit or show climate information which is associated with particular emissions scenarios. This tool is for generating such information. If you use Cygwin, MAGICC6 is used and otherwise MAGICC7 is used.
Method	Preparing emissions data from AIM/CGE and running MAGICC which is publically available.
Main program directory	/Tools/MAGICC. MAGICC itself is located under the directory / MAGICC/MAGICC6_4Download and the data processing is made by the programs in / MAGICC/CGE2MAGICC
Execution file	/Tools// MAGICC/CGE2MAGICC/cge2magicc.bat
Input file	Output/global/global_17/gdx/emissions.gdx. this file includes emissions scenarios. Other emissions that are not covered by AIMHub is interpolated from CMIP6 ScenarioMIP data which is stored in original MAGICC7. This can be specified by the file /tools/magicc/CGE2magicc7/data/OtherGasMap.txt. This text file needs to specify scenario names and other gas emissions mapping by using tab separated format. Default is SSP2-4.5W scenario.
Output file	The output file is gdx file named as /output/magic/iiasa_database_climate.gdx
Other considerations	This tool can be run under IIASA database submission form tool.
Output file	The output file is the text file for submissions located as /output/iiasa_database/ iiasa_database_final.txt.
Other considerations	Some variables are not allowed to submit for some projects, in such cases we must specify the variables which should be eliminated from this data submissions. Those variables should be written in /tools/iiasa_data_submission/data/eliminates.txt

Chapter 10

Tips for MIP participations

10.1 Defining new scenarios

- Judge whether the exercise requires new socioeconomic assumptions or climate policy assumptions
  - The socioeconomic assumption revision is needed for assuming the demographic, economic, technological and other resource aspects.
  - Climate assumption usually changes the climate target, emissions pathways and carbon price paths and so on.

10.2 Socioeconomic assumption

- Add new socioeconomic assumptions in prog/prog/scenario/socioeconomic/
  - Usually copy SSP2 and rename it.
  - Then, specify each exercise assumptions. The specification would potentially be in various files.
  - If you need to change the parameters (not model structure), usually you just change the prog/scenario.gms or prog/inc_prog/020_socioeconomic_assumption.gms

10.3 Adding variables to the IIASA data system

1) List up the variables which have not used earlier in the CGE system but newly required.

Using vlookup function in excel is useful for this procedure.
Then, add them into the excel file (/doc/variable_list_IAMC.xlsx map)

2) Scenario name defining and mapping

- iiasadatabase/define/scenario.set

- iiasadatabase/define/scenario.map

3) include parameters

- you should specify the variables list for the submission in the iiasa_database/define/include_parameter.set
- This can be done by using the third sheet in /doc/variable_list_IAMC.xlsx

Chapter 11

Model features

[1] This chapter documents a main model structure and how to implement scenario assumptions for the analysis of long-term climate mitigation taken by AIM/Hub. There are six aspects which are going to be discussed. First, macro economy, labor and population treatment are explained. Second, energy supply sectors representation is described. Energy supply sectors are one of the key elements for decarbonizing economic systems. Thrid, energy demand sectors are discussed. Forth, agrilture and land use is critically important for stringent climate mitigation policy since large bioenergy implementation combined with carbn capture and storge, and afforestation would be thought as measures which enales so-called negative emissions. Fifth, non-energy related GHG reduction measures follow. They are mostly related to agricultrural sectors. Sixth, we discuss how to add new sectors into the CGE system.

11.1 Introduction

This section documents a main model structure and how to implement scenario assumptions for the analysis of long-term climate mitigation taken by AIM/CGE V2.0 (we call AIM/CGE from here). AIM/CGE is a multi-region and multi-sectors recursive dynamic type CGE model. There are several features to understand the behaviors of this model in conjunction with future scenarios. There are six topics as follows and they will be explained by each section later.

1) Macroeconomic, labor, population

2) Energy supply

3) Energy demand

4) Agriculture and land use

5) GHG reduction measures other than changing energy system

6) How to implement new production sectors or goods (not accounted in the base year)

In this document, we put much more priority on showing how the scenario outcomes of this model are generated than just explaining either model structure or scenario

[1] Parts of this section may overlap with other sections.

assumptions. We keep a basic rule that each section provides following structure as much as possible.

- The importance of the factors
- The fundamental logics of the basic model structure
- How the exogenous assumptions are fed into the model for future simulations
- Actual parameter settings
- Limitation and remained issues that should be improved further version.

11.2 Demographic and macroeconomic change

11.2.1 Population and labor participation

Future demographic change is one of the key drivers to change the future goods demand including energy and food. On the other hand, the production side is also affected by the demographic change through labor participation.

The population and labor forces are exogenous parameters for AIM/CGE. The macroeconomic growth is also the exogenous assumption.

The first-order effect of population change is the household consumption. The household consumption is formulated as LES (Linear Expenditure System) and it consists of two factors for each commodity consumption; namely subsistence consumption and marginal share of consumption. The population change directly effects on the former factor.

The population increase ratio relative to previous year is multiplied to the subsistence consumption parameter $\beta^{m}_{r,ch,h}$. The latter factor, marginal share of consumption, specifies how the household money excluding subsistence consumption is spent and the expenditure share of each commodity is determined. Thus, it is not directly influenced by the population change. The intermediate inputs of agricultural commodity are also associated with population change.

There might be a discussion about the assumption in fixing population. The population and labor force could be affected by the future climate change impact through change of health condition including change of agricultural goods availability or migration induced by the environmental change. We ignore basically in the mitigation analysis. The exception can be seen in the study highlighting climate change impact (Hasegawa et al. 2016).

11.2.2 Macroeconomic change

Future macro-economic assumption also causes goods demand and supply. The macroeconomic growth is also the exogenous assumption. Usually the GDP change is used for the macroeconomic assumption for the Integrated Assessment Models' (IAMs) future scenario simulation. However, the actual outcome from the model is not exactly same as the assumptions. Therefore, the GDP assumption is used for calculating total factor productivity (TFP) and TFP is totally exogenous parameter for the model.

The economic growth is realized by three factors: labor force change, accumulated capital and total factor of productivity. The labor force is the one of the three main drivers of the GDP. The labor force change is exogenous variable for this model. The production sectors are basically [2] assumed to have multi nested CES (Constant Elasticity of Substitution) function. Therefore, if the labor wage is constant, labor force change ratio is directly affects to the GDP change.

The GDP assumptions for the future scenarios are used in the scenario analysis while GDP is endogenously determined in the CGE model. As is mentioned previously, economic growth is realized by labor force, capital and TFP. Thus, there are four degree of freedom. Labor is exogenous as indicated previously. Total capital accumulation is also determined a priori for a year since the total capital which is able to participate in production is previous year's capital formulation plus accumulation with certain of depreciation. Then, TFP is an unknown parameter. We use the GDP assumptions to calculate TFP change.

Let the total labor, capital and GDP be given and the Hicks-neutral technical change is assumed. Then, the TFP annual change is determined as below.

$$GDP_r = tfp_r \cdot F(K_r, L_r) \ , \forall r \in R \tag{2}$$

Where

tfp_r : TFP change ratio to previous year in region r,

gdp_r : expected GDP assumptions in region r,

L_r : Total labor participation in region r,

K_r : Total accumulated capital in region r.

The CES function is used for the function F. The TFP change ratio derived from the above equation is multiplied to the all sectors. This TFP change calculation is made only for the scenario excluding climate mitigation (what we call BaU scenario) and the scenarios with climate change mitigation adopt the BaU scenario's TFP change under same socioeconomic assumptions.

11.3 Energy supply

The energy supply is classified into three parts. They are fossil fuel extraction, bioenergy supply, power supply including renewable energy. These energy supply sectors play a key role to determine the future carbon price under climate mitigation scenarios. The current amount of CO2 emission itself from power sectors is relatively larger than other sectors and this sector has large potential to reduce the emissions.

