Model Documentation

BAEGEMv22.1 and BAEGEM database2017 – the BAEconomics computable general equilibrium model of the world economy

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1. Overview

BAEGEM is a recursively dynamic computable general equilibrium (CGE) model of the world economy. The model was developed by BAEconomics Pty Ltd using a global social accounting matrix (SAM) and other satellite datasets (i.e. energy and emission datasets). Each individual economy (representing 21 countries or regions) in the model is represented by a set of rational, interdependent economic agents whose flows of goods and money are quantified in the social accounting matrix (SAM). These economic agents are producers, consumers, governments, investors, importers, exporters, and international transportation providers.

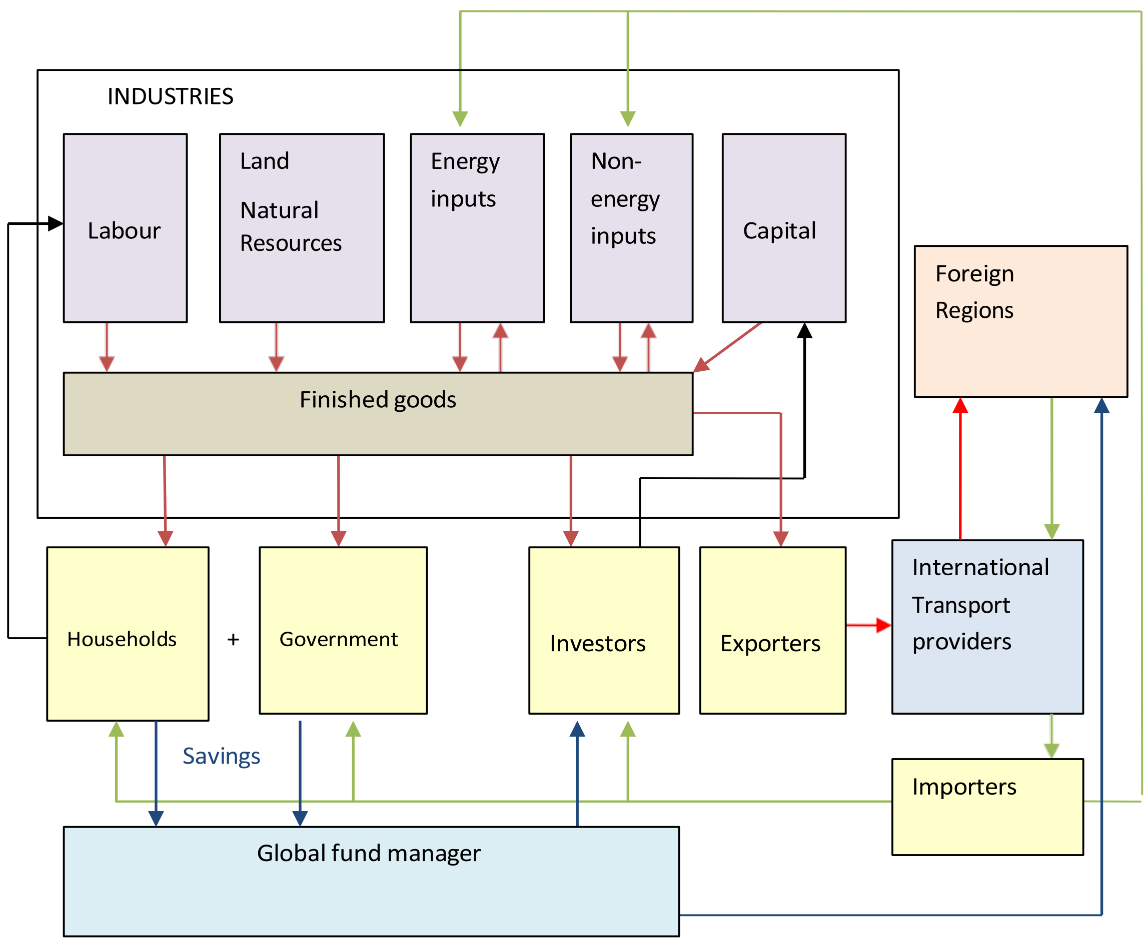
BAEGEM assumes that the world economy reflected in the SAM for 2017 is in general equilibrium. This is a state where money received by each economic agent is equal to their own expenditure. It is also a state derived from multiple input-output tables where demand for each good and service is equal to its individual supply. For each one-year time step from 2018, BAEGEM simulates the transactions between each economic agent by assuming prices are flexible enough to clear all product and factor markets simultaneously. Product and factor markets are assumed to be flexible, and a new equilibrium can be achieved in the same year with no excess supply or demand. It is further assumed that, for every year from 2018, the balance of payments for each economy is in equilibrium.

