To pdf - GEM-E3

From IAMC-Documentation

Reference card - GEM-E3

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The reference card is a clearly defined description of model features. The numerous options have been organized into a limited amount of default and model specific (non default) options. In addition some features are described by a short clarifying text.

Legend:

- □ not implemented
- **☑** implemented
- **☑** implemented (not default option)

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About

Name and version GEM-E3

Institution and users Institute of Communication And Computer Systems (ICCS), Greece, .

Documentation GEM-E3 documentation consists of a referencecard and detailed model

documentation

Model scope and methods

Model documentation: Model scope and methods - GEM-E3

Objective The model puts emphasis on: i) The analysis of market instruments for energy-

related environmental policy, such as taxes, subsidies, regulations, emission permits etc., at a degree of detail that is sufficient for national, sectoral and Worldwide policy evaluation. ii) The assessment of distributional consequences of programmes and policies, including social equity, employment and cohesion for

less developed regions.

Concept General equilibrium

Solution method The model is formulated as a simultaneous system of equations with an equal

number of variables. The system is solved for each year following a time-forward path. The model uses the GAMS software and is written as a mixed non-linear complementarity problem solved by using the PATH algorithm using the standard

solver options.

Anticipation Myopic

Temporal dimension Base year:2011, time steps: Five year time steps, horizon: 2050

Spatial dimension Number of regions:38

1. Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, United Kingdom, Greece, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Poland, Portugal, Slovakia, Slovenia, Sweden, Romania, USA, Japan, Canada, Brazil, China, India, Oceania, Russian federation, Rest of Annex I, Rest of the World **Policy** Taxes, Permits trading, Subsidies, Energy efficiency standards, CO2 standards, **implementation** Emission reduction targets, Trade agreements.

Socio economic drivers

Model	documenta	ition: Socio)-economic (drivers - (jEM-E3	

Exogenous drivers

Development

Exogenous GDP

Total Factor Productivity
Labour Productivity
Capital Technical progress
Exogenous GDP

Materials Technical progress
GDP per capita
Learning-by-doing
Education level
Labour participation rate

Macro economy

Model documentation: Macro-economy - GEM-E3

Economic sectors

☑ Agriculture

☐ Urbanisation rate

☑ Industry

☑ Energy

☑ Transport

☑ Services

☑ other

Note: GEM-E3 represents 29 sectors: Agriculture, Coal, Crude Oil, Oil, Gas, Electricity supply, Ferrous and non ferrous metals, Chemical Products, Other energy intensive, Electric Goods, Transport equipment, Other Equipment Goods, Consumer Goods Industries, Construction, Transport (Air), Transport (Land), Transport (Water), Market Services, Non Market Services, Coal fired, Oil fired, Gas

fired, Nuclear, Biomass, Hydro

electric, Wind, PV, CCS coal, CCS Gas

Cost measures

Welfare loss
Consumption loss

Coal
Coil
Gas
Uranium
Electricity
Bioenergy crops
Food crops

☐ Capital

☑ Emissions permits

☑ GDP loss

☐ Area under MAC☐ Energy system costs

☑ Non-energy goods

☑ Agriculture

☑ Ferrous and non ferrous metals

☑ Chemical Products

☑ Other energy intensive

☑ Electric Goods

☑ Transport equipment

☑ Other Equipment Goods

☑ Consumer Goods Industries

Note: The model links all countries and sectors through endogenous bilateral trade transactions.

Energy

Model documentation: Energy - GEM-E3

Behaviour

The GEM-E3 model endogenously computes energy consumption, depending on energy prices, realised energy efficiency expenditures and autonomous energy efficiency improvements. Each agent decides how much energy it will consume in order to optimise its behaviour (i.e. to maximise profits for firms and utility for households) subject to technological constraints (i.e. a production function). At a sectoral level, energy consumption is derived from profit maximization under a nested CES (Constant Elasticity of Substitution) specification. Energy enters the production function together with other production factors (capital, labour, materials). Substitution of energy and the rest of the production factors is imperfect (energy is considered an essential input to the production process) and it is induced by changes in the relative prices of each input. Residential energy consumption is derived from the utility maximization problem of households. Households allocate their income between different consumption categories and savings to maximize their utility subject to their budget constraint. Consumption is split between durable (i.e. vehicles, electric appliances) and non-durable goods. For durable goods, stock accumulation depends on new purchases and scrapping. Durable goods consume (non-durable) goods and services, including energy products. The latter are endogenously determined depending on the stock of durable goods and on relative energy prices.

Resource use	☑ Coal ☑ Oil	☐ Uranium☑ Biomass
Electricity technologies	☑ Gas ☑ Coal ☑ Gas ☑ Oil ☑ Nuclear ☑ Biomass	 ✓ Wind ✓ Solar PV □ CCS ✓ Hydropower ✓ CCS
Conversion technologies	□ CHP□ Heat pumps□ Hydrogen	☐ Fuel to gas ☐ Fuel to liquid
Grid and infrastructure	✓ Electricity☐ Gas☐ Heat	□ CO2 □ H2
Energy technology substitution	☑ Discrete technology choices☐ Expansion and decline constraints	☐ System integration constraints
Energy service sectors	☑ Transportation☑ Industry	☑ Residential and commercial

Land-use

Model documentation: Land-use - GEM-E3; Non-climate sustainability dimension - GEM-E3

Land-use

☑ GEM-E3 considers land as a separate production factor

Other resources

Model documentation: N	on-climate sustainability dimension - GEM	<i>1-E3</i>
Other resources	□ Water□ Metals	☐ Cement
Emissions and c	elimate	
Model documentation: E	missions - GEM-E3; Climate - GEM-E3	
Green house gasses	☑ CO2 ☑ CH4 ☑ N2O	☑ HFCs ☑ CFCs ☑ SF6
Pollutants	☑ NOx ☑ SOx □ BC	□ OC □ Ozone
Climate indicators	□ CO2e concentration (ppm)□ Climate damages \$ or equivalent	☐ Radiative Forcing (W/m²) ☐ Temperature change (°C)
	Note: GEM-E3 model does not include climate indicators.	

Model Documentation - GEM-E3

1) Model scope and methods - GEM-E3

The General Equilibrium Model for Economy-Energy-Environment (GEM-E3) is a multi-regional, multi-sectoral, recursive dynamic computable general equilibrium (CGE) model which provides details on the macro-economy and its interaction with the environment and the energy system. It is an empirical, large scale model written entirely in structural form.

GEM-E3 incorporates micro-economic mechanisms and institutional features within a consistent macro-economic framework and avoids the representation of behaviour in reduced form. The GEM-E3 model includes projections of: full Input-Output tables by country/region, national accounts, employment, balance of payments, public finance and revenues, household consumption, energy use and supply, GHG emissions and atmospheric pollutants.

The model features perfect competition market regimes, discrete representation of power producing technologies, semiendogenous learning by doing effects, equilibrium unemployment, option to introduce energy efficiency standards, formulates emission permits for GHG and atmospheric pollutants. The environmental module includes flexibility instruments allowing for a variety of options when simulating emission abatement policies, including: different allocation schemes (grandfathering, auctioning, etc.), user-defined bubbles for traders, various systems of exemptions, various systems for revenue recycling, etc.

1.1) Model concept, solver and details - GEM-E3

The scope of GEM-E3 is general in two terms: it includes all simultaneously interrelated markets and represents the system at the appropriate level with respect to geography, the sub-system (energy, environment, economy) and the dynamic mechanisms of agent's behaviour.

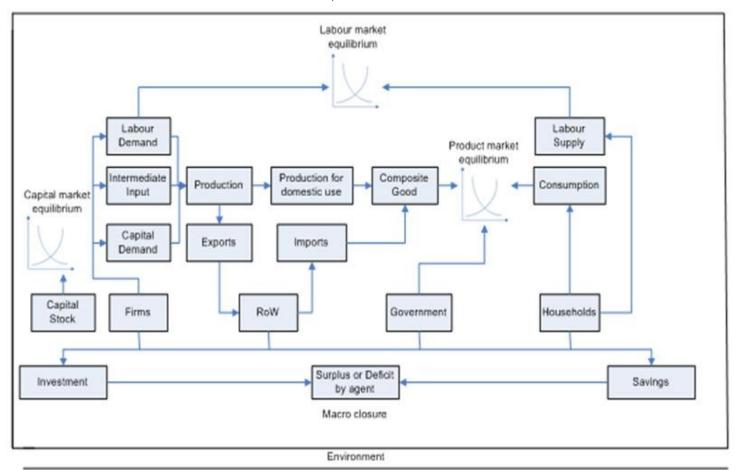
The model is not limited to comparative static evaluation of policies. The model is dynamic in the sense that projections change over time. Its properties are mainly manifested through stock/flow relationships, technical progress, capital accumulation and agents' (myopic) expectations.