11.3.1 Fossil fuel extraction

Fossil fuel extraction costs are projected to increase in the future in line with the current situation. This is mainly due to the limitation of cheap fossil fuel resource reserves and the increase in demand.

There are three fossil fuel extraction sectors within this CGE model; namely coal, crude oil and natural gas. The cost of fossil fuel mining is determined by the assumptions of those sectors' production function. The production structure is as shown below. This structure is assumed for other sectors excluding energy transformation sectors.

Each producer (represented by an activity) is assumed to maximize profits, defined as the difference between revenue earned and the cost of factors and intermediate inputs. Profits are maximized subject to a production technology, the structure of which is shown in Figure 4. At the top level, there is non-energy related GHG emission and

[2] Power sectors have different structure as shown in the formula

conventional inputs. Conventional inputs technology is specified by a Leontief function of the quantities of energy, value-added, aggregate non-energy intermediate input and resource input.

The model calculates the extraction cost curve using Rogner (1997) and U.S. Geological Survey (2000), and accordingly the production costs increase by region and fuel. We calculate cumulative fuel extraction every year in recursive iterations. The input of the fossil fuel sector is thought to increase based on the extraction cost curve. All inputs coefficients associated with production function are assumed to be increased according to the extraction cost curve [3].

11.3.2 Power generation

Given the electricity demand, the technological share (e.g. Conventional fossil fuel fired, solar, wind and so on) is determined by the power generation prices of each technology. A logit function is used for this selection. The power generation prices for each technology are determined by each production function.

There are two parameters in the equation. The exponent of the logit is exogenously determined for not only future scenario simulation, but also the calibration procedure and we tentatively use the value 2.

The other parameter appeared in the equation is share parameter for each power generation. That parameter is basically calibrated in the base year. The calibrated share parameter can be interpreted as the representation of preference, political decision or the results of any factors other than cost. In the future simulation, we need to update this parameter since the currently unused or less used technologies such as renewable technologies are not appropriately represented in base year's share parameter. Therefore, we assumed that at a certain year the sum of share parameters for the renewable technologies (wind, solar and biomass) supposed to have same share as fossil fired power and the same values are shared by the renewable technologies (if the fired power share parameter is 1, the wind, solar and biomass have 0.33 for each) [4]. The year which has above treatment is tentatively 2050. To realize the objective parameters, we update the parameters with annual constant ratios for each technology.

The price of electricity generated by renewable energy source is assumed to be declined in the future. The future technological cost of renewable energy is uncertain. Hence, we follow the assumptions of Energy Technology Perspective (IEA 2012) for the reference. The input coefficients of intermediate goods and production factors in renewable energy sectors are changed overtime according to the (IEA 2012)'s perspective. Power sector is disaggregated in detailed as mentioned previously. Solar, wind, biomass and geothermal energy power generation are included as renewable energy sources. The actual assumptions used in the model are shown in Table 11.1 to Table 11.6. The expected output price of each technology in 2050 is calculated based on these assumptions. The input coefficients of those sectors are assumed to be changed with constant ratio through 2050. This ratio is computed from the cost of base year and shown in the Tables. The conventional fossil fired power is assumed to have annual 0.5% improvement for the entire period. Note that considering variations in capacity factor of variable renewable energy, we use AIM/Technology's output as 11.2.

The return of the capital should have two components; namly pure investment return without profit and profit (premium) parts. For the former one, we calculate the

[3] To avoid drastic change of the price, we put maximum annual change ratio as 5%.

[4] Thus, this approach has an advantage to foresee long-term future share of the technologies but near-term forecast would not be relatively good at.

base year capital return ratio ($) to capacity expressed by physical GW by assuming all vitages are equally accumulated meaning that depreciation of 4% is assumed to the old capital and add up for life time. The profit part is quite uncertainty which would also be dependent on the countries' general interest rates. Here it would be difficult to identify the rates and thus we assume annual 3%. Then, we apply the capital return for the future scenarios.

Table 11.1: Capacity factor (%)

	2010	2020	2030	2040	2050
E_COL	85	85	85	85	85
E_GAS	85	85	85	85	85
E_OIL	85	85	85	85	85
E_HYD	40	40	40	40	40
E_NUC	85	85	85	85	85
E_SPV	18	19	20	20.5	21
E_WIN	30	32.1	34.3	35.5	36.8
E_GEO	70	70	70	70	70
E_BIO	85	85	85	85	85
E_ORN	70	70	70	70	70
E_BIN	85	85	85	85	85

Table 11.2: Capacity factors for VRE by regions (%)

Region	E_SPV	E_WIN
JPN	13.5	42.9
CHN	19.2	34.2
IND	16.6	25.1
XSE	15.1	38.4
XSA	17.6	28.7
XME	18.4	38.2
XOC	20.5	41.5
CAN	11.6	38.2
USA	16.5	31
TUR	15.5	36.2
BRA	30	56.8
XLM	21.6	41.9
XAF	21.4	35.6
XNF	18.5	38.1
XE25	14.5	29.9
XER	13.4	37.2
CIS	12.5	30

Table 11.3: Initial investment cost ($/MW)

	2010	2020	2030	2040	2050
E_COL	2100	2100	2100	2100	2100

E_GAS	865	865	865	865	865
E_OIL	2070	2070	2070	2070	2070
E_HYD	7320	7320	7320	7320	7320
E_NUC	4600	4350	4250	4125	4000
E_SPV	4000	1880	1440	930	420
E_WIN	1800	1600	1550	1425	1300
E_GEO	6000	6000	6000	6000	6000
E_BIO	2050	2050	2050	2050	2050
E_ORN	2400	2400	2400	2400	2400
E_BIN	4250	4250	4250	4250	4250

Table 11.4: Life time (year)

	2010	2020	2030	2040	2050
E_COL	40	40	40	40	40
E_GAS	40	40	40	40	40
E_OIL	40	40	40	40	40
E_HYD	30	30	30	30	30
E_NUC	30	30	30	30	30
E_SPV	40	40	40	40	40
E_WIN	20	20	20	20	20
E_GEO	30	30	30	30	30
E_BIO	40	40	40	40	40
E_ORN	30	30	30	30	30
E_BIN	40	40	40	40	40

Table 11.5: Operation and Management cost ($/kWh)

	2010	2020	2030	2040	2050
E_COL	46	46	46	46	46
E_GAS	20	20	20	20	20
E_OIL	46	46	46	46	46
E_HYD	10	10	10	10	10
E_NUC	115	109	106	103.5	101
E_SPV	40	19	14	12.5	11
E_WIN	36	32	31	30.5	30
E_GEO	10	10	10	10	10
E_BIO	46	46	46	46	46
E_ORN	10	10	10	10	10
E_BIN	46	46	46	46	46

Table 11.6: Cost share of transmission and distribution cost (-)

E_COL	0.4976828
E_GAS	0.5112085

E_OIL	0.5112085
E_HYD	0.4976828
E_NUC	0.4976828
E_SPV	0.7817224
E_WIN	0.7817224
E_GEO	0.4976828
E_BIO	0.5112085
E_ORN	0.4976828
E_BIN	0.5112085

11.3.3 Biomass energy supply

There are two types of biomass energy; what we call traditional and modern bioenergy. The former is mainly used in the low income countries and wood, charcoal, crop residue and animal manure are the main energy sources. They are usually combusted directly. The latter biomass is used in two ways. One is refined for the bio-liquid fuel and the other is combusted by power generation plants. The biofuel is used as transport sector. The demand of the biofuel will be addressed in the section.