The central core of the BAEGEM model is built on the familiar approaches of the GTAP model (Hertel 1997) and the GTEM model (Pant 2007). Producers use primary factors and intermediate inputs to produce final products. Final products are purchased by domestic households, governments, producers, investors, and exporters to meet their individual demands. Each year households and governments save a portion of their income, and the money is allocated to a fund manager for investment in regions with the highest returns adjusted for risk. The key interactions between economic agents in BAEGEM is illustrated in figure 1. The substitution between inputs in the production sectors and the selection of the consumption bundle in the household sector are shaped by neoclassical economic theory; producers minimise their production costs for a given output while consumers maximise their satisfaction under a consumption budget constraint.

In addition to the core module, BAEGEM includes three interlinked satellite modules:

(i) the government module; (ii) the energy module, and (iii) the greenhouse gas emissions module. The government module is used to represent government budget positions and the interactions with expenditure and tax revenue. The energy module is used to demonstrate the physical flows of energy in and out of each sector. The greenhouse gas module is used to model the flows of greenhouse gases in each economy and their interaction with climate change parameters and climate and energy policies. All satellite modules in BAEGEM can be detached from the core module if they are not required. With all the modules coupled together, BAEGEM is ideally suited for analysing energy policies, greenhouse gas emissions, government budget positions, global demand for energy, mining and agricultural commodities, trade and impacts of major projects.

Figure 1.1 A schematic diagram of BAEGEM



BAEGEM is written in GEMPACK (Horridge et al. 2018), a suite of economic modelling software specially designed for CGE modelling. For each one-year time-step, the model simultaneously solves a system of linear and non-linear equations that primarily determine quantities and prices of commodities purchased by each economic agent. The results will automatically update the SAM for the current simulation period and become the new input for the next period. This reflects the recursive dynamics of the model where the computation repeats itself for every year for a specified period and produces an updated SAM for every year with supply and demand equal in all markets.

A suite of models based on the BAEGEM structure have been developed to study developing countries and the impact on those economies of the development of very large mineral projects. These models are known as MINCGEM. Details of MINCGEM-Mongolia, for example, can be found in Fisher et al. (2011).

2. BAEGEM database

BAEGEM2017 is the latest database and represents the state of the world economy in 2017. It has been derived from several sources. The central core of the BAEGEM2017 database is a global Social Accounting Matrix (SAM), which captures the annual flow of economic transactions among households, governments, producers, investors, and international transportation providers in 2017. Key economic transactions in the SAM such as household consumption, government consumption, investment, exports and imports are created by benchmarking with the 2017 national accounts data from the International Monetary Fund and the United Nations. The input-output structure of each production sector is derived from the GTAP v10.0 database (Narayanan et al. 2015) and various national input-output tables. For Australia, the construction of the 2017 SAM is supplemented by the industry gross value-added data and industry import and export data from the Australian Bureau of Statistics (ABS). To achieve a balanced SAM for 2017, a generalised RAS method is used to reconcile data from various sources with more weight given to more recent data.

The standard BAEGEM2017 database divides the world into 21 regions and 24 production sectors. Each production sector is assumed to produce a single, homogenous commodity within their regions. The full list of regions and production sectors is shown in Table 1.1. As shown in Table 1.1, the current BAEGEM2017 database has a strong focus on energy and mineral commodities.

Table 1.1 Economies and production sectors represented in BAEGEM2017

No.	Economy	No.	Production sector
1	US	1	Crop
2	Canada	2	Livestock
3	Mexico	3	Forestry
4	UK	4	Fishing
5	EU27	5	Thermal coal
6	Former Soviet Union	6	Coking coal
7	Rest of Europe	7	Oil
8	China	8	Gas
9	India	9	Coal Products
10	Japan	10	Oil Products
11	Korea	11	Iron Ore
12	Australia	12	Other mining
13	Indonesia	13	Food, Beverages, and Tobacco
14	Mid-income ASEAN	14	Chemicals and Chemical Products
15	Low-income ASEAN	15	Non-Metallic Mineral Manufacturing
16	Reat of Asia	16	Iron and Steel Manufacturing
17	Brazil	17	Non-Ferrous Metal Manufacturing
18	Rest of Latin America	18	Other Manufacturing
19	Middle East	19	Electricity
20	South Africa (country)	20	Gas Supply
21	Rest of Africa	21	Construction
		22	Land Transport
		23	Water and Air Transport
		24	Services

BAEGEM has the capacity to model more than 21 regions and 24 production sectors. However, more granularity increases the simulation times. For projects requiring more granularity, regions or production sectors from the table above can be disaggregated. For example, copper mining can be disaggregated from the other mining sector listed in Table 1.1.

