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AIM/CGE [basic] manual

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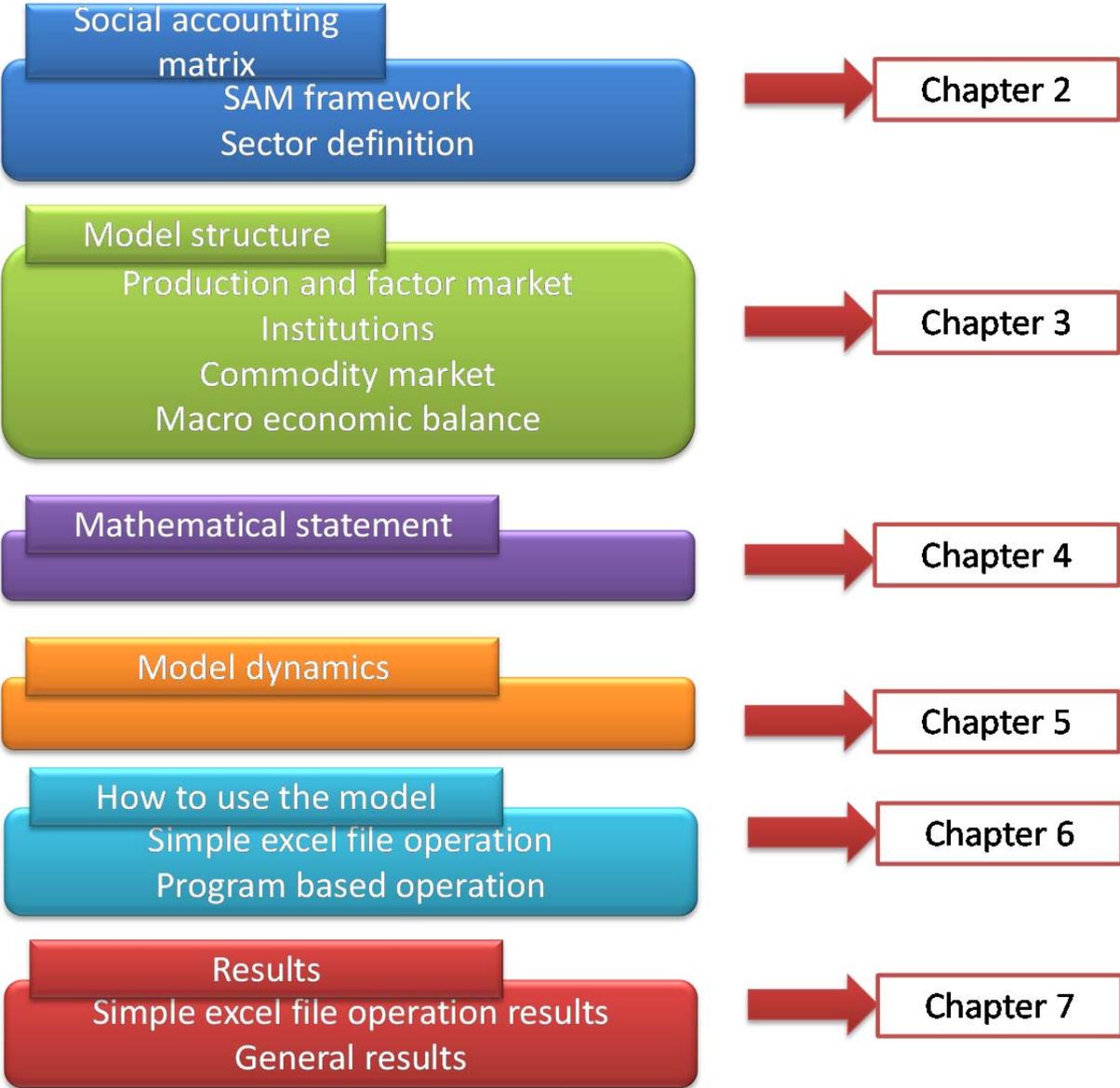
Abstract;

This document describes about AIM/CGE2.0 model which is widely used in the AIM(Asia-Pacific Integrated Modeling) group assessments. AIM/CGE2.0 model is recursive type computable general equilibrium model and it can simulate energy supply and demand with the description about whole economic transaction. The basic idea of the model, model structure, fomula and how to deal with are documented in detail.

Key words;

Computable General Equilibrium model, Social Accounting Matrix, Energy Balance Table

Outline of this document



Directory Structure

	└─data		
		110211IIASA_RCPGHG_AGLU.gdx RCP AG_LU data	
		AEEI_mod.gdx AEEI modification data	
		Driver.gdx Driver data in Energy Economy Driver Database (EEDD)	
		economy.gdx Economic data in Energy Economy Driver Database (EEDD)	
		Energy.gdx Energy data in EEDD	
		scenario_parameter.gdx.gdx file for scenario parameters	
		TB_energy_balance.gdx Energy input-output table	
		TB_SAM.gdx Social accounting matrix	
		└─bond_BCOC a directory for BC and OC emission data	
			BCOC.gdx BC and OC aggregated emission data in GDX file
			original_BCOC.xls BC and OC original emission data and mapping in excel file
		└─define a directory for set and map of BC and OC data	
		fuel.map map for fuel type	
		fuel.set set for original fuel	
		fuel_EB.map map of original BC and OC fuel, and Energy balance energy source	
		region.map map of region	
		region.set set of region	
		sector.map map for aggregated sector	
		sector.set set for original sector	
		sector_AC.map map for CGE's sector and original sector	
		sector_EB.map map of original BC and OC sector , and Energy balance flow	
		└─edgar a directory for EDGAR 4.0 emission data	
		edgar.gdx EDGAR 4.0 emission data in.gdx file	
		emission.xls EDGAR 4.0 emission data in excel file	
		└─define a directory for set and map files of EDGAR 4.0 emission data	
		all_source.set emission source set	
		ch4_source.set CH ₄ emission source set	
		CO2_nonorg_source.set CO ₂ non organic emission source set	
		CO2_source.set CO ₂ organic emission source set	
		CO_source.set CO emission source set	
		N2O_source.set N ₂ O emission source set	
		NH3_source.set NH ₃ emission source set	
		NMVOC_source.set NMVOC emission source set	
		NOX_source.set NO _x emission source set	
		SO2_source.set SO ₂ emission source set	

	region.map	map for EDGAR country definition and AIM 106 regions
	region.set	set for EDGAR country definition
	└─orig	a directory for EDGAR 4.0 original emission data
	CH4_v4.1_EM_1970_2010.csv	CH4 emission data
	CO2_excl_organic_C_v4.1_EM_1970_2010.csv	CO2 emission data
	CO2_org_C_only_v4.1_EM_1970_2010.csv	CO2 emission data
	CO_v4.1_EM_1970_2010.csv	CO emission data
	N2O_v4.1_EM_1970_2010.csv	CH4 emission data
	NH3_v4.1_EM_1970_2010.csv	NH3 emission data
	NMVOC_v4.1_EM_1970_2010.csv	NMVOC emission data
	NH3_v4.1_EM_1970_2010.csv	NH3 emission data
	NOx_v4.1_EM_1970_2010.csv	NOx emission data
	SO2_v4.1_EM_1970_2010.csv	SO2 emission data
	└─emission_factor	a directory for emission factors
	Emission_factor.xls	original emission factor data in excel file
	Emission_factor.gdx	original emission factor data in gdx file
	└─emission_path	a directory for emission factors
	BSgdx	Burden share data
	IP.xls	AIM/Impact policy model's results emission pathway
	S-6_global.xls	S-6 emission pathway
	└─xls	
	20030427ene_fossil.xls	fossil fuel extraction cost in excel file
	aeai_scenario.xls	Autonomous Energy Efficiency Improvement scenario in excel file
	tfp.xls	TFP growth rate in excel file
	non-energy.xls	Non-energy use in data
	renewable.xls	Renewable energy capacity
	scenario_base.xls	GDP and population scenario data (GEO4) in excel file
	└─define	a directory for set and map files
	activity.set	a set file for activities
	commodity.set	a set file for commodities
	country.set	a set file for countries
	economic_category.set	a set file for economic industrial classification used in EEDD
	economic_indicator.set	a set file for economic indicators used in EEDD
	flow.set	a set file for energy flow used in EEDD
	itax_commodity.map	a map file of sales tax set to commodities set
	itax_commodity.set	a set file for sales tax
	product.set	a set file for energy products used in EEDD
	Si.map	a map file from the original SAM classification to that of CGE

	Si.set	a set file for original SAM row and column components
	Sk_economy.map	a map for EEDD classification to that of CGE
	Sk_economy_A.map	a map for EEDD classification to that of CGE
	└─region	
	region**.map	map from 106 region to ** regions
	region**.set	set for ** regions code
	region**_sres.map	map from SRES classification to ** regions
	region**_agg.map	map from ** regions to world total and Asian total
	region**_aei.map	map from ** regions to AEEI classification
	└─doc	
	AIM_CGE.pptx	presentation file of this model
	AIM_CGE_manual.doc	this document file
	Region_classification.xls	regional classification
	Table.xlsx	tables are included in this file
	└─inc_prog	program files included in the main programs are in this directory
	adjust_calib.gms	a program for adjustment of calibration data
	aei_inc.gms	a program for adjustment of aei setting
	ap_ghg_emission.gms	a program for air pollutants and GHG emission calibration
	calibration.gms	a program for calibrating parameters
	capital_stock.gms	a program for physical and human capital preparation
	CCS_industry.gms	a program for CCS setting
	check_infes.gms	a program for checking the infeasibility of the equations
	close_act.gms	a program for closing small power sectors
	combine_gdx.gms	a program for combining GDX files
	combine_gdx2.gms	a program for combining GDX files and analyzing
	data_import.gms	a program for loading, modifying SAM
	DIAGNOSTICS.INC	a program for diagnostic of SAM
	edgar_incprog.gms	a program for including EDGAR files
	elasticity.gms	a program for defining initial elasticity
	ene_bal_make.gms	a program for make energy balance of model simulation results
	equations.gms	a program for defining equations
	equ_marg.gms	a program for setting marginal value of equations
	factor_decomp.gms	a program for an analysis of decomposition
	global_model_dec.gms	a program for defining the global model
	load_pre.gms	a program for loading previous year's results (recursive model)
	LOWER.INC	a program for setting lower boundary of variables
	LOWER_release.INC	a program for releasing lower boundary of variables
	Kyoto_protocol.gms	a program for Kyoto protocol and Copenhagen pledge emission constraint
	one_region_model_dec.gms	a program for defining the one region model

	output_stat.gms	a program for adding statistical information to the analysis
	parameter_in.gms	a program for re-calculating parameters
	pre_year.gms	a program for defining previous year
	release_fix.inc	a program for releasing lo and up boundary of variables
	renew_production_calib.gms	a program for calibration of renewable energy (for AIM_CGE.gms)
	renew_production.gms	a program for calibration of renewable energy (for scenario.gms)
	sam_bal_dec.inc	a program for declaration of sambal.inc program
	sambal.inc	a program for balancing SAM
	scale_global.gms	a program for scaling variables and equations
	set00.gms	a program for setting default parameters
	unload_results.gms	a program for unloading the simulation results
	xls_output_global.gms	a program for unloading the simulation results of excel file
	VARFIX.inc	a program for setting fix attribution for variables
	VARINIT.INC	a program for setting initial attribution for variables
	VARINIT_iteration.INC	a program for setting initial attribution for variables (iteration)
	└─archive	a directory for archiving old files
	└─output	a directory including results
	temp.gdx	a temporary file to make gdx file including results
	temp2.gdx	a temporary file to make gdx file including intermediate results
	temp.xls	a temporary file to make excel file including results
	└─country	a sub-directory including country model results
	JPN_BaU.gdx	JPN's BaU case results
	JPN_CM.gdx	JPN's CM case results
	└─JPN	a directory for storage JPN's results
	2005.gdx	JPN's base year case in gdx file
	└─BaU	a directory for BaU
	2005.gdx	BaU 2005 results in gdx file
	2006.gdx	BaU 2006 results in gdx file
	└─CM	
	2005.gdx	CM 2005 results in gdx file
	2006.gdx	CM 2006 results in gdx file
	└─gdx	
	analysis.gdx	main indicators of simulation results in gdx file
	final_results.gdx	all of the results are included
	└─xls	
	JPN.xls	JPN's main indicator results in excel file

└─global	a sub-directory including global model results
└─┬─global_3	a directory for storage global 3 region results
└─temp	temporary directory
└─prog	
AEEI_mod.gms	AEEI setting program file
AIM_CGE.gms	main CGE program file
CGEdata_input.xlsx	input format
conopt.opt	CONOPT option file
emission.gms	a program for preparation of emission and its factor data
gmsproj.gpr	project file
Operation_file.gms	a program for operating this CGE model
scenario_parameter.gms	a program for making scenario parameters
path.opt	PATH option file
scenario.gms	secondary CGE program file
└─SAVE	temporary conditions are saved in this directory
global3.g00	global temporary file
JPN.g00	JPN's temporary file
└─scenario	a directory for programs of scenarios
BAU.gms	a program for setting scenario BAU case
CM.gms	a program for setting scenario CM case

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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 ten years.¹. The CGE model is used for the analysis of global and country CO₂ emissions, mitigation costs or carbon taxes. Recently, we rebuilt the CGE model called as “AIM/CGE2.0” referring to “A standard CGE model” which was developed by Lofgren *et al.* (2002)². This document describes the new of CGE model. 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

¹ T. Masui, Y. Matsuoka, M. Kainuma, (2006) Long-term CO₂ emission reduction scenarios in Japan, Environmental Economics and Policy Studies, Volume 7, Number 3, 347-366.

² Lofgren H., R. L. Harris and S. Robinson (2002); A Standard Computable General Equilibrium (CGE) model in GAMS, IFPRI.

We acknowledge to the authors of the reports and International Food Policy Research Institute since many parts of the model development and documentation are based on their report and programming codes.

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 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 Table 1.

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

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 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 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 transfer 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/CGE couples multiple accounting framework 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 below. The AIM/CGE2.0 default column shows the default classification and the original SAM column shows the classification of the original SAM data. The default classification has 19 non-energy sectors and 19 energy sectors. The commodity is same as in sector one.

Table 2 Sector classification

AIM/CGE[basic] default code	Original SAM		ISIC rev3 code	CPC code	GTAP
	Code	Description			
AGR	AGH	Agriculture	01		PDR, WHT, GRO, V_F, OSD, C_B, PFB, OCR, CTL, OAP, RMK, WOL
FRS	FRS	Forestry	02		FRS
AGR	FSH	Fishery	05		FSH
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	Meat products		2111, 2112, 2113, 2114, 2161, 2162	CMT, OMT
FPR	VOL	Vegetable oils and fats		2163, 2164, 2165, 2166, 2167, 2168, 2169, 217, 218	VOL
FPR	MIL	Dairy products		22	MIL
FPR	SGR	Sugar		235	SGR
FPR	OFD	Food products nec		212, 213, 214, 215, 2311, 2312, 2313, 2314, 2315, 2316, 2317, 2318, 232, 233, 234, 236, 237, 239	PCR, OFD
FPR	B_T	Beverages and Tobacco		24, 25	B_T
TEX	TEX	Textiles and Apparel and Leather	17, 18, 19, 243		TEX, WAP, LEA
LUM	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
P_C	P_C	Petroleum and coal refinery	231, 232, 233		P_C
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
MCH	FMP	Metal products	28		FMP
MCH	OME	Machinery	29, 31, 33		OME
MCH	ELE	Electric equipment	30, 32		ELE
TRN	MVH	Motor Vehicles	34		MVH
TRN	OTN	Other Transport nes	35		OTN
OMF	OMF	Other Manufacturing	36, 37		OMF
E_COL	E_COL	Coal-fired generation without CCS			
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_ORN	E_TID	wave-activated power generation			
E_WIN	E_WIN	wind-power generation			
E_BIO	E_BIO	biomass-power generation			
E_ORN	E_ORN	other renewable energy power generation			
E_COL	C_COL	Coal-fired CHP plant	part of 401		ELY
E_OIL	C_OIL	Oil-fired CHP plant			
E_GAS	C_GAS	Gas-fired CHP plant			
E_NUC	C_NUC	nuclear CHP power generation plant			
E_GEO	C_GEO	geothermal CHP power generation plant			
E_BIO	C_BIO	Biomass CHP power generation plant			
E_ORN	C_ORN	Other renewable energy source CHP power generation plant			
E_COL	H_COL	Coal heat supply plant			
E_OIL	H_OIL	Oil heat supply plant			
E_GAS	H_GAS	Gas heat supply plant			
E_GEO	H_GEO	Geothermal heat supply plant			
E_BIO	H_BIO	Biomass heat supply plant			
E_ORN	H_ORN	Other renewable energy heat supply plant			
EC_COL		Coal-fired generation with CCS			
EC_OIL		Oil-fired generation with CCS			
EC_GAS		Gas-fired generation with CCS			
EC_BIO		biomass-fired generation with CCS			
GDT	GDT	Gas manufacture distribution	402, 403		GDT
CSS	WTR	Water	41		WTR
CNS	CNS	Construction	45		CNS
CSS	TRD	Trade and wholesale and retail	50, 51, 52, 55		TRD
TRS	TRS	Transport and communications	60, 61, 62, 63, 64		OTP, OTP, WTP, CMN
CSS	FIR	Finance, Insurance, Real estate etc	65, 66, 67, 70, 71, 72, 73, 74, dwellings		OFI, ISR, OBS, DWE
CSS	CSS	Community, Social Services nes	75, 80, 85, 90, 91, 92, 93, 94, 95, 99		ROS, OSG

3. Model Structure

The AIM/CGE model explains all of the payments recorded in the SAM. The energy commodity transaction and GHG emissions are particularly dealt 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 balance and balance of payment and so on. An overview of this structure is shown in Figure 1.

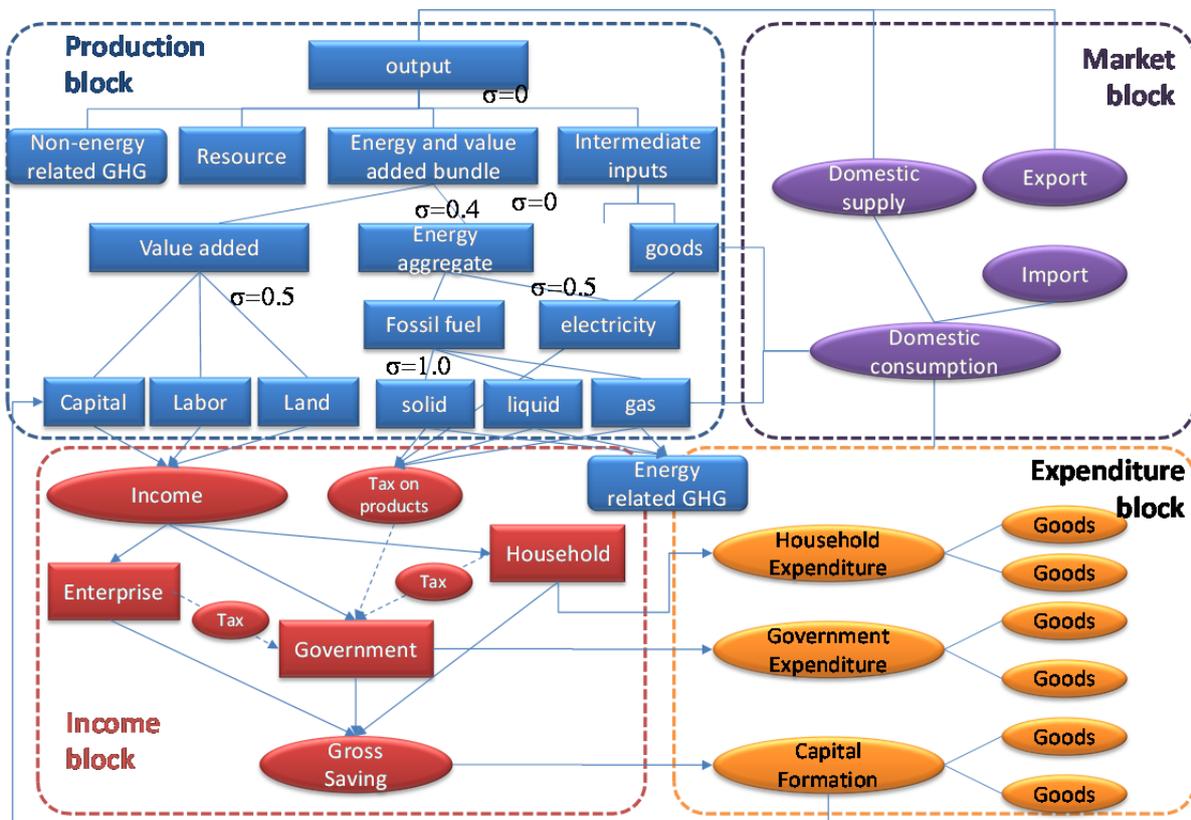


Figure 1 Overview of AIM/CGE model structure (for one region)³

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) function is used for household consumption.

³ The production function excludes emission gases in this figure. Moreover, this production function is applied to only non energy transformation sectors

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 2. At the top level, there is non-energy related GHG emission and conventional inputs. This GHG emission treatment is described in detailed by Hyman⁴. 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 is specified by a CES function of electricity and aggregated fossil fuel inputs. The aggregated fossil fuel input is again nested by the CES function of each fossil fuel input. The aggregate intermediate input is a Leontief function of disaggregated intermediate inputs.