The biofuel is supplied from 1st and 2nd generation technologies. The former is made from cereals, sugars and vegetable oils, which can easily be extracted using conventional technology. The latter is made from lignocellulosic biomass or woody crops, agricultural residues or waste, which makes it harder to extract the required fuel under current technology. This model assumes that the biomass supply is nested by logit function and there are three nodes; namely 1st generation biofuels, 2nd generation biofuel from energy purpose grown crops (e.g. switch grass), and wastes (crop residue or wood residue). The three sources are individually treated as a single production sector.

The 2nd generation biofuels made from purpose grown energy crops are assumed to input land. The yields of them for tropical, temperate and boreal zones are assumed 15, 10 and 12 ton/hector respectively. The other 2nd generation biofuels made from wastes does not input land or any agricultural commodities as production factors. Instead, this production sector assumed to have available potential limitations which are calculated from the amount of crop residue, wood residue and livestock manure generated in previous years. We assumed that half of the potential can be practically or economically available for the energy fuel production.

Table 11.7: Input coefficients of biofuel production (thousand $ per toe of biofuel production).

	1st -gen	2nd-gen from purpose grown energy crops	2nd-gen from waste base
Agricultural products[5]	2.000		
Energy crop[6]		2.000	2.000
Chemistry	0.083	0.124	0.124
Transport	0.025	0.083	0.083
Other services	0.025	0.041	0.041

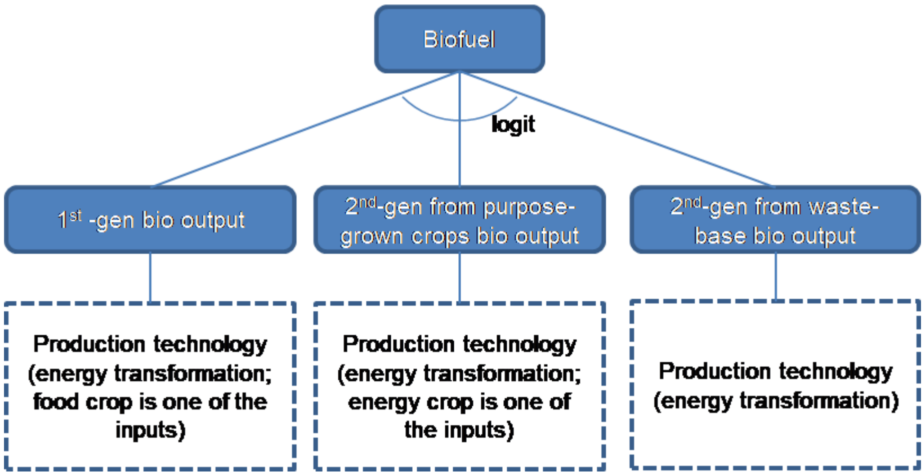

Figure 11.1: Biomass supply

Labor	0.141	0.124	0.124
Capital	0.141	0.430	0.455

Each region has specific crops to be used for 1st generation biofuel production. For instance, Brazil utilizes sugarcane while US produces it from maize. Therefore, we assume each region has such specific biofuel crops and only that crop can be used for biofuel production. The 1st generation biofuel production sector is assumed input such agricultural products and the input coefficients is derived from biomass conversion energy efficiency 0.5. The other input coefficients are shown in table 11.7.

11.3.4 Other energy transformation sectors

Other than those of energy transformation sectors such as petroleum refineries and town gas distribution sectors assumed to keep the same production structure as shown in power sector. It's input coefficients are also constant including energy transformation efficiency.

11.4 Energy demand

The energy demand, in this document, is classified as final energy consumption defined in energy balance table (International Energy Agency 2018) [31]. It generally consists of five or six sectors; industry, transportation, residential, commercial, non-energy use and other sectors[7]. Actual AIM/CGE has more disaggregated sectors and for example iron and steel, and food processing are classified as part of industrial sectors. The model has two options how to determine these energy demands. One is using traditional functions such as CES function for production sectors. The other option enables to consider bottom-up energy technological information and the energy demand explicitly

[5] Agricultural products and energy crops input are accounted as toe per toe of biofuel production.
[6] Agricultural products and energy crops input are accounted as toe per toe of biofuel production.
[7] Residential and commercial are sometimes treated as single aggregated building sector.

determined by the detailed energy technologies (Fujimori et al. 2014) [32]. In this section, the former method is explained.

11.4.1 Production sectors

Total energy

The general production structure of energy end-use sectors is illustrated in Figure 3.2. The energy demand is associated with the bundle of value-added and energy. The aggregated energy and value-added branch is assumed a fixed coefficient to output of that sector while the energy and value-added are assumed to have substitution relationship.

There are three main factors to determine energy demand. First is the production itself and it is driven by the value-added growth which consists of labor, capital and their productivities. In other words, GDP growth drives energy demand. However, the GDP and energy demand is not linearly linked and usually energy demand growth rate is slower than GDP even the relationship of energy and value added prices are constant. This is the second factor to change the energy demand and realized by technological progress (the effect of more efficient energy device) or energy service demand efficiency improvement (e.g. floor space of office is not so expand as the economic value of output), or mixture of them. We normally call this factor as AEEI (Autonomous Energy Efficiency Improvement) and multiply coefficients to the energy efficiency. the AEEI is changed as a function of GDP growth. In principle, the AEEI is high when a country has a high GDP growth rate, whereas it is low in low GDP growth areas (van Ruijven et al. 2010). If GDP growth is negative, AEEI is fixed as zero. If GDP growth ranges from 0-3%, 3-5%, and over 5%, annual AEEI is assumed to be 1%, 1.5%, and half of the GDP growth percentage, respectively.

The third one is price factor. The ratio of energy and value-added inputs are determined by those of relative price relationship. The relative price and volume input relationship can be derived from the maximization profit condition subject to the CES production function. The ratio of value-added and energy is determined by the share parameters (which are usually calibrated from base year's data) and the price ratio associated with substitution elasticity.

Energy mix

The next story is how to determine the energy source mix to satisfy final energy demand. Energy has several forms such as solid, liquid and gaseous and so on. The energy mix is associated with each sector's activity and its technologies. For instance, the boiler could use any types of energy to obtain certain amount of energy while current car uses liquid (partly electricity and gas) but not solid type fuel. Therefore, the energy source mix is not determined by simple cost minimization mechanism. However, the relatively cheaper energy sources may be attractive than others. To meet these mechanisms and to keep simplicity to solve the large system equilibrium model, the energy source mix is assumed to be determined by the CES function. The elasticity of substitution among the energy forms is 2.0 (Figure 13.3). The AEEI should differ across energy sources to reflect the energy consumption composite switch from coal to oil, gas, or electricity. Therefore, coal, gas, and electricity are assumed to have 1%, -0.5%, and -1% annual changes. Because previous studies did not report these values, these numbers are arbitrarily assigned. The AEEI for the traditional biomass usage was assumed to be 1% annually.

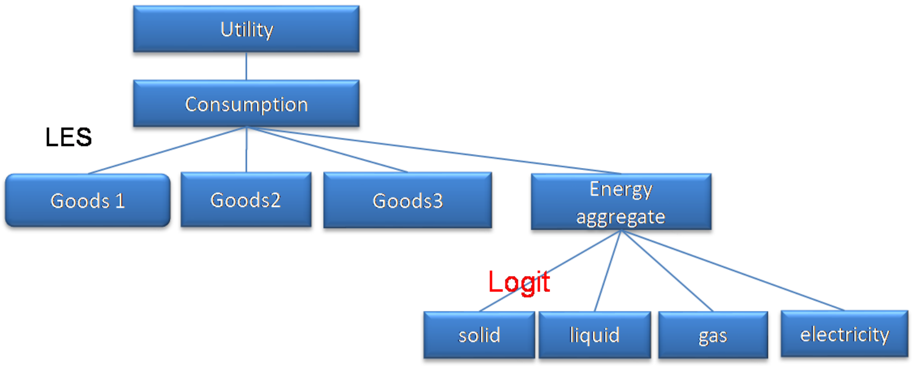

Figure 11.2: Household demand structure

11.4.2 Residential sectors

The household consumption is determined by the LES as explained earlier. The energy demand is treated as two kinds of household goods. One is associated with the car usage energy demand and the other is rest of the energy demand. There is a definition difference between energy balance table and social accounting matrix in terms of how to account the energy consumption by private household cars. The social accounting matrix deals with the fuel consumption in order to drive household car is accounted as part of household consumption while energy balance treats it as transport sector's energy consumption. To deal with the household energy demand consistently, we separately treat the car fuel and rest of energy.