The design of GEM-E3 model has been developed following four main guidelines:

- Model design around a basic general equilibrium core in a modular way so that different modelling options, market regimes and closure rules are supported by the same model specification
- Fully flexible (endogenous) coefficients in production and in consumer's demand
- Calibration to a base year data set, incorporating detailed Social Accounting Matrices as statistically observed
- Dynamic mechanisms, through the accumulation of capital stock.

The GEM-E3 model starts from the same basic structure as the standard World Bank models. Following the tradition of these models, GEM-E3 is built on the basis of a Social Accounting Matrix (SAM). The model is calibrated to a base year data set that comprises a full SAM for each country/region represented in the model. Bilateral trade flows are also calibrated for each sector represented in the model, taking into account trade margins and transport costs. Consumption and investment is built around transition matrices linking consumption by purpose to demand for goods and investment by origin to investment by destination. The initial starting point of the model therefore, includes a very detailed treatment of taxation and trade.

Figure 1: GEM-E3 economic circuit



The GEM-E3 model is built in a modular way around its central CGE core. It supports defining several alternative regimes and closure rules without having to re-specify or re-calibrate the model. The most important of these options are presented below:

- Capital mobility across sectors and/or countries
- Flexible or fixed current account (with respect to the foreign sector)
- Flexible or fixed labour supply
- Market for pollution permits national/international, environmental constraints
- Fixed or flexible public deficit
- Perfect competition or Nash-Cournot competition assumptions for market competition regimes.

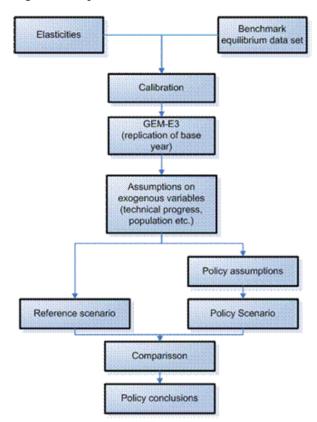
Reference scenario and counterfactual simulations

Once the model is calibrated, the next step is to define a reference case scenario. The reference case scenario includes all already decided policies. The key drivers of economic growth in the model are labour force, total factor productivity and the expectations on sectoral growth.

The "counterfactual" equilibria can be computed by running the model under assumptions that diverge from those of the reference scenario. This corresponds to scenario building. In this case, a scenario is defined as a set of changes of exogenous variables, for example a change in the tax rates. Changes of institutional regimes, that are expected to occur in the future, may be reflected by changing values of the appropriate elasticities and other model parameters that allow structural shifts (e.g. market regime). These changes are imposed on top of the assumptions of the reference scenario thereby modifying it.

To perform a counterfactual simulation it is not necessary to re-calibrate the model. The different steps for performing a counterfactual simulation in GEM-E3 are depicted in the figure below.

Figure 2: Steps for scenario simulation in GEM-E3



A counterfactual simulation is characterized by its impact on consumer's welfare or through the equivalent variation of his welfare function. The approach adopted in most of the applied general equilibrium models regards the use of the monetary utility function, which measures the nominal income that the consumer needs for a given price vector in order to be at the same welfare level with a different income level and a price vector. With this measure it is possible to quantify the effects on welfare of alternative policy scenarios. This measure shows the income that should be given to/taken off the consumer so as to be found at the same welfare level found with the reference scenario prices. A positive value of this measure means a positive change in consumer welfare. The equivalent variation can be, under reasonable assumptions, directly mapped to some of the endogenous variables of the model such as consumption, employment and price levels.

The most important results, provided by GEM-E3, are as follows:

- Dynamic annual projections in volume, value and deflators of national accounts by country
- Full Input-Output tables for each country/region identified in the model
- Distribution of income and transfers in the form of a social accounting matrix by country
- Employment, capital, investment by country and sector
- Greenhouse gasses, atmospheric emissions, pollution abatement capital, purchase of pollution permits and damages
- Consumption matrix by product and investment matrix by ownership branch
- Public finance, tax incidence and revenues by country
- Full bilateral trade matrices.

Solution algorithm

The model is formulated as a simultaneous system of equations with an equal number of variables. The system is solved for each year following a time-forward path. The model uses the GAMS software and is written as a mixed non-linear complementarity problem solved by using the PATH algorithm using the standard solver options.

The model is modularly built allowing the user to select among a number of alternative closure options and market institutional regimes depending on the issue under study.

History of GEM-E3

The GEM-E3 model is the result of a collaborative effort by the National Technical University of Athens (NTUA/E3M-Lab, leading partner), Katholieke Universiteit of Leuven (KUL), University of Manheim and the centre for European Economic Research (ZEW), Ecole Centrale de Paris (ERASME) as the core modelling team. NTUA/E3M-Lab have maintained and further developed the GEM-E3 model in various aspects including the introduction of market imperfections, the construction of GEM-E3 world version, bottom-up representation of power generation technologies, equilibrium unemployment, a complete coverage of all GHG, and the introduction of semi-endogenous growth features.

Applications of the model have been carried out for several Directorate Generals of the European Commission (economic affairs, competition, environment, taxation, research) and for national authorities. GEM-E3 is used regularly to provide analytical support to European Commission services, particularly with regards to the economics of climate change.

1.3) Temporal dimension - GEM-E3

GEM-E3 is a recursive dynamic model solved sequentially over time. In GEM-E3 model agents have myopic expectations. Their future planning is based on current prices. It is assumed that investment that takes place in time t increases the production capacity at time t+1. The current version of the GEM-E3 is calibrated to 2011 (base year data). The model runs up to 2050 with 5 year time steps.

1.4) Spatial dimension - GEM-E3

The GEM-E3 model is a multi-regional model representing 38 countries/regions and 31 sectors of production. EU countries are represented individually in the GEM-E3 (Table 1). The countries/regions are linked through endogenous bilateral trade flows. Total demand is allocated between domestic products and imported products, following the Armington specification. In this specification, branches and sectors use a composite commodity which combines domestically produced and imported goods, which are considered as imperfect substitutes (Armington assumption). Each country buys and imports at the prices set by the supplying countries following their export supply behaviour. The buyer of the composite good (domestic) seeks to minimise his total cost and decides the mix of imported and domestic products so that the marginal rate of substitution equals the ratio of domestic to imported product prices. The GEM-E3 model requires detailed bilateral trade matrices for all regions and commodities included in the model. GTAP database provides such matrices together with bilateral duties and transportation costs. For countries that are not identified separately in GTAP the UN Comtrade database is used in order to extract the relevant data.

Table 1: Countries/regions represented in the GEM-E3 model

Austria	Finland	Malta	Canada
Belgium	France	Netherlands	Brazil
Bulgaria	United Kingdom	Poland	China
Croatia	Greece	Portugal	India
Cyprus	Hungary	Slovakia	Oceania
Czech Republic	Ireland	Slovenia	Russian Federation
Germany	Italy	Sweden	Rest of Annex I
Denmark	Lithuania	Romania	Rest of the World
Spain	Luxembourg	USA	
Estonia	Latvia	Japan	

1.5) Policy - GEM-E3

The GEM-E3 model has been extensively used by several DGs of the European Commission for policy analysis. Indicative works include those of Paroussos and Kouvaritakis (2003), Kouvaritakis et al. (2005) and Kouvaritakis and Paroussos (2006). GEM-E3 has also been used in a series of research projects funded by the European Commission like the MEDPRO (http://www.medpro-foresight.eu/) and the AMPERE (http://ampere-project.eu/web/) project. GEM-E3 is a general-purpose model that aims at coping with the specific orientation of the policy issues that are actually considered at the level of the European Commission. Policies are analysed as counterfactual dynamic scenarios and are compared against reference model runs. Policies are then evaluated through their impact on sectoral growth, finance, income distribution and global welfare.

The GEM-E3 model intends to cover the general subject of sustainable economic growth, and to support the study of related policy issues. Sustainable economic growth is considered to depend on combined environmental and energy strategies that will ensure stability of economic development. The general issue, to be analysed with GEM-E3, regards the conditions under which economic growth, and its distributional pattern, can be sustained in the presence of environmental constraints or energy shortages and even reinforced by means of an adequate technological and market-oriented policy.