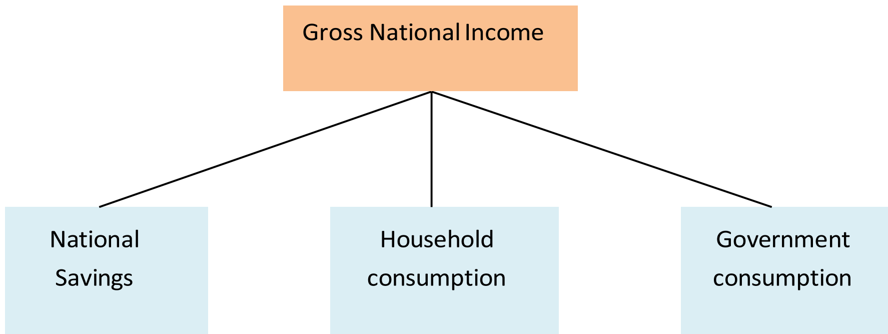
Physical energy data and electricity generation mix data in the standard BAEGEM2017 database were collected from IEA publications. Australian emissions for 2017 were collected from the Australian Department of Environment. International emissions for 2017 were derived from the GTAP10.0 database, the IEA CO_2 emission database and the EDGAR 6.0 database (Crippa et al. 2020). The data in the government module was sourced from the IMF World Economic Outlook database.

3. Modelling Framework

3.1 Allocation of national income between final consumptions and savings

Gross National Income (GNI) is the national income earned by its citizens, including income obtained from other economies. It is modelled explicitly in BAEGEM, along with GDP. The allocation of national income for each economy is based on its preferences for private and public goods and investment. Unlike other CGE models, fixed proportion or fixed preference utility functions are not used in BAEGEM to define these preferences. Instead, it allows the shares of household consumption, government consumption and national savings to be determined exogenously or by extrapolation from recent national account data. For each time step, the distribution between household and government consumption and national savings is set to equal GNI (Figure 3.1).

Figure 3.1 Distribution of national income



National savings (S) is defined as a function of GNI and the average propensity to save (APS):

(1) $S = f_1(GNI, APS)$

Under the default condition, APS is either unchanged or moved slightly in one direction. Users are allowed to alter the APS by using their own estimates.

Government consumption (G) is defined as a function of budget deficit (BD) and public debt to GDP ratio (DGDP) from the previous year, plus GNI in the current year and a slack variable (ε):

(2) $G = f_2(GNI, BD_{-1}, DGDP_{-1}, \varepsilon)$

BD, DGDP and GNI are determined endogenously within the model. A higher budget deficit or public debt to GDP ratio in one year has a negative effect on public consumption the following year. Under the default condition, ε is set to 0 and has no influence on public consumption. By choosing a suitable ε, users may alter the growth rate of government consumption.

Household consumption (C) in region *i* is defined as the residual of the GNI identity:

(3) $$C = GNI - G - S$$

3.2 Primary factors for production

Capital, labour, land and natural resources are included as primary factors of production. Capital is further divided into mining capital and non-mining capital. Mining capital is exclusively used by mining sectors while non-mining capital is used by all production sectors. Land is used exclusively by the agriculture sector while natural resources are used exclusively by the mining and energy sectors. Rent paid to each primary factor forms part of the gross value-added for each production sector.

In terms of the supply dynamics, land and natural resources supplies are modelled as a function of market price where an increase in market price will increase the supply for that factor. Labour is assumed to be mobile across production sectors but immobile across economies. Labour supply in an economy is a function of population and demographics.

Under the default condition, labour supply growth rates are derived from the recent UN Population Prospects (United Nations 2022).

Physical capital stock is divided into mining capital stock and non-mining capital stock, consistent with two types of capital rent. It is assumed that each type of capital stock *i* loses its production capacity by a depreciation rate *Depr(i,r)* every year but gains back additional capacity from new real investment *Qcgds(i,r)*:

(4) $$K_{i,t} = K_{i,t-1}(1 - Depr_i) + Qcgd_{i,t}$$

where $K_{i,t}$ is the capital stock for capital *i* at period *t*.