The total car energy consumptions or other energy demand are determined goods prices and income of household under LES. We basically assumed 1.0 and 0.5 as income elasticity for the car energy usage and rest of household energy consumption. The income elasticity can be derived from the LES function and it is fixed assumption for the future simulation. However, the derived income elasticity depends on the parameter $\beta^{m}_{r,ch,h}$ and goods prices. In order to realize the constant income elasticity, the parameters are calibrated recursively.

Energy source mix is determined by logit function for each energy demand. The structure of household energy demand is shown in Figure 11.2. The exponent parameters for the car fuel are -1.0 and those of other energy demand are 0.2. Currently in the energy balance table does not account electricity consumption for road transport. However, electric vehicle could be one of the options in the future. Hence, the share parameter of the logit function is updated in the future. So in year 2015 the electric vehicle is assumed to start and at that year 0.1% of the share is assumed. This share is used for the logit functions' share parameter. Then, after that year the share parameter is linearly changed according to the electricity price. The biofuel for road transport is also similarly treaded, but the starting year is 2006.

11.5 Agriculture and land use

Regarding with agriculture and land use there three topics should be discussed in this section. First is how the agricultural commodities' productions are determined. Second is the demand side story. How the demand is modeled and trade is also included. Third, the production side has land completion and how the land completion is realized within this model is explained.

11.5.1 Agricultural commodities production

Producers are assumed to maximize profits subject to technology (production functions) and prices of inputs. The first-order conditions for profit maximization essentially define the factor demands and output supply behavior of producers. The production structure is same as other industrial sectors except for land input treatment. The land input is assumed multiplying a coefficient to output. However, in some cases this fixed coefficient approach makes difficult to solve the program if the land constraint is substantially critical. Therefore, the term related to output price elasticity is multiplied to the fixed coefficient. The price elasticity is very small (say 0.05) and the model results can be interpreted as the land input is almost treated as Leontief type input. Whether the treatment that land input is fixed technology has reality or not should be concerned carefully. The main technologies related to improving land efficiency are fertilizer inputs, advanced cultivar, optimizing planting date and irrigation. When we consider the climate change impact, the constraints caused by climate change are water and temperature. These conditions can be partly controlled by the latter three technologies. The cultivars and planting date are what we call autonomous adaptation and it would not change the production cost so much. GAEZ (Masutomi et al. 2009) [33] results are usually fed into this CGE model to analyze climate change impact and within GAEZ framework the cultivars and planting date are already considered. Therefore, the last irrigation is the remained technology which could change the yield and production cost. However, the irrigation is not always accounted as production cost but as social infrastructure (reservoirs and canal). It makes difficult to analyze the relationship of production cost and irrigation technologies. Tentatively, we don't touch about this issue in this version but we need to consider this limitation to interpret the results of this model.

The future land input coefficient, which is yield, is exogenous assumption and based on IFPRI's IMAPCT (Msangi et al. 2010) [34] and Table 11.8 shows actual numbers used in the default scenario. It does not include climate change impact.

The livestock land productivity is assumed to be corresponding to the livestock goods demand change. For instance, if the meet demand is supposed to be 1.5 folds, then its land productivity is also assumed as well. This mechanism is based on the historical evidence that we could not find any relationship between grazing land productivity and other factors like economic development level whereas the grazing area looked rather constant.

Table 11.8: Future yield assumptions

	Rice	Wheat	Other grains	Oil crops	Sugar crops
USA	0.7%	1.0%	1.1%	0.8%	0.7%
XE25	1.2%	0.3%	0.8%	0.9%	0.4%
XER	1.0%	1.3%	1.3%	1.4%	1.1%
TUR	0.2%	1.0%	0.7%	0.5%	1.1%
XOC	0.1%	1.0%	1.3%	0.6%	0.4%
CHN	0.8%	0.9%	1.5%	1.0%	0.9%
IND	1.3%	0.8%	2.1%	0.8%	0.5%

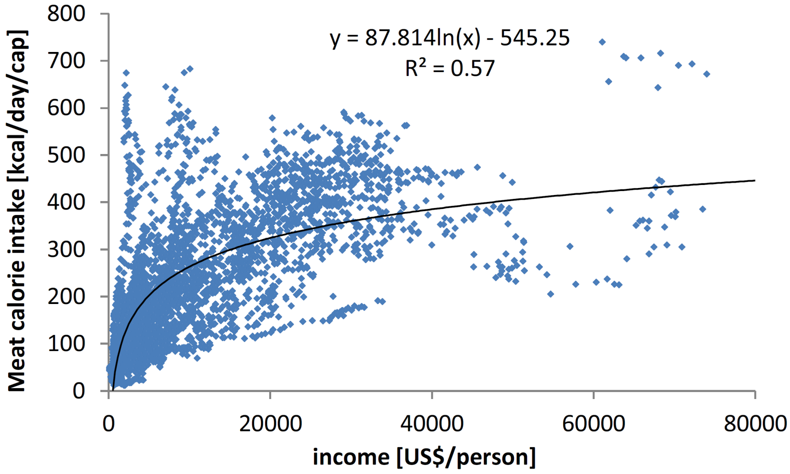

Figure 11.3: Time-series and cross-country data on meat calorie intake and income (1980-2009, source: World Bank (2013) [27] for income and Food and Agriculture Organization of the United Nations (2013) [36] for calorie intake)

JPN	0.3%	0.6%	0.6%	0.2%	0.6%
XSE	1.0%	1.8%	1.4%	-0.4%	0.8%
XSA	0.9%	1.4%	1.4%	0.9%	1.4%
CAN	-	1.8%	1.6%	0.1%	1.0%
BRA	0.8%	1.7%	1.8%	0.9%	1.1%
XLM	0.6%	1.3%	1.4%	0.6%	1.1%
CIS	1.7%	2.0%	2.1%	1.4%	1.4%
XME	1.2%	2.2%	2.0%	1.0%	1.1%
XNF	0.7%	1.3%	1.3%	1.3%	0.8%
XAF	2.0%	2.1%	1.5%	0.9%	0.8%

11.5.2 Demand of agricultural commodities

As section 11.2.1 shows, the household expenditure is represented by LES function. The parameters dealt with LES are changed overtime.

At least food related goods are crucial for this model, their parameters are carefully treated, since they are physically accounted in this model. We assumed food consumption income elasticity according to two sources. One is the historical observation. If we could find the relationship between the income level and food consumption, then that relationship is adopted. For the other goods we follow FAO's perspective [35]. The livestock goods are former cases and one of the examples is plotted in Figure 11.3. The latter goods income elasticity is shown in Table 11.9.

Table 11.9: Income elasticity of crop consumption

	Cereal	Oil crops	Sugar crops	Other crops

USA	-0.04	0.10	-0.03	-0.14
XE25	-0.04	0.10	-0.03	-0.14
XER	-0.03	0.27	0.05	-0.04
TUR	-0.02	0.10	0.04	-0.01
XOC	-0.04	0.10	-0.03	-0.14
CHN	-0.06	0.19	0.22	-0.09
IND	0.03	0.26	0.10	0.18
JPN	-0.04	0.10	-0.03	-0.14
XSE	-0.01	0.23	0.12	0.08
XSA	0.03	0.26	0.10	0.18
CAN	-0.04	0.10	-0.03	-0.14
BRA	0.04	0.24	-0.02	-0.07
XLM	0.04	0.24	-0.02	-0.07
CIS	-0.03	0.27	0.05	-0.04
XME	-0.04	0.16	0.06	-0.02
XNF	-0.04	0.16	0.06	-0.02
XAF	0.22	0.37	0.39	0.07

As for intermediate inputs not used as the feeding for livestock is determined by income and price elasticities derived from the household consumption function.