The model intends, in particular, to analyse the global climate change issue a theme that embraces several aspects and interactions within the economy, energy and environment systems. To reduce greenhouse gas emissions it is necessary to achieve substantial gains in energy conservation and in efficiency in electricity generation, as well as to perform important fuel substitutions throughout the energy system, in favour of less carbon intensive energy forms.

Within the context of increasingly competitive markets, new policy issues arise. For example, it is necessary to give priority to market-oriented policy instruments, such as carbon taxes and pollution permits, and to consider market-driven structural changes, in order to maximise effectiveness and alleviate macroeconomic consequences. Re-structuring of economic sectors and re-location of industrial activities may be also induced by climate change policies. This may have further implications on income distribution, employment, public finance and the current account.

The model is designed to support the analysis of distributional effects that are considered in two senses: distribution among countries and distribution among social and economic groups within each country. The former issues involve changes in the allocation of capital, sectoral activity and trade and have implications on public finance and the current account of member states. The assessment of allocation efficiency of policy is often termed "burden sharing analysis", which refers to the allocation of efforts (for example taxes), over different countries and economic agents. The analysis is important to adequately define and allocate compensating measures aiming at maximizing economic cohesion. Regarding both types of distributional effects, the model can also analyse and compare coordinated versus non coordinated policies in the European Union.

Technical progress and infrastructure can convey factor productivity improvement to overcome the limits towards sustainable development and social welfare. For example, European RTD strategy and the development of pan-European infrastructure are conceived to enable long-term possibilities of economic growth. The model is designed to support analysis of structural features of economic growth related to technology and evaluate the derived economic implications for competitiveness, employment and the environment.

The model puts emphasis on:

- The analysis of market instruments for energy-related environmental policy, such as taxes, subsidies, regulations, emission permits etc., at a degree of detail that is sufficient for national, sectoral and World-wide policy evaluation.
- The assessment of distributional consequences of programmes and policies, including social equity, employment and cohesion for less developed regions.
- The standard need of the European Commission to periodically produce detailed economic, energy and environment policy scenarios.

2) Socio-economic drivers - GEM-E3

The main drivers of growth in the GEM-E3 model are:

- Population growth
- Technical progress
- Capital accumulation.

In the GEM-E3 model total population and active population growth rates are set exogenously. The model computes endogenously unemployment rates for skilled and unskilled labour. Technical progress can be exogenous or endogenous based on learning by doing, learning by research functions. Investment decisions by firms are endogenous and are based on Tobin's q.

2.1) Population - GEM-E3

Population and population growth are exogenous to the GEM-E3 model. Projections on the EU countries up to 2050 have been extracted from the "2015 Ageing report" prepared by the European Commission. For non-EU countries the ILO projections are used.

2.2) Economic activity - GEM-E3

The model captures the inter-relations of all economic agents of the economic system and computes endogenously sectoral production, sectoral value added, GDP and its components, incomes and employment.

3) Macro-economy - GEM-E3

The model represents 38 countries/regions where each of the EU countries is represented separately. The model considers 31 sectors of production including separately each of the power generation sectors. The sectoral aggregation of the model is summarized in the following table.

Table 2: GEM-E3 sectoral aggregation

1. Agriculture	11. Non-metallic minerals	21. Non-Market services	30. Coal CCS
2. Coal	12. Electric goods	Power Technologies	31. Gas CCS
3. Crude oil	13. Transport equipment	22. Coal fired	
4. Oil	14. Other equipment goods	23. Oil fired	
5. Gas	15. Consumer goods	24. Gas fired	
6. Electricity supply	16. Construction	25. Nuclear	
7. Ferrous metals	17. Transport (Air)	26. Biomass	
8. Non-ferrous metals	18. Transport (Water)	27. Hydroelectric	
9. Chemical products	19. Transport (Land)	28. Wind	
10. Paper products	20. Market services	29.PV	

The GEM-E3 model provides details on the macro-economy and its interaction with the environment and the energy system. The economy is represented in detail at macro level and also at micro level through detailed representation of agents' behavior. The model incorporates micro-economic mechanisms and institutional features within a consistent macro-economic framework and avoids the representation of behaviour in reduced form.

At micro level the model formulates in detail the supply and demand behaviour of the economic agents (production, consumption, investment, employment, allocation of their financial assets). Demand from the economic agents and the public sector form total domestic demand. Total demand is allocated between domestic and imported products. In this specification, a composite commodity which combines domestically produced and imported goods (imperfect substitutes) is used. Each country buys and imports at the prices set by the supplying countries.

Firms respond to market demand and formulate demand for intermediate inputs and factors of production (labour, capital, resources). They supply their goods and select a production technology so as to maximize their profit within the current year. The firms can change their stock of capital by undertaking investments. Supply and demand mechanisms determine equilibrium prices. In this process the GEM-E3 model takes fully into account macro level interactions and simultaneously includes all interrelated markets. The model formulates separately the supply or demand behaviour of the economic agents which are considered to optimize individually their objective while market derived prices guarantee global equilibrium, allowing the consistent evaluation of distributional effects of policies.

Model prices are the result of market equilibrium (demand and supply effects). On derived prices appropriate taxation is applied, to form prices as perceived by consumers. The main leading price is that of the composite good. Depending on the destination of a commodity, differentiated taxation may be applied, as for example indirect taxation or VAT.

The equilibrium of the real part is achieved simultaneously in the goods market and in the labour market. In the goods market a distinction is made between tradable and non tradable goods. For the tradable goods the equilibrium condition refers to the equality between the supply of the composite good, related to the Armington equation, and the domestic demand for the composite good. This equilibrium combined with the sales identity, guarantees that total resource and total use in value for each good are identical. For the non tradable, there is no Armington assumption and the good is homogeneous. The equilibrium condition serves then to determine domestic production.

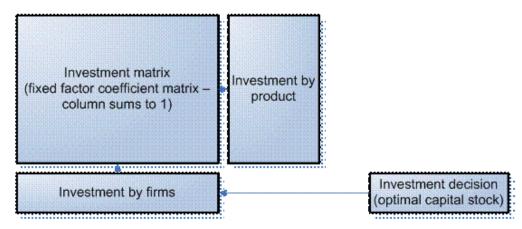
The model is modularly built allowing the user to select among a number of alternative closure options and market institutional regimes depending on the issue under study. The GEM-E3 model includes projections of: full Input-Output tables by country/region, national accounts, employment, balance of payments, public finance and revenues, household consumption, energy use and supply, GHG emissions and atmospheric pollutants. The model considers the appropriate level with respect to geography, the sub-system (energy, environment, economy) and the dynamic mechanisms of agent's behaviour.

Investments

GEM-E3 is a recursive dynamic model (solved sequential over time). The sequential equilibria are linked through a motion equation regarding the update of the capital stock. According to the standard neoclassical approach agents investment decision depends on the rental cost of capital in the presence of adjustment costs and on its replacement cost. In GEM-E3 agents have

myopic expectations. Their future planning is based on current prices. The basic methodological approaches to investment specification include the accelerator model and q of Tobin (1969).

Figure 3: Investment decisions of firms



Investment covers the change in firm's potential plus the capital depreciation. Using the average Tobin's q according to Hayashi (1982) the firm decides the optimal level of investment according to the rental price of capital and its replacement cost. It is also assumed that the firms always replace the depreciated capital.

The investment function takes into account: i) adjustment/installment investment costs, ii) flexibility to replace capital, iii) speed of adjustment, iv) exogenous firm's expectations on future profitability and v) productivity of capital. Investment increases the production potentials of the firm from the following period. The unit cost of capital results as the dual price of the equilibrium function of the available and the demanded capital stock.

Firm's investment is translated into demand for investment goods which are produced from the rest of the sectors of the economy through an investment matrix of constant coefficients. The investment demand of each branch is transformed into a demand by product, through fixed technical coefficients, derived from an investment matrix by product and ownership branch. The investment matrix is computed using the intermediate goods used in the production of capital goods and data provided in the literature on the inputs delivered by the sectors of the economy to the investments undertaken by each sector of production.

The standard approach when no additional data are available, is to use the same coefficient structure for each branch. This approach can be extended when additional information is available on investment by branch and on the structure of capital formation. In order to make changes in the investment matrix a simple procedure is followed. The initial investment matrix (with the same coefficients in each branch) is updated with the new investment shares. Then a RAS procedure is followed in order to ensure that the total of each row and column of the investment matrix remains constant and that the model remains balanced.