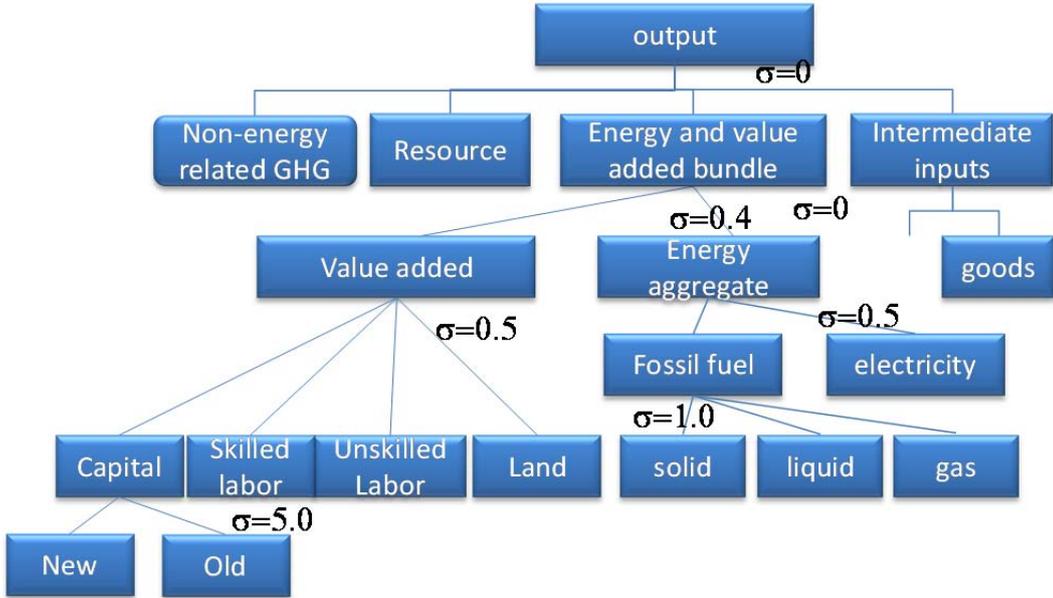


Figure 2 Production structure (Non-energy transformation sectors)

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. The structure is similar to the non-energy transformation sectors but the energy bundle is different.

⁴ Hyman, R.C., J.M. Reilly, M.H. Babiker, A. De Masin, and H.D. Jacoby, (2003); Modeling non-CO2 greenhouse gas abatement. Environmental Modeling and Assessment, 8: 175-186.

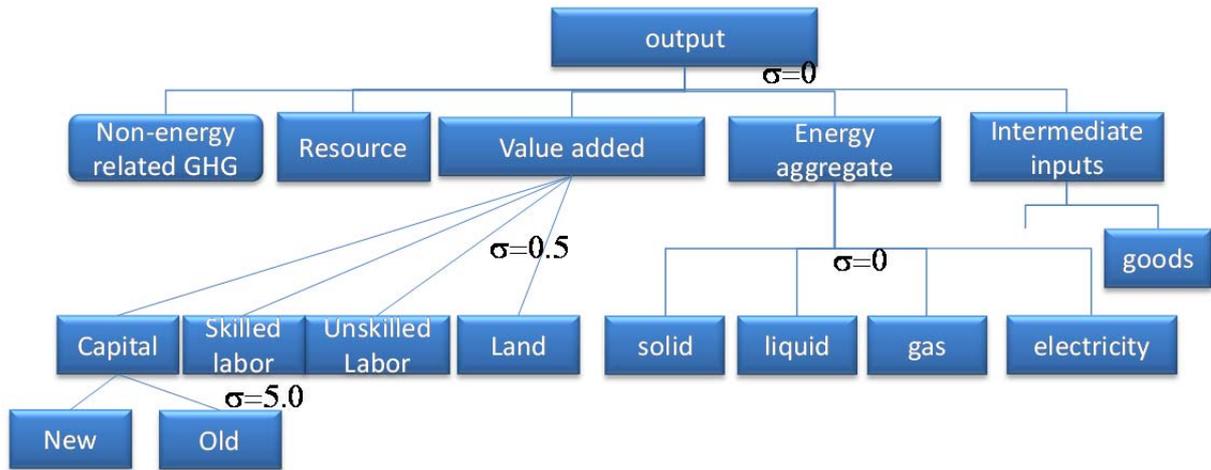


Figure 3 Production structure (Energy transformation sectors)

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 capital, 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. Old capital is assumed to be fixed to each sector, which is named the putty-clay assumption. Thus, every sector of old capital has a specific price. On the other hand, other production factors have only one price.

3.2. Institutions

In the CGE model, institutions are represented by: households, enterprises, the government, and the rest of the world⁵. 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

⁵ 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.

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 function is used as the aggregation function⁶. 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.

⁶ Energy commodity has specific treatment. It is discussed below

The AIM/CGE model treats the volume of energy commodities⁷ 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 commodities market transaction, 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. 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.

3.5. Air pollutants and GHG emissions

The CGE model includes air pollutants and GHG emissions module. The emission gases treated in this model are CO, NH₃, NMVOC, NO_x, SO₂, BC, OC, CO₂, CH₄ and N₂O. 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.c. CO₂ 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. In addition, biomass consumption is also introduced in this model to estimate the air pollutants.

⁷ Coal (COA), crude oil (OIL), natural gas (GAS), petroleum products (P_C), town gas (GDT) and electricity (ELY)

Table 3 Emission sources

Emission source related to activity level		Emission source related to fuel combustion	
IPCC category	Explanation	IPCC category	Explanation
2A	Production of minerals	1A1a	Public electricity and heat production
2A1	Cement production	1A1bc	Other Energy Industries
2A2	Lime production	1A2	Manufacturing Industries and Construction
2B	Production of chemicals	1A3a	Domestic aviation
2C	Production of metals	1A3b	Road transportation
2D	Production of pulp/paper/food/drink	1A3c	Rail transportation
2G	Non-energy use of lubricants/waxes (CO2)	1A3d	Inland navigation
3A	Solvent and other product use: paint	1A3e	Other transportation
3B	Solvent and other product use: degrease	1A4	Residential and other sectors
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		

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 trade⁸, energy and CO₂ emissions, and system constraints. New items (sets, parameters, and variables) are defined the first time that they appear in the equations. Table 4 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 Notational principles

Item	Notation
Endogenous variables	Upper-case Latin letters without a bar
Exogenous variables	Upper-case Latin letters with a bar
Parameters	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

4.1. Price block

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

$$PM_{r,c} = PWM_c \cdot dis_imp_{r,c} \cdot (1 + tm_{r,c}) \cdot EXR_r, \quad \forall c \in CM \quad (4.1)$$

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

$c \in C$: a set of commodities (also referred to as c' and C'),

$c \in CM (\subset C)$: a set of imported commodities,

PWM_c : world import price (c.i.f) of commodity c ,

$PM_{r,c}$: composite commodity price (including import tax and transaction costs),

$dis_imp_{r,c}$: price difference of the import commodity c ,

$tm_{r,c}$: 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(4.1) 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 (4.1) for every imported commodity.

⁸ The equations in the “International trade block” are involved only if you chose a global model.

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

$$PE_{r,c} = PWE_c \cdot dis_exp_{r,c} \cdot (1 - te_{r,c}) \cdot \overline{EXR}_r, \quad \forall r \in R, c \in CE \quad (4.2)$$

$c \in CE (\subset C)$: a set of exported commodities (with domestic production),

$PE_{r,c}$: export price of commodity c ,

PWE_c : f.o.b. export world price,

$dis_exp_{r,c}$: price difference of the export commodity c ,

$te_{r,c}$: 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

$$PDD_{r,c} = PDS_{r,c}, \quad \forall r \in R, c \in CD \quad (4.3)$$

$c \in CD (\subset C)$: 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 (4.3) defines the demand prices as the supply price.

Absorption

$$PQ_{r,c} \cdot QQ_{r,c} = PDD_{r,c} \cdot QD_{r,c} + PM_{r,c} \cdot QM_{r,c}, \quad \forall r \in R, c \in (CD \cup CM) \quad (4.4)$$

$PQ_{r,c}$: 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 (4.4) 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

$$PQ_{r,c} \cdot QQ_{r,c} = PQD_{r,c} \cdot \left(\sum_{a \in A} pfdq_{r,c,a} \cdot QINT_{r,c,a} + \sum_{h \in H} pfdq_{r,c,h} \cdot QH_{r,c,h} \right) + pfdq_{r,c,"gov"} \cdot QG_{r,c} + pfdq_{r,c,"S-I"} \cdot QINV_{r,c}, \quad \forall r \in R, c \in CX \quad (4.5)$$

$PQD_{r,c}$: composite commodity price excluding sales tax,

$pfdq_{r,c,ac}$: 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

$$QX2_{r,c} = QX_{r,c} + stch_{r,c}, \quad \forall r \in R, c \in CX \quad (4.6)$$

$QX_{r,c}$: 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

$$PX2_{r,c} \cdot QX2_{r,c} = PX_{r,c} \cdot QX_{r,c}, \quad \forall r \in R, c \in CX \quad (4.7)$$

$PX_{r,c}$: aggregate producer price for commodity,

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

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

Marketed Output Value

$$PX2_{r,c} \cdot QX2_{r,c} = PDS_{r,c} \cdot QD_{r,c} + PE_{r,c} \cdot QE_{r,c}, \quad \forall r \in R, c \in CX \quad (4.8)$$

$c \in CX (\subset C)$: 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 .

Activity Price

$$PA_{r,a} \cdot QA_{r,a} \cdot (1 + RQUOQA_{r,a}) = \sum_{c \in C} PXAC_{r,a,c} \cdot QXAC_{r,a,c}, \quad \forall r \in R, a \in A \quad (4.9)$$

$a \in A$: 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 ,

$RQUOQA_{r,a}$: Shadow subsidies of the fixed activity level.

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.

If the activity level is fixed, the complementary subsidies are generated as $RQUOQA$.

Aggregate Non-energy Intermediate Input Price

$$PINTA_{r,a} = \sum_{c \in CNEN} PQ_{r,c} \cdot pfdq_{r,c,a} \cdot QINT_{r,c,a} (1 + tqd_{r,c,a}) \cdot ica_{r,c,a}, \quad \forall r \in R, a \in A \quad (4.10)$$

$c \in CNEN$: a set of non-energy commodities,

$PINTA_{r,a}$: aggregate intermediate input price for activity a ,

$QINTA_{r,a}$: quantity of aggregate intermediate input,

$tq_{r,c,a}$: 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)

$$PA_{r,a} \cdot (1 - ta_{r,a}) \cdot QA_{r,a} = PVAE_{r,a} \cdot QVAE_{r,a} + PINTA_{r,a} \cdot QINTA_{r,a} + PRES_{r,a} \cdot QRES_{r,a} \\ + GHGCA_NENE_{r,a} + VRENCAP_{r,a} \cdot QA_{r,a} + \sum_{emcm \in EMCM} QRED_{r,emcm,a}, \quad \forall r \in R, a \in ACES \quad (4.11)$$

Activity Revenue and Costs (Energy transformation sector)

$$PA_{r,a} \cdot (1 - ta_{r,a}) \cdot QA_{r,a} = PVA_{r,a} \cdot QVA_{r,a} + PINTA_{r,a} \cdot QINTA_{r,a} + PENE_{r,a} \cdot QENE_{r,a} \\ + PRES_{r,a} \cdot QRES_{r,a} + GHGCA_NENE_{r,a} + VRENCAP_{r,a} \cdot QA_{r,a} + \sum_{emcm \in EMCM} QRED_{r,emcm,a}, \quad \forall r \in R, a \in ALEO \quad (4.12)$$

$a \in ACES (\subset A)$: 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 $emcm$,
 $emcm \in EMCM$: a set of emission reduction counter measures (CCS).

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 (4.11) 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 counter measures for CCS technology cost is $QRED$.

Resource Input Price

$$PA_{r,a} = PRES_{r,a}, \quad \forall r \in R, a \in A \quad (4.13)$$

Resource inputs price is assumed equal as the activity price.

Consumer Price Index

$$CPI_r = \sum_{c \in C} PQD_{r,c} \cdot dfpq_{r,c,"hub"} \cdot (1 + tqd_{r,c,"hub"}) \cdot cwt_{r,c} \quad \forall r \in R \quad (4.14)$$

$cwt_{r,c}$: weight of commodity c in the consumer price index,

CPI_r : consumer price index (exogenous variable).

Producer Price Index for Nontraded Market Output

$$DPI_r = \sum_{c \in C} PDS_{r,c} \cdot dwts_{r,c} \quad \forall r \in R \quad (4.15)$$

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

Equations (4.14) and (4.15) 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-à-vis the numéraire price index.

Export Price Index

$$EPI_r = \sum_{c \in C} PE_{r,c} \cdot ewts_{r,c} \quad \forall r \in R \quad (4.16)$$

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

Import Price Index

$$MPI_r = \sum_{c \in C} PM_{r,c} \cdot mwts_{r,c} \quad \forall r \in R \quad (4.17)$$

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

Governmental consumption Price Index

$$GPI_r = \sum_{c \in C} PQD_{r,c} \cdot dfpq_{r,c,"gov"} \cdot (1 + tqd_{r,c,"gov"}) \cdot gws_{r,c} \quad \forall r \in R \quad (4.18)$$

$gws_{r,c}$: weight of commodity c in the government price index,
 GPI_r : Government price index.

Capital Formation Price Index

$$IPI_r = \sum_{c \in C} PQD_{r,c} \cdot dfpq_{r,c,"S-I"} \cdot (1 + tqd_{r,c,"gov"}) \cdot iwts_{r,c} \quad \forall r \in R \quad (4.19)$$

$iwts_{r,c}$: 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 above.

4.2. 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.

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

$$QVA_{r,a} = iva_{r,a} \cdot QA_{r,a}, \quad \forall r \in R, a \in ALEO \quad (4.20)$$

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

$$QENE_{r,a} = iena_{r,a} \cdot QA_{r,a}, \quad \forall r \in R, a \in ALEO \quad (4.21)$$

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

$$QVAE_{r,a} = ivae_{r,a} \cdot QA_{r,a}, \quad \forall r \in R, a \in ACES \quad (4.22)$$

Leontief Technology: Demand for Aggregate Non-energy Intermediate Input

$$QINTA_{r,a} = inta_{r,a} \cdot QA_{r,a}, \quad \forall r \in R, a \in A \quad (4.23)$$

Leontief Technology: Demand for Resource Input

$$QRES_{r,a} = ires_{r,a} \cdot QA_{r,a}, \quad \forall r \in R, a \in A \quad (4.24)$$

$iva_{r,a}$: 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.

As for the energy transformation sectors, a Leontief function at the top of the conventional inputs are equations (4.20), (4.21), (4.23) and (4.24) 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 equation (4.20), (4.21) are related by equation (4.22).

Energy and Value-Added composite

$$QVAE_{r,a} = \alpha_{r,a}^{vae} \cdot \left(\delta_{r,a}^{vae} \left(\frac{QENE_{r,a}}{1 - ADEEI_{r,a}} \right)^{-\rho_{r,a}^{vae}} + (1 - \delta_{r,a}^{vae}) QVA_{r,a}^{-\rho_{r,a}^{vae}} \right)^{\frac{1}{\rho_{r,a}^{vae}}}, \quad \forall r \in R, a \in ACES \quad (4.25)$$

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

$$\frac{\left(\frac{QENE_{r,a}}{1 - ADEEI_{r,a}} \right)}{QVA_{r,a}} = \left(\frac{\delta_{r,a}^{vae}}{1 - \delta_{r,a}^{vae}} \cdot \frac{PENE_{r,a}}{PVA_{r,a}} \right)^{\frac{1}{1 + \rho_{r,a}^{vae}}}, \quad \forall r \in R, a \in ACES \quad (4.26)$$

$\alpha_{r,a}^{vae}$: efficiency parameter in the CES energy and value-added function,

$\delta_{r,a}^{vae}$: CES energy and value-added function share parameter in activity a,

$\rho_{r,a}^{vae}$: CES energy and value-added function exponent,

$ADEEI_{r,a}$: Additional energy efficiency improvement coefficient.

Energy and Value-Added composite balance

$$QVAE_{r,a} \cdot PVAE_{r,a} = QENE_{r,a} \cdot PENE_{r,a} + QVA_{r,a} \cdot PVA_{r,a}, \quad \forall r \in R, a \in ACES \quad (4.27)$$

Additional energy efficiency improvement (Industry)

$$ADEEI_{r,a} = 1 - \left(\frac{PENE_{r,a}}{PENE_{r,a}^{bau}} \right)^{-\sigma_{r,a}^{eff}}, \quad \forall r \in R, a \in ACES \quad (4.28)$$

$PENE_{r,a}^{bau}$: Energy price (BaUcase)

Non-energy transformation sectors determine their energy and value added inputs as shown previously. CES function is applied to these inputs. If the climate mitigation is taken into account, the additional energy improvement caused by the energy price increase is defined as $1 - ADEEI$. This energy improvement is calculated by the energy price relative to that of BaU case.

If there were an industry using no energy, the value added is defined as below.

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

$$QVAE_{r,a} = QVA_{r,a}, \quad \forall r \in R, a \in ACES \quad (4.29)$$

Value-Added and Factor Demands

$$QVA_{r,a} = \alpha_{r,a}^{va} \cdot \left(\sum_{f \in F} \delta_{r,a}^{va} \cdot QF_{r,f,a}^{-\rho_{r,a}^{va}} \right)^{-\frac{1}{\rho_{r,a}^{va}}}, \quad \forall r \in R, a \in A \quad (4.30)$$

Factor Demand

$$WF_{r,f} \cdot WFDIST_{r,f,a} = PVA_{r,a} \cdot (1 - tva_{r,a}) \cdot QVA_{r,a} \cdot \left(\sum_{f \in F} \delta_{r,a}^{va} \cdot QF_{r,f,a}^{-\rho_{r,a}^{va}} \right)^{-1} \cdot \delta_{r,a}^{va} \cdot QF_{r,f,a}^{-\rho_{r,a}^{va}-1}, \quad (4.31)$$

$$\forall r \in R, a \in A, f \in F$$

$f \in F (= F')$: a set of factors,

$tva_{r,a}$: rate of value-added tax for activity a,

$\alpha_{r,a}^{va}$: efficiency parameter in the CES value-added function,

$\delta_{r,a}^{va}$: CES value-added function share parameter for factor f in activity a,

$\rho_{r,a}^{va}$: CES value-added function exponent,

$QF_{r,f,a}$: quantity demanded of factor f from activity a,

$WF_{r,f}$: average price of factor,

$WFDIST_{r,f,a}$: factor price distortion factor for factor f in activity a.

Equation (4.30) states that, for each activity, the quantity of value-added is a CES function of disaggregated factor quantities. According to equation (4.31), 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 (4.31) 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 (for example, equation (4.35)). 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.

Capital aggregation: CES Function

$$QF_{r,ncap,a} = \alpha_{r,a}^f \cdot \left(\delta_{r,a}^f \cdot QF_{r,ncap,a}^{-\rho_{r,a}^f} + (1 - \delta_{r,a}^f) \cdot QF_{r,ncap,a}^{-\rho_{r,a}^f} \right)^{\frac{1}{\rho_{r,a}^f}}, \quad \forall r \in R, a \in A \quad (4.32)$$

Capital aggregation of CES Technology: old and new capital - Input Ratio

$$\frac{QF_{r,ncap,a}}{QF_{r,ncap,a}} = \left(\frac{\delta_{r,a}^f}{1 - \delta_{r,a}^f} \cdot \frac{WF_{r,ncap} \cdot WFDIST_{r,ncap,a}}{WF_{r,ncap} \cdot WFDIST_{r,ncap,a}} \right)^{\frac{1}{1 + \rho_{r,a}^f}}, \quad \forall r \in R, a \in A \quad (4.33)$$

Capital Input Costs

$$QF_{r,ncap,a} \cdot WF_{r,ncap} \cdot WFDIST_{r,ncap,a} = \sum_{f \in FCAP} QF_{r,f,a} \cdot WF_{r,f} \cdot WFDIST_{r,f,a}, \quad \forall r \in R, a \in A \quad (4.34)$$

$f \in FCAP (= F)$: A set of capital (new and old; “ncap” and “cap”)

$\alpha_{r,a}^f$: efficiency parameter in the CES capital input function,

$\delta_{r,a}^f$: CES capital input function share parameter,

$\rho_{r,a}^f$: CES capital input function exponent.

Capital vintage is taken into account and the old and new capitals are aggregated by the CES function.

Disaggregated Intermediate Input Demand

$$QINT_{r,c,a} = ica_{r,c,a} \cdot QINT_{r,a}, \quad \forall r \in R, a \in A, c \in CNEN \quad (4.35)$$

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

For each activity, the demand for disaggregated intermediate inputs is determined via a standard Leontief formulation as the level of aggregate intermediate input use times a fixed intermediate input coefficient.