11.5.3 Land competition and allocation mechanism

A function whereby land is an input for the production of crops and livestock products, and landowners change its use in accordance with the prices of producer goods on cropland, pastureland, and forest. The model has a land nesting strategy, which is similar to the treatment in Sands and Edmonds [37] and Wise and Calvin [38]. Land is categorized in one of three ecological zones, and there is a land market for each zone. Allocation of land by sector is formulated as a multi-nominal logit function to reflect differences in substitutability across land categories with land rent. In that, the function assumes that land owner of each region and Agro-ecological Zone (AEZ) decides land sharing among options with the land rent depending on production on each land (i.e. crops, livestock and wood products). We deal with all land excluding desert, rock, ice, tundra, and built-up land. The model has 18 AEZ classifications.

Figure 11.4 shows the nesting diagram of land with an AEZ classification. We deal with all land, excluding desert, rock, ice, tundra, and built-up land. There are 18 AEZ classifications. At the top is all land, which is divided into two main types of nodes: forest land and non-forest land. The forest land node contains two competing uses: primary forest (unmanaged forest) and secondary forest (managed forest). The non-forest land could be divided; all grassland and cropland. The grassland could be divided into primary grassland (unmanaged pasture) and grazing grassland (managed pasture that which feeds marketed livestock) which is divided further into each livestock (1 to n). The cropland could be divided further into cropland for each crop (1 to n) and fallow land. One approach of the nesting strategies is based on the assumption that the land regions are small enough that all competing options are equally substitutable. This assumption implies that it is easy to switch from forest to wheat as it is to switch from corn to wheat. However, this conversion would not happen unless wheat was more profitable than forest or corn. In that, the function assumes that land owner of

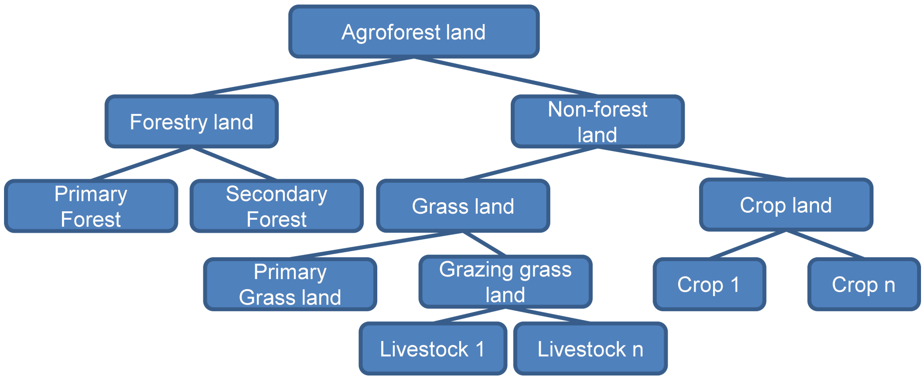

Figure 11.4: Land allocation structure

each region and AEZ sub-region decides land sharing among options depending on the land rent from production on each land (i.e. crops, livestock and wood products). To calibrate the function for both of the managed and unmanaged lands in the base year, we used the mean base-year land rent of the managed land as that of the unmanaged land because of unavailable data for the unmanaged land. Carbon stock on forest land is evaluated by price in the case of climate mitigation scenario. Land rent of forest includes both of revenue of wood product and the price of the carbon stock.

11.6 GHG reduction measures other than changing energy system

11.6.1 CCS (Carbon Capture and Storage)

CCS technology is one of the key technologies for climate mitigation and this subsection explains how it is treated in the model. CCS captures the CO2 using chemical processes and stores the carbon underground or in the deep sea. It is mainly available for the large point CO2 emission sources. Fired power plants, biomass power plants, oil refineries and coal transformation plants, non-metal and mineral, chemical, and paper and pulp industries are supposed to be able to apply CCS technology in this study. These sectors input CCS services as intermediate inputs and the CCS service is assumed to be provided by a CCS service sector which has independent production function.

The costs of the technology are different among sectors and are shown in Table 11.10. These costs have been taken from IEA (2008) [39]. Since IEA (2008)[39] provides a range of the cost estimates we took medium values. When the GHG emission price becomes higher than these costs, CCS technology is installed with a maximum increase ratio of 5 % per year. CCS is assumed to be installable after 2020 since it is still under examination.

Table 11.10: CCS technology cost

	sectors	price (US$/t$CO_2$)

Manufacturing	petroleum refinery coal transformation	100
	non-metal and mineral	200
	paper and pulp	150
	chemical	150
Power	Coal fired	100
	Oil fired	80
	Gas fired	80
	Biomass fired	80

11.6.2 Non-CO2 reduction

As for the non-energy-related GHG emissions reductions in areas such as agricultural CH4 and N2O emissions, the following equation is used. A similar method is already discussed by Hyman et al. (2003) [3]. The parameter is taken from Lucas et al. (2007) [26]

11.6.3 Land use related counter measures

Once carbon is priced, the stock of the forestry is potentially assumed to have value. This carbon value is assumed to be additional land rent for the forestry and it makes forestry larger. The value itself is discounted carbon value. Life time of forestry that can absorb carbon is assumed as 60 years and interest rate is 5%. The amount of carbon absorption made by afforestation is depending on the age of the trees. The carbon stock is differentiated across AEZ.

11.7 How to implement new production sectors or goods (not accounted in the base year)

The sectors or goods which are not recorded in the base year (e.g. solar power, biofuel and so on) need to be assumed explicitly in future some year. Advanced renewable energy or CCS technologies are under this treatment. The list of the sectors and goods and the starting years are shown in Table 11.11.

Table 11.11: List of sectors and goods which are not accounted base year, but newly introduced in the future scenarios and the starting years

	Goods or sectors	Starting year
Goods	Biofuel	2006
	CCS service for cement	2021
	CCS service for furnaces	2021
	CCS service for other manufacturing	2021
	CCS service for coal fired power plant	2021
	CCS service for other fired power plant and biomass refinery	2021
Sectors	1st -gen biofuel	2006
	2nd-gen biofuel from purpose grown energy crops	2015
	2nd-gen biofuel from waste base	2015

	Purpose grown energy crops	2015
	Nuclear	2006
	Wind	2006
	Solar	2006
	Biomass fired power	2006

To implement those sectors or goods, the production input coefficients or demand of the goods should be formulated. The same production structures as those of US are assumed for the nuclear, renewable power energies. The coefficients of the production are shown in Table 11.12 for power generation. The demand of the generated power is assumed very small portion in the starting year (0.1% of the total generation) and this assumption is made on the share parameter.

The CCS technologies inputs four factors as labor, capital, chemical products, transport, and other services. The cost shares are assumed 0.1, 0.4, 0.1, 0.3 and 0.1 respectively. The assumed input coefficients are based on (IEA 2008).

Table 11.12: Input coefficients for power generation (thousand $ per toe of electricity production).[8]

	Nuclear	Solar	Wind	Biomass fired
Energy crops*				2.5
Other manufacturing	0.022	0.027	0.027	0.058
Electricity*	0.067			
Construction	0.041	0.049	0.049	0.099
Transport	0.068	0.081	0.080	0.161
Other services	0.106	0.126	0.125	0.250
Labor	0.095	0.113	0.113	0.226
Capital	0.545	0.537	0.538	0.206

[8]Electricity and energy crop inputs are accounted as toe per toe of electricity production

Bibliography

[1] Masui, T. et al. An emission pathway for stabilization at 6 wm − 2 radiative forcing. Climatic Change **109**, 59–76 (2011).