Public investment, assumed exogenous in the model, is performed by the branch of non-market services. Transfers to the households are computed as an exogenous rate per head times the population. On the receipt side, the model distinguishes between 9 categories of receipts namely: i) indirect taxes, ii) environmental taxes, iii) direct taxes, iv) value added taxes, v) production subsidies, vi) social security contributions, vii) import duties, viii) foreign transfers and viiii) government firms. These receipts are coming from product sales (i.e. from branches) and from sectors (i.e. agents). The receipts from product sales in value, which include indirect taxes, the VAT, subsidies and duties, are computed from the corresponding receipts in value, given the tax base and the tax rate. The receipts from agents are computed from the tax base and the tax rate (social security contributions, direct taxation), share of government in total capital income (for government firm's income) or exogenous (transfers from and to the ROW).

Transfers

The model allows for a free variation of the balance of payments, while the real interest rate is kept fixed. An alternative approach, implemented in the GEM-E3 model as an option, is to set the current account of a country or of the total EU with the rest of the World to a pre-specified value, in fact a time-series set of values, expressed as percentage of GDP. This value is

obtained either as a result from the baseline scenario or is given by the modeller as a share of GDP. As a shadow price of this constraint, a shift of the real interest rate at the level of the EU is endogenously computed. This shift is proportionally applied to the real interest rates of each member-state.

The only direct transfers and value flows between branches and sectors in the model, refer to government revenue/expenditures through taxes/subsidies and world revenue/expenditures through imports/exports. Flows considered as revenues of branches (in fact product demand) coming from sectors are detailed in: final consumption of products by sector in value, which includes exports, investment by product and sector in value and stock variation in value.

The transfers between sectors include income flows as described in the SAM. These transfers formulate the disposable income of the households. The most important of these transfers include:

- The dividends the firms pay to the households, which is proportional to the net revenues of the firms
- The social benefits that the government pays to the households, which depends on the number of employees by branch and the rate of government payments to the unemployed
- The direct taxes on the firms which is again proportional to the net revenues of the firms (now excluding dividends) and the households, where the tax is proportional to their disposable income
- The payments of individuals to the government for social security.

The transfers between factors of production and the economic sectors are given in the SAM. The most important of these transfers include:

- Revenues of sectors coming from factors, e.g. labour income of households. Flows considered as revenues of factors coming from branches represent the value added, in value
- Flows from factors to factors and from factors to branches are equal to zero
- Factor payments to sectors are coming from value added and distributed according to an exogenous structure.

The savings of each sector, which if summed up on all economic sectors are equal to total investments, are computed as the difference between revenues which consists of the receipts from the branches plus income from factors and sectors) and expenditures (which include final consumption and transfers to factors and sectors. The surplus/deficit of each sector, which is evaluated by subtracting investment and stock variation from gross savings, ensures that total sector savings equal total sector investments (this equality does not hold on a sector level).

3.1) Production system and representation of economic sectors - GEM-E3

The demand of products by the consumers, the producers (for intermediate consumption and investment) and the public sector constitutes the total domestic demand. This total demand is allocated between domestic products and imported products, following the Armington specification. In this specification, branches and sectors use a composite commodity which combines domestically produced and imported goods, which are considered as imperfect substitutes (Armington assumption).

Household demand is determined by the decision to allocate income between current and future consumption (this decision derives from the utility maximization subject to an inter-temporal budget constraint which states that all available disposable income will be spend at the present or at some time in the future) and by the allocation of current expenditure among different consumption categories. Consumption categories include non-durable consumption categories (food, culture etc.) and services from durable goods (cars, heating systems and electric appliances). Based on myopic assumptions about the future, the household decides the amount of leisure that wishes to forsake in order to acquire the desired amount of income (thus also defining labour supply behaviour).

At the second stage, total household consumption is disaggregated into demand for specific consumption goods. For this the integrated model of consumer demand for non-durables and durables, developed by Conrad and Schröder (1991) is implemented. Households obtain utility from consuming a non-durable good or service and from using a durable good. The

consumer decide on the desired stock of the durable based not on its relative purchase cost and on the cost of goods linked with that durable.

With regards to the firms, in GEM-E3 production technologies are formulated in an endogenous manner allowing for pricedriven demand for intermediate goods. Factor demand is derived from Shephard's lemma. In this process it is assumed that the stocks of capital and labour are proportional to the optimal flows in volume. At each level of the nesting scheme of the production function, demand for a factor at a lower level of the nesting scheme is linked to bundle to which it belongs, with different substitution elasticities at each level. This gives finally a cost-minimising demand for each production factor.

Behavioural change

GEM-E3 model combines micro and macro analysis. At micro level the model contains a detailed representation of economic agents' (firms, households, public sector) behavior. The model formulates the supply and demand behaviour of the economic agents regarding production, consumption, investment, employment and allocation of their financial assets. The demand of products by the consumers, the producers (for intermediate consumption and investment) and the public sector constitutes the total domestic demand. This total demand is allocated between domestic products and imported products, following the Armington specification. In this specification, branches and sectors use a composite commodity which combines domestically produced and imported goods, which are considered as imperfect substitutes (Armington assumption). Each country buys and imports at the prices set by the supplying countries following their export supply behaviour. The buyer of the composite good (domestic) seeks to minimise his total cost and decides the mix of imported and domestic products so that the marginal rate of substitution equals the ratio of domestic to imported product prices.

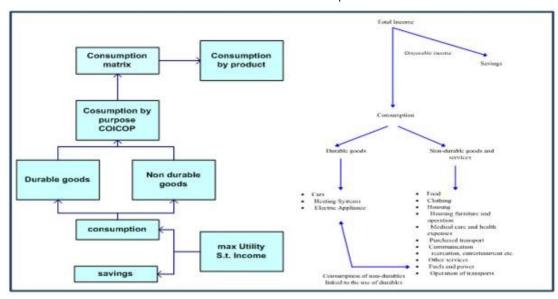
In the GEM-E3 model prices are the result of market equilibrium (demand and supply effects). On derived prices appropriate taxation is applied, to form prices as perceived by consumers. The main leading price is that of the composite good. Depending on the destination of a commodity, differentiated taxation may be applied, as for example indirect taxation or VAT.

Households' behavior

Households in the GEM-E3 SAM are identified as a single social group (a single representative household is modeled). Households maximize their inter-temporal utility under an inter-temporal budget constraint. The demand functions are derived by solving the maximization problem, under general assumptions regarding expectations and steady state conditions. These demand functions allocate the expected income of the household, depending on the formulation of the problem, between consumption goods and future consumption (savings). This is the default formulation of households' behaviour. Alternatively household behavior is modeled so that the consumer allocates its expected income between present, future consumption and leisure. Households receive income from their ownership of production factors, from other institutions and transfers from the rest of the world. Household expenditure is allocated between consumption, tax payment and savings.

The representative household firstly decides on the allocation of its income between present and future consumption of goods. At a 2nd stage the household allocates its total consumption expenditure between the different consumption categories available. The consumption categories are split in non-durable consumption categories (food, culture etc.) and services from durable goods (cars, heating systems and electric appliances). For this allocation an integrated model of consumer demand for non-durables and durables, developed by Conrad and Schröder (1991) is implemented. The rationale behind the distinction between durables and non-durables is that the households obtain utility from consuming a non-durable good or service and from using a durable good. So for the latter the consumer has to decide on the desired stock of the durable based not only on the relative purchase cost of the durable, but also on the cost of those goods that are needed in connection with the durable (as for example fuels for cars or for heating systems). The general form that is described above is being depicted with a nesting scheme as it is appeared below.

Figure 4: The consumption structure of the GEM-E3 model



Firms' behavior

In the GEM-E3 model firms are modeled to maximize their profits, constrained by the physical capital stock (fixed within the current period) and the available technology. Producers can change their physical capital stock over time through investment. Capital stock data by sector of production are not available either from GTAP or from EUROSTAT databases (it is computed in the calibration phase of the model).

Each producer (represented by an activity) is assumed to maximize profits, defined as the difference between the revenue earned and the cost of factors and intermediate inputs. Profits are maximized subject to its production technology. Domestic production is defined by branch. It is assumed that each branch produces a single good which is differentiated from any other good in the economy.

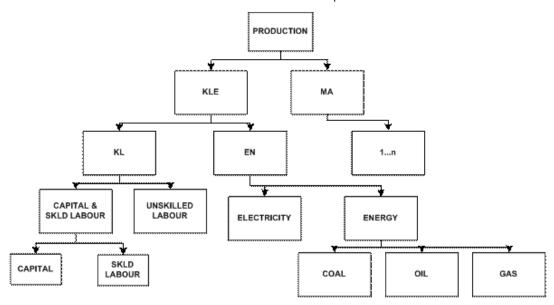
Production functions in GEM-E3 exhibit a nested separability scheme, involving capital, skilled and unskilled labour, energy and materials and are based on a CES neo-classical type of production function. The exact nesting scheme of production in GEM-E3 has been selected to match available econometric data on KLEM substitution elasticities and the specific features of each activity. The optimal production behaviour can be represented in the primal or the dual formulation. Their equivalence, under certain assumptions, can be verified by the theory of production behaviour.