Energy Input Technology: CES Function

$$QENE_{r,a} = \alpha_{r,a}^{el} \cdot \left(\delta_{r,a}^{el} \cdot QINT_{r,ely,a}^{-\rho_{r,a}^{el}} + (1 - \delta_{r,a}^{el}) \cdot QFFL_{r,a}^{-\rho_{r,a}^{el}} \right)^{\frac{1}{\rho_{r,a}^{el}}}, \quad \forall r \in R, a \in ACES_ENE \quad (4.36)$$

Energy Input CES Technology: Electricity – Fossil Fuel -Input Ratio

$$\frac{QINT_{r,ely,a}}{QFFL_{r,a}} = \left(\frac{\delta_{r,a}^{el}}{1 - \delta_{r,a}^{el}} \cdot \frac{PQD_{r,ely,a} \cdot (1 + tqd_{r,ely,a})}{PFFL_{r,a}} \right)^{\frac{1}{1 + \rho_{r,a}^{el}}}, \quad \forall r \in R, a \in ACES_ENE \quad (4.37)$$

Energy Input Costs

$$PENE_{r,a} \cdot QENE_{r,a} = PQD_{r,ely,a} \cdot (1 + tqd_{r,ely,a}) \cdot QINT_{r,ely,a} + PFFL_{r,a} \cdot QFFL_{r,a}, \quad \forall r \in R, a \in ACES_ENE \quad (4.38)$$

$PFFL_{r,a}$: price of (aggregate) fossil fuel input,

$QFFL_{r,a}$: quantity of (aggregate) fossil fuel input,

$a \in ACES_ENE (c \in A)$: a set of activities with a CES function at energy nest,

$\alpha_{r,a}^{el}$: efficiency parameter in the CES energy input function,
 $\delta_{r,a}^{el}$: CES energy input function share parameter,
 $\rho_{r,a}^{el}$: CES energy input function exponent.

Activities excluding energy transformation sector, which is specified by a set of $ACES_ENE$, have CES energy input technology. The energy input is disaggregated into electricity and fossil fuel. The exponent, $\rho_{r,a}^{el}$ is a transformation of the elasticity of substitution between electricity and the aggregate fossil fuel input: the higher this elasticity, the smaller the value of $\rho_{r,a}^{el}$ and the larger the optimal change in the ratios between the quantities of electricity and the fossil fuel input aggregate in response to changes in their relative prices.

Fossil fuel consumption and Its allocation

$$QFFL_{r,a} = \alpha_{r,a}^{ff} \cdot \left(\sum_{c \in CFF} \delta_{r,c,a}^{ff} \cdot QINT_{r,c,a}^{-\rho_{r,a}^{ff}} \right)^{\frac{1}{\rho_{r,a}^{ff}}}, \quad \forall r \in R, a \in ACES_ENE \quad (4.39)$$

First-Order Condition for Fossil Fuel Consumption

$$\begin{aligned} PQD_{r,c} \cdot dfpq_{r,c,a} \cdot (1 + tqd_{r,c,a}) + GHGCA_ENE_{r,c,a} \\ = PFFL_{r,a} \cdot QFFL_{r,a} \left(\sum_{cp \in CFF} \delta_{r,cp,a}^{ff} \cdot QINT_{r,cp,a}^{-\rho_{r,a}^{ff}} \right)^{\frac{1}{1+\rho_{r,a}^{ff}}} \delta_{r,a,c}^{ff} \cdot QINT_{r,c,a}^{-\rho_{r,a}^{ff}-1}, \end{aligned} \quad (4.40)$$

$\forall r \in R, a \in ACES_ENE, c \in CFF$

$\alpha_{r,a}^{ff}$: shift parameter for domestic commodity aggregation function,
 $\delta_{r,c,a}^{ff}$: shift parameter for domestic commodity aggregation function,
 $\rho_{r,a}^{ff}$: domestic commodity aggregation function exponent,
 $GHGCA_ENE_{r,a,c}$: GHG emission cost related to energy consumption,
 $c \in CFF$: a set of fossil fuel commodities (COA, OIL, GAS, P_C, GDT).

Aggregate fossil fuel consumption is defined as a CES aggregate. The optimal quantity of fossil fuel consumption is inversely related to the each fossil fuel price. $QFFL$ appears as the aggregated energy consumption, bought at the price, PQ plus GHG emission cost related to energy consumption.

Energy Consumption of Energy Transformation sector

$$QINT_{r,c,a} = QENE_{r,a} \cdot iene_{r,c,a}, \quad \forall r \in R, a \in ALEO_ENE, c \in ENE \quad (4.41)$$

$a \in ALEO_ENE (\subset A)$: a set of activities with a CES function at energy nest,
 $iene_{r,c,a}$: energy commodity consumption ratio.

The Leontief energy commodity consumption technology is specified for the energy transformation sector. The price of the aggregate energy is defined as below;

Energy Costs of Energy Transformation Sector

$$PENE_{r,a} \cdot QENE_{r,a} = \sum_{c \in ENE} \{ PINT_{r,c,a} \cdot (1 + tqd_{r,c,a}) \cdot QINT_{r,c,a} + GHGCA_ENE_{r,c,a} \}, \quad \forall r \in R, a \in ALEO_ENE \quad (4.42)$$

Commodity Production and Allocation

$$QXAC_{r,a,c} = \theta_{r,a,c} \cdot QA_{r,a}, \quad \forall r \in R, a \in A, c \in CX \quad (4.43)$$

$\theta_{r,a,c}$: yield of output c per unit of activity a

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

Commodity Production and Allocation (non-energy commodities)

$$QX_{r,c} = \alpha_{r,c}^{ac} \cdot \left(\sum_{a \in A} \delta_{r,a,c}^{ac} \cdot QXAC_{r,a,c}^{-\rho_{r,c}^{ac}} \right)^{\frac{1}{\rho_{r,c}^{ac}}}, \quad \forall r \in R, c \in (CX - ENE) \quad (4.44)$$

$\alpha_{r,c}^{ac}$: shift parameter for domestic commodity aggregation function,

$\delta_{r,a,c}^{ac}$: shift parameter for domestic commodity aggregation function,

$\rho_{r,c}^{ac}$: domestic commodity aggregation function exponent,

$c \in ENE$: a set of energy commodities (COA, OIL, GAS, P_C, ELY, GDT).

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

$$PXAC_{r,a,c} = PX_{r,c} \cdot QX_{r,c} \cdot \left(\sum_{ap \in A} \delta_{r,ap,c}^{ac} \cdot QXAC_{r,ap,c}^{-\rho_{r,c}^{ac}} \right)^{-1} \cdot \delta_{r,a,c}^{ac} \cdot QXAC_{r,a,c}^{-\rho_{r,c}^{ac}-1}, \quad \forall r \in R, a \in A, c \in (CX - ENE) \quad (4.45)$$

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 (4.44)). The optimal quantity of the commodity from each activity source is inversely related to the activity-specific price (equation (4.45)). 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 (4.44) and (4.45) 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.

Share of Commodity Production and Allocation (energy commodities)

$$SHAC_{r,a,c} = \frac{\psi_{r,a,c}^{ac} \left(\frac{PXAC_{r,a,c}}{pxac_{r,a,c}^{pre}} \right)^{\eta_{r,a,c}^{ac}}}{\sum_{ap \in A} \psi_{r,ap,c}^{ac} \left(\frac{PXAC_{r,ap,c}}{pxac_{r,ap,c}^{pre}} \right)^{\eta_{r,ap,c}^{ac}}}, \quad \forall r \in R, c \in (CX \cap ENE) \quad (4.46)$$

$SHAC_{r,a,c}$: share of the commodity c produced by activity a ,

$\psi_{r,a,c}^{ac}$: Previous year's share of the commodity c produced by activity a ,

$pxac_{r,a,c}^{pre}$: Previous year's producer price of commodity c for activity a ,

$\eta_{r,a,c}^{ac}$: Elasticity of domestic commodity aggregation.

Commodity Production and Allocation (energy commodities)

$$QXAC_{r,a,c} = QX_{r,c} \cdot SHAC_{r,a,c}, \quad \forall r \in R, a \in A, c \in (CX \cap ENE), \quad (4.47)$$

Aggregate marketed production of the energy commodity is defined as a share function. The share is determined by the ratio of the current and previous year's price. The volume is calculated by multiplying the share and the total produced commodity volume.

Balance of the output and commodity aggregate (energy commodities)

$$\sum_{a \in A} QXAC_{r,a,c} \cdot PXAC_{r,a,c} = QX_{r,c} \cdot PX_{r,c}, \quad \forall r \in R, c \in (CX \cap ENE), \quad (4.48)$$

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

$$QX2_{r,c} = \alpha_{r,c}^t \cdot \left(\delta_{r,c}^t \cdot QE_{r,c}^{\rho_{r,c}^t} + (1 - \delta_{r,c}^t) \cdot QD_{r,c}^{\rho_{r,c}^t} \right)^{\frac{1}{\rho_{r,c}^t}}, \quad \forall r \in R, c \in (CE \cap CD - ENE) \quad (4.49)$$

$\alpha_{r,c}^t$: a CET function shift parameter,

$\delta_{r,c}^t$: a CET function share parameter,

$\rho_{r,c}^t$: a CET function exponent.

Equations (4.49) and (4.50) address the allocation of marketed domestic output, defined in equation (4.44), to two alternative destinations: domestic sales and exports for non-energy commodities. Equation (4.49) 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 of ρ^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)

$$\frac{QE_{r,c}}{QD_{r,c}} = \left(\frac{PE_{r,c}}{PDS_{r,c}} \cdot \frac{1 - \delta_{r,c}^t}{\delta_{r,c}^t} \right)^{\frac{1}{\rho_{r,c}^t - 1}}, \quad \forall r \in R, c \in (CE \cap CD - ENE) \quad (4.50)$$

Equation (4.50) defines the optimal mix between exports and domestic sales. Equations (4.8), (4.49), and (4.50) 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 (4.50) 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

$$QX2_{r,c} = QD_{r,c} + QE_{r,c}, \quad \forall r \in R, c \in (CE \cap CEN) \cup (CD \cap CDN) \quad (4.51)$$

$c \in CEN (\subset C)$: 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)

$$SHQE_{r,c} = \frac{\psi_{r,c}^t \left(\frac{PE_{r,c}}{pe_{r,c}^{pre}} \right)^{\eta_{r,c}^t}}{\psi_{r,c}^t \left(\frac{PE_{r,c}}{pe_{r,c}^{pre}} \right)^{\eta_{r,c}^t} + (1 - \psi_{r,c}^t) \left(\frac{PDS_{r,c}}{pds_{r,c}^{pre}} \right)^{\eta_{r,c}^t}}, \quad \forall r \in R, c \in (CE \cap CD \cap ENE) \quad (4.52)$$

$SHQE_{r,c}$: share of domestically sold and export commodity c ,

$\psi_{r,c}^t$: Previous year's share of export to domestically produced commodity c ,

$\eta_{r,c}^t$: Elasticity of domestic produced commodity aggregation,

$pe_{r,c}^{pre}$: Previous year's export price of commodity c ,

$pds_{r,c}^{pre}$: Previous year's domestic supply price of commodity c .

Exported energy commodities

$$QE_{r,c} = QX2_{r,c} \cdot SHQE_{r,c}, \quad \forall r \in R, c \in (CE \cap CD \cap ENE) \quad (4.53)$$

Domestically sold energy commodities

$$QD_{r,c} = QX2_{r,c} \cdot (1 - SHQE_{r,c}), \quad \forall r \in R, c \in (CE \cap CD \cap ENE) \quad (4.54)$$

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)

$$QQ_{r,c} = \alpha_{r,c}^q \cdot \left(\delta_{r,c}^q \cdot QM_{r,c}^{-\rho_{r,c}^q} + (1 - \delta_{r,c}^q) \cdot QD_{r,c}^{-\rho_{r,c}^q} \right)^{\frac{1}{\rho_{r,c}^q}}, \quad \forall r \in R, c \in (CM \cap CD - ENE) \quad (4.55)$$

$\alpha_{r,c}^q$: an Armington function shift parameter,

$\delta_{r,c}^q$: an Armington function share parameter,

$\rho_{r,c}^q$: 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)

$$\frac{QM_{r,c}}{QD_{r,c}} = \left(\frac{PDD_{r,c}}{PM_{r,c}} \cdot \frac{\delta_{r,c}^q}{1 - \delta_{r,c}^q} \right)^{\frac{1}{\rho_{r,c}^q + 1}}, \quad \forall r \in R, c \in (CM \cap CD - ENE) \quad (4.56)$$

Equation (4.56) 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 (4.4), (4.55), and (4.56) 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

$$QQ_{r,c} = QD_{r,c} + QM_{r,c}, \quad \forall r \in R, c \in (CD \cap CMN) \cup (CM \cap CDN) \quad (4.57)$$

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

The Armington function is replaced by equation (4.57) 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)

$$SHQM_{r,c} = \frac{\psi_{r,c}^m \left(\frac{PM_{r,c}}{pm_{r,c}^{pre}} \right)^{\eta_{r,c}^m}}{\psi_{r,c}^m \left(\frac{PM_{r,c}}{pm_{r,c}^{pre}} \right)^{\eta_{r,c}^m} + (1 - \psi_{r,c}^m) \left(\frac{PDD_{r,c}}{pdd_{r,c}^{pre}} \right)^{\eta_{r,c}^m}}, \quad \forall r \in R, c \in (CM \cap CD \cap ENE) \quad (4.58)$$

$SHQM$: share of domestically sold and imported commodity c ,

$\psi_{r,c}^m$: Previous year's share of import to domestically produced commodity c ,

$\eta_{r,c}^m$: Elasticity of domestic consumption commodity aggregation,

$pm_{r,c}^{pre}$: Previous year's import price of commodity c ,

$pdd_{r,c}^{pre}$: Previous year's domestic demand price of commodity c .

Imported energy commodities

$$QM_{r,c} = QQ_{r,c} \cdot SHQM_{r,c}, \quad \forall r \in R, c \in (CM \cap CD \cap ENE) \quad (4.59)$$

Domestically sold energy commodities

$$QD_{r,c} = QQ_{r,c} \cdot (1 - SHQM_{r,c}), \quad \forall r \in R, c \in (CM \cap CD \cap ENE) \quad (4.60)$$

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. Institution block

Factor Income

$$YF_{r,f} = \sum_{a \in A} WF_{r,f} \cdot WFDIST_{r,f,a} \cdot QF_{r,f,a} + \text{transfr}_{r,f} \cdot EXR_r, \quad \forall r \in R, f \in F \quad (4.61)$$

$YF_{r,f}$: income of factor f ,

$\text{transfr}_{r,f}$: factor transfer from abroad.

Institutional Factor Incomes

$$YIF_{r,i,f} = \text{shif}_{r,i,f} \cdot \left((1 - \text{tf}_{r,f}) \cdot YF_{r,f} - \text{transfr}_{r,f} \cdot EXR_r \right), \quad \forall r \in R, i \in INSD, f \in F \quad (4.62)$$

$i \in INS$: 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 ,

$\text{shif}_{r,i,f}$: share of domestic institution i in income of factor f ,

$\text{tf}_{r,f}$: direct tax rate for factor f ,

$\text{transfr}_{r,f}$: factor transfer to abroad.

Equation (4.61) defines the total income of each factor. In equation (4.62), this income is split 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

$$\begin{aligned} YI_{r,i} = & \sum_{f \in F} YIF_{r,i,f} + TRII_Resource_{r,i} \\ & + \text{shincome}_{r,i} \cdot GHGTCOST_r + VRENCAPTOT_{r,i} \\ & + (PGHG_G + PGHG_IMP_QUO_r - PGHG_EXP_QUO_r) \cdot GHG_IMP_r \cdot EXR_r \cdot \text{shincome}_{r,i} \\ & + \text{shincome}_{r,i} \cdot \sum_{a \in A} \sum_{emcm \in EMCM} QRED_{r,emcm,a} \\ & + \text{shincome}_{r,i} \cdot \sum_{a \in A} RQUOQA_{r,a} \cdot QA_{r,a} \cdot PA_{r,a} \\ & + \text{shres}_{r,i} \cdot \sum_{a \in A} PRES_{r,a} \cdot QRES_{r,a}, \quad \forall r \in R, i \in INSDNG \end{aligned} \quad (4.63)$$

$i \in INSDNG (\subset INSD)$: 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,

$\text{shincome}_{r,i}$: total income share of GHG emission cost for institution i ,

$\text{shres}_{r,i}$: 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.

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 (4.63)), transfers from other domestic nongovernment institutions (defined below in equation(4.65)), 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

$$VRENCAPTOT_{r,"ent"} = \sum_{a \in A} VRENCAP_{r,a} \quad \forall r \in R \quad (4.64)$$

Household Consumption Expenditures

$$EH_{r,h} = (1 - shii_use_{r,h}) (1 - MPS_{r,h}) \cdot (1 - TINS_{r,h}) \cdot YI_{r,h} - GHGCH_{r,h}, \quad \forall r \in R, h \in H \quad (4.65)$$

$h \in H (\subset INSDNG)$: 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 ,

$GHGCH_{r,h}$: GHG emission cost of household h in region r .

Among the domestic nongovernment institutions, only households demand commodities. In equation (4.66), the total value of consumption spending is defined as the income that remains after direct taxes, savings, and transfers to other domestic nongovernment institutions.

Household Consumption Spending

$$\begin{aligned} & \left(PQD_{r,c} \cdot dfpq_{r,c,h} \cdot (1 + tqd_{r,c,h}) + \sum_{g \in G} PGHG_r \cdot gwp_g \cdot efffc_{r,c,h,g} \right) \cdot QH_{r,c,h} \\ & = \left(PQD_{r,c} \cdot dfpq_{r,c,h} \cdot (1 + tqd_{r,c,h}) + \sum_{g \in G} PGHG_r \cdot gwp_g \cdot efffc_{r,c,h,g} \right) \cdot \gamma_{r,c,h}^m \cdot (1 - ADEEI_{r,h})^{-1}, \quad \forall r \in R, c \in C, \forall h \in H \\ & + \beta_{r,c,h}^m \cdot \left(EH_{r,h} - \sum_{c' \in C} \left(PQD_{r,c'} \cdot dfpq_{r,c',h} \cdot (1 + tqd_{r,c',h}) + \sum_{g \in G} PGHG_r \cdot gwp_g \cdot efffc_{r,c',h,g} \right) \cdot \gamma_{r,c',h}^m \cdot (1 - ADEEI_{r,h})^{-1} \right) \end{aligned} \quad (4.66)$$

$\gamma_{r,c,h}^m$: subsistence consumption of marketed commodity c for household h ,

$\beta_{r,c,h}^m$: marginal share of consumption spending on marketed commodity c for household h .

Additional energy efficiency improvement (Household)

$$ADEEI_{r,h} = 1 - \left(\frac{PENE_H_{r,h}}{PENE_H_{r,h}^{bau}} \right)^{-\sigma_{r,h}^{eff}}, \quad \forall r \in R, h \in H \quad (4.67)$$

$PENE_H_{r,h}$: Energy price of household

$PENE_H_{r,h}^{bau}$: Energy price of household (BaUcase)

Energy price of household

$$PENE_H_{r,h} = \frac{\sum_{c \in ENE} \left(PQD_{r,c} \cdot dfpq_{r,c,h} \cdot (1 + tqd_{r,c,h}) + \sum_{g \in G} PGHG_r \cdot gwp_g \cdot effc_{r,c,h,g} \right) \cdot QH_{r,c,h}}{\sum_{c \in ENE} QH_{r,c,h}}, \quad \forall r \in R, \forall h \in H \quad (4.68)$$

It is assumed that each household maximizes a ‘‘Stone-Geary’’ utility function subject to a consumption expenditure constraint. The resulting first-order conditions, equations (4.66), 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.

Investment Demand

$$QINV_{r,c} = IADJ_r \cdot \overline{qinv_{r,c}}, \quad \forall r \in R, c \in C \quad (4.69)$$

$IADJ_r$: investment adjustment factor (exogenous variable),

$\overline{qinv_{r,c}}$: 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

$$QG_{r,c} = \overline{GADJ_r} \cdot \overline{qg_{r,c}}, \quad \forall r \in R, c \in C \quad (4.70)$$

$\overline{GADJ_r}$: 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.