3.3 Investment

It is assumed that investors are allowed to allocate their new investment freely across all economies. For each period, new investment is added to its own type of domestic capital stock and increases domestic production capacity. Once capital formation is completed, the existing capital stock is not allowed to move across economies. The real investment allocated to an economy is represented by the following equation:

(5) $$Qcgd_{i,r} = \frac{A_{i,r} S_r}{Pcgd_{i,r}} e^{\rho_{i,r}(\beta_{i,r} r_{i,r} - \overline{r_i})}$$

where $Pcgd_{i,r}$ is the price of capital goods *i*, S_r is the regional savings, $\rho_{i,r}$ is a responsiveness parameter with respect to expected rate of return differential and it is greater than zero. $\beta_{i,r}$ is a risk factor parameter and it is also greater than zero. $r_{i,r}$ is the expected rate of return of capital *i* in region r. $\overline{r_i}$ is the average global return of capital *i.*

$A_{i,r}$ is an adjustment factor such that $\sum_{i,r} S_r = \sum_{i,r} A_{i,r} S_r e^{\rho_{i,r}(\beta_{i,r} r_{i,r} - \overline{r_i})}$

As shown in equation 5, the real investment for capital goods *i* rise if its expected rate of return increases or national savings in the region increases, with other variables remaining the same. The parameter $\beta_{i,r}$ represents the risk factor perceived by international investors. $\beta_{i,r}$ is generally set to less than 1 for developing economies and greater than 1 for developed economies. Economies with a higher degree of openness or political stability attract a relatively higher value.

The parameter $\rho_{i,r}$ calibrates the investment response with respect to the expected rate of return differential. $\rho_{i,r}$ for mining capital is generally set relatively higher than that for non-mining capital as mining capital is exclusively used by mining sectors. $A_{i,r}$ is an adjustment factor that can be treated as exogenous or endogenous. If it is treated as exogenous, at least one $A_{i,r}$ must be treated as endogenous to ensure global investment is equal to global savings in nominal terms.

It should be noted that BAEGEM is a recursive dynamic model and does not have the capability to provide forward-looking insight on the expected rate of return. Therefore, the expected rate of return for capital goods *i* in equation 5 is replaced by the current rate of return during implementation. That is, when the model is doing the computation for 2023, the expected rate of return is the computed rate of return for 2023.

The above assumption is not ideal because investment decisions are largely based on investors' perceptions about the future, rather than current or historical performance. However, modelling investment and expected rates of return are among some of the most difficult tasks for macroeconomic modellers. In this regard, BAEGEM provides an option for users to implement their own projections if better information is available. This option is well suited to some modelling exercises where major investment in a section of the economy has been independently estimated.

3.4 Household consumption

The quantity of goods and services consumed in a region is modelled as a utility maximisation problem faced by an average, representative consumer. In each year, the representative consumer receives a per person expenditure budget (*C/pop*), which is equal to the total household consumption expenditure derived in section 3.1 divided by regional population (*pop)*. Given the per person expenditure budget, the representative consumer chooses a bundle of composite goods and services based on prices and the respective regional preference. The total household demand is thus the quantity of goods and services chosen in the bundle multiplied by regional population.

The consumption preference of the representative consumer is represented by a Constant Difference in Elasticity (CDE) implicit expenditure function:

(6) $$1=\sum_{i} B_i U^{\beta_i \gamma_i} (P_i / E)^{\beta_i}$$

where U, E and P_i are utility, per person expenditure and price of commodity *i* while B_i, β_i, γ_i denote the distribution, substitution and expansion parameters.

The CDE functional form was first proposed by Hanoch (1975). It is not a fully flexible functional form but it is globally regular. It satisfies the theoretical criteria in relation to whether a functional form can be used to describe consumer expenditure behaviour, namely: (a) convexity; (b) monotonicity; (c) homogeneity; (d) adding-up and (e) non-negativity. Further, the CDE functional form is non-homothetic. It allows budget share spent on each commodity to change over time as national income grows. This property is important because empirical evidence suggests that consumers spend proportionally larger shares of their income on luxury goods when certain income levels are exceeded.

The calibration of the CDE expenditure function is slightly more complicated than a CES function but it is less demanding than flexible functional forms. The own-price and cross-price Allen partial elasticities of substitution of the CDE expenditure function are simply a function of a single parameter, α_i, plus consumption shares (Equations 7 and 8).