In the model the dual formulation is used and the long run unit cost function is of the nested CES type with factor-augmenting technical change, i.e. price diminishing technical change. The firm (at branch level) decides its supply of goods or services given its selling price and the prices of production factors.

The production technology exhibits constant return of scale. The firm supplies its good and selects a production technology so as to maximize its profit within the current year, given the fact that the firm cannot change the stock of productive capital within this period of time. The firm can change its stock of capital the following year, by investing in the current one. Since the stock of capital is fixed within the current year, the supply curve of domestic goods is upwards sloping and exhibits decreasing return to scale.

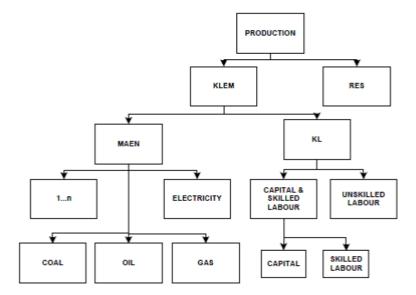
Non-energy sectors: At the 1st level, production is split into two aggregates, one consisting of capital, labour and energy bundle (KLE) and the other consisting of materials (MA). At the 2nd level, (KLE) is split in two aggregates, one consisting of capital and labour bundle (KL), and the other consisting of energy (ENG). (MA) is further divided in its component parts (e.g. Agriculture, Industrial activities, Services etc.). At the 3rd level (KL) is split into capital and skilled labour bundle (KL_skld), which is further decomposed at the 4th level between Capital and skilled Labour and unskilled labour (_L_unskld_), whereas (ENG) is split in electricity and fuels (EN).

Figure 5: Production nesting scheme in the GEM-E3 model - Non energy sectors



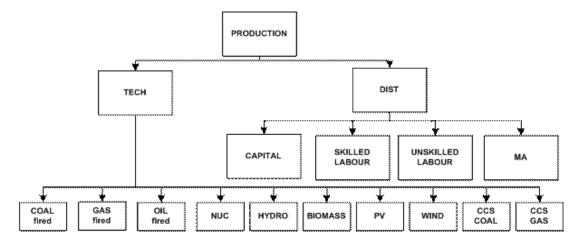
Resource sectors: For the sectors whose production is based on natural resources, at the 1st nesting level production is split between fossil fuel resources (RES) and an aggregate bundle consisting of capital, labour and material-energy (KLEMrs). The latter at the 2nd stage is disaggregated in the material-energy bundle (MAENrs) and the capital-labour bundle (KL). At the 3rd level the capital-labour bundle (KL) is split in capital and skilled labour (KL_skld) and in unskilled labour. The material-energy bundle (MAENrs) is divided into its component parts. Finally capital-skilled labour bundle is spit into capital and skilled labour.

Figure 6: Production nesting scheme in the GEM-E3 model - Resource sectors



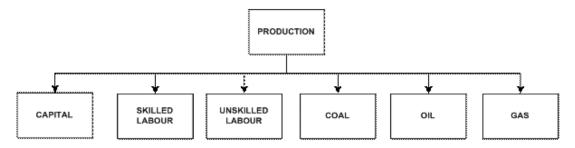
Power supply sectors: At the 1st nesting level of the power supply sector, production is split into two aggregates, one consisting of a bundle of power producing technologies (TECH) and the other of the transmission and distribution part (DIST). At the 2nd level, all power producing technologies identified in the model are in the same nest whereas the (DIST) bundle is disaggregated to capital, skilled and unskilled labour and materials.

Figure 7: Production nesting scheme in the GEM-E3 model - Electricity supply



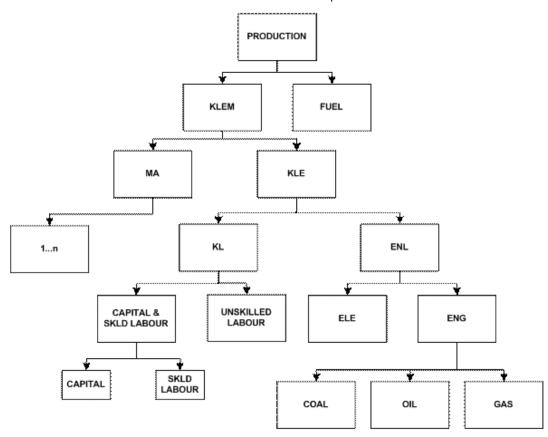
Power producing technologies: one level production function that includes capital, skilled and unskilled labour and fuels is assumed.

Figure 8: Production nesting scheme in the GEM-E3 model - Power producing technologies



Refineries: the nesting structure is similar to the non-energy sectors with a change in the top level of the nest where the two aggregates are now (KLEM) and fuels (FUEL).

Figure 9: Production nesting scheme in the GEM-E3 model - Refineries



Firms address their products to three market segments namely to the domestic market, to the other EU countries and to the rest of the world. Prices are derived through demand/supply interactions. In any iteration of the model run and before global equilibrium is achieved, producers face demand for their products. To this demand they respond with a price. For the PC sectors, since these operate under constant returns to scale and the number of firms is very large, this price depends only on their marginal cost of production.

The producer is assumed not to differentiate his price according to the market to which he sells his products. He therefore sells his products at the same price (equal to his marginal cost reduced by the amount of production subsidies that he receives).

Government behavior

The Governments' behaviour is exogenous in GEM-E3. Government's final demand by product is obtained by applying fixed coefficients to the exogenous volume of government consumption.

3.2) Capital and labour markets - GEM-E3

Labour Market

The GEM-E3 model adopts the EUROSTAT definition of the labour force and thus it is computed by multiplying the participation rate to total active population. The databases mainly used to extract these data are the EUROSTAT, ILO and World Bank. The GEM-E3 model has detailed representation of skilled and unskilled labour force by sector of activity, including detailed representation of labour force in the power generation sectors.

The formulation of the labour market adopted in the GEM-E3 assumes the presence of imperfections and rigidities which shift the exogenous labour supply (in the alternative version the utility-derived labour supply), to the left and upwards. Wages drive the balancing of the shifted labour supply with labour demand. Thus involuntary unemployment arises as a result of the distorted labour market equilibrium. The model distinguishes labour between skilled and unskilled labour. Capital and skilled

labour substitute each other (except for power generation technologies, where capital and skilled labour complement each other), at the 4th level of production, while capital and skilled labour bundle are substitutes with unskilled labour at the 3rd level of the production. Equilibrium unemployment is modeled for both skilled and unskilled labour.

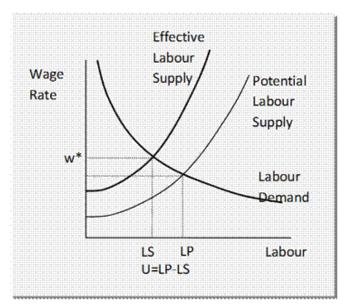
It is assumed that, due to labour market imperfections and frictions, the employees enjoy a wage premium (a wage rent) on top of the wage rate that would correspond to equilibrium between potential labour supply and labour demand. The wage rate premium leads to a displacement to the left of the potential labour supply curve. The displaced supply curve corresponds to effective labour supply.

In the standard version of the GEM-E3 model labour market is perfect in the sense that wages adjust until there is no excess labour supply and hence unemployment. The model considers the notion of voluntary unemployment through the choice of household for leisure (when the alternative version of labour market is used). In the standard version the representation of involuntary unemployment is based on the efficiency wages approach by Shapiro and Stiglitz (1984).

The wage rate premium is endogenous to the model and is assumed to be the consequence of the existence of Principal-Agent relations: the firms are obliged to pay a wage premium to induce employees not to shirk; as a result effective labour supply is determined through efficiency wages.

The balancing of labour demand with effective, rather than potential, labour supply implies that equilibrium unemployment is determined as the difference between potential and effective labour. This is illustrated in the Figure below which shows unemployment U as difference between potential equilibrium labour LP and effective labour equilibrium LS, corresponding to wage rate w* which includes the wage rent reflecting market imperfections.