Government Revenue

$$\begin{aligned}
YG_r = & \sum_{i \in INSDNG} TINS_{r,i} \cdot YI_{r,i} + \sum_{f \in F} tf_{r,f} \cdot YF_{r,f} + \sum_{a \in A} ta_{r,a} \cdot PA_{r,a} \cdot QA_{r,a} + \sum_{a \in A} tva_{r,a} \cdot PVA_{r,a} \cdot QVA_{r,a} \\
& + \sum_{c \in CM} tm_{r,c} \cdot PWM_c \cdot QM_{r,c} \cdot \overline{EXR}_r + \sum_{c \in CE} te_{r,c} \cdot PWE_c \cdot QE_{r,c} \cdot \overline{EXR}_r \\
& + \sum_{c \in C} \sum_{a \in A} tqd_{r,c,a} \cdot dfpq_{r,c,a} \cdot PQD_{r,c} \cdot QINT_{r,c,a} + \sum_{c \in C} \sum_{h \in H} tqd_{r,c,h} \cdot dfpq_{r,c,h} \cdot PQD_{r,c} \cdot QH_{r,c,h} \\
& + \sum_{c \in C} tqd_{r,c,"gov"} \cdot dfpq_{r,c,"gov"} \cdot PQD_{r,c} \cdot QG_{r,c} + \sum_{c \in C} tqd_{r,c,"S-I"} \cdot dfpq_{r,c,"S-I"} \cdot PQD_{r,c} \cdot QINV_{r,c} \quad (4.71) \\
& + \sum_{f \in F} YIF_{r,gov,f} + TRII_Resource_{r,gov} \\
& + GHGTCOST_r \cdot shincome_{r,"gov"} \\
& + GHG_IMP_r \cdot EXR_r \cdot (PGHG_G + PGHG_IMP_QUO_r - PGHG_EXP_QUO_r) \\
& + shincome_{r,"gov"} \cdot \sum_{a \in A} QA_{r,a} \cdot VRENCAP_{r,a} + shres_{r,"gov"} \cdot \sum_{a \in A} PRES_{r,a} \cdot QRES_{r,a} \quad \forall r \in R
\end{aligned}$$

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

$$EG_r = \sum_{c \in C} PQD_{r,c} \cdot dfpq_{r,c,"gov"} \cdot (1 + tqd_{r,c,"gov"}) \cdot QG_{r,c} + TRII_Use_{r,"gov"} \quad \forall r \in R \quad (4.72)$$

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

$$TRII_Use_{r,i} = shii_use_{r,i} \cdot (1 - MPS_{r,i}) \cdot (1 - TINS_{r,i}) \cdot YI_{r,i}, \quad \forall r \in R, i \in INSDNG \quad (4.73)$$

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

$$TRII_Use_{r,"gov"} = \overline{trnsfr_CRT_{r,"gov"}} \cdot CPI_r \quad \forall r \in R \quad (4.74)$$

$\overline{trnsfr_CRT_{r,"gov"}}$: governmental transfer in base year

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

Transfer resource

$$TRII_Resource_{r,i} = shii_resource_{r,i} \cdot \left(crt_in_r \cdot \overline{EXR}_r - crt_out_r \cdot \overline{EXR}_r + \sum_{i'} TRII_Use_{r,i'} \right), \quad \forall r \in R, i \in INSD \quad (4.75)$$

$shii_resource_{r,i}$: 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.

4.4. International trade block

Imported commodity

$$QWM_{r,c} = QM_{r,c}, \quad \forall r \in R, c \in CM \quad (4.76)$$

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

Internationally traded commodity equals each countries imports.

Exported commodity

$$QWE_{r,c} = QE_{r,c}, \quad \forall r \in R, c \in CE \quad (4.77)$$

$QWE_{r,c}$: 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

$$\begin{aligned} & \sum_{r \in R} (1 - tw_{r,c}) \cdot PWM_c \cdot QWM_{r,c} \cdot dis_imp_{r,c} \\ & = \sum_{r \in R} PWE_c \cdot QWE_{r,c} \cdot dis_exp_{r,c} + PTRS_c \cdot QTRS_c, \quad \forall c \in (CM \cap CE) \end{aligned} \quad (4.78)$$

$tw_{r,c}$: 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 (4.78).

World trade volume balance

$$\sum_{r \in R} QWM_{r,c} = (1 - \lambda_c^w) \cdot \sum_{r \in R} (QWE_{r,c} - QTRS_c), \quad \forall c \in (CM \cap CE) \quad (4.79)$$

λ_c^w : depreciation rate of traded commodity c .

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

Transport service demand

$$QTRS_c = tsh_c \cdot \sum_r QWE_{r,c}, \quad \forall c \in C_TRS \quad (4.80)$$

CIF and FOB relationship

$$PTRS_c \cdot QTRS_c = \sum_{r'} tw_{r',c} \cdot PWM_c \cdot QWM_{r',c} \cdot dis_imp_{r',c}, \quad \forall c \in C_TRS \quad (4.81)$$

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.

4.5. 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)

$$TBH_{r,h} = \frac{EH_{r,h}}{CPI_r} \cdot bioc_{r,h} \cdot biod_{r,h} \quad \forall r \in R, h \in H \quad (4.82)$$

Biomass consumption (Industry)

$$TBI_{r,a} = QA_{r,a} \cdot bioc_{r,a} \cdot biod_{r,a} \quad \forall r \in R, a \in A \quad (4.83)$$

$TBH_{r,h}$: 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 .

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 (4.82) represents household biomass consumption and the activity level is defined as household expenditure divided by CPI. The industrial biomass consumption is shown in (4.83).

4.6. Air pollutants and GHG emissions

As is mentioned already in section 3.5, 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)

$$EMALI_{r,a,g} = QA_{r,a} \cdot efac_{r,a,g} \cdot (1 - NERED_{r,a,g}) \cdot (1 + \chi_{r,a,g}) - \sum_{emcm \in EMCM} \left(\frac{QRED_{r,emcm,a}}{\eta_{emcm,a}} \right), \quad \forall r \in R, a \in A, g \in G \quad (4.84)$$

$g \in G$: a set of emission gases,

$EMALI_{r,a,g}$: emissions non-energy related emission by industrial activity a ,

$efac_{r,ac,g}$: emission factors for emissions related to activity level by sector ac ,

$NERED_{r,a,g}$: emission reduction caused by the ghg emission price,

$\chi_{r,a,g}$: reference case emission reduction coefficient.

Additional emission reductions related to activity level (Industrial activity)

$$NERED_{r,a,g} = 1 - (PGHG_r + 1)^{-\sigma_{r,a,g}^{ghg}}, \quad \forall r \in R, a \in A, g \in G \quad (4.85)$$

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

Emissions related to activity level (household)

$$EMALH_{r,h,g} = \frac{EH_{r,h}}{CPI_r} \cdot efac_{r,h,g} \quad \forall r \in R, h \in H, g \in G \quad (4.86)$$

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

The emissions related to activity level such as CO₂ emission from cement production is calculated by multiplying the activity level by the emission factor $efac$. However, non-energy related GHG emission related to activity levels such as CH₄ emission from rice fields and CO₂ emission from the cement industry is defined at the top nest of the production function.

If a 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)

$$EMFFI_{r,c,a,g} = QINT_{r,c,a} \cdot enur_{r,c,a} \cdot efffc_{r,c,a,g} \quad \forall r \in R, c \in ENE, a \in A, g \in G \quad (4.87)$$

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

$efffc_{r,c,a,g}$: emission factors for emissions fossil fuel combustion by sector ac consuming of goods c ,

$enur_{r,c,a}$: energy-used ratio (1-non-energy-use ratio).

Emissions related to fossil fuel combustion (household)

$$EMFFH_{r,c,h,g} = QH_{r,c,h} \cdot efffc_{r,c,h,g} \quad \forall r \in R, c \in ENE, h \in H, g \in G \quad (4.88)$$

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

The CO₂ emitted by industrial activity is calculated in equation (4.87). 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 CO₂ is multiplied by three kinds of parameters which are “flag of fossil fuel transformation”, “carbon fraction” and “CO₂ emission coefficient” as below.

$$efffc_{r,c,h,g} = pflag_{c,a} \cdot pc_c \cdot pco2_c \quad \forall r \in R, c \in ENE, a \in A, g \in G^{CO2} \quad (4.89)$$

$g \in G^{CO2}$: a set of CO₂,

$pflag_{c,a}$: flag for fossil fuel transformation,

pc_c : carbon fraction,

$pco2_c$: CO₂ emission coefficient.

“Flag of fossil fuel transformation” $pflag$ has 0 for fossil fuel transformation sectors (P_C and GDT in this model) and 1 for the other sectors. “Carbon fraction” pc denotes what ratio of carbon contained in fossil fuel would be converted into CO₂. Finally, “CO₂ emission coefficient” $pco2_c$ is the emission coefficient.

The emission factor $efffc$ of non-CO₂ is calibrated by EDGAR 4.1 emission inventory data⁹ and Bond *et al.*¹⁰ with EMEP/EEA air pollutant emission inventory guidebook 2009¹¹ and IPCC guideline¹².

Emissions related to biomass combustion (Industrial activity)

$$EMBII_{r,a,g} = TBI_{r,a} \cdot efbio_{r,a,g} \quad \forall r \in R, a \in A, g \in G \quad (4.90)$$

$EMBII_{r,a,g}$: emissions related to biomass combustion emitted by industrial activity a ,

$efbio_{r,a,g}$: emission factors for emissions fossil fuel combustion by sector ac .

Emissions related to biomass combustion (household activity)

$$EMBIH_{r,h,g} = TBH_{r,h} \cdot efbio_{r,h,g} \quad \forall r \in R, h \in H, g \in G \quad (4.91)$$

$EMBIH_{r,h,g}$: 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 $efbio$.

GHG emission total in a region

$$GHGT_r = \sum_{g \in G} gwp_g \cdot \left\{ \begin{array}{l} \left(\sum_{h \in H} \sum_{c \in C} EMFFH_{r,c,h,g} + \sum_{a \in A} \sum_{c \in C} EMFFI_{r,c,a,g} \right) \\ + \left(\sum_{h \in H} EMALH_{r,h,g} + \sum_{a \in A} EMALI_{r,a,g} \right) \\ + \left(\sum_{h \in H} EMBIH_{r,h,g} + \sum_{a \in A} EMBII_{r,a,g} \right) \end{array} \right\} \quad \forall r \in R \quad (4.92)$$

$GHGT_r$: GHG emission from region r (CO₂ equivalent),

gwp_g : global warming potential of gas g .

Region total GHG emission (CO₂ equivalent) is the summation of industry and household emissions

⁹ Download from <http://edgar.jrc.ec.europa.eu/index.php> on 4th, Aug., 2010.

¹⁰ Bond, T.C., E. Bhardwaj, R. Dong, R. Jogani, S. Jung, C. Roden, D.G. Streets, S. Fernandes, and N. Trautmann, (2007); Historical emissions of black and organic carbon aerosol from energy-related combustion, 1850-2000. Global Biogeochemical Cycles 21: GB2018, doi:10.1029/2006GB002840.

¹¹ EEA (Europe Environmental Agency) (2009); EMEP/EEA air pollutant emission inventory guidebook 2009, No.9.

¹² IPCC, (2006); IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan

weighted by gwp_g ($CO_2=1$, $CH_4=23$ and $N_2O=296$).

GHG emission includes emission trading

$$GHGT_CT_r = GHGT_r - GHGT_IMP_r \cdot \forall r \in R \quad (4.93)$$

$GHGT_CT_r$: 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

$$\overline{ghgt_imp_cap}_r - GHGT_IMP_r \geq 0 \perp PGHG_IMP_QUO_r \geq 0 \quad \forall r \in R \quad (4.94)$$

GHG emission exporting trading upper limit

$$GHGT_IMP_r - \overline{ghgt_exp_cap}_r \geq 0 \perp PGHG_EXP_QUO_r \geq 0 \quad \forall r \in R \quad (4.95)$$

GHG emission price nad international price

$$PGHG_r = EXR_r \cdot (PGHG_G + PGHG_IMP_QUO_r - PGHG_EXP_QUO_r) \quad \forall r \in R \quad (4.96)$$

$\overline{ghgt_imp_cap}_r$: GHG emission trading (import) limit,

$\overline{ghgt_exp_cap}_r$: GHG emission trading (export) limit,

$PGHG_r$: GHG emission price in region r (US\$/tC).

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

$$\overline{ghgc}_r - GHGT_CT_r \geq 0 \perp PGHG_r \geq 0 \quad \forall r \in R \quad (4.97)$$

\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.

GHG emission cost of energy (Industry)

$$GHGCA_ENE_{r,c,a} = PGHG_r \cdot \sum_{g \in G} gwp_g \cdot EMFFI_{r,c,a,g} \quad \forall r \in R, a \in A \quad (4.98)$$

GHG emission cost of non-energy (Industry)

$$GHGCA_NENE_{r,a} = PGHG_r \cdot \sum_{g \in G} gwp_g \cdot (EMBI_{r,a,g} + EMALI_{r,a,g}) \quad \forall r \in R, a \in A \quad (4.99)$$

GHG emission cost of household

$$GHGCH_{r,h} = PGHG_r \cdot \sum_{g \in G} gwp_g \cdot \left(\sum_{c \in C} EMFFH_{r,c,h,g} + EMALH_{r,h,g} + EMBIH_{r,h,g} \right) \quad \forall r \in R, h \in H \quad (4.100)$$

GHG total cost

$$GHGTCOST_r = \sum_{a \in A} GHGCA_{r,a} + \sum_{h \in H} GHGCH_{r,h} \quad \forall r \in R \quad (4.101)$$

GHG cost consists of those of activity and household.

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

Global GHG emission constraint

$$\overline{ghgtot_c} - \sum_{r \in R} GHGT_CT_r \geq 0 \quad \perp PGHG_G \geq 0 \quad (4.102)$$

$\overline{ghgtot_c}$: global GHG emission constraint,

$PGHG_G$: GHG emission price corresponding to the global emission constraint.

Global GHG emission constraint price

$$PGHG_G = PGHG_r, \quad \forall r \in R \quad (4.103)$$

Global GHG emission trading total

$$\sum_{r \in R} GHG_IMP_r = 0 \quad (4.104)$$

Net GHG emission trading should be zero globally.

GHG emission related to the international bankers

$$EMFFINT = \sum_{r \in R} \sum_{c \in C} \lambda_c \cdot QWE_{r,c} \cdot efit_c \quad (4.105)$$

$EMFFINT$: emission from international bankers,

$efit_c$: emission coefficient of international bankers.

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

4.7. System constraint block

Factor Markets

$$\sum_{a \in A} QF_{r,f,a} = \overline{QFS}_{r,f}, \quad \forall r \in R, f \in F \quad (4.106)$$

$\overline{QFS}_{r,f}$: quantity supplied of factor (exogenous variable).

Equation (4.106) 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.

Composite Commodity Markets

$$\begin{aligned} QQ_{r,c} + (QX2_{r,c} + QM_{r,c}) \cdot loss_{r,c} + stch2_{r,c} \\ = \sum_{a \in A} QINT_{r,c,a} + \sum_{h \in H} QH_{r,c,h} + QG_{r,c} + QINV_{r,c}, \quad \forall r \in R, c \in C \end{aligned} \quad (4.107)$$

$loss_{r,c}$: distribution loss rate,

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

Equation (4.107) imposes equality between quantities supplied (from equations (4.55), (4.56) and (4.57)) and demanded of the composite commodity. The demand side includes endogenous terms (from equations (4.35), (4.66), (4.69) and (4.70)) 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 (4.69) and (4.70)). 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

$$\begin{aligned} \sum_{c \in CM} PM_{r,c} \cdot QM_{r,c} + transfr_crt_out_r + GHG_IMP_r \cdot PGHG_r \\ = \sum_{c \in CE} PE_{r,c} \cdot QE_{r,c} + transfr_crt_in_r + \overline{FSAV}_r \quad \forall r \in R \end{aligned} \quad (4.108)$$

\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, in effect, 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

$$YG_r = EG_r + GSAV_r \quad \forall r \in R \quad (4.109)$$

$GSAV_r$: 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(4.110).

Direc Tax Rate

$$TINS_{r,i} = \overline{tins}_{r,i} \cdot \left(1 + \overline{TINSADJ}_r \cdot \overline{tins01}_{r,i}\right) + \overline{DTINS}_{r,i} \cdot \overline{tins01}_{r,i}, \quad \forall r \in R, i \in INSDNG \quad (4.110)$$

$\overline{tins}_{r,i}$: rate of direct tax on domestic institutions i ,

$\overline{TINSADJ}_r$: direct tax scaling factor (= 0 for base; exogenous variable),

$\overline{tins01}_{r,i}$: 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 (4.110) 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 $tins01$ (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 $tins01$).

Institutional Savings Rates

$$MPS_{r,i} = \overline{mps}_{r,i} \cdot \left(1 + \overline{MPSADJ}_r \cdot \overline{mps01}_{r,i}\right) + \overline{DMPS}_r \cdot \overline{mps01}_{r,i}, \quad \forall r \in R, i \in INSDNG \quad (4.111)$$

$\overline{mps}_{r,i}$: base savings rate for domestic institution i ,

\overline{MPSADJ}_r : savings rate scaling factor (= 0 for base),

$\overline{mps01}_{r,i}$: 0-1 parameter with 1 for institutions with potentially flexed direct tax rates,

\overline{DMPS}_r : 0-1 parameter with 1 for institutions with potentially flexed direct tax rates.

Equation (4.111) defines the savings rates of domestic nongovernment institutions. Its structure is the same as that of equation (4.110). 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

$$\begin{aligned} \sum_{i \in \text{INSDNG}} MPS_{r,i} \cdot (1 - TINS_{r,i}) \cdot YI_{r,i} + GSAV_r + \overline{FSAV_r} \cdot \overline{EXR_r} \\ = \sum_{c \in C} PQ_{r,c} \cdot (1 + tq_{r,c, "I-S"}) \cdot QINV_{r,i} \quad \forall r \in R \end{aligned} \quad (4.112)$$

Equation (4.112) 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 (4.111)). 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

$$\sum_{r \in R} FSAV_r = 0 \quad (4.113)$$

Global investment 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.

4.8. Activity constraint block

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)

$$renew_up_{r,a} - QA_{r,a} \geq 0 \quad VRENCAP_{r,a} \geq 0, \quad \forall r \in R, a \in A = \{renew_up_{r,a} > 0\} \quad (4.114)$$

renew_up_{r,a}: capacity of the activity level *a* (for power sector energy).

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

$$sh_ely_up_{r,a} - \frac{QXAC_{r,a,"ely"}}{QX_{r,"ely"}} \geq 0, \quad VRENCAP_{r,a} \geq 0, \quad \forall r \in R, a \in A = \{sh_ely_up_{r,a} > 0\} \quad (4.115)$$

$sh_ely_up_{r,a}$: Power generation share of activity a .

Activity constraint (QUOTA)

$$quota_{ragg,aagg} = \sum_{r \in Map_Ragg(r,ragg)} \sum_{a \in Map_aagg(a,aagg)} \sum_{c \in C} QA_{r,a} \cdot \theta_{r,a,c} \geq 0 \perp RQUOQA_agg_{ragg,aagg} \geq 0, \quad (4.116)$$

$$\forall ragg \in Ragg, aagg \in Aagg$$

$aagg \in Aagg$: a set of aggregated activity,

$ragg \in Ragg$: a set of aggregated regions,

$quota_{ragg,aagg}$: quota of aggregated region $ragg$ and aggregated activity $aagg$.

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

Reduction measures (for non-energy related GHG emissions)

$$QRED_{r,emcm,a} = \xi_{emcm,a}^{\max} \cdot \eta_{emcm,a} \cdot \sum_{g \in G} gwp_g \cdot EMALI_{r,a,g} \cdot \left(\frac{PGHG_r}{\eta_{emcm,a} \cdot (1 + SURGHG_{r,emcm,a})} \right)^2, \quad (4.117)$$

$$\forall r \in R, a \in A, emcm \in EMC M 0$$

$emcm \in EMC M 0 (\subset EMC M)$: a subset of emission reduction counter measures which are for non-energy related emissions,

$SURGHG_{r,emcm,a}$: Complementary variable for the upper boundary of the counter measure installation.

Reduction measures upper boundary (for non-energy related GHG emissions)

$$\xi_{emcm,a}^{\max} \cdot \eta_{emcm,a} \cdot \sum_{g \in G} gwp_g \cdot EMALI_{r,a,g} \geq QRED_{r,emcm,a} \perp SURGHG_{r,emcm,a} \geq 0, \quad \forall r \in R, a \in A, emcm \in EMC M 0 \quad (4.118)$$

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 (\$/tonCO₂eq) is η . The installation percentage has upper boundary as ξ . The constraint equation of the boundary is shown as in the equation. The complementary variable is $SURGHG$.

The following equations are the reduction counter measures for energy related GHG emission and biomass power plant absorption. The equation structures are same the non-energy related GHG emissions.

Reduction measures (for Energy related GHG emissions)

$$QRED_{r,emcm,a} = \xi_{emcm,a}^{\max} \cdot \eta_{emcm,a} \cdot \sum_{c \in ENE} \sum_{g \in G} gwp_g \cdot EMFFI_{r,a,c,g} \cdot \left(\frac{PGHG_r}{\eta_{emcm,a} \cdot (1 + SURGHG_{r,emcm,a})} \right), \quad (4.119)$$

$$\forall r \in R, a \in A, emcm \in EMC M 1$$

$emcm \in EMC M 1 (\subset EMC M)$: a subset of emission reduction counter measures which are for energy related

emissions.

Reduction measures (for biomass power plant GHG absorption)

$$QRED_{r,emcm,a} = \xi_{emcm,a}^{\max} \cdot \eta_{emcm,a} \cdot \sum_{g \in G} gwp_g \cdot EMBII_{r,a,g} \cdot \left(\frac{PGHG_r}{\eta_{emcm,a} \cdot (1 + SURGHG_{r,emcm,a})} \right), \quad (4.120)$$

$$\forall r \in R, a \in A, emcm \in EMCM2$$

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

Reduction measures upper boundary (for energy related GHG emissions)

$$\xi_{emcm,a}^{\max} \cdot \eta_{emcm,a} \cdot \sum_{c \in ENE} \sum_{g \in G} gwp_g \cdot EFFII_{r,a,c,g} \geq QRED_{r,emcm,a} \perp SURGHG_{r,emcm,a} \geq 0, \quad (4.121)$$

$$\forall r \in R, a \in A, emcm \in EMCM1$$

Reduction measures upper boundary (for biomass power plant GHG absorption)

$$\xi_{emcm,a}^{\max} \cdot \eta_{emcm,a} \cdot \sum_{g \in G} gwp_g \cdot EMBII_{r,a,g} \geq QRED_{r,emcm,a} \perp SURGHG_{r,emcm,a} \geq 0, \forall r \in R, a \in A, emcm \in EMCM2 \quad (4.122)$$

5. Model dynamics

This section describes the feature of model dynamics¹³.