[2] Löfgren, H., Harris, R. L. & Robinson, S. A standard computable general equilibrium (cge) model in gams. Report, IFPRI (2001). URL http://ideas.repec.org/p/fpr/tmddps/75.html.

[3] Hyman, R., Reilly, J., Babiker, M., De Masin, A. & Jacoby, H. Modeling non-co2 greenhouse gas abatement. Environmental Modeling and Assessment **8**, 175–186 (2003). URL http://dx.doi.org/10.1023/A%3A1025576926029.

[4] JRC. Edgar emissions database (2012). URL http://edgar.jrc.ec.europa.eu.

[5] Bond, T. C. et al. Historical emissions of black and organic carbon aerosol from energy-related combustion, 1850–2000. Global Biogeochemical Cycles **21** (2007). URL https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2006GB002840.

[6] IPCC. 2006 ipcc guidelines for national greenhouse gas inventories, prepared by the national greenhouse gas inventories programme. book, IGES (2006). URL http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm.

[7] Dai, H. et al. The impacts on climate mitigation costs of considering curtailment and storage of variable renewable energy in a general equilibrium model. Energy Economics **64**, 627–637 (2017). URL https://www.sciencedirect.com/science/article/pii/S0140988316300391.

[8] Bijl, D. L., Bogaart, P. W., Kram, T., de Vries, B. J. M. & van Vuuren, D. P. Long-term water demand for electricity, industry and households. Environmental Science and Policy **55, Part 1**, 75–86 (2016). URL http://www.sciencedirect.com/science/article/pii/S1462901115300745.

[9] Kc, S. & Lutz, W. The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100. Global Environmental Change (2017).

[10] Fujimori, S. et al. Ssp3: Aim implementation of shared socioeconomic pathways. Global Environmental Change-Human and Policy Dimensions **42**, 268–283 (2017). URL https://www.sciencedirect.com/science/article/pii/S0959378016300838.

[11] Fujimori, S., Dai, H., Masui, T. & Matsuoka, Y. Global energy model hindcasting. Energy **114**, 293–301 (2016). URL https://www.sciencedirect.com/science/article/pii/S0360544216311112.

[12] Roelfsema, M. et al. Taking stock of national climate policies to evaluate implementation of the paris agreement. Nature Communications **11**, 2096 (2020). URL https://doi.org/10.1038/s41467-020-15414-6.

[13] Fujimori, S., Oshiro, K., Shiraki, H. & Hasegawa, T. Energy transformation cost for the japanese mid-century strategy. Nature Communications **10**, 4737 (2019). URL https://doi.org/10.1038/s41467-019-12730-4.

[14] Dai, H., Herran, D. S., Fujimori, S. & Masui, T. Key factors affecting long-term penetration of global onshore wind energy integrating top-down and bottom-up approaches. Renewable Energy **85**, 19–30 (2016). URL https://www.sciencedirect.com/science/article/pii/S0960148115300239.

[15] Herran, D. S., Dai, H., Fujimori, S. & Masui, T. Global assessment of onshore wind power resources considering the distance to urban areas. Energy Policy **91**, 75–86 (2016). URL https://www.sciencedirect.com/science/article/pii/S0301421515302366.

[16] Hasegawa, T. et al. Quantifying the economic impact of changes in energy demand for space heating and cooling systems under varying climatic scenarios. Palgrave Communications **2** (2016). URL https://www.nature.com/articles/palcomms201613.

[17] Hasegawa, T., Fujimori, S., Ito, A., Takahashi, K. & Masui, T. Global land-use allocation model linked to an integrated assessment model. Science of the Total Environment **580**, 787–796 (2017). URL https://www.sciencedirect.com/science/article/pii/S0048969716327097.

[18] Wu, W. et al. Global advanced bioenergy potential under environmental protection policies and societal transformation measures. GCB Bioenergy **11**, 1041–1055 (2019). URL https://doi.org/10.1111/gcbb.12614.

[19] Fujimori, S., Hasegawa, T. & Masui, T. AIM/CGE V2.0: Basic Feature of the Model, 305–328 (Springer Singapore, Singapore, 2017). URL https://doi.org/10.1007/978-981-10-3869-3_13.

[20] Rao, S. et al. Future air pollution in the shared socio-economic pathways. Global Environmental Change-Human and Policy Dimensions **42**, 346–358 (2017). URL https://www.sciencedirect.com/science/article/pii/S0959378016300723.

[21] Rogner, H.-H. An assessment of world hydrocarbon resources. Annual Review of Energy and the Environment **22**, 217–262 (1997). URL http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.22.1.217.

[22] Hasegawa, T., Fujimori, S., Takahashi, K. & Masui, T. Scenarios for the risk of hunger in the twenty-first century using shared socioeconomic pathways. Environmental Research Letters **10** (2015). URL <GotoISI>://WOS:000348501800011.

[23] Fujimori, S. & Masui, T. How dematerialization contributes to a low carbon society? Ecology and the Environment **143**, 315–326 (2011).

[24] statistics, C. o. i. & steel. Handbook for iron and steel statistics (Commitee on iron and steel statistics, Japan, 2006).

[25] OECD. Stan database. Report, Organization for Economic Cooperation and Development (2005).

[26] Lucas, P. L., van Vuuren, D. P., Olivier, J. G. J. & den Elzen, M. G. J. Long-term reduction potential of non-co2 greenhouse gases. Environmental Science and Policy **10**, 85–103 (2007).

[27] Bank, T. W. World development indicators (2019). URL `http://data.worldbank.org/data-catalog/world-development-indicators`.

[28] Shinichiro, F. et al. Measuring the sustainable development implications of climate change mitigation. Environmental Research Letters (2020). URL `http://iopscience.iop.org/10.1088/1748-9326/ab9966`.

[29] Fujimori, S., Hanasaki, N. & Masui, T. Projections of industrial water withdrawal under shared socioeconomic pathways and climate mitigation scenarios. Sustainability Science **12**, 275–292 (2017). URL `https://link.springer.com/article/10.1007/s11625-016-0392-2`.

[30] Kriegler, E. et al. Diagnostic indicators for integrated assessment models of climate policy. Technological Forecasting and Social Change (2014).

[31] International Energy Agency, I. World Energy balances (Paris, France, 2018).

[32] Fujimori, S., Mosui, T. & Matsuoka, Y. Development of a global computable general equilibrium model coupled with detailed energy end-use technology. Applied Energy **128**, 296–306 (2014). URL `https://www.sciencedirect.com/science/article/pii/S0306261914004371`.

[33] Masutomi, Y., Takahashi, K., Harasawa, H. & Matsuoka, Y. Impact assessment of climate change on rice production in asia in comprehensive consideration of process/parameter uncertainty in general circulation models. Agriculture, Ecosystems and Environment **131**, 281–291 (2009).

[34] Msangi, S., Ewing, M., Rosegrant, M. W. & Zhu, T. Biofuels, food security, and the environment: A 2020/2050 perspective 65–94 (2010).

[35] FAO. Statistical yearbook (2013). URL `http://www.fao.org/economic/ess/ess-fs/fs-data/en/#.UrE-GPQ7t8E`.

[36] United Nations, U. National Accounts Main Aggregates Database (New York, USA, 2013). URL `https://unstats.un.org/unsd/snaama/methodology.pdf`.

[37] Sands, R. & Edmonds, J. Climate change impacts for the conterminous usa: An integrated assessment. Climatic Change **69**, 127–150 (2005). URL `http://dx.doi.org/10.1007/s10584-005-3616-5`.