Figure 10: Illustration of equilibrium unemployment



An approach for simulating involuntary unemployment relates to the assumption that there is a negative correlation between wages and unemployment. This approach is consistent with the efficiency wages theory of Shapiro & Stiglitz (1984) which states that productivity/quality of labour has a positive correlation with wages. In periods with high unemployment firms are not motivated to offer high wages to attract higher quality labour or to increase productivity of existing workers. On the other hand, at low unemployment rates it is efficient for firms to offer wages above their equilibrium level, because they seek for increases in labour productivity and for reducing the probability of someone quitting the job and hence reducing costs from the recruitment of new personnel. In the GEM-E3 model the efficiency wage approach was finally selected to be the default option for representing involuntary (equilibrium) unemployment. This modelling approach was preferred because of its empirical validation, by using for example Blanchflower and Oswald (1994), its simplicity, and the fact that it is parsimonious in parameters. The specification of efficiency wages in GEM-E3 is based on Shapiro & Stiglitz and Annabi (2003) approaches. The procedure is identical both for skilled and unskilled labour. Efficiency wage is an increasing function of quit rate, the probability of finding a job, the interest rate and the unemployment benefit. In equilibrium the number of workers that are unemployed should equal the number of workers that fill a vacancy.

The implementation of involuntary unemployment in the GEM-E3 model requires additional data (i.e. unemployment levels, minimum wages etc.) that are extracted mainly from the CESifoDICE and EUROSTAT databases.

Capital Market

Three alternative choices for the capital mobility are assumed in the model:

- i) Capital is immobile between sectors and between regions.
- ii) Mobility across sectors but not across regions.
- iii) Full mobility across sectors and regions.

3.3) Monetary instruments - GEM-E3

The model allows for a free variation of the balance of payments, while the real interest rate is kept fixed. An alternative approach, implemented in the GEM-E3 model as an option, is to set the current account of a country or of the total EU with the rest of the world (RoW) to a pre-specified value, in fact a time-series set of values, expressed as percentage of GDP. This value is obtained either as a result from the baseline scenario or is given by the modeller as a share of GDP through the parameter \$share_ca_{er,t}\$. As a shadow price of this constraint, a shift of the real interest rate at the level of the EU is endogenously computed. This shift is proportionally applied to the real interest rates of each member-state.

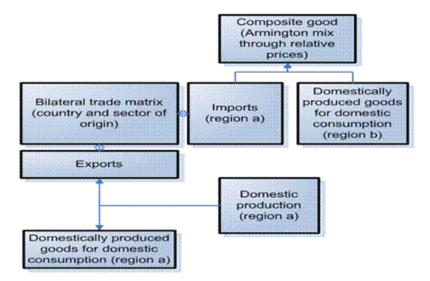
This mechanism enables a robust comparison between scenarios since the modeler does not allow for additional borrowing/lending (in GEME-E3 borrowing/lending is in real terms the balance of trade) of the country due to scenario policies but instead allows for an endogenous change of the real interest rate of the country/region. For example, in a climate policy scenario with a fixed current account as a share of GDP (fixed in baseline levels), the country/region under constraint cannot increase its imports as a reaction to increased unit cost of energy and thereby sustain levels of consumption and welfare but instead has to face an increased real interest rate.

The option of a constant current account as a percentage of GDP is activated in the model by a switch parameter.

3.4) Trade - GEM-E3

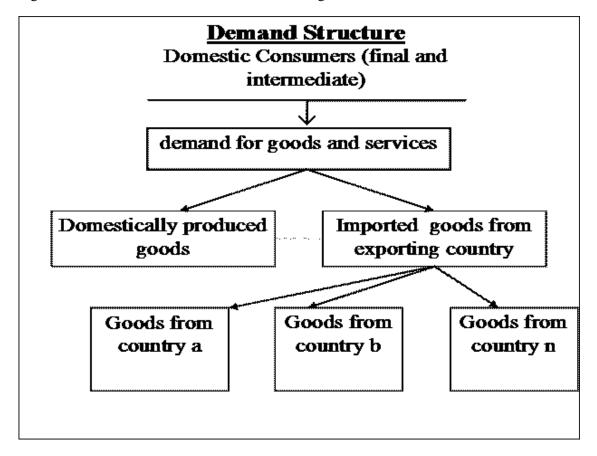
Total domestic demand consists of the demand of products by the consumers, the producers (for intermediate consumption and investment) and the public sector. This is allocated between domestic products and imported products, according to the Armington specification. Each country buys and imports at the prices set by the supplying countries following their export supply behaviour.

Figure 11: Trade matrix for EU and the rest of the world



GEM-E3 employs a nested commodity aggregation hierarchy, in which branch's i total demand is modelled as demand for a composite good or quantity index Yi which is defined over demand for the domestically produced variant and the aggregate import good. At a next level, demand for imports is allocated across imported goods by country of origin. Bilateral trade flows are thus treated endogenously in GEM-E3.

Figure 12: Domestic demand and trade flows nesting scheme



The minimum unit cost of the composite good determines its selling price. This is formulated through a CET unit cost function, involving the selling price of the domestic good, which is determined by goods market equilibrium, and the price of imported goods, which is taken from the 2nd level Armington. By applying Shephard's lemma, total demand for domestically produced goods and for imported goods is derived.

Export of services from country cr to country cs will be equal to the bilateral import of services of country cs from cr. The model ensures analytically that, the balance of trade matrix in value and the global Walras law is verified in all cases. A trade flow from one country to another country matches, by construction, the inverse flow. The model ensures this symmetry in volume, value and deflator. Thus the model guarantees (in any scenario run) all balance conditions applied to the world trade matrix, as well as the Walras law at the level of the planet.

3.5) Technological change - GEM-E3

Technical progress is explicitly represented in the GEM-E3 in the production function, either exogenously or endogenously, depending on the R&D expenditure by private and public sector and taking into account spillovers effects. Technological progress is based on the myopic expectations of the participant agents. The production technology exhibits constant returns to scale. Firms supply their goods and select a production technology so as to maximise their profit within the current year, given the fact that they cannot change the stock of productive capital within this period of time. The stock of capital is fixed within the current year. Firms can change their stock of capital the following year, by investing in the current one.

4) Energy - GEM-E3

4.1) Energy resource endowments - GEM-E3

GEM-E3 considers only energy related depletable resources. Coal, oil and gas sectors are associated with the respective reserves. For the depletable resource sectors reserves are considered to be a discrete production factor. The international price of the fossil fuel is calculated so as to balance total supply and total demand of reserves.

4.2) Energy conversion - GEM-E3

Table 3: Alternative power generation technologies

	Coal	Oil	Gas	Coal w/ CCS	Oil w/ CCS	Gas w/ CCS	Biomass	Bio w/ CCS	Non- Biomass renewables	Nuclear	Other
Electricity	x	X	X	X		x	X		X	x	
Liquids											
Gases											
Solids											
Heat											
Hydrogen											
Other											

Alternative power generation technologies (conventional: coal, oil, gas and RES: hydro, biomass, solar, wind, coal and gas CCS and nuclear) are represented separately in the GEM-E3. "Electricity" sector represents power transmission and distribution. For the depletable resource sectors (coal, oil, gas) reserves are considered to be a discrete production factor. The international price of the fossil fuel is calculated so as to balance total supply and total demand.

Energy and fuels enter at different levels of the nesting scheme of the production function, always linking the demand for them at a lower level of the nesting scheme to the bundle to which they belong, with different substitution elasticities at each level. This gives finally a cost-minimising demand for energy and fuels. For the non-energy sectors energy is split at the 4th level of production between electricity and fuels. For the sectors whose production is based on natural resources, production is split at the 1st nesting level between fossil fuel resources and an aggregate bundle consisting of capital, labour and material-energy. The latter at the 2nd stage is disaggregated into the material-energy bundle. At the 3rd level the material-energy bundle is divided into its component parts. Production of power supply sectors is split at the 1st level of the power supply sector into the

bundle of power producing technologies and the transmission and distribution part. At the 2nd level, all power producing technologies identified in the model are in the same nest. Transmission and distribution bundle is disaggregated to capital, skilled and unskilled labour and materials. For the power producing technologies one level of production function (including capital, labour and fuels) is considered.

4.2.1) Electricity - GEM-E3

CGE models have been criticized for their simplified modelling approach of the energy system. The usual CGE representation of the energy production by means of aggregate production functions fails to capture crucial characteristics of the sector reducing the credibility of simulations related to energy policies and technology dynamics. The bottom up models employed instead, ignore the feedbacks from the interaction of the energy sector with the wider economy within which it operates.