(7) $$APE_{i,k}=\alpha_i+\alpha_k+\sum_{m}(s_m \alpha_m)$$

(8) $$APE_{i,i}=2\alpha_i+\sum_{m}(s_m \alpha_m)-s_i \alpha_i$$

where $\alpha_i = 1-\beta_i$ and s_i is consumption share

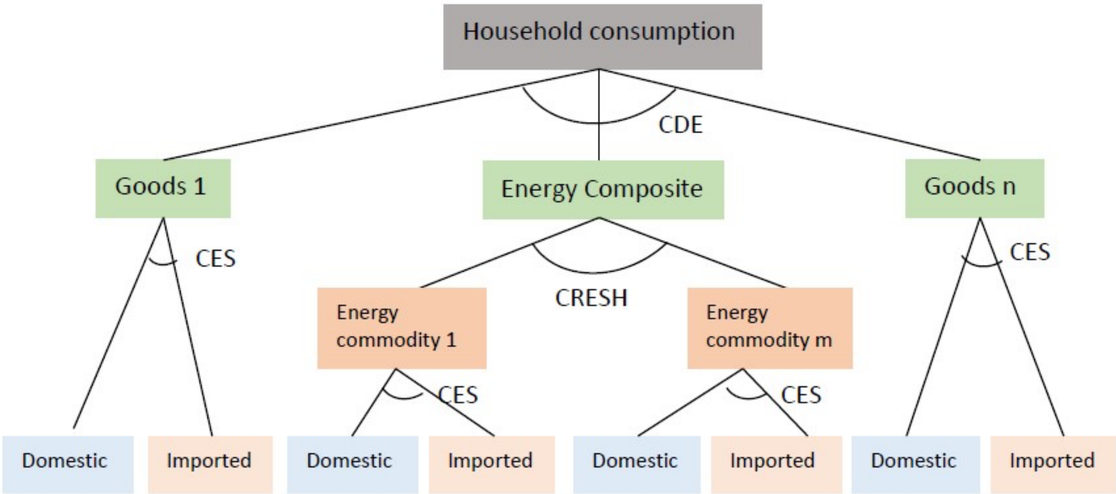
The income elasticities of demand are a function of consumption shares, α_i and γ_i

(equation 9). After the own-price and cross-price Allen partial elasticities of substitution are calibrated, the observed income elasticities of demand can be used to calibrate expenditure function.

(9) $$EY_i=\frac{\gamma_i(1-\alpha_i)}{[\sum_{m}(s_m \gamma_m)]}+\sum_{m}(s_m \gamma_m \alpha_m)+\alpha_i-\sum_{m}(s_m \alpha_m)$$

As shown in figure 3.2, household consumption demand is modelled by three nested levels. First, a CDE functional form is used to determine the demand for the energy composite and other individual commodities. At the second level, a CRESH functional form is used to determine the demand for individual energy commodities including electricity and gas. At the third level, a CES functional form is used to determine domestic and imported shares of each commodity.

Figure 3.2 Decision tree for household consumption



3.5 Government consumption

The quantity of goods and services consumed by the government is modelled by a similar methodology for households except the top decision level is replaced by a Cobb-Douglas function. This implies the share of expenditure of each composite commodity at the top level is invariant to the total expenditure, but each commodity can be substituted at the lower levels.