5.1. Capital

AIM/CGE 2.0 can be categorized as a recursive dynamic model. The capital stock is determined by the previous year's capital stock, capital formation and capital depreciation.

$$QF_{r,"cap",a}^t = QF_{r,"cap",a}^{t-1} \cdot (1 - dep_r^{t-1}) \quad \forall r \in R, t \in T \quad (5.1)$$

Where

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

dep_r^t : 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.

$$\overline{QFS_{r,"NCAP"}^t} = \sum_c QINV_{r,c}^{t-1} \quad \forall r \in R, t \in T \quad (5.2)$$

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 database¹⁴.

5.2. Labor

The population and labor is dynamically determined.

$$labor_stock_r^t = labor_stock_r^{t-1} \cdot lab_gr_r^t \quad \forall r \in R, t \in T \quad (5.3)$$

$labor_stock_r^t$: labor stock in time t and region r ,

$lab_gr_r^t$: labor stock (annual) growth rate in time t and region r .

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

$$QFS_{r,f}^t = labor_stock_r^t \quad \forall r \in R, t \in T, f \in F_{lab} \quad (5.4)$$

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

The current version assumes the growth rate is as the data published by UN population prospects 2008¹⁵.

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 5.1 and 5.2. The efficiency parameter $\alpha_{r,a}^{va}$ stands for

¹³ The programs which are described in this chapter are from [../scenario/BaU.gms]

¹⁴

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

¹⁵ United Nations, (2008); World Population Prospects, The 2008 Revision Population Database

TFP in this model, thus the $\alpha_{r,a}^{va}$ (appeared in equation (4.30)) is calculated with GDP growth target,

$$\alpha_{r,a}^{va*} = \frac{QVA_{r,a}^{t-1} \cdot (1 + gdp_gr_r^{t*})}{\left(\sum_{f \in F} \delta_{r,a}^{va} \cdot (QF_{r,f,a}^{t-1} \cdot (1 + fac_gr_{r,f}^t))^{-\rho_{r,a}^{va}} \right)^{-\frac{1}{\rho_{r,a}^{va}}}}, \quad \forall r \in R, a \in A \quad (5.5)$$

$\alpha_{r,a}^{va*}$: adjusted efficiency parameter in the CES value-added function,

$gdp_gr_r^{t*}$: expected GDP growth target (annual growth rate),

$fac_gr_{r,f}^t$: expected factor input growth rate (calculated by 5.1 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;

$$iene_{r,c,a}^t = iene_{r,c,a}^{base_year} \cdot aeei_{r,c,a}^t, \quad \forall r \in R, c \in ENE, a \in A \quad (5.6)$$

$$iend_{r,ca}^t = iene_{r,c,a}^{base_year} \cdot \sum_{c \in ENE} iene_{r,c,a}^{base_year} \cdot aeei_{r,c,a}^t, \quad \forall r \in R, a \in ACES_ENE \quad (5.7)$$

$$\gamma_{r,c,h}^{m^t} = \gamma_{r,c,h}^{m^{t-1}} \cdot aeei_{r,c,h}^t, \quad \forall r \in R, c \in ENE, h \in H \quad (5.8)$$

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

CES parameters determining energy consumption is also dynamically calibrated.

6. How to use the model

We prepared two options to use the model. One is for the GAMS beginners and it utilizes an excel file. The other is for the experimenter of GAMS and this CGE model. The former is easy to be used but users can make less change into the model assumption. The latter may be difficult for the beginner to understand the programs but after you learn about GAMS and this CGE program you can manage the programs and add modification as you want. This chapter describes both ways and section 6.1 shows how to deal with the easy excel file. In the section 6.2, the program structure and how to run the programs are shown.

6.1. Simple excel file operation

One simple excel file namely [/prog/input_data.xlsx] is prepared for the demo operation of CGE model. This excel file allows users to set basic defaults and input fundamental information before running the CGE model.

6.1.1. Input fundamental information

Generally, different colors have different meaning for each cell. Cell in grey color is for the title/label, cell in white color is for exogenous value, cells in green color is automatically calculated value from inputted information, and last is cell in yellow color for inputted information. **Therefore, users can just only modify the cells in yellow color.**

Table 5 meaning of the colors in the excel input format

Meaning of color in sheet's cells
title/label
exogenous value
automatically calculated value from inputted information
inputted information

a. Basic information

In “Basic information” sheet, default settings are provided. These settings are:

- **Country name:** please choose your country’s name from the provided list (*15 countries* as in “Sheet 1”).
- **Base year** is fixed to be 2005. So, please choose **target year** of your simulation from the provided list (*2025, 2030, 2050*).
- **Number of scenarios:** there is only 1 scenario for Business-as-Usual (BaU). Meanwhile, there might be up to 3 scenarios for Counter Measure (CM). Thus, you can choose the number of CM cases from the provided list (*1, 2, 3*).
- **Gases:** this is where you can decide which sort of gases you want to simulate in the model, which can be chosen from the provided list (*Energy CO2, All CO2, All GHG*).
- **Counter Measures:** this part sets the default for all scenarios by choosing “on” or ”off”. **In BaU scenario, all the countermeasures must be OFF.** You can decide different settings for CM scenarios. These countermeasures are: carbon tax, Carbon Capture and Storage (CCS), Additional Energy Efficiency Improvement (EEI), non-CO2 emission reduction, emission trading, and land-use.
- **Autonomous Energy Efficiency Improvement (AEEI):** this part sets more detail for the energy efficiency improvement. You can choose the improvement level from provided list (*middle, high, low*).
- **CCS:** this part is for detail setting of CCS, that are starting year (*2020,2025,2030,2035,2040,2045*) and installation speed (*middle, high, low*).

b. Numeral information (GDP, Population, GHG emission gap, Emission trading, NUC, HYD)

The latter sheets provide numeral information to be inputted in the CGE model. They are GDP, population, GHG emission cap, emission trading, nuclear (NUC) and hydro (HYD) power installation.

- **For GDP and Population:** base year’s actual value is provided. If you have actual value for the year rather than base year, you can input; otherwise you can input the growth rate of different periods into appropriate yellow cells (2005-2010,2011-2020,2021-2030,2031-2040,2041-2050) so that the actual value will be calculated accordingly (into green cells) based on the base year’s value.
- **For GHG emission cap and emission trading:** the simulation is different for different periods (2005-2010,2011-2020,2021-2030,2031-2040,2041-2050). You can decide and input the value of simulation for different periods in different CM scenarios (in yellow cells). Actual value will be automatically calculated (in green cells) based on the loaded data and the ratio which you input into yellow cells. For GHG emission cap, the value of BaU (in white cells) is automatically loaded from CGE model’s results. Meanwhile, GHG emission trading does not have value in BaU scenario.
- **For NUC and HYD:** Value of BaU scenario is also loaded from CGE model’s results. Meanwhile, the value for CM scenarios is depended on the national energy development policy, whether the government would like to promote nuclear power and/or increase the hydro power capacity. The users can input such information into yellow color according to the policy of their countries.

6.1.2. Operation of CGE model through [input_data.xlsm]

After input all the required information, please click the “Run” button (located in “Basic information” sheet) to operate the CGE model. Figure 4 shows the simple operation of CGE model by using excel file.

Country Name	Japan	Run BaU			
Base year	2005	Run CM1			
Target year	2050	Run CM2			
Number of Scenarios		Run CM3			
BaU	1	Run All			
CM (1-3)	3				
Gases	Energy CO2				
Counter Measures	BaU	CM1	CM2	CM3	
Carbon Tax	off	on	on	on	
CCS	off	on	on	off	
Additional EEI	off	on	on	on	
Non-CO2 emission reduction	off	on	on	on	
Emission Trading	off	on	off	on	
Land Use	off	on	on	on	
AEEI (Autonomous Energy Efficiency Improvement)	middle				
CCS (Carbon Capture and Storage)		CM1	CM2	CM3	
Start year		2020	2020	2020	
Installation speed		middle	high	middle	

Figure 4 Overview of simple excel operation

6.2. Program based operation

6.2.1. Program structure

There are two stages to use this AIM/CGE model (as shown in Figure 5). 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.

AIM/CGE model is started by running [operating_file.gms] in the [/prog] directory. [operating_file.gms] controls the two main programs [AIM_CGE.gms] and [scenario.gms]. Firstly, it runs [AIM_CGE.gms]. [AIM_CGE.gms] 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.

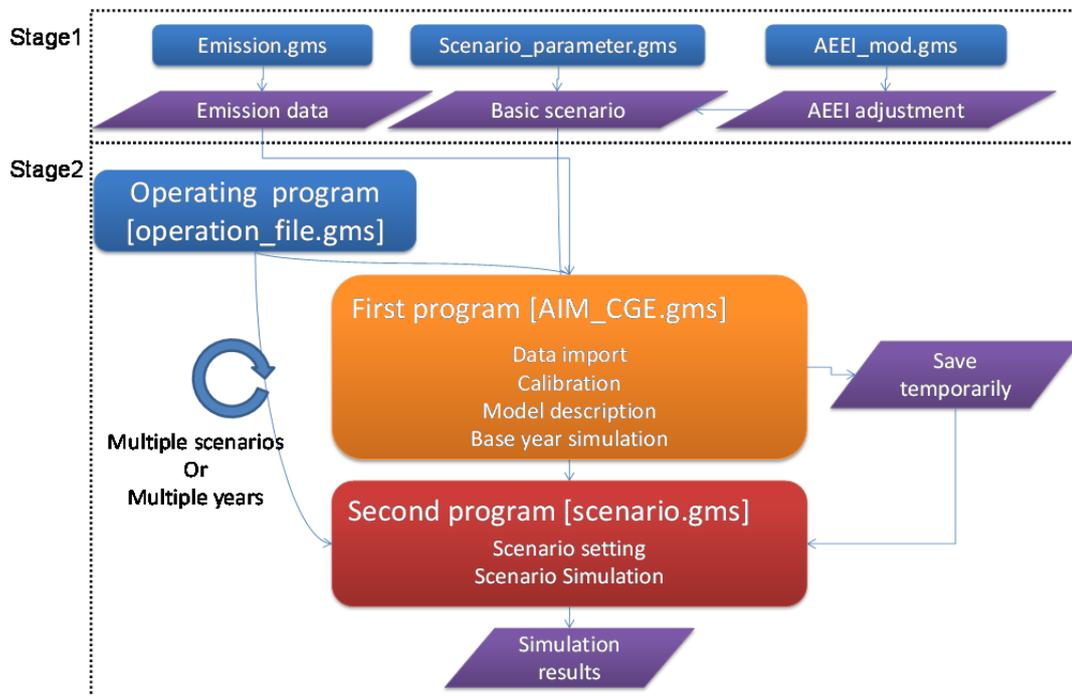


Figure 5 Overview of the program structure

Although the AIM/CGE model runs just by executing [operating_file.gms], it requires some preparation before running it. Section 6.2.4 shows what should be prepared.

6.2.2. AIM_CGE.gms

[AIM_CGE.gms] consists of mainly 7 parts (without declaration of sets, parameters, variables and so on).

The structure of [AIM_CGE.gms] is drawn in Figure 6. Left-side boxes represent the 7 procedures and some program files are included in each procedure, so the program names are shown in right side of that figure.

The list of the components and their contents are described in Table 6¹⁶.

¹⁶ 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.

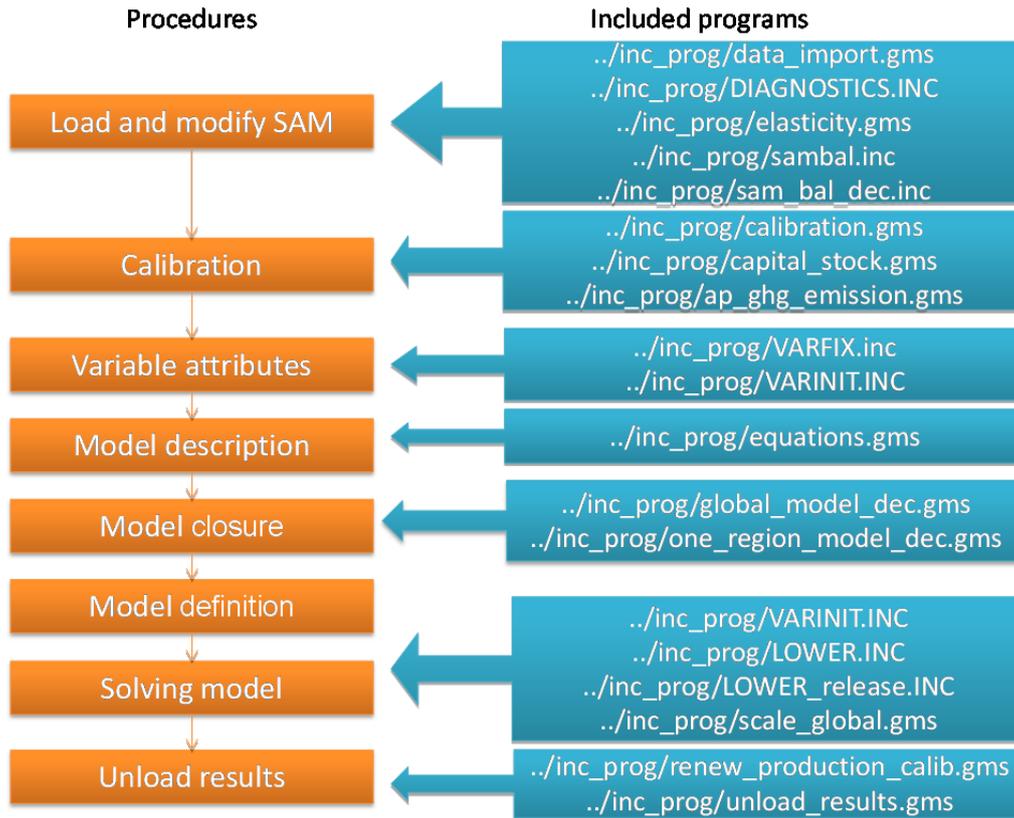


Figure 6 AIM_CGE.gms structure

Table 6 List of AIM_CGE.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 ../inc_prog/VARINIT.INC
	1-12	Solving model	The model is solved for the base with some optional tests of robustness	../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

6.2.3. scenario.gms

[scenario.gms] includes 5 main parts which are shown as Figure 7. The list of the components of [scenario.gms] and their contents are also shown in Table 7.

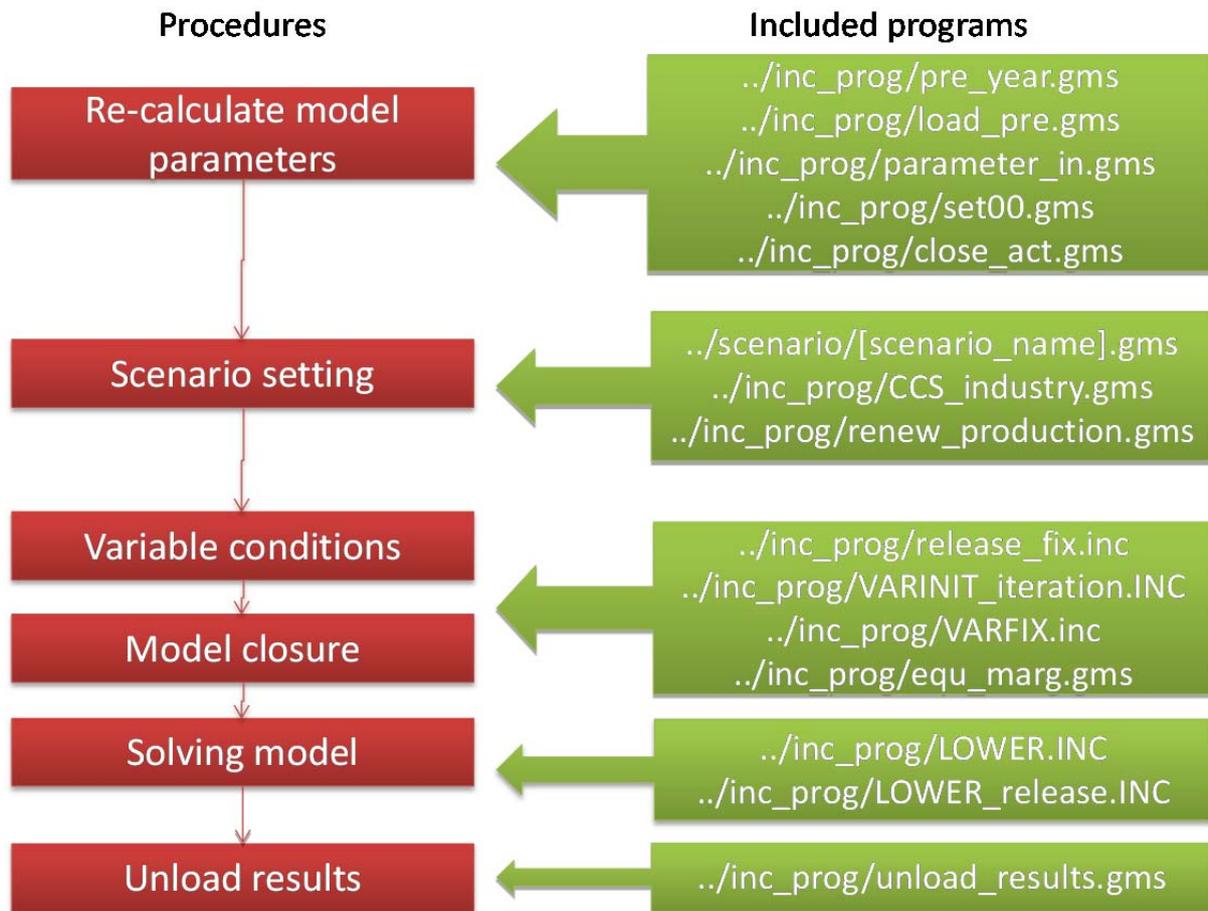


Figure 7 scenario.gms structure

Table 7 List of scenario.gms components

Program	Section	Section Name	Description	Included file
scenario.gms	2-1	Initialize model parameters	Re-calculate model parameters. They are same as the base year.	../inc_prog/pre_year.gms ../inc_prog/load_pre.gms ../inc_prog/parameter_in.gms ../inc_prog/set00.gms ../inc_prog/close_act.gms
	2-2	Scenario setting	Set Scenario by changing model parameters	../scenario/[scenario_name].gms ../inc_prog/CCS_industry.gms ../inc_prog/renew_production.gms
	2-3	Release variable conditions and fixing variables not in model at zero	Release variable conditions such as lower and upper boundary. And put the fixing condition.	../inc_prog/release_fix.inc ../inc_prog/VARINIT_iteration.INC ../inc_prog/VARFIX.inc ../inc_prog/equ_marg.gms
	2-4	Model closure	Macro and micro closure rules are selected by fixing selected	
	2-5	Solve statement	The model is solved for the scenarios	../inc_prog/LOWER.INC ../inc_prog/LOWER_release.INC
	2-6	Unload results	Unload scenario simulation results	../inc_prog/unload_results.gms

6.2.4. Preparation

Before executing the program, two preparations should be carried out. One is to input codes into [operation_file.gms]. The second is to prepare the assumed scenario. The concrete (or quantitative) scenario

must be described in GAMS code. This section describes how to prepare these things.

6.2.5. Putting codes into [operation_file.gms]

The target country and kinds of scenarios should be specified in [operation_file.gms]. The followings are extracted from the first part of [operation_file.gms].

There are 4 codes that should be checked and modified. They are located on the lines starting from “\$setglobal”.

(1) Global [on/off] (line 8)

If your model is a global model, write [on] just after [\$setglobal global].

(2) Region numbers (line 11)

If you chose a global model, the region numbers should be written after [\$setglobal RM].

(3) Region code (line 15)

If you chose one country model, the region code should be written just after [\$setglobal Sr]. Regional codes are listed in Table 8.

Table 8 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 Central 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		

(4) Base year (line 19)

Calibration year can be changed by writing the base year in this line.

(5) Target year (line 22)

Future target year can be changed by writing the final year in this line.

(6) Scenario code (line 25)

The scenario codes should be described after [\$setglobal SCENARIO_LIST]. If you deal with multiple scenarios, input all codes separated by a comma.

(7) GHG cap code (line 27)

The user can choose GHG emission cap or carbon tax scenario. If you want the cap scenario, the switch should be on. In addition, the actual cap should be ordered at the beginning of [CM.gms]

(8) GHG emission trading code (line 27)

The user can choose whether emission trading is available or not. If you want to install the emission trading mechanism, the switch should be on. In addition, you can determine the boundary of the emission trading capacity. It should be written in [scenario.gms] around line 575-580.

```

*This file is an operating file to conduct standard AIM/CGE model.
*The standard AIM/CGE model is applicable to both single region and world.
*This is controlled by the following switch.
*If you handle global model write "on" after "global", otherwise write "ff".
$setglobal global on          !! switch for global or local simulation; global [on /off]
*When you select global on, the region number should be determined.
*Write down the number of regions after "RM"
$setglobal RM 35

*When you select single country model, the region should be specified.
*Write down the code of the target region after "Sr"
$setglobal Sr JPN

*The base year for calibration can be changed from 1971 to 2005
*Specify the base year below
$setglobal base_year 2005

*Specify the target year below
$setglobal target_year 2050

*Finally, scenarios are written below.
*Write the list of the scenario name after "SCENARIO_LIST" separated by comma ",".
$setglobal SCENARIO_LIST BaU
*Before running this program make sure that
*you have created scenario file in [../scenario] directory

```

Figure 8 First part of [operation_file.gms]

An example is shown in the actual program, so it is recommended to refer to the program.