The development of a modelling framework that encompasses the multi market equilibrium of top down models with an engineering consistent representation of power producing technologies constitutes a long-standing challenge in applied energy policy analysis. Many different approaches have been employed to link bottom up and top down models and can be classified in two main categories:

- Hard link approach, that is, integrating both bottom-up and top-down features in a consistent modelling framework. Such an integrated framework is provided by the specification of market equilibrium models as mixed complementarity problems.
- Soft-link or decomposition approach where bottom-up and top-down models are run independently of each other. In this case results from one model are fed into the other, and vice versa.

A characteristic example of the first category is found in Boehringer (1998) where the electricity generating technologies are modeled as specific activities within a mathematical-programming representation of the electricity sector, which is embedded directly in a computable general equilibrium model. In particular his approach is based on the complementarity formulation of the general equilibrium problem while the representation of the electricity producing sectors is based on Koopmans (1951) activity analysis framework. The standard aggregate production functions (C.E.S. or CD) used in the model are replaced by a set of discrete Leontief technologies (fixed input/output vector).

Towards the same direction lies McFarland et al. (2004), who suggest a more flexible format through a C.E.S. representation of energy technologies. Their approach consists of splitting the energy sector using engineering bottom up data and then calibrate the model's smooth production functions on these data. In particular in their approach the cost estimates on capital, labour, and fuel inputs are used directly as the CES share parameters. The nesting scheme of the production function allows for the appropriate input substitution while the control of technology penetration rate is based on an endogenous quasi fixed factor coefficient introduced at the top level of the C.E.S. production function. Each technology produces electricity through a C.E.S. aggregation of its primary and secondary inputs (low elasticities of substitution chosen at this nesting level), while total electricity production results from a CES aggregation of all power technologies represented in the model (high elasticities of substitution at this nesting level).

A disadvantage of this approach lies in its treatment of investment decisions. That is, investment is either allocated to electricity technologies exogenously or decided at the level of the aggregate electricity sector and then allocated to each technology using a logit function. This investment formulation although it allows for multiple technologies with different costs to coexist is not sufficient to represent the investment behavior of the electricity sector (i.e. each sector should decide the level of investment as a function of its profit function and then this investment demand should be translated to demand for investment products produced by other sectors). In addition the non-smooth (kinked) representation of power supply results in sharp shifts in the technology mix of electricity production implying unrealistic swift switching between technologies.

The second category refers mainly to a decomposition method that links bottom up models with top down by combining different mathematical formats - mixed complementarity and mathematical programming. In Boehringer & Rutherford (2008) mixed complementarity methods (MCP) are used to solve the top-down economic equilibrium model and quadratic programming (QP) to solve the underlying bottom-up energy supply model. Then they reconcile equilibrium prices and quantities between both models through an iterative procedure portray this iterative solution process).

Hybrid Bottom Up Top Down (BUTD*)* CGE models are still rare in the policy modelling literature due to difficulties arising from the integration of macroeconomic and engineering data in a consistent way. E3M-Lab has designed and incorporated into the GEM-E3 model a bottom up top down module. The motivation for this development was the need for a better

representation of the electricity sector investment decision. Toward this end, electricity producing technologies were treated as separate production sectors while their investment decision is discrete. The advantage of this approach is that it is fully consistent with the general equilibrium framework while it leads to a full identification of the technologies.

The Input-Output tables represent the electricity sector as an aggregate of two activities, the power generation and the transmission and distribution of electricity. This detail is not sufficient for the development of the bottom up model, so it has been necessary to split the Input-Output column and row in different activities, some corresponding to power generation by technology and the rest corresponding to transmission and distribution of electricity. The split was performed by combining data from energy balances and company- related economic data on generation and transmission and distribution activities by country. The aggregate data were based on Eurostat, IEA and USA DOE statistics. For example, the disaggregation shows that the generation cost accounts for over half of total cost and in most E.U. countries they account for over 60% while transmission costs range between 5% and 10%.

In order to disaggregate the power sector appropriate mapping has been specified between the entries of the Input-Output table and the engineering information retrieved from the technical databases. For this purpose data on capital cost, fixed operating and maintenance cost, fuel cost and other variable operating and maintenance costs, related to the energy producing technologies to be incorporated in the model following cost elements have been extracted from the engineering database.

The unit costs have been associated with the corresponding cost elements of the Input-Output statistics, according to the following principles: i) annualised capital costs correspond broadly to operating surpluses, ii) fuel costs correspond to the fuel input, iii) fixed operating and maintenance cost correspond to non-energy inputs (materials), iv) variable operating and maintenance costs are associated with wages and salaries paid to employees in power generation. Since the entire GEM-E3 model is calibrated on the social accounting matrices the macroeconomic data have been kept constant and the market and cost shares of the technologies have been appropriately adjusted. The purpose of the calibration has been to depart as little as possible from the flows suggested by the engineering information while respecting exactly the totals appearing in the original input output table. For this purpose a cross entropy method has been applied.

The model represents separately 10 conventional and RES power generation technologies. The technologies incorporated in the GEM-E3 model are presented in the following table.

T. 1.1. 4. E1 4	1	4 1 1		CEM E2 1.1
Table 4: Electricity	producing	technologies	represented in	GEMI-E3 model

No	Description	No	Description
1	Coal fired	6	Hydro electric
2	Oil fired	7	Wind
3	Gas fired	8	CSP and Photovoltaics
4	Nuclear	9	Coal CCS
5	Biomass	10	Gas CCS

Generation costs are conceived in three categories: i) investment costs, ii) operating and maintenance costs and iii) fuel costs. Unit cost data and projections to the future for the first two categories are extracted from the TECHPOL and PRIMES database. The fuel costs depend on other variables of the GEM-E3. The data for each technology as introduced in the model are presented in the following table.

Table 5: Electricity production cost shares

	Coal fired	Oil fired	Gas fired	Nuclear	Biomass	Hydro electric	Wind	PV
Agriculture					25.0			
Coal	24.3							
Oil		70.6						
Gas			73.2					
Chemicals				6.7				
Other equipment goods	5.0	0.5	0.5	0.5	1.5	1.0	9.8	0.8
Construction	3.0	2.0	4.7	1.0	1.5	3.0	5.8	6.7
Capital	56.6	22.3	19.3	87.6	67.4	80.3	8.0	83.2
Labour	11.1	4.7	2.2	4.2	4.6	15.7	4.4	9.2
Total	100	100	100	100	100	100	100	100

Source: Calculations based on TECHPOL and PRIMES databases

The shares of each technology in power generation in the base year are introduced from energy balance statistics. Some of the potential technologies that may develop in the future are not used in the base year. Since the production function for power generation is calibrated to the base year, it is necessary to introduce artificially small shares even for the non existing technologies in order to allow for the possibility of their penetration in the future under market conditions.

The development of the database on technology market shares and share of transmission and distribution cost to total cost of electricity production has been based on the TECHPOL database, the ENERDATA database and the PRIMES model database.

4.2.6) Grid, pipelines and other infrastructure - GEM-E3

In the GEM-E3 model the transmission and distribution of electricity are represented at aggregate level. "Electricity" sector accounts for transmission and distribution. Data from Eurostat, IEA and USA DOE have been employed so as to calculate the transmission and distribution costs by technology.

4.3) Energy end-use - GEM-E3

The Input Output representation of all economic activities allows to capture the energy transactions made by each intermediate and final consumer.

4.3.1) Transport - GEM-E3

The GEM-E3 transport module is designed to analyze how the transformation of the transport sector affects the economy through multiple channels either directly (investment in infrastructure, the purchasing of vehicles and fuels of new technology, the cost of acquiring transport services, etc.) or/and indirectly (changes in activity of all sectors, foreign trade, consumption and labour and capital markets, including the eventual crowding out effects due to higher cost of mobility compared to business-as-usual). It incorporates a detailed representation of the transport sector, as well as fleet choice and energy consumption. In this respect, sectors and commodities are split according to the transport modes and means utilized in standard transport models. The model distinguishes the technologies for transport means, and endogenizes the choice of technologies in the simulation of investment by sectors providing transport services and the purchasing of durable goods by households. Finally, the operation of the transport means is related to the sectors producing the energy commodities, including alternative fuels, such as electricity and biofuels.

As regards the transport modes, the sectorial split follows and further extends the classification used by the GTAP database. This extension splits the GTAP data in passenger and freight transport by mode and further disaggregates the modes into rail and road as well as distinguishes between public and private transport. This extension is based on several transport databases where data for turnover by transport sector, transport activity, volumes of transported goods in international trade and transport prices and margins for freight transport modes are available. The decomposed data are organised in Input-Output tables, international transport table, the matrix of consumption by purpose and by product and the investment matrix.