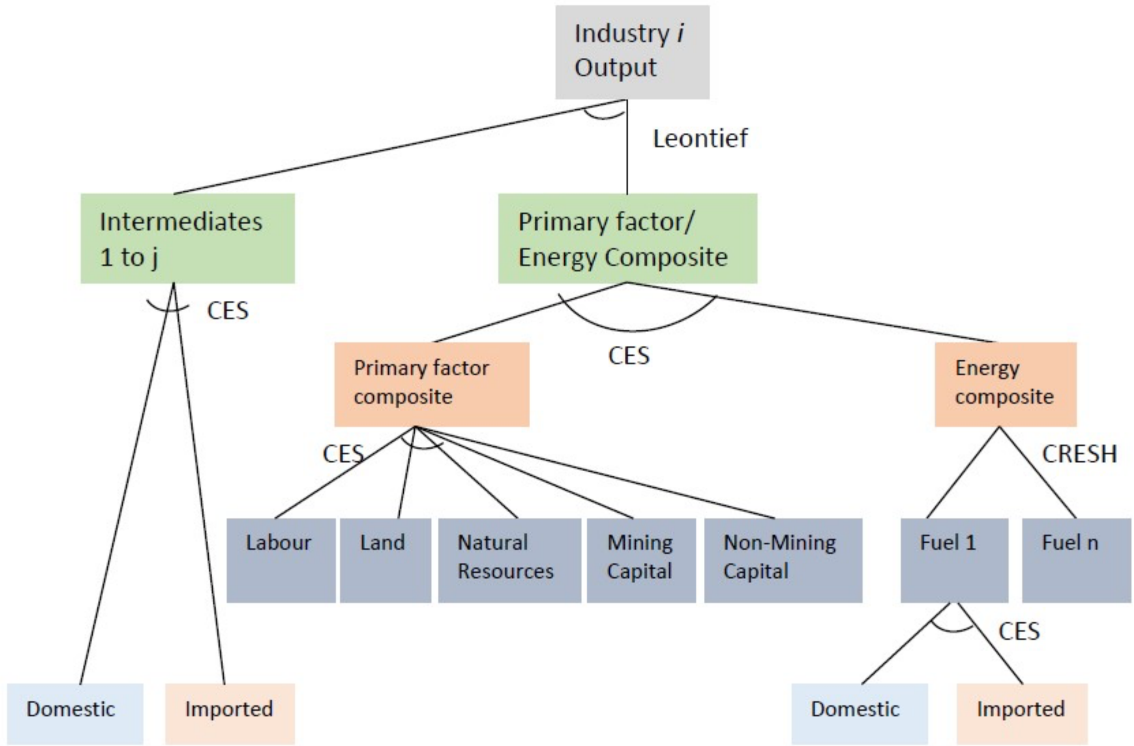
3.6 Production

The latest BAEGEM model 24 production sectors simultaneously (Table 1.1). It assumes each production sector produces a single, homogenous commodity inside each economy. Firms in each production sector behave competitively such that the total revenue received by the sector is equal to the cost of production including payment for primary factors. The total input demand for a production sector is modelled under the assumption of an average firm. For each year, the average firm minimises expenditure for the whole production sector based on its information on sectoral output, prices and substitutability between inputs.

3.6.1 Input demand for production sectors

As shown in figure 3.3, input demand for each production sector is modelled by a four-level nested structure. At the top level a Leontief function is used to determine the quantity of non-energy commodities and the energy-primary factor composite required for a given output. At the second level, a CES function is used to separate the quantity of the energy-primary factor composite into an energy composite and a primary factor composite. At the third level, a CRESH functional form is used to determine the input demand for individual energy commodities while a CES function is used to determine the input requirements of individual primary factors. At the bottom level, a CES function is used to determine the domestic and imported shares of each commodity input.

Figure 3.3 Input demand for production sectors



3.6.2 Technology bundle sectors

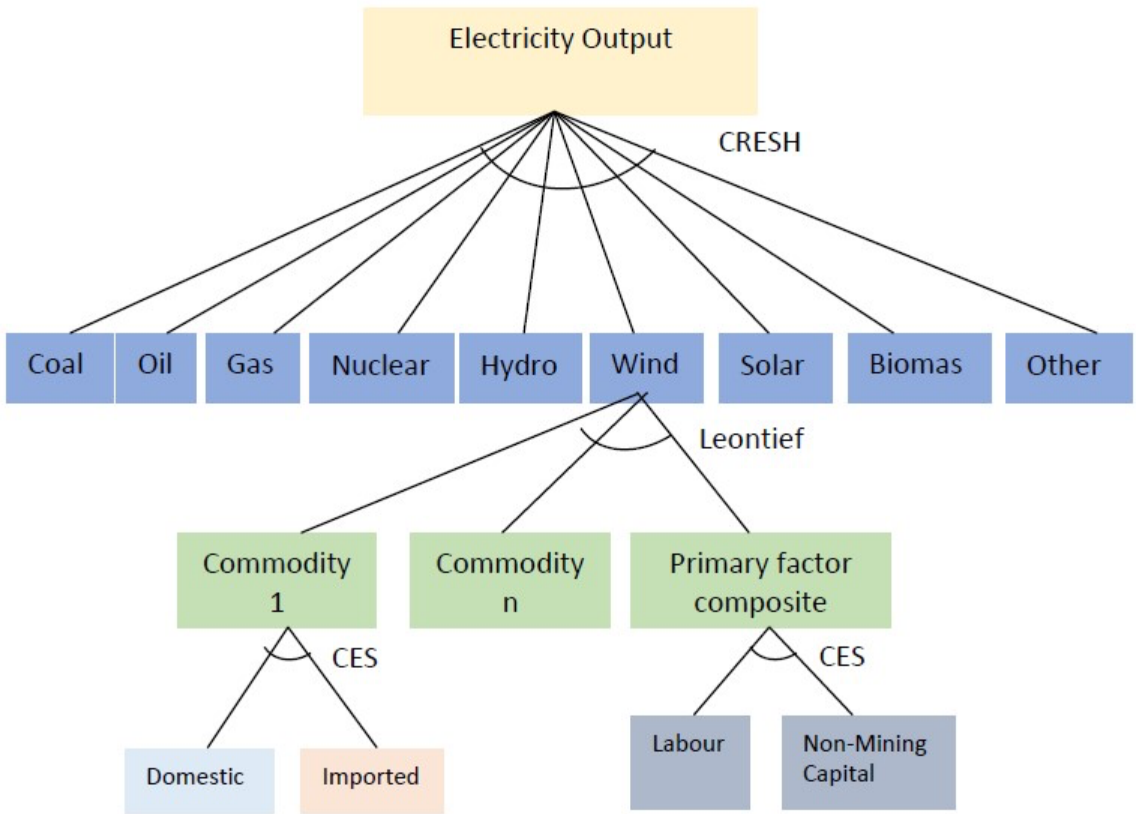
In BAEGEM, the electricity sector, the iron and steel manufacturing sector and the road transport sector are modelled separately as 'technology-bundle' sectors. Input decisions for these production sectors are slightly different to those shown in figure 3.3. The 'technology bundle' approach was initially used by GTEM (Pant 2007) in modelling substitution between production technologies. It is assumed that each technology in a sector produces the same finished product but uses a different mix of inputs. Therefore, any substitutions between production technologies would have implications for the balance of supply and demand in the whole economic system.