6.2.6. Scenario making

Each scenario should be written in individual gams program. In addition, the file name must be the same as you have named the scenario name in [operation_file.gms]. The files should be located in the [/scenario] directory. For example, example programs are the two scenarios “BaU” and “CM” as shown in [operation_file.gms]. There are two files [scenario/BAU.gms] and [scenario/CM.gms].

These scenario program files include assumptions for each scenario, such as GDP, energy use, and so on. The following is a list of the assumptions written into the programs.

- (1) GHG emission constraint
- (2) Labor stock
- (3) Capital stock
- (4) Target GDP growth rate
- (5) TFP (Total Factor productivity)
- (6) AEEI (Autonomous energy efficiency improvement)
- (7) Biomass consumption reduction rate
- (8) CCS technology on or off
- (9) Renewable energy capacity

7. Result

If you operate the program by excel file [input_data.xlsx], the basic indicators are shown in the same file. Section 7.1 states how to see the [input_data.xlsx] results. In case you did not use that excel base operation, or you want to see more indicators, read section 7.2.

7.1. Simple excel file operation results

In the case of operating CGE model through a simple excel file namely [input_data.xlsx], we aim to reduce the workload for users in executing the model as well as checking so many related files. Therefore, we pick up some main analytical indicators and put the figures of their results into the “Basic information” sheet where users can see how their settings for the model would affect the results at the same time.

These chosen main indicators are:

- **GDP:** Gross Domestic Products
- **TFC_f:** Total Final Energy Consumption by economic sectors
- **TPES_s:** Total Primary Energy Supply by energy types
- **POWER:** Electricity generation
- **GHG:** total GHG emission
- **PGHG:** GHG emission price

For detail of more analytical indicators, please refer to section 7.2 and the excel file in output folder (namely “country_code”.xlsx)

7.2. General results

After executing [operation_file.gms] without any errors, there are some results files or directories.

- (1) [../output/country/"country_code"/"scenario_name"] directory contains all simulation results for each year. (currently country_code is [JPN] and scenario_name is [BaU] and [CM])
- (2) [../output/country/"country_code" / "country_code"/"scenario_name".gdx] consists of the separated gdx files shown in (1).
- (3) [../output/country/"country_code" /xls/"country_code".xlsx] contains the main indicators shown below.

Table 9 List of the sheets in excel files [../output/country/"country_code"/xls/"country_code".xlsm]

Sheet name	contents
2005_calibration	energy balance table ratio of original data to model results in 2005
2005_BaU	Energy balance table in 2005
Kaya	Decomposition analysis
POP	Population
GDP	GDP
GDP_sh	GDP share
GHG	GHG emission CO2 equivalent
PGHG	GHG emission price
GHG_IMP	GHG emission trading (net import)
CO2	Energy related CO2 emission by sectors
ELY_PRD	Electricity production
ELY_fire	Electricity production
TPES	Total primary energy supply
TFC	Total final energy consumption
TPES_s	Total primary energy supply by fuel
TFC_s	Total final energy consumption by fuel
Energy_intensity	Energy supply to GDP
GHG_intensity	GHG emission to GDP
POWER	Electricity production by power plants

In sheet "Kaya", there are graphs drawing decomposition analysis. An example is shown below. The bar represents average annual change of GHG emission factors for each period. Table 10 lists the series used in decomposition analysis.

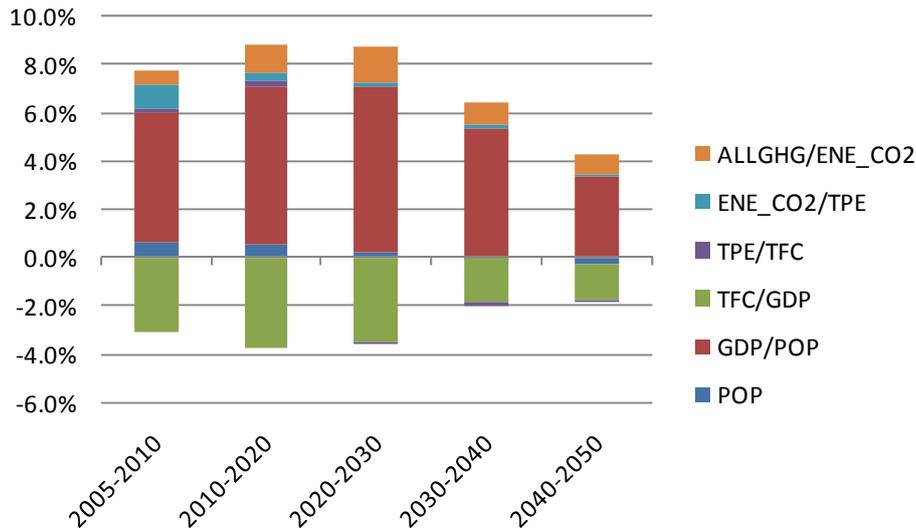


Figure 9 Decomposition analysis graph example

Table 10 series of decomposition

Series name	contents
POP	Population
GDP/POP	GDP per capita
TFC/GDP	Total final energy consumption per GDP
TPE/TFC	Total primary energy supply per Total final enregy consumption
ENE_CO2/TPE	CO2 emission by fuel combustion per total enregy supply
ALLGHGENE_CO2	total GHGemission per CO2 emission by fuel combustion

(4) [../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 below¹⁷.

[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")

¹⁷ There are other parameters but ignore them in this case. They are just temporal parameters.

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)

The 9th parameter, Penergy_b, represents energy balance table made from the estimated SAM. Classifications of the rows and columns are shown below¹⁸. 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.

Table 11 List of row and column components in energy balance table

Row (Flow)		column (energy source)	
code	description	code	description
PRD	Production	EB_F_COL	Coal
IMP	Import	EB_F_CRU	Crude oil
EXP	Export	EB_F_NGS	Natural gas
STC	Stock change	EB_F_OIL	Oil products
TPES	Total primary energy supply	EB_F_HYD	Hydropower
EB_PWR	Power plants (without CCS)	EB_F_NUC	Nuclear
EB_CCS	Power plants (with CCS)	EB_F_SPV	Solar
EB_PEN	Power plants (energy use)	EB_F_WIN	Wind
EB_P_C	Petroleum refinery and coal transformation	EB_F_GEO	Geothermal
EB_GWK	Gaswork	EB_F_ORN	Other renewable
EB_EMN	Fossil fuel mining	EB_F_BIO	Biomass
EB_LOSS	Distribution loss	EB_F_ELY	Electricity and Heat
EB_TFC	Total final consumption	EB_TOT	Total
EB_TIN	Total industry		
EB_I_S	Iron and Steel		
EB_NFM	Non-ferous metal		
EB_CRP	Chemical		
EB_NMM	Non-mineral and non-metartic		
EB_MCH	Machinery		
EB_OMN	Other mining		
EB_FPR	Food processing		
EB_TEX	Textile		
EB_LUM	Wood product producer		
EB_PPP	Paper, pulp and printing		
EB_CNS	Construction		
EB_XIN	Other industry		
EB_TRS	Transport		
EB_RSD	Residential		
EB_SER	Commercial		
EB_AGR	Agriculture		
EB_NEU	Non-energy use		

¹⁸ 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.

Table 12 Example of energy balance table in 2005 USA

		Coal	Crude oil	Natural gas	Oil products	Hydropower	Nuclear	Solar	Wind	Geothermal	Other renewable	Biomass	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 ELY	
Production	PRD	675099	362543	457124		29652	225430	2103	4840	34176	2248	11218		1804434
Import	IMP	30518	556139	108649	139611								4296	839212
Export	EXP	-37973	-8148	-20782	-91078								-2735	-160716
Total primary energy supply	TPES	667644	910534	544991	48533	29652	225430	2103	4840	34176	2248	11218	1561	2482930
Power plants	EB PWR	-316636		-170275	-74698	-29652	-225430	-2103	-4840	-34176	-2248	-11139	388819	-482378
Power plants (energy use)	EB PEN												-20938	-20938
Petroleum refinery and coal transformation	EB P C	-163291	-901666	-20772	991131									-94598
Gaswork	EB GWK	-9028		45004										35977
Fossil fuel mining	EB EMN	-6140	-5156	-29452									-1923	-42671
distribution loss	EB LOSS	-33599	-3712		-13533								-6774	-57618
Total final consumption	EB TFC	138951		369497	951433							79	360744	1820704
Total industry	EB TIN	108359		115887	184892							49	92618	501804
Iron and Steel	EB I S	6637		10228	6688							0	6735	30287
Non-ferrous metal	EB NFM	7193		6878	2561							1	6877	23510
Chemical	EB CRP	12870		27385	129827							2	22601	192686
Non-mineral and non-metatic	EB NMM	15745		10218	5732							1	4220	35916
Machinery	EB MCH	7126		13096	6964							0	14072	41259
Other mining	EB OMN	6248		2091	2846								2459	13645
Food processing	EB FPR	10008		14236	5764							2	8069	38079
Textile	EB TEX	6207		3507	2311							0	2888	14913
Wood product producer	EB LUM	6122		2998	3644							10	3086	15859
Paper, pulp and printing	EB PPP	10717		13438	8446							28	11332	43962
Construction	EB CNS	6477		1774	2426							0	1290	11967
Other industry	EB XIN	13008		10040	7682							5	8987	39721
Transport	EB TRS			19126	384227							10	1399	404762
Residential	EB RSD	9378		161591	318109							18	150098	639194
Commercial	EB SER	9548		72892	40291							3	111541	234275
Agriculture	EB AGR	11666			23915								5088	40669
Total (TPES-TFC+Energy transformation)	TOT	0	0	0	0	0	0	0	0	0	0	0	0	0

The way to convert CGE model variables to an energy balance table is shown below. In the Table 13, the numbers are written for each cell and the number corresponds to Table 14. Table 14 shows correspondence from CGE variables to the energy balance table. Sectors and energy sources mapping are show in Table 15 and Table 16.

Table 13 Cell numbers of energy balance table

		Coal	Crude oil	Natural gas	Oil products	Hydropower	Nuclear	Solar	Wind	Geothermal	Other renewable	Biomass	Electricity and Heat
		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 ELY
Production	PRD	1							2			3	
Import	IMP	4											4
Export	EXP	5											5
Stock change	STC	6											
Total primary energy supply	TPES	7											
Power plants without CCS	EB PWR	8							9				10
Power plants with CCS	EB CCS	11										12	13
Power plants (energy use)	EB PEN	15											14
Petroleum refinery and coal transformation	EB P C	17		18	16								17
Gaswork	EB GWK	17		18	17								17
Fossil fuel mining	EB EMN	19											19
distribution loss	EB LOSS	20											20
Total final consumption	EB TFC	21											21
Total industry	EB TIN	21											21
Iron and Steel	EB I S	21											21
Non-ferrous metal	EB NFM	21											21
Chemical	EB CRP	21											21
Non-mineral and non-metatic	EB NMM	21											21
Machinery	EB MCH	21											21
Other mining	EB OMN	21											21
Food processing	EB FPR	21											21
Textile	EB TEX	21											21
Wood product producer	EB LUM	21											21
Paper, pulp and printing	EB PPP	21											21
Construction	EB CNS	21											21
Other industry	EB XIN	21											21
Transport	EB TRS	22											22
Residential	EB RSD	23											23
Commercial	EB SER	23											23
Agriculture	EB AGR	23											23
Non-energy use	EB NEU	24											24

Table 14 List of the 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	=	Biomass and biomass electricity

	$QXAC_{r,"bio","com_ely"} + \sum_h TBH_{r,h} + \sum_a TBI_{r,a}$	generation
4	$= QM_{r,c}$	Import quantity of tradable commodity
5	$= -QE_{r,c}$	Export quantity of tradable commodity (negative)
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. “ <i>ele_factor_a</i> ” 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). “ <i>ele_factor_a</i> ” 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	$= -loss_{r,c} \left(\sum_a QXAC_{r,c,a} + QM_{r,c} \right)$	(Production + import) multiplied by loss rate
21	$= QINT_{r,c,a} * (1 - non_energy_rate_{r,c,a})$	Intermediate inputs of the energy products (excluding non-energy use)
22	$= QH_{r,c,h} + QINT_{r,c,"trs"} * road_rate_{r,c}$	Transport sector’s energy use + household fuel use by car
23	$= QH_{r,c,h} - QINT_{r,c,"trs"} * road_rate_{r,c}$	Household consumption – household fuel use by car
24	$= QINT_{r,c,a} * non_energy_rate_{r,c,a}$	Intermediate inputs of the energy products multiplied by non-energy use rate

Note:

- (1) Export includes international marine and aviation bunkers
- (2) Oil products includes petroleum products and coal products

Table 15 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_ORN
			EB_CCS
		EC_OIL	
		EC_GAS	
		EC_BIO	
EB_P_C	Petroleum refinery and coal transformation	P_C	
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-metarie	NMM
	EB_MCH	Machinery	MCH
	EB_OMN	Other mining	OMN
	EB_FPR	Food processing	FPR
	EB_TEX	Textile	TEX
	EB_LUM	Wood product producer	LUM
	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

Table 16 Energy source mapping

energy balance table energy sources	CGE commodity	
EB_F_COL	Coal	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

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Appendix (Mathematical statement)

(1) SETS

$a \in A$: a set of activities

$a \in ACES(\subset A)$: a set for non-energy transformation

$a \in ALEA(\subset A)$: a set for energy transformation

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

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

$c \in CFF$: a set of fossil fuel commodities (COA, OIL, GAS, P_C, GDT)

$c \in C$: a set of commodities (also referred to as c' and C')

$c \in CE(\subset C)$: a set of exported commodities (with domestic production)

$c \in CM(\subset C)$: a set of imported commodities

$c \in CD(\subset C)$: a set of commodities with domestic sales of domestic output

$c \in CX(\subset C)$: a set of commodities with domestic output

$c \in CNEN$: a set of non-energy commodities

$c \in ENE$: a set of energy commodities (COA, OIL, GAS, P_C, ELY, GDT)

$c \in CEN(\subset C)$: non-exported commodities (complement of CE)

$c \in CDN(\subset C)$: commodities without domestic market sales of domestic output (complement of CD)

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

$c \in C_TRS$: a set of transport service

$emcm \in EMCM$: a set of emission reduction counter measures (CCS)

$emcm \in EMCM0(\subset EMCM)$: a subset of emission reduction counter measures which are for non-energy related emissions

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

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

$f \in F (= F')$: a set of factors

$f \in FCAP (= F)$: A set of capital (new and old; "ncap" and "cap")

$r \in R$: a set of regions

$i \in INS$: 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)

$i \in INSDNG(\subset INSD)$: a set of domestic nongovernment institutions

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

$g \in G$: a set of emission gases

$g \in G^{CO_2}$: a set of CO₂

$aagg \in Aagg$: a set of aggregated activity

$ragg \in Ragg$: a set of aggregated regions

(2) PARAMETERS

1) Latin letters

$bioc_{r,ac}$: biomass consumption coefficient to the activity level of sector ac

$biod_{r,ac}$: decreasing rate of biomass consumption of sector ac

crt_in_r : transfer from rest of the world

crt_out_r : transfer to rest of the world

$cwts_{r,c}$: weight of commodity c in the consumer price index

$dwt_{r,c}$: weight of commodity c in the producer price index

$dis_imp_{r,c}$: price difference of the import commodity c

$dis_exp_{r,c}$: price difference of the export commodity c

$efacl_{r,ac,g}$: emission factors for emissions related to activity level by sector ac

$efbio_{r,ac,g}$: emission factors for emissions fossil fuel combustion by sector ac

$efffc_{r,c,ac,g}$: emission factors for emissions fossil fuel combustion by sector ac consuming of goods c

$efit_c$: emission coefficient of international bankers

$enur_{r,c,ac}$: energy-used ratio (1-non-energy-use ratio)

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

gwp_g : global warming potential of gas g

$gwt_{r,c}$: weight of commodity c in the government price index

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

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

$iena_{r,a}$: quantity of aggregate energy input 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

$iva_{r,a}$: quantity of value-added per activity unit

$ivae_{r,a}$: quantity of value-added energy composite per activity unit

$iwt_{r,c}$: weight of commodity c in the capital formation price index

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

$mps01_{r,i}$: 0-1 parameter with 1 for institutions with potentially flexed direct tax rates

$loss_{r,c}$: distribution loss rate

pc_c : carbon fraction

$pco2_c$: CO₂ emission coefficient

$pdd_{r,c}^{pre}$: Previous year's domestic demand price of commodity c

$pds_{r,c}^{pre}$: Previous year's domestic supply price of commodity c

$pe_{r,c}^{pre}$: Previous year's export price of commodity c

$pflag_{c,a}$: flag for fossil fuel transformation

$pdfq_{r,c,ac}$: price differences of commodity price among inputs sectors

$pm_{r,c}^{pre}$: Previous year's import price of commodity c

$pxac_{r,a,c}^{pre}$: Previous year's producer price of commodity c for activity a

$quota_{ragg, aagg}$: quota of aggregated region $ragg$ and aggregated activity $aagg$
 $renew_{up, ra}$: capacity of the activity level a (for power sector energy)
 $sh_ely_up_{r, a}$: Power generation share of activity a
 $stch_{r, c}$: stock change of commodity c (positive)
 $stch2_{r, c}$: Stock change of commodity c (negative)
 $shif_{r, i, f}$: share of domestic institution i in income of factor f
 $shii_resource_{r, i}$: a ratio of transfer to institution i of total transfer in a country
 $shii_use_{r, i}$: share of net income of i
 $shincome_{r, i}$: total income share of GHG emission cost for institution i
 $shres_{r, i}$: resource income share of institution i
 $ta_{r, a}$: tax rate for activity
 $te_{r, c}$: export tax rate
 $tf_{r, f}$: direct tax rate for factor f
 $tins01_{r, i}$: 0.1 parameter with 1 for institutions with potentially flexed direct tax rates
 $tm_{r, c}$: import tariff rate
 $tq_{r, c, ac}$: rate of sales tax (as share of composite price inclusive of sales tax). Suffix ac includes activity a and institution i
 $transfr_crt_in_r$: current transfer from rest of the world
 $transfr_crt_out_r$: current transfer to rest of the world
 $transfr_f_{r, f}$: factor transfer from abroad
 $transfr_{r, f}$: factor transfer to abroad
 tsh_c : share of international trade service to world total international trade service
 $tva_{r, a}$: rate of value-added tax for activity a
 $tw_{r, c}$: international trade cost ratio
 $capital_stock_r^t$: capital stock in time t and region r
 dep_r^t : capital depreciation rate in time t and region r
 $labor_stock_r^t$: labor stock in time t and region r
 $lab_gr_r^t$: labor stock (annual) growth rate in time t and region r
 $gdp_gr_r^*$: GDP growth target (annual growth rate)
 $fac_gr_{r, f}^t$: Factor input growth rate (calculated by 5.1 and 5.2)
 $aeei_{r, c, ac}^t$: annual AEEI rate of energy commodity c , sector ac , time t and region r

2) Greek letters

.