[38] Wise, M. & Calvin, K. Gcam 3.0 agriculture and land use; technical description of modeling approach. Report (2011).

[39] IEA. CO2 Capture and Storage – A Key Carbon Abatement Option (2008).

Chapter 12

Appendix I (Marginal abatement cost and reduction cost in non-energy emissions)

The marginal abatement cost is represented as equation $EFFIMPR\_PRICE\_CONS$. The total abatement cost can be represented by the following equation. To simplify the expression, $ABTC\_NCS_{r,a,g,emsc}$, $PGHG$, $NERED$ and $\sigma^{ghg}_{r,a,g,emsc}$ are shortened as Z, P, X and σ

$$
\begin{aligned}
Z &= \int_0^{X_0} PdX \\
&= \int_0^{X_0} (1-X)^{-1/\sigma} - 1dX \\
&= \left[(-1/\sigma+1)^{-1}(-1)(1-X)^{-1/\sigma+1} - X\right]_0^{X_0} \\
&= \left[\left(\frac{\sigma}{1-\sigma}\right)(1-X)^{\left(\frac{\sigma-1}{\sigma}\right)} - X\right]_0^{X_0} \\
&= \left(\frac{\sigma}{1-\sigma}\right)(1-X_0)^{\left(\frac{\sigma-1}{\sigma}\right)} - X_0 - \frac{\sigma}{1-\sigma}
\end{aligned}
$$

This integration is applied to the baseline emissions and thus $E(1-X)^{(-1)}$ should be muliplied.

Chapter 13

Appendix II (List of coutries and mapping with global 17 regions)

Table 13.1: List of countries

Native Region Code	Native Region Name	ISO Code	Country
XLM	Rest of Brazil	ABW	Aruba
XSA	Rest of Asia	AFG	Afghanistan
XAF	Other Africa	AGO	Angola
XLM	Rest of Brazil	AIA	Anguilla
#N/A	#N/A	ALA	Åland Islands
XER	Rest of Europe	ALB	Albania
XER	Rest of Europe	AND	Andorra
XLM	Rest of Brazil	ANT	Netherlands Antilles
XME	Middle East	ARE	United Arab Emirates
XLM	Rest of Brazil	ARG	Argentina
CIS	Former USSR	ARM	Armenia
XSA	Rest of Asia	ASM	American Samoa
#N/A	#N/A	ATA	Antarctica
XSA	Rest of Asia	ATF	French Southern Territories
XLM	Rest of Brazil	ATG	Antigua and Barbuda
XOC	New Zealand and Australia	AUS	Australia
XE25	EU	AUT	Austria
CIS	Former USSR	AZE	Azerbaijan
XAF	Other Africa	BDI	Burundi
XE25	EU	BEL	Belgium
XAF	Other Africa	BEN	Benin
XAF	Other Africa	BFA	Burkina Faso

Continue to next page

Continued from previous page

Native Region Code	**Native Region Name**	**ISO Code**	**Country**
XSA	Rest of Asia	BGD	Bangladesh
XER	Rest of Europe	BGR	Bulgaria
XME	Middle East	BHR	Bahrain
XLM	Rest of Brazil	BHS	Bahamas
XER	Rest of Europe	BIH	Bosnia and Herzegovina
#N/A	#N/A	BLM	Saint Barthélemy
CIS	Former USSR	BLR	Belarus
XLM	Rest of Brazil	BLZ	Belize
XLM	Rest of Brazil	BMU	Bermuda
XLM	Rest of Brazil	BOL	Bolivia, Plurinational State of
BRA	Brazil	BRA	Brazil
XLM	Rest of Brazil	BRB	Barbados
XSA	Rest of Asia	BRN	Brunei Darussalam
XSA	Rest of Asia	BTN	Bhutan
XLM	Rest of Brazil	BVT	Bouvet Island
XAF	Other Africa	BWA	Botswana
XAF	Other Africa	CAF	Central African Republic
CAN	Canada	CAN	Canada
XSA	Rest of Asia	CCK	Cocos (Keeling) Islands
XER	Rest of Europe	CHE	Switzerland
XLM	Rest of Brazil	CHL	Chile
CHN	China	CHN	China
XAF	Other Africa	CIV	Côte d'Ivoire
XAF	Other Africa	CMR	Cameroon
XAF	Other Africa	COD	Congo, the Democratic Republic of the
XAF	Other Africa	COG	Congo
XSA	Rest of Asia	COK	Cook Islands
XLM	Rest of Brazil	COL	Colombia
XAF	Other Africa	COM	Comoros
XAF	Other Africa	CPV	Cape Verde
XLM	Rest of Brazil	CRI	Costa Rica
XLM	Rest of Brazil	CUB	Cuba
XSA	Rest of Asia	CXR	Christmas Island
XLM	Rest of Brazil	CYM	Cayman Islands
XE25	EU	CYP	Cyprus
XE25	EU	CZE	Czech Republic
XE25	EU	DEU	Germany
XAF	Other Africa	DJI	Djibouti
XLM	Rest of Brazil	DMA	Dominica
XE25	EU	DNK	Denmark
XLM	Rest of Brazil	DOM	Dominican Republic
XNF	North Africa	DZA	Algeria
XLM	Rest of Brazil	ECU	Ecuador

Continue to next page

Continued from previous page

Native Region Code	**Native Region Name**	**ISO Code**	**Country**
XNF	North Africa	EGY	Egypt
XAF	Other Africa	ERI	Eritrea
XAF	Other Africa	ESH	Western Sahara
XE25	EU	ESP	Spain
XE25	EU	EST	Estonia
XAF	Other Africa	ETH	Ethiopia
XE25	EU	FIN	Finland
XSA	Rest of Asia	FJI	Fiji
XLM	Rest of Brazil	FLK	Falkland Islands (Malvinas)
XE25	EU	FRA	France
XER	Rest of Europe	FRO	Faroe Islands
XSA	Rest of Asia	FSM	Micronesia, Federated States of
XAF	Other Africa	GAB	Gabon
XE25	EU	GBR	United Kingdom
CIS	Former USSR	GEO	Georgia
#N/A	#N/A	GGY	Guernsey
XAF	Other Africa	GHA	Ghana
XER	Rest of Europe	GIB	Gibraltar
XAF	Other Africa	GIN	Guinea
XLM	Rest of Brazil	GLP	Guadeloupe
XAF	Other Africa	GMB	Gambia
XAF	Other Africa	GNB	Guinea-Bissau
XAF	Other Africa	GNQ	Equatorial Guinea
XE25	EU	GRC	Greece
XLM	Rest of Brazil	GRD	Grenada
XLM	Rest of Brazil	GRL	Greenland
XLM	Rest of Brazil	GTM	Guatemala
XLM	Rest of Brazil	GUF	French Guiana
XSA	Rest of Asia	GUM	Guam
XLM	Rest of Brazil	GUY	Guyana
CHN	China	HKG	Hong Kong
XSA	Rest of Asia	HMD	Heard Island and McDonald Islands
XLM	Rest of Brazil	HND	Honduras
XER	Rest of Europe	HRV	Croatia
XLM	Rest of Brazil	HTI	Haiti
XE25	EU	HUN	Hungary
XSE	Rest of East and South East Asia	IDN	Indonesia
#N/A	#N/A	IMN	Isle of Man
IND	India	IND	India
XSA	Rest of Asia	IOT	British Indian Ocean Territory
XE25	EU	IRL	Ireland
XME	Middle East	IRN	Iran, Islamic Republic of