The 'technology bundle' approach is a bottom-up approach because it ensures the total output of all identified technologies is equal to the output of the sector. The purpose of integrating a bottom-up approach into BAEGEM is to better represent the technology specific detail of key production sectors while retaining the benefits of the top-down interactions with other sectors in the economy. The main assumption is that the commodity produced by each production technology is a homogenous product and thus outputs can be aggregated in quantity terms. For each time-step, substitution between technologies is determined by the progress of each technology and price differentials.

The input demand for the electricity sector is shown in figure 3.4. The total GWh produced by the sector is the total output of 9 technologies including coal, oil, gas, nuclear, hydro, wind, solar, biomass, and other renewable technologies. The substitution possibilities between electricity technologies are governed by a Constant Ratios of Elasticity of Substitution and Homothetic (CRESH) aggregation function. The CRESH functional form is a generalisation of the CES function and allows different elasticity of substitutions between its elements. In other words, certain technologies identified in the framework can be more substitutable with other technologies. The use of the family of CRESH aggregation functions accounts for the fact that electricity, which is a homogenous output, can be generated in an economy simultaneously from different technologies with different production costs. This approach prevents the model generating a result where the lowest cost technology takes the whole market.

The direction of technology substitution in the sector is affected by the price movement of inputs identified in the nested, multi-stage production structure. As shown in figure 3.4, each technology uses fixed proportion combinations of intermediate inputs and a primary factor composite to produce electricity output in the second level, subject to technological progress. At the next level, producers determine the quantity of individual primary factors and the domestic and imported shares of each intermediate input they need via CES functions. Price changes in any inputs identified in the production structure affect the differential costs of production between technologies, which in turn affect substitution between technologies. The same input demand structure is applied to the iron and steel manufacturing sector and the road transport sector.