$\alpha_{r, a}^f$: efficiency parameter in the CES capital input function,

$\alpha_{r,a}^{vae}$: efficiency parameter in the CES energy and value-added function
 $\alpha_{r,a}^{va}$: efficiency parameter in the CES value-added function
 $\alpha_{r,a}^{el}$: efficiency parameter in the CES energy input function
 $\alpha_{r,a}^{ff}$: shift parameter for domestic commodity aggregation function
 $\alpha_{r,c}^{ac}$: shift parameter for domestic commodity aggregation function
 $\alpha_{r,c}^t$: a CET function shift parameter
 $\alpha_{r,c}^q$: an Armington function shift parameter
 $\beta_{r,c,h}^m$: marginal share of consumption spending on marketed commodity c for household h
 $\gamma_{r,c,h}^m$: subsistence consumption of marketed commodity c for household h
 λ_c^w : depreciation rate of traded commodity c

$\rho_{r,a}^f$: CES capital input function exponent.
 $\rho_{r,a}^{vae}$: CES energy and value-added function exponent
 $\rho_{r,a}^{va}$: CES value-added function exponent
 $\rho_{r,a}^{el}$: CES energy input function exponent
 $\rho_{r,a}^{ff}$: domestic commodity aggregation function exponent
 $\rho_{r,c}^{ac}$: domestic commodity aggregation function exponent
 $\rho_{r,c}^t$: a CET function exponent
 $\rho_{r,c}^q$: an Armington function exponent
 $\delta_{r,a}^f$: CES capital input function share parameter,
 $\delta_{r,a}^{vae}$: CES energy and value-added function share parameter in activity a
 $\delta_{r,a}^{va}$: CES value-added function share parameter for factor f in activity a
 $\delta_{r,a}^{el}$: CES energy input function share parameter
 $\delta_{r,c,a}^{ff}$: shift parameter for domestic commodity aggregation function
 $\delta_{r,a,c}^{ac}$: shift parameter for domestic commodity aggregation function
 $\delta_{r,c}^t$: a CET function share parameter
 $\delta_{r,c}^q$: an Armington function share parameter
 $\theta_{r,a,c}$: yield of output c per unit of activity a
 $\psi_{r,a,c}^{ac}$: Previous year's share of the commodity c produced by activity a
 $\psi_{r,c}^t$: Previous year's share of export to domestically produced commodity c
 $\psi_{r,c}^m$: Previous year's share of import to domestically produced commodity c

$\eta_{r,a,c}^{ac}$: Elasticity of domestic commodity aggregation
 $\eta_{r,c}^t$: Elasticity of domestic produced commodity aggregation
 $\eta_{r,c}^m$: Elasticity of domestic consumption commodity aggregation
 $\chi_{r,a,g}$: reference case emission reduction coefficient

$\sigma_{r,a,g}^{ghg}$:relasticity of the additional emission reductions of non-energy related emissions

(3) Exogenous variables

$\overline{DTINS}_{r,i}$:change in domestic institution tax share (= 0 for base; exogenous variable)

\overline{FSAV}_r :foreign savings (FCU) (exogenous variable)

\overline{GADJ}_r : government consumption adjustment factor (exogenous variable)

\overline{ghgc}_r : GHG emission constraint

$\overline{ghgt_imp_cap}_r$: GHG emission trading (import) limit

$\overline{ghgt_exp_cap}_r$: GHG emission trading (export) limit

$\overline{ghgtot_c}$: global GHG emission constraint

$\overline{mps}_{r,i}$: base savings rate for domestic institution i

\overline{MPSADJ}_r : savings rate scaling factor (= 0 for base)

$\overline{QFS}_{r,f}$: quantity supplied of factor (exogenous variable)

$\overline{qg}_{r,c}$: government consumption adjustment factor (exogenous variable)

$\overline{qinv}_{r,c}$: base-year quantity of fixed investment demand

$\overline{tins}_{r,i}$: rate of direct tax on domestic institutions i

$\overline{TINSADJ}_r$: direct tax scaling factor (= 0 for base; exogenous variable)

$\overline{transfr_CRT}_{r,"gov"}$: governmental transfer in base year

(4) Endogenous variables

$ADEEI_{r,a}$: Additional energy efficiency improvement coefficient

CPI_r : consumer price index (exogenous variable)

DPI_r : producer price index for domestically marketed output

$DMPS_r$:0-1 parameter with 1 for institutions with potentially flexed direct tax rates

EG_r : government expenditures

$EMALI_{r,a,g}$: emissions non-energy related emission by industrial activity a

$EMFFINT$: emission from international bankers

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

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

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

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

$EMBI_{r,a,g}$: emissions related to biomass combustion emitted by industrial activity a

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

EPI_r : export price index

EXR_r : exchange rate country r

GPI_r : Government price index
 $GHGCA_NENE_{r,a}$: GHG emission cost related biomass_burning and CCS negative emissions of activity a in region r
 $GHGCA_ENE_{r,a,c}$: GHG emission cost related to energy consumption
 GHG_IMP_r : GHG emission credit import (net)
 $GHGCH_{r,h}$: GHG emission cost of household h in region r
 $GHGTCOST_r$: GHG emission cost
 $GHGT_r$: GHG emission from region r (CO₂ equivalent)
 $GHGT_CT_r$: GHG emission from region r (CO₂ equivalent) includes emission permit import
 $GSAV_r$: government savings
 $IADJ_r$: investment adjustment factor (exogenous variable)
 IPI_r : Capital formation price index
 MPI_r : import price index
 $MPS_{r,i}$: marginal propensity to save for domestic nongovernment institution (exogenous variable)
 $NERED_{r,a,g}$: emission reduction caused by the ghg emission price
 $PA_{r,a}$: activity price (gross revenue per activity unit)
 $PVAE_{r,a}$: price of (aggregate) energy and value-added bundle (non-energy transformation sector)
 $PDD_{r,c}$: demand price for commodity produced and sold domestically
 $PDS_{r,c}$: supply price for commodity produced and sold domestically
 $PE_{r,c}$: export price of commodity c
 $PENE_{r,a}$: price of (aggregate) energy input

 $PENE_{r,h}^{bau}$: Energy price (BaUcase)

 $PENE_H_{r,h}$: Energy price of household

 $PENE_H_{r,a}^{bau}$: Energy price of household (BaUcase)

 $PFFL_{r,a}$: price of (aggregate) fossil fuel input
 $PGHG_r$: GHG emission price in region r (US\$/tC)
 $PGHG_G_r$: 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
 $PGHG_G$: GHG emission price corresponding to the global emission constraint
 $PINTA_{r,a}$: aggregate intermediate input price for activity a
 $PM_{r,c}$: composite commodity price (including import tax and transaction costs)
 $PQ_{r,c}$: composite commodity price excluding sales tax
 $PQD_{r,c}$: composite commodity price excluding sales tax
 $PRES_{r,a}$: price of resource input
 $PTRS_c$: price of international trade service
 $PVA_{r,a}$: price of (aggregate) value-added
 PWM_c : world import price (c.i.f) of commodity c
 PWE_c : f.o.b. export world price
 $PX_{r,c}$: aggregate producer price for commodity

$PX2_{r,c}$: aggregate producer price for commodity including stoch change effects
 $PXAC_{r,a,c}$: producer price of commodity c for activity a
 $QA_{r,a}$: quantity (level) of activity
 $QD_{r,c}$: quantity sold domestically of domestic output
 $QE_{r,c}$: quantity of exports
 $QENE_{r,a}$: quantity of (aggregate) energy input
 $QF_{r,f,a}$: quantity demanded of factor f from activity a
 $QFFL_{r,a}$: quantity of (aggregate) fossil fuel input
 $QG_{r,c}$: government consumption demand for commodity
 $QH_{r,c,h}$: quantity of consumption of marketed commodity c for household h
 $QINT_{r,c,a}$: quantity of commodity c as intermediate input to activity a
 $QINTA_{r,a}$: quantity of aggregate intermediate input
 $QINV_{r,c}$: quantity of fixed investment demand for commodity
 $QM_{r,c}$: quantity of imports of commodity
 $QQ_{r,c}$: quantity of goods supplied to domestic market (composite supply)
 $QRED_{r,emcm,a}$: input of counter emission reduction counter measures of activity a and measure $emcm$
 $QRES_{r,a}$: quantity of resource input
 $QTRS_c$: quantity of international trade service
 $QVA_{r,a}$: quantity of (aggregate) value-added
 $QVAE_{r,a}$: quantity of (aggregate) energy and value-added bundle (non-energy transformation sector)
 $QWM_{r,c}$: quantity of imports of commodity
 $QWE_{r,c}$: quantity of exports of commodity
 $QX_{r,c}$: aggregate marketed quantity of domestic output of commodity
 $QX2_{r,c}$: aggregate marketed quantity of domestic output of commodity including stock change
 $QXAC_{r,a,c}$: marketed output quantity of commodity c from activity a
 $RQUOQA_{r,a}$: Shadow subsidies of the fixed activity level
 $SHAC_{r,a,c}$: share of the commodity c produced by activity a
 $SHQE_{r,c}$: share of domestically sold and export commodity c
 $SHQM$: share of domestically sold and imported commodity c
 $SURGHG_{r,emcm,a}$: Complementary variable for the upper boundary of the counter measure installation
 $TBH_{r,h}$: biomass consumption by household h
 $TBI_{r,a}$: biomass consumption by activity a
 $TINS_{r,i}$: direct tax rate for institution i
 $TRII_Resource_{r,i}$: transfers to institution i
 $TRII_Use_{r,i}$: transfers from institution i
 $VRENCAP_{r,a}$: Rent of electricity capacity activity a in region r
 $VRENCAPTOT_r$: rent related to electricity capacity
 $WF_{r,f}$: average price of factor
 $WFDIST_{r,f,a}$: factor price distortion factor for factor f in activity a
 YG_r : government revenue
 $YF_{r,f}$: income of factor f
 $YI_{r,i}$: income of institution i (in the set INSDNG)

$YIF_{r,i,f}$: income to domestic institution i from factor f

(5) EQUATION

Import Price

$$PM_{r,c} = PWM_c \cdot dis_imp_{r,c} \cdot (1 + tm_{r,c}) \cdot EXR_r, \quad \forall c \in CM$$

Export Price

$$PE_{r,c} = PWE_c \cdot dis_exp_{r,c} \cdot (1 - te_{r,c}) \cdot \overline{EXR}_r, \quad \forall r \in R, c \in CE$$

Demand Price of Domestic Non-traded Goods

$$PDD_{r,c} = PDS_{r,c}, \quad \forall r \in R, c \in CD$$

Absorption

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

Commodity market monetary balance

$$PQ_{r,c} \cdot QQ_{r,c} = PQD_{r,c} \cdot \left(\sum_{a \in A} pfdq_{r,c,a} \cdot QINT_{r,c,a} + \sum_{h \in H} pfdq_{r,c,h} \cdot QH_{r,c,h} \right) + pfdq_{r,c,"gov"} \cdot QG_{r,c} + pfdq_{r,c,"S-I"} \cdot QINV_{r,c}, \quad \forall r \in R, c \in CX$$

Marketed Output with stock change

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

Marketed Output Value with stock change

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

Marketed Output Value

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

Activity Price

$$PA_{r,a} \cdot QA_{r,a} \cdot (1 + RQUOQA_{r,a}) = \sum_{c \in C} PXAC_{r,a,c} \cdot QXAC_{r,a,c}, \quad \forall r \in R, a \in A$$

Aggregate Non-energy Intermediate Input Price

$$PINTA_{r,a} = \sum_{c \in CNEN} PQ_{r,c} \cdot pfdq_{r,c,a} \cdot QINT_{r,c,a} (1 + tqd_{r,c,a}) \cdot ica_{r,c,a}, \quad \forall r \in R, a \in A$$

Activity Revenue and Costs (Non-energy transformation sector)

$$PA_{r,a} \cdot (1 - ta_{r,a}) \cdot QA_{r,a} = PVAE_{r,a} \cdot QVAE_{r,a} + PENE_{r,a} \cdot QENE_{r,a} + PRES_{r,a} \cdot QRES_{r,a} + GHGCA_NENE_{r,a} + VRENCAP_{r,a} \cdot QA_{r,a} + \sum_{emcm \in EMCM} QRED_{r,emcm,a}, \quad \forall r \in R, a \in ACES$$

Activity Revenue and Costs (Energy transformation sector)

$$PA_{r,a} \cdot (1 - ta_{r,a}) \cdot QA_{r,a} = PVA_{r,a} \cdot QVA_{r,a} + PINTA_{r,a} \cdot QINTA_{r,a} + PENE_{r,a} \cdot QENE_{r,a} + PRES_{r,a} \cdot QRES_{r,a} + GHGCA_NENE_{r,a} + VRENCAP_{r,a} \cdot QA_{r,a} + \sum_{emcm \in EMCM} QRED_{r,emcm,a}, \quad \forall r \in R, a \in ALEO$$

Resource Input Price

$$PA_{r,a} = PRES_{r,a}, \quad \forall r \in R, a \in A$$

Consumer Price Index

$$CPI_r = \sum_{c \in C} PQD_{r,c} \cdot dfpq_{r,c,"hurb"} \cdot (1 + tqd_{r,c,"hurb"}) \cdot cwtS_{r,c}, \quad \forall r \in R$$

Producer Price Index for Nontraded Market Output

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

Export Price Index

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

Import Price Index

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

Governmental consumption Price Index

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

Capital Formation Price Index

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

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

$$QVA_{r,a} = iva_{r,a} \cdot QA_{r,a}, \quad \forall r \in R, a \in ALEO$$

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

$$QENE_{r,a} = iena_{r,a} \cdot QA_{r,a}, \quad \forall r \in R, a \in ALEO$$

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

$$QVAE_{r,a} = iva_{e,r,a} \cdot QA_{r,a}, \quad \forall r \in R, a \in ACES$$

Leontief Technology: Demand for Aggregate Non-energy Intermediate Input

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

Leontief Technology: Demand for Resource Input

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

Energy and Value-Added composite

$$QVAE_{r,a} = \alpha_{r,a}^{vae} \cdot \left(\left(\frac{QENE_{r,a}}{1 - ADEEI_{r,a}} \right)^{-\rho_{r,a}^{vae}} + QVA_{r,a}^{-\rho_{r,a}^{vae}} \right)^{-\frac{1}{\rho_{r,a}^{vae}}}, \quad \forall r \in R, a \in ACES$$

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

$$\frac{\left(\frac{QENE_{r,a}}{1 - ADEEI_{r,a}} \right)}{QVA_{r,a}} = \left(\frac{\delta_{r,a}^{vae} \cdot PENE_{r,a}}{1 - \delta_{r,a}^{vae} \cdot PFFL_{r,a}} \right)^{\frac{1}{1 + \rho_{r,a}^{vae}}}, \quad \forall r \in R, a \in ACES$$

Energy and Value-Added composite balance

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

Additional energy efficiency improvement (Industry)

$$ADEEI_{r,a} = 1 - \left(\frac{PENE_{r,a}}{PENE_{r,a}^{bau}} \right)^{-\sigma_{r,a}^{eff}}, \quad \forall r \in R, a \in ACES$$

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

$$QVAE_{r,a} = QVA_{r,a}, \quad \forall r \in R, a \in ACES$$

Value-Added and Factor Demands

$$QVA_{r,a} = \alpha_{r,a}^{va} \cdot \left(\sum_{f \in F} \delta_{r,a}^{va} \cdot QF_{r,f,a}^{-\rho_{r,a}^{va}} \right)^{-\frac{1}{\rho_{r,a}^{va}}}, \quad \forall r \in R, a \in A$$

Factor Demand

$$WF_{r,f} \cdot WFDIST_{r,f,a} = PVA_{r,a} \cdot (1 - tva_{r,a}) \cdot QVA_{r,a} \cdot \left(\sum_{f \in F} \delta_{r,a}^{va} \cdot QF_{r,f,a}^{-\rho_{r,a}^{va}} \right)^{-1} \cdot \delta_{r,a}^{va} \cdot QF_{r,f,a}^{-\rho_{r,a}^{va}-1}, \\ \forall r \in R, a \in A, f \in F$$

Capital aggregation: CES Function

$$QF_{r,ncap,a} = \alpha_{r,a}^f \cdot \left(\delta_{r,a}^f \cdot QF_{r,ncap,a}^{-\rho_{r,a}^f} + (1 - \delta_{r,a}^f) \cdot QF_{r,ncap,a}^{-\rho_{r,a}^f} \right)^{-\frac{1}{\rho_{r,a}^f}}, \quad \forall r \in R, a \in A$$

Capital aggregation of CES Technology: old and new capital - Input Ratio

$$\frac{QF_{r,ncap,a}}{QF_{r,ncap,a}} = \left(\frac{\delta_{r,a}^f}{1 - \delta_{r,a}^f} \cdot \frac{WF_{r,ncap} \cdot WFDIST_{r,ncap,a}}{WF_{r,ncap} \cdot WFDIST_{r,ncap,a}} \right)^{\frac{1}{1 + \rho_{r,a}^f}}, \quad \forall r \in R, a \in A$$

Capital Input Costs

$$QF_{r,ncap,a} \cdot WF_{r,ncap} \cdot WFDIST_{r,ncap,a} = \sum_{f \in FCAP} QF_{r,f,a} \cdot WF_{r,f} \cdot WFDIST_{r,f,a}, \quad \forall r \in R, a \in A$$

Disaggregated Intermediate Input Demand

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

Energy Input Technology: CES Function

$$QENE_{r,a} = \alpha_{r,a}^{el} \cdot \left(\delta_{r,a}^{el} \cdot QINT_{r,ely,a}^{-\rho_{r,a}^{el}} + (1 - \delta_{r,a}^{el}) \cdot QFFL_{r,a}^{-\rho_{r,a}^{el}} \right)^{-\frac{1}{\rho_{r,a}^{el}}}, \quad \forall r \in R, a \in ACES_ENE$$

Energy Input CES Technology: Electricity – Fossil Fuel -Input Ratio

$$\frac{QINT_{r,ely,a}}{QFFL_{r,a}} = \left(\frac{\delta_{r,a}^{el}}{1 - \delta_{r,a}^{el}} \cdot \frac{PQD_{r,ely,a} \cdot (1 + tqd_{r,ely,a})}{PFFL_{r,a}} \right)^{\frac{1}{1 + \rho_{r,a}^{el}}}, \quad \forall r \in R, a \in ACES_ENE$$

Energy Input Costs

$$PENE_{r,a} \cdot QENE_{r,a} = PQ_{r,ely,a} \cdot (1 + tqd_{r,ely,a}) \cdot QINT_{r,ely,a} + PFFL_{r,a} \cdot QFFL_{r,a}, \quad \forall r \in R, a \in ACES_ENE$$

Fossil fuel consumption and Its allocation

$$QFFL_{r,a} = \alpha_{r,a}^{ff} \cdot \left(\sum_{c \in CFF} \delta_{r,c,a}^{ff} \cdot QINT_{r,c,a}^{-\rho_{r,a}^{ff}} \right)^{-\frac{1}{\rho_{r,a}^{ff}}}, \quad \forall r \in R, a \in ACES_ENE$$

First-Order Condition for Fossil Fuel Consumption

$$PQD_{r,c} \cdot dfpq_{r,c,a} \cdot (1 + tqd_{r,c,a}) + GHGCA_ENE_{r,c,a} \\ = PFFL_{r,a} \cdot QFFL_{r,a} \left(\sum_{c \in CFF} \delta_{r,c,a}^{ff} \cdot QINT_{r,c,a}^{-\rho_{r,a}^{ff}} \right)^{\frac{1}{1 + \rho_{r,a}^{ff}}} \delta_{r,c,a}^{ff} \cdot QINT_{r,c,a}^{-\rho_{r,a}^{ff}-1}, \\ \forall r \in R, a \in ACES_ENE, c \in CFF$$

Energy Consumption of Energy Transformation sector

$$QINT_{r,c,a} = QENE_{r,a} \cdot iene_{r,c,a}, \quad \forall r \in R, a \in ALEO_ENE, c \in ENE$$

Energy Costs of Energy Transformation Sector

$$PENE_{r,a} \cdot QENE_{r,a} = \sum_{c \in ENE} \left\{ PINT_{r,c,a} \cdot (1 + tqd_{r,c,a}) \cdot QINT_{r,c,a} + GHGCA_ENE_{r,c,a} \right\}, \quad \forall r \in R, a \in ALEO_ENE$$

Commodity Production and Allocation

$$QXAC_{r,a,c} = \theta_{r,a,c} \cdot QA_{r,a}, \quad \forall r \in R, a \in A, c \in CX$$

Commodity Production and Allocation (non-energy commodities)

$$QX_{r,c} = \alpha_{r,c}^{ac} \cdot \left(\sum_{a \in A} \delta_{r,a,c}^{ac} \cdot QXAC_{r,a,c}^{-\rho_{r,c}^{ac}} \right)^{\frac{1}{\rho_{r,c}^{ac}}}, \quad \forall r \in R, c \in (CX - ENE)$$

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

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

Share of Commodity Production and Allocation (energy commodities)

$$SHAC_{r,a,c} = \frac{\psi_{r,a,c}^{ac} \left(\frac{PXAC_{r,a,c}}{pxac_{r,a,c}^{pre}} \right)^{\eta_{r,a,c}^{ac}}}{\sum_{ap \in A} \psi_{r,ap,c}^{ac} \left(\frac{PXAC_{r,ap,c}}{pxac_{r,ap,c}^{pre}} \right)^{\eta_{r,ap,c}^{ac}}}, \quad \forall r \in R, c \in (CX \cap ENE)$$

Commodity Production and Allocation (energy commodities)

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

Balance of the output and commodity aggregate (energy commodities)

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

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

$$QX2_{r,c} = \alpha_{r,c}^t \cdot \left(\delta_{r,c}^t \cdot QE_{r,c}^{\rho_{r,c}^t} + (1 - \delta_{r,c}^t) \cdot QD_{r,c}^{\rho_{r,c}^t} \right)^{\frac{1}{\rho_{r,c}^t}}, \quad \forall r \in R, c \in (CE \cap CD - ENE)$$

Export-Domestic Supply Ratio (Non-energy commodities)

$$\frac{QE_{r,c}}{QD_{r,c}} = \left(\frac{PE_{r,c}}{PDS_{r,c}} \cdot \frac{1 - \delta_{r,c}^t}{\delta_{r,c}^t} \right)^{\frac{1}{\rho_{r,c}^t - 1}}, \quad \forall r \in R, c \in (CE \cap CD - ENE)$$

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

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

Share of the Domestically sold and export (energy commodities)

$$SHQE_{r,c} = \frac{\psi_{r,c}^t \left(\frac{PE_{r,c}}{pe_{r,c}^{pre}} \right)^{\eta_{r,c}^t}}{\psi_{r,c}^t \left(\frac{PE_{r,c}}{pe_{r,c}^{pre}} \right)^{\eta_{r,c}^t} + (1 - \psi_{r,c}^t) \left(\frac{PDS_{r,c}}{pds_{r,c}^{pre}} \right)^{\eta_{r,c}^t}}, \quad \forall r \in R, c \in (CE \cap CD \cap ENE)$$