The production of biofuels is explicit (following the methodology of GTAP). For the production of the biofuels bio-gasoline and biodiesel production sectors are involved both of which use feedstock from agriculture sectors. Biofuels are further disaggregated according to the feedstock and the methods used for their production. Transport sectors and households consume oil products, gas, biofuels and electricity for transport purposes.

The model distinguishes between the sectors producing conventional vehicles and a sector producing electric vehicles, in order to capture price differentials of car types and the impacts of global competition on car manufacturing. The electric vehicles sector is linked to endogenous learning functions for the possibility of cost reduction, largely due to batteries, as a function of production volume.

The stock of vehicles (transport sector) and the cars (durable goods), changes with respect to time due to mobility and scrappage. Vehicle types – technologies are chosen according to the relative costs (i.e. purchasing cost, running costs and cost factors reflecting uncertainty factors depending on technology maturity and the availability of recharging or refuelling infrastructure). The cost of conventional technologies is penalised when they do not meet the CO2 standards. Taxes, revenues, subsidies and expenditures for public infrastructure are all part of the public budget, which deficits or surpluses influence the economy through their impact in the interest rates. Hence, the model captures the economy-wide effects of the public funding of transport sectors and infrastructure, and the effects of fuel taxation or potential subsidisation of new car technologies.

Modelling demand for transport services by business sectors

At the top two levels of the nested structure, the model represent substitution possibilities between capital, labour, aggregate energy, aggregate transport and aggregate materials (Figure 13). Thus the usual capital-labour-energy-materials (KLEM) substitution scheme has been extended by introducing aggregate transport services (KLEMT). It is further assumed that there are no substitution possibilities between aggregate transport and aggregate materials in production, as such substitution makes no sense in reality.

At the next level of the nested choices, aggregate demand for transport is divided into two broad categories:

- (1) Transportation of goods from the production area to the selling point (freight transport) and
- (2) Business trips of firms' employees.

Transportation of goods and employees are considered as complementary inputs; hence the overall transport demand is distributed between these two categories in fixed proportions.

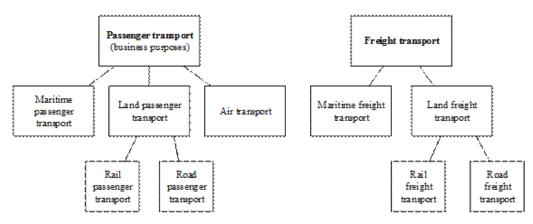
The next level (Figure 14) of the nested choices treats choice of transport modes, based on relative costs. The elasticities of the CES function at this level reflect limitations of substitution between transport modes due to geographical and infrastructure factors. The freight transport category is disaggregated into two transport modes: land and water freight transportation. Air freight transportation has not been considered, since it only holds a limited share in total cargo movement. At the lowest nest, demand for land transport is allocated between road and rail transport. Regarding transportation of firm's employees, the model considers air, land and water transport as possible choices.

Firms are assumed to sell their products at their gate when they are destined to international consumers (who then buy transport services for the delivery of their purchased goods). Firms include transportation costs in their selling price when their products are destined to domestic consumers. Transport services for internationally transported goods are allocated by country in fixed proportions using a global transportation price for each transport mode (air, road, rail and water freight). The global price of transport services for each transport mode is calculated as the weighted average price of each transport service supplier (weights being the volume of sales of each supplier).

Figure 13: Upper levels of the nesting scheme in production functions of business sectors

File:Figure 13 Upper levels of the nesting scheme in production functions of business sectors.gif

Figure 14: Nesting scheme for the choice of transport modes in production functions of business sectors



Modelling private transportation

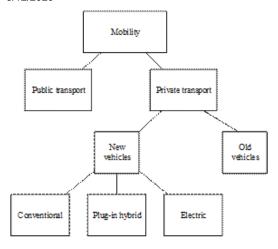
The model distinguishes durable and non-durable goods. The household's budget bears the entire amount to be paid for purchasing a durable good, as the model simulates 5-year steps and usually loans for durable goods are totally paid off in this period (except of house mortgage loans, which are treated differently). The model tracks lifetime of durable goods and the dynamics of their stock. The choice of technology for a durable good, such as a car, an electric appliance, a heating equipment, etc., is explicit in the model. Thus for cars the model formulates the choice between conventional and new technology cars, e.g. electric cars, based on relative total cost of transportation, which includes the influence of factors such as technology maturity and availability of recharging, refuelling infrastructure. The use of durable good implies consumption of non-durable goods and services, such as fuels, maintenance, insurance, taxes, etc. Simple cost functions, which distinguish different technologies, relate consumption of non-durable goods to the holding of durable goods. For meeting mobility needs, the households are modelled to make a choice between using a car (which is a durable good) or public transport (Figure 3). This choice depends on preference parameters and relative costs, involving comparison between public transport fare and variable costs of car use. Elasticity parameters limit substitution possibilities between public and private transport reflecting quality of public transportation network, congestion, travelling distance and comfort. The fares of public transport are cost-reflective and calculated by sector that supplies transport services to passengers.

As regards the technology and fuel mix of private cars, the model distinguishes the following technologies: conventional vehicles with internal combustion engine (including hybrids not pug-in), plug-in hybrid vehicles, battery electric vehicles and fuel cells.

The functional forms used to model the mix of private and public transportation for households are based on the constant elasticity of substitution functional forms. The demand functions derived from utility or cost optimisation involve relative costs of transportation. The choice of technology for the purchasing of new cars follows a Weibull functional form, which derives from discrete choice theory, see Fosgerau and Bierlaire (2009); Mattsson et al. (2014). The output of this function is the frequency of choice of each technology, which is equivalent to the market shares of technologies in new car registrations. The frequency of choices depends on relative generalized cost of transport calculated by technology, including purchasing costs, fuel costs depending on efficiency and the price of the fuel (determined in the part of the model dealing with supply of fuels, i.e. oil products, biofuels, gas and electricity), as well as cost parameters reflecting technology uncertainty, availability of recharging or refuelling infrastructure and others.

In the model there is no relation of car choice to the type of trip that the new candidate car will serve for, and so the model lacks influence of trip distance and frequency on car choices.

Figure 15: Households' transport demand nesting scheme



(Source: Karkatsoulis, P., Siskos, P., Paroussos, L. & Capros, P. Simulating deep CO2 emission reduction in transport in a general equilibrium framework: the GEM-E3T model. Transportation Research Part D: Transport and Environment (forthcoming).)

4.3.2) Residential and commercial sectors - GEM-E3

Demand per consumer category is decomposed into deliveries by sector of production in the consumption matrix. These matrices are usually reported in consumer's prices, i.e. VAT and margins are included in the price of the delivery and moreover margins are not considered as a separate delivery by a service branch. In the GEM-E3 model, this matrix is transformed in producer's prices.

To this end, the following procedure is applied:

- given the VAT rates for the different consumer categories, a consumption matrix without VAT is computed
- the margins included in the deliveries by branch are evaluated as the difference between the consumption matrix deliveries (without VAT) and the IO deliveries
- Margins are allocated between the services branches.

In the cases where consumption matrices are not available from statistical sources, they are computed through the following way:

- The consumption per consumer category is extracted from the National-Accounts (final consumption of households on the economic territory, by purpose) and corrected for the consumption by tourist,
- Given the VAT rates for the different consumer categories, the total consumption per category without VAT is computed,
- Total deliveries are taken from the Input-Output tables,
- Once the row and columns totals of the consumption matrix are computed for each country/region a RAS procedure is applied (the initial coefficients for the RAS are taken from countries with available consumption matrices).

Household consumption is decomposed into demand for specific consumption goods. This distinguishes between durable and non-durable goods. Households have to decide on the desired stock of the durable based not only on its relative purchase cost but also on the cost of those goods that are needed in connection with the durable (as for example fuels for cars or for heating systems). Energy is the main linked non-durable good. Energy complements the use of durables in order for them to provide a positive service flow. Consumption of energy does not affect the expenditure of durables through the change in preferences but rather through the additional burden in the user cost.

In the efficiency module developed for GEM-E3 model households and firms invest to improve efficiency of energy use which means that the economy substitute materials (equipment, insulation, etc.) and services (e.g. provided by technicians for installation) for energy. The amount of investment on energy saving technology is exogenous. It is assumed that the investment expenditure produce results one period after it takes place and continuously for a period of at least 20 years. The purpose of the investment concerns only the reduction of the unit consumption of energy in the sector or energy use of households, in which the investment takes place. That is, in the new setup agents use part of their income to acquire goods and services