Figure 3.4 Input demand for the electricity sector

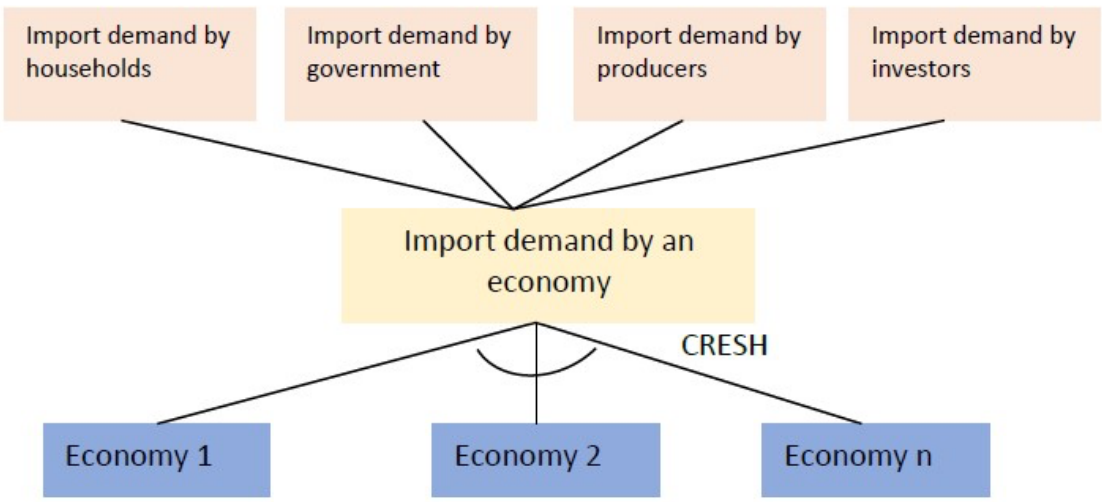


3.7 International Trade

The demand for commodities from foreign sources is modelled by a two-step approach (figure 3.5). First, sectoral import demand from households, government, producers and investors are added together to get a regional total for each economy. Next, the importer determines the quantity of imports from each individual economy based on the regional total and a CRESH aggregation function.

The use of a CRESH aggregation function implies that a commodity produced from one foreign source is not a perfect substitute for a commodity produced in the same production sector by another foreign source. In other words, this justifies importation of a commodity from various regions instead of from the region with the lowest price. It should be noted that exports are not modelled separately in BAEGEM as imports of commodity *i* from region *A* to region *B* are equal to exports from region *B* to region *A*. This two-step approach is commonly used by CGE models because it reduces the burden of creating separate sets of bilateral trade data for each economic agent.

Figure 3.5 Import demand for commodity *i*



3.8 International Transportation

The international transportation margin is modelled as a decision-making process by a fictitious international transportation provider. The demand for international transportation from region *A* to region *B* is modelled to grow proportionally with real exports, adjusted by technological improvement in the transportation service sectors. No substitution is allowed for the transport mode. Supply of transportation services to the international transportation provider is sourced from all regions based on a Cobb-Douglas expenditure function.

3.9 Tracking government income and expenditure

The government module is used to monitor government debt over the projection period from its interactions with expenditure and revenue. Total government revenue in BAEGEM divides into tax revenue and non-tax revenue. Tax revenue collected from economic activities is recorded in the base year SAM. Taxes include taxes on final consumption, taxes on intermediate inputs, taxes on production output, taxes paid by firms for use of primary factors, taxes paid by capital and labour, import and export tariffs, and taxes on emissions. Each of these revenue sources are modelled explicitly by BAEGEM.

Tax revenue from each revenue source is linked directly to its tax rate and the total value of economic activity. Non- tax revenue is modelled as a proportion of the total capital rent received by the economy.

3.10 Tracking the world energy balance

The energy module tracks production of primary and secondary energy, and consumption of final energy by government, households, firms and exporters in energy units. Changes in energy balances from one year to another are linked directly to the results computed in the core module. Changes in production of primary and secondary energy are derived from the quantity produced by each energy commodity. Changes in consumption of final energy are derived from the quantity consumed by each consumption sector. The energy database in the base year is derived from the IEA energy balance database.

3.11 Tracking greenhouse gas emissions

The greenhouse gas emissions module tracks six emission gases (i.e. CO_2, CH_4, N_2O, HFCs, PFCs and SF_6) over the course of production, transformation, consumption and combustion. For each time step, emissions of each gas are computed from the change in total economic activities and change in emission factors.

Projections of global average temperature changes since the beginning of the industrial revolution can be computed from the greenhouse gas emissions pathways projected in BAEGEM by coupling the greenhouse gas emissions module with a reduced form climate model such as MAGGIC/SCENGEN 7. The projections of radiative forcing agents other than the six gases tracked by BAEGEM are selected from emission scenarios in MAGICC/SCENGEN 7 (Meinshausen et al. 2011) according to modelling criteria, assumptions and applications.

BAEGEM assumes constant proportionality of emissions with respect to the quantity of fossil fuel combusted over time for a given technology. The disaggregated CO_2 emissions for the base year are derived from the GTAP 10.0 database with adjustments to ensure that aggregate combustion emissions at the country level are consistent with the IEA combustion emission database.

Non-combustion emissions, such as fugitive emissions from fossil fuel mining, enteric fermentation in livestock production and chemical transformation in manufacturing processes, are assumed to move proportionally with their production levels adjusted by EMF21 marginal abatement curves (Weyant et al. 2006). The use of marginal abatement curves in the module allows a gradual reduction of non-combustion emissions per unit of output with additional reduction opportunities when the carbon price increases. The disaggregated non-CO_2 emissions for the base year are derived from the US EPA database (US EPA 2012) and the GTAP 10.0 database with adjustments to ensure that aggregated non-CO_2 emissions are consistent with the latest IEA non- CO_2 emissions database.

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