Continue to next page

Continued from previous page

Native Region Code	**Native Region Name**	**ISO Code**	**Country**
XME	Middle East	IRQ	Iraq
XER	Rest of Europe	ISL	Iceland
XME	Middle East	ISR	Israel
XE25	EU	ITA	Italy
XLM	Rest of Brazil	JAM	Jamaica
#N/A	#N/A	JEY	Jersey
XME	Middle East	JOR	Jordan
JPN	Japan	JPN	Japan
CIS	Former USSR	KAZ	Kazakhstan
XAF	Other Africa	KEN	Kenya
CIS	Former USSR	KGZ	Kyrgyzstan
XSE	Rest of East and South East Asia	KHM	Cambodia
XSA	Rest of Asia	KIR	Kiribati
XLM	Rest of Brazil	KNA	Saint Kitts and Nevis
XSE	Rest of East and South East Asia	KOR	Korea, Republic of
XME	Middle East	KWT	Kuwait
XSE	Rest of East and South East Asia	LAO	Lao People's Democratic Republic
XME	Middle East	LBN	Lebanon
XAF	Other Africa	LBR	Liberia
XNF	North Africa	LBY	Libyan Arab Jamahiriya
XLM	Rest of Brazil	LCA	Saint Lucia
XER	Rest of Europe	LIE	Liechtenstein
XSA	Rest of Asia	LKA	Sri Lanka
XAF	Other Africa	LSO	Lesotho
XE25	EU	LTU	Lithuania
XE25	EU	LUX	Luxembourg
XE25	EU	LVA	Latvia
#N/A	#N/A	MAC	Macao
#N/A	#N/A	MAF	Saint Martin (French part)
XNF	North Africa	MAR	Morocco
XER	Rest of Europe	MCO	Monaco
CIS	Former USSR	MDA	Moldova, Republic of
XAF	Other Africa	MDG	Madagascar
XSA	Rest of Asia	MDV	Maldives
XLM	Rest of Brazil	MEX	Mexico
XSA	Rest of Asia	MHL	Marshall Islands
XER	Rest of Europe	MKD	Macedonia, the former Yugoslav Republic of
XAF	Other Africa	MLI	Mali
XE25	EU	MLT	Malta

Continue to next page

Continued from previous page

Native Region Code	Native Region Name	ISO Code	Country
XSE	Rest of East and South East Asia	MMR	Myanmar
XER	Rest of Europe	MNE	Montenegro
XSE	Rest of East and South East Asia	MNG	Mongolia
XSA	Rest of Asia	MNP	Northern Mariana Islands
XAF	Other Africa	MOZ	Mozambique
XAF	Other Africa	MRT	Mauritania
XLM	Rest of Brazil	MSR	Montserrat
XLM	Rest of Brazil	MTQ	Martinique
XAF	Other Africa	MUS	Mauritius
XAF	Other Africa	MWI	Malawi
XSE	Rest of East and South East Asia	MYS	Malaysia
XAF	Other Africa	MYT	Mayotte
XAF	Other Africa	NAM	Namibia
XSA	Rest of Asia	NCL	New Caledonia
XAF	Other Africa	NER	Niger
XSA	Rest of Asia	NFK	Norfolk Island
XAF	Other Africa	NGA	Nigeria
XLM	Rest of Brazil	NIC	Nicaragua
XSA	Rest of Asia	NIU	Niue
XE25	EU	NLD	Netherlands
XER	Rest of Europe	NOR	Norway
XSA	Rest of Asia	NPL	Nepal
XSA	Rest of Asia	NRU	Nauru
XOC	New Zealand and Australia	NZL	New Zealand
XME	Middle East	OMN	Oman
XSA	Rest of Asia	PAK	Pakistan
XLM	Rest of Brazil	PAN	Panama
XSA	Rest of Asia	PCN	Pitcairn
XLM	Rest of Brazil	PER	Peru
XSE	Rest of East and South East Asia	PHL	Philippines
XSA	Rest of Asia	PLW	Palau
XSA	Rest of Asia	pdf	Papua New Guinea
XE25	EU	POL	Poland
XLM	Rest of Brazil	PRI	Puerto Rico
XSE	Rest of East and South East Asia	PRK	Korea, Democratic People's Republic of
XE25	EU	PRT	Portugal
XLM	Rest of Brazil	PRY	Paraguay
#N/A	#N/A	PSE	Palestinian Territory, Occupied
XSA	Rest of Asia	PYF	French Polynesia

Continue to next page

Continued from previous page

Native Region Code	Native Region Name	ISO Code	Country
XME	Middle East	QAT	Qatar
XAF	Other Africa	REU	Réunion
XER	Rest of Europe	ROU	Romania
CIS	Former USSR	RUS	Russian Federation
XAF	Other Africa	RWA	Rwanda
XME	Middle East	SAU	Saudi Arabia
XAF	Other Africa	SDN	Sudan
XAF	Other Africa	SEN	Senegal
XSE	Rest of East and South East Asia	SGP	Singapore
XLM	Rest of Brazil	SGS	South Georgia and the South Sandwich Islands
XAF	Other Africa	SHN	Saint Helena, Ascension and Tristan da Cunha
XER	Rest of Europe	SJM	Svalbard and Jan Mayen
XSA	Rest of Asia	SLB	Solomon Islands
XAF	Other Africa	SLE	Sierra Leone
XLM	Rest of Brazil	SLV	El Salvador
XER	Rest of Europe	SMR	San Marino
XAF	Other Africa	SOM	Somalia
XLM	Rest of Brazil	SPM	Saint Pierre and Miquelon
XER	Rest of Europe	SRB	Serbia
#N/A	#N/A	SSD	South Sudan
XAF	Other Africa	STP	Sao Tome and Principe
XLM	Rest of Brazil	SUR	Suriname
XE25	EU	SVK	Slovakia
XE25	EU	SVN	Slovenia
XE25	EU	SWE	Sweden
XAF	Other Africa	SWZ	Swaziland
XAF	Other Africa	SYC	Seychelles
XME	Middle East	SYR	Syrian Arab Republic
XLM	Rest of Brazil	TCA	Turks and Caicos Islands
XAF	Other Africa	TCD	Chad
XAF	Other Africa	TGO	Togo
XSE	Rest of East and South East Asia	THA	Thailand
CIS	Former USSR	TJK	Tajikistan
XSA	Rest of Asia	TKL	Tokelau
CIS	Former USSR	TKM	Turkmenistan
XSE	Rest of East and South East Asia	TLS	Timor-Leste
XSA	Rest of Asia	TON	Tonga
XLM	Rest of Brazil	TTO	Trinidad and Tobago
XNF	North Africa	TUN	Tunisia

Continue to next page

Continued from previous page

Native Region Code	**Native Region Name**	**ISO Code**	**Country**
TUR	Turkey	TUR	Turkey
XSA	Rest of Asia	TUV	Tuvalu
XSE	Rest of East and South East Asia	TWN	Taiwan, Province of China
XAF	Other Africa	TZA	Tanzania, United Republic of
XAF	Other Africa	UGA	Uganda
CIS	Former USSR	UKR	Ukraine
XSA	Rest of Asia	UMI	United States Minor Outlying Islands
XLM	Rest of Brazil	URY	Uruguay
USA	USA	USA	United States
CIS	Former USSR	UZB	Uzbekistan
XER	Rest of Europe	VAT	Holy See (Vatican City State)
XLM	Rest of Brazil	VCT	Saint Vincent and the Grenadines
XLM	Rest of Brazil	VEN	Venezuela, Bolivarian Republic of
XLM	Rest of Brazil	VGB	Virgin Islands, British
XLM	Rest of Brazil	VIR	Virgin Islands, U.S.
XSE	Rest of East and South East Asia	VNM	Viet Nam
XSA	Rest of Asia	VUT	Vanuatu
XSA	Rest of Asia	WLF	Wallis and Futuna
XSA	Rest of Asia	WSM	Samoa
XME	Middle East	YEM	Yemen
XAF	Other Africa	ZAF	South Africa
XAF	Other Africa	ZMB	Zambia
XAF	Other Africa	ZWE	Zimbabwe

end