Exported energy commodities

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

Domestically sold energy commodities

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

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

$$QQ_{r,c} = \alpha_{r,c}^q \cdot \left(\delta_{r,c}^q \cdot QM_{r,c}^{-\rho_{r,c}^q} + (1 - \delta_{r,c}^q) \cdot QD_{r,c}^{-\rho_{r,c}^q} \right)^{\frac{1}{\rho_{r,c}^q}}, \quad \forall r \in R, c \in (CM \cap CD - ENE)$$

Import-Domestic Demand Ratio (non-energy commodities)

$$\frac{QM_{r,c}}{QD_{r,c}} = \left(\frac{PDD_{r,c} \cdot 1 - \delta_{r,c}^q}{PM_{r,c} \cdot \delta_{r,c}^q} \right)^{\frac{1}{\rho_{r,c}^q + 1}}, \quad \forall r \in R, c \in (CM \cap CD - ENE)$$

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

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

Share of the domestically sold and imported (energy commodities)

$$SHQM_{r,c} = \frac{\psi_{r,c}^m \left(\frac{PM_{r,c}}{pm_{r,c}^{pre}} \right)^{\eta_{r,c}^m}}{\psi_{r,c}^m \left(\frac{PM_{r,c}}{pm_{r,c}^{pre}} \right)^{\eta_{r,c}^m} + (1 - \psi_{r,c}^m) \left(\frac{PDD_{r,c}}{pdd_{r,c}^{pre}} \right)^{\eta_{r,c}^m}}, \quad \forall r \in R, c \in (CM \cap CD \cap ENE)$$

Imported energy commodities

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

Domestically sold energy commodities

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

Factor Income

$$YF_{r,f} = \sum_{a \in A} WF_{r,f} \cdot WFDIST_{r,f,a} \cdot QF_{r,f,a} + \text{transfr}_{-f,r,f} \cdot EXR_r, \quad \forall r \in R, f \in F$$

Institutional Factor Incomes

$$YIF_{r,i,f} = \text{shif}_{r,i,f} \cdot \left((1 - \text{tf}_{r,f}) \cdot YF_{r,f} - \text{transfr}_{r,f} \cdot EXR_r \right), \quad \forall r \in R, i \in \text{INSD}, f \in F$$

Income of non-governmental domestic Institution

$$\begin{aligned} YI_{r,i} = & \sum_{f \in F} YIF_{r,i,f} + \text{TRII_Resource}_{r,i} \\ & + \text{shincome}_{r,i} \cdot \text{GHGTCOST}_r + \text{VRENCAPTOT}_{r,i} \\ & + (\text{PGHG_G} + \text{PGHG_IMP_QUO}_r - \text{PGHG_EXP_QUO}_r) \cdot \text{GHG_IMP}_r \cdot \text{EXR}_r \cdot \text{shincome}_{r,i} \\ & + \text{shincome}_{r,i} \cdot \sum_{a \in A} \sum_{\text{emcm} \in \text{EMCM}} QRED_{r,\text{emcm},a} \\ & + \text{shincome}_{r,i} \cdot \sum_{a \in A} RQUOQA_{r,a} \cdot QA_{r,a} \cdot PA_{r,a} \\ & + \text{shres}_{r,i} \cdot \sum_{a \in A} PRES_{r,a} \cdot QRES_{r,a}, \quad \forall r \in R, i \in \text{INSDNG} \end{aligned}$$

Total rent of electricity capacity

$$\text{VRENCAPTOT}_{r,"ent"} = \sum_{a \in A} \text{VRENCAP}_{r,a} \quad \forall r \in R$$

Household Consumption Expenditures

$$EH_{r,h} = (1 - \text{shii_use}_{r,h}) (1 - \text{MPS}_{r,h}) \cdot (1 - \text{TINS}_{r,h}) \cdot YI_{r,h} - \text{GHGCH}_{r,h}, \quad \forall r \in R, h \in H$$

Household Consumption Spending

$$\begin{aligned} & \left(PQD_{r,c} \cdot dfpq_{r,c,h} \cdot (1 + tqd_{r,c,h}) + \sum_{g \in G} PGHG_r \cdot gwp_g \cdot effc_{r,c,h,g} \right) \cdot QH_{r,c,h} \\ & = \left(PQD_{r,c} \cdot dfpq_{r,c,h} \cdot (1 + tqd_{r,c,h}) + \sum_{g \in G} PGHG_r \cdot gwp_g \cdot effc_{r,c,h,g} \right) \cdot \gamma_{r,c,h}^m \cdot (1 - ADEEI_{r,h})^{-1}, \quad \forall r \in R, c \in C, \forall h \in H \\ & + \beta_{r,c,h}^m \cdot \left(EH_{r,h} - \sum_{c' \in C} \left(PQD_{r,c'} \cdot dfpq_{r,c',h} \cdot (1 + tqd_{r,c',h}) + \sum_{g \in G} PGHG_r \cdot gwp_g \cdot effc_{r,c',h,g} \right) \cdot \gamma_{r,c',h}^m \cdot (1 - ADEEI_{r,h})^{-1} \right) \end{aligned}$$

Additional energy efficiency improvement (Household)

$$ADEEI_{r,h} = 1 - \left(\frac{PENE_H_{r,h}}{PENE_H_{r,h}^{bau}} \right)^{-\sigma_{r,h}^{eff}}, \quad \forall r \in R, h \in H$$

Energy price of household

$$PENE_H_{r,h} = \frac{\sum_{c \in ENE} \left(PQD_{r,c} \cdot dfpq_{r,c,h} \cdot (1 + tqd_{r,c,h}) + \sum_{g \in G} PGHG_r \cdot gwp_g \cdot effc_{r,c,h,g} \right) \cdot QH_{r,c,h}}{\sum_{c \in ENE} QH_{r,c,h}}, \quad \forall r \in R, \forall h \in H$$

Investment Demand

$$QINV_{r,c} = IADJ_r \cdot \overline{qinv_{r,c}}, \quad \forall r \in R, c \in C$$

Government Consumption Demand

$$QG_{r,c} = \overline{GADJ_r} \cdot \overline{qg_{r,c}}, \quad \forall r \in R, c \in C$$

Government Revenue

$$\begin{aligned} YG_r = & \sum_{i \in INSDNG} TINS_{r,i} \cdot YI_{r,i} + \sum_{f \in F} tf_{r,f} \cdot YF_{r,f} + \sum_{a \in A} ta_{r,a} \cdot PA_{r,a} \cdot QA_{r,a} + \sum_{a \in A} tva_{r,a} \cdot PVA_{r,a} \cdot QVA_{r,a} \\ & + \sum_{c \in CM} tm_{r,c} \cdot PWM_c \cdot \overline{QM}_{r,c} \cdot \overline{EXR}_r + \sum_{c \in CE} te_{r,c} \cdot PWE_c \cdot \overline{QE}_{r,c} \cdot \overline{EXR}_r \\ & + \sum_{c \in C} \sum_{a \in A} tqd_{r,c,a} \cdot dfpq_{r,c,a} \cdot PQD_{r,c} \cdot \overline{QINT}_{r,c,a} + \sum_{c \in C} \sum_{h \in H} tqd_{r,c,h} \cdot dfpq_{r,c,h} \cdot PQD_{r,c} \cdot QH_{r,c,h} \\ & + \sum_{c \in C} tqd_{r,c,"gov"} \cdot dfpq_{r,c,"gov"} \cdot PQD_{r,c} \cdot QG_{r,c} + \sum_{c \in C} tqd_{r,c,"S-I"} \cdot dfpq_{r,c,"S-I"} \cdot PQD_{r,c} \cdot QINV_{r,c} \\ & + \sum_{f \in F} YIF_{r,gov,f} + TRII_Resource_{r,gov} \\ & + GHGTCOST_r \cdot shincome_{r,"gov"} \\ & + GHG_IMP_r \cdot EXR_r \cdot (PGHG_G + PGHG_IMP_QUO_r - PGHG_EXP_QUO_r) \\ & + shincome_{r,"gov"} \cdot \sum_{a \in A} QA_{r,a} \cdot VRENCAP_{r,a} + shres_{r,"gov"} \cdot \sum_{a \in A} PRES_{r,a} \cdot QRES_{r,a} \quad \forall r \in R \end{aligned}$$

Government Expenditure

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

Transfer use

$$TRII_Use_{r,i} = shii_use_{r,i} \cdot (1 - MPS_{r,i}) \cdot (1 - TINS_{r,i}) \cdot YI_{r,i}, \quad \forall r \in R, i \in INSDNG$$

Government transfer use

$$TRII_Use_{r,"gov"} = \overline{trnsfr_CRT_{r,"gov"}} \cdot CPI_r \quad \forall r \in R$$

Transfer resource

$$TRII_Resource_{r,i} = shii_resource_{r,i} \cdot \left(crt_in_r \cdot \overline{EXR}_r - crt_out_r \cdot \overline{EXR}_r + \sum_{i'} TRII_Use_{r,i'} \right), \quad \forall r \in R, i \in INSD$$

Imported commodity

$$QWM_{r,c} = QM_{r,c}, \quad \forall r \in R, c \in CM$$

Exported commodity

$$QWE_{r,c} = QE_{r,c}, \quad \forall r \in R, c \in CE$$

World trade nominal balance

$$\begin{aligned} & \sum_{r \in R} (1 - tw_{r,c}) \cdot PWM_c \cdot QWM_{r,c} \cdot dis_imp_{r,c} \\ &= \sum_{r \in R} PWE_c \cdot QWE_{r,c} \cdot dis_exp_{r,c} + PTRS_c \cdot QTRS_c, \quad \forall c \in (CM \cap CE) \end{aligned}$$

World trade volume balance

$$\sum_{r \in R} QWM_{r,c} = (1 - \lambda_c^w) \cdot \sum_{r \in R} (QWE_{r,c} - QTRS_c), \quad \forall c \in (CM \cap CE)$$

Transport service demand

$$QTRS_c = tsh_c \cdot \sum_r QWE_{r,c}, \quad \forall c \in C_TRS$$

CIF and FOB relationship

$$PTRS_c \cdot QTRS_c = \sum_{r'} tw_{r',c} \cdot PWM_c \cdot QWM_{r',c} \cdot dis_imp_{r',c}, \quad \forall c \in C_TRS$$

Biomass consumption (Household)

$$TBH_{r,h} = \frac{EH_{r,h}}{CPI_r} \cdot bioc_{r,h} \cdot biod_{r,h} \quad \forall r \in R, h \in H$$

Biomass consumption (Industry)

$$TBI_{r,a} = QA_{r,a} \cdot bioc_{r,a} \cdot biod_{r,a} \quad \forall r \in R, a \in A$$

Emissions related to activity level (Industrial activity)

$$\begin{aligned} EMALI_{r,a,g} &= QA_{r,a} \cdot efacl_{r,a,g} \cdot (1 - NERED_{r,a,g}) \cdot (1 + \chi_{r,a,g}) \\ &\quad - \sum_{emcm \in EMCM} \left(\frac{QRED_{r,emcm,a}}{\eta_{emcm,a}} \right), \quad \forall r \in R, a \in A, g \in G \end{aligned}$$

Additional emission reductions related to activity level (Industrial activity)

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

Emissions related to activity level (household)

$$EMALH_{r,h,g} = \frac{EH_{r,h}}{CPI_r} \cdot efacl_{r,h,g} \quad \forall r \in R, h \in H, g \in G$$

Emissions related to fossil fuel combustion (Industrial activity)

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

Emissions related to fossil fuel combustion (household)

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

Emissions related to biomass combustion (Industrial activity)

$$EMBII_{r,a,g} = TBI_{r,a} \cdot efbio_{r,a,g} \quad \forall r \in R, a \in A, g \in G$$

Emissions related to biomass combustion (household activity)

$$EMBIH_{r,h,g} = TBH_{r,h} \cdot efbio_{r,h,g} \quad \forall r \in R, h \in H, g \in G$$

GHG emission total in a region

$$GHGT_r = \sum_{g \in G} gwp_g \cdot \left\{ \begin{array}{l} \left(\sum_{h \in H} \sum_{c \in C} EMFFH_{r,c,h,g} + \sum_{a \in A} \sum_{c \in C} EMFFI_{r,c,a,g} \right) \\ + \left(\sum_{h \in H} EMALH_{r,h,g} + \sum_{a \in A} EMALI_{r,a,g} \right) \\ + \left(\sum_{h \in H} EMBIH_{r,h,g} + \sum_{a \in A} EMBII_{r,a,g} \right) \end{array} \right\} \quad \forall r \in R$$

GHG emission includes emission trading

$$GHGT_CT_r = GHGT_r - GHGT_IMP_r \quad \forall r \in R$$

GHG emission importing trading upper limit

$$\overline{ghgt_imp_cap_r} - GHGT_IMP_r \geq 0 \perp PGHG_IMP_QUO_r \geq 0 \quad \forall r \in R$$

GHG emission exporting trading upper limit

$$GHGT_IMP_r - \overline{ghgt_exp_cap_r} \geq 0 \perp PGHG_EXP_QUO_r \geq 0 \quad \forall r \in R$$

GHG emission price nad international price

$$PGHG_r = EXR_r \cdot (PGHG_G + PGHG_IMP_QUO_r - PGHG_EXP_QUO_r) \quad \forall r \in R$$

GHG emission constraint

$$\overline{ghgc_r} - GHGT_CT_r \geq 0 \perp PGHG_r \geq 0 \quad \forall r \in R$$

GHG emission cost of energy (Industry)

$$GHGCA_ENE_{r,c,a} = PGHG_r \cdot \sum_{g \in G} gwp_g \cdot EMFFI_{r,c,a,g} \quad \forall r \in R, a \in A$$

GHG emission cost of non-energy (Industry)

$$GHGCA_NENE_{r,a} = PGHG_r \cdot \sum_{g \in G} gwp_g \cdot (EMBI_{r,a,g} + EMALI_{r,a,g}) \quad \forall r \in R, a \in A$$

GHG emission cost of household

$$GHGCH_{r,h} = PGHG_r \cdot \sum_{g \in G} gwp_g \cdot \left(\sum_{c \in C} EMFFH_{r,c,h,g} + EMALH_{r,h,g} + EMBIH_{r,h,g} \right) \quad \forall r \in R, h \in H$$

GHG total cost

$$GHGTCOST_r = \sum_{a \in A} GHGCA_{r,a} + \sum_{h \in H} GHGCH_{r,h} \quad \forall r \in R$$

Global GHG emission constraint

$$\overline{ghgtot_c} - \sum_{r \in R} GHGT_CT_r \geq 0 \quad \perp PGHG_G \geq 0$$

Global GHG emission constraint price

$$PGHG_G = PGHG_r, \quad \forall r \in R$$

Global GHG emission trading total

$$\sum_{r \in R} GHG_IMP_r = 0$$

GHG emission related to the international bankers

$$EMFFINT = \sum_{r \in R} \sum_{c \in C} \lambda_c \cdot QWE_{r,c} \cdot efit_c$$

Factor Markets

$$\sum_{a \in A} QF_{r,f,a} = \overline{QFS}_{r,f}, \quad \forall r \in R, f \in F$$

Composite Commodity Markets

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

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

$$\begin{aligned} \sum_{c \in CM} PM_{r,c} \cdot QM_{r,c} + transfr_crt_out_r + GHG_IMP_r \cdot PGHG_r \\ = \sum_{c \in CE} PE_{r,c} \cdot QE_{r,c} + transfr_crt_in_r + \overline{FSAV}_r \quad \forall r \in R \end{aligned}$$

Government Balance

$$YG_r = EG_r + GSAV_r \quad \forall r \in R$$

Direc Tax Rate

$$TINS_{r,i} = \overline{tins}_{r,i} \cdot (1 + \overline{TINSADJ}_r \cdot tins01_{r,i}) + \overline{DTINS}_{r,i} \cdot tins01_{r,i}, \quad \forall r \in R, i \in INSDNG$$

Institutional Savings Rates

$$MPS_{r,i} = \overline{mps}_{r,i} \cdot (1 + \overline{MPSADJ}_r \cdot mps01_{r,i}) + \overline{DMPS}_r \cdot mps01_{r,i}, \quad \forall r \in R, i \in INSDNG$$

Savings–Investment Balance

$$\begin{aligned} \sum_{i \in \text{INSDNG}} \text{MPS}_{r,i} \cdot (1 - \text{TINS}_{r,i}) \cdot \text{YI}_{r,i} + \text{GSAV}_r + \overline{\text{FSAV}}_r \cdot \overline{\text{EXR}}_r \\ = \sum_{c \in \text{C}} \text{PQ}_{r,c} \cdot (1 + \text{tq}_{r,c, "I-S"}) \cdot \text{QINV}_{r,i} \quad \forall r \in \text{R} \end{aligned}$$

Global Investment Balance

$$\sum_{r \in \text{R}} \text{FSAV}_r = 0$$

Activity constraint (Upper boundary)

$$\text{renew_up}_{r,a} - \text{QA}_{r,a} \geq 0 \quad \text{VRENCAP}_{r,a} \geq 0, \quad \forall r \in \text{R}, a \in \text{A} = \{\text{renew_up}_{r,a} > 0\}$$

Activity constraint (QUOTA)

$$\begin{aligned} \text{quota} \text{a}_{\text{ragg}, \text{aagg}} = \sum_{r \in \text{Map_Ragg}(r, \text{ragg})} \sum_{a \in \text{Map_aagg}(a, \text{aagg})} \sum_{c \in \text{C}} \text{QA}_{r,a} \cdot \theta_{r,a,c} \geq 0 \perp \text{RQUOQA_aagg}_{\text{ragg}, \text{aagg}} \geq 0, \\ \forall \text{ragg} \in \text{Ragg}, \text{aagg} \in \text{Aagg} \end{aligned}$$

Reduction measures (for non-energy related GHG emissions)

$$\begin{aligned} \text{QRED}_{r, \text{emcm}, a} = \xi_{\text{emcm}, a}^{\max} \cdot \eta_{\text{emcm}, a} \cdot \sum_{g \in \text{G}} \text{gwp}_g \cdot \text{EMALI}_{r, a, g} \cdot \left(\frac{\text{PGHG}_r}{\eta_{\text{emcm}, a} \cdot (1 + \text{SURGHG}_{r, \text{emcm}, a})} \right)^2, \\ \forall r \in \text{R}, a \in \text{A}, \text{emcm} \in \text{EMCM0} \end{aligned}$$

Reduction measures upper boundary (for non-energy related GHG emissions)

$$\xi_{\text{emcm}, a}^{\max} \cdot \eta_{\text{emcm}, a} \cdot \sum_{g \in \text{G}} \text{gwp}_g \cdot \text{EMALI}_{r, a, g} \geq \text{QRED}_{r, \text{emcm}, a} \perp \text{SURGHG}_{r, \text{emcm}, a} \geq 0, \forall r \in \text{R}, a \in \text{A}, \text{emcm} \in \text{EMCM0}$$

Reduction measures (for Energy related GHG emissions)

$$\begin{aligned} \text{QRED}_{r, \text{emcm}, a} = \xi_{\text{emcm}, a}^{\max} \cdot \eta_{\text{emcm}, a} \cdot \sum_{c \in \text{ENE}} \sum_{g \in \text{G}} \text{gwp}_g \cdot \text{EMFFI}_{r, a, c, g} \cdot \left(\frac{\text{PGHG}_r}{\eta_{\text{emcm}, a} \cdot (1 + \text{SURGHG}_{r, \text{emcm}, a})} \right), \\ \forall r \in \text{R}, a \in \text{A}, \text{emcm} \in \text{EMCM1} \end{aligned}$$

Reduction measures (for biomass power plant GHG absorption)

$$\begin{aligned} \text{QRED}_{r, \text{emcm}, a} = \xi_{\text{emcm}, a}^{\max} \cdot \eta_{\text{emcm}, a} \cdot \sum_{g \in \text{G}} \text{gwp}_g \cdot \text{EMBII}_{r, a, g} \cdot \left(\frac{\text{PGHG}_r}{\eta_{\text{emcm}, a} \cdot (1 + \text{SURGHG}_{r, \text{emcm}, a})} \right), \\ \forall r \in \text{R}, a \in \text{A}, \text{emcm} \in \text{EMCM2} \end{aligned}$$

Reduction measures upper boundary (for energy related GHG emissions)

$$\begin{aligned} \xi_{\text{emcm}, a}^{\max} \cdot \eta_{\text{emcm}, a} \cdot \sum_{c \in \text{ENE}} \sum_{g \in \text{G}} \text{gwp}_g \cdot \text{EFFII}_{r, a, c, g} \geq \text{QRED}_{r, \text{emcm}, a} \perp \text{SURGHG}_{r, \text{emcm}, a} \geq 0, \\ \forall r \in \text{R}, a \in \text{A}, \text{emcm} \in \text{EMCM1} \end{aligned}$$

Reduction measures upper boundary (for biomass power plant GHG absorption)

$$\xi_{\text{emcm}, a}^{\max} \cdot \eta_{\text{emcm}, a} \cdot \sum_{g \in \text{G}} \text{gwp}_g \cdot \text{EMBII}_{r, a, g} \geq \text{QRED}_{r, \text{emcm}, a} \perp \text{SURGHG}_{r, \text{emcm}, a} \geq 0, \forall r \in \text{R}, a \in \text{A}, \text{emcm} \in \text{EMCM2}$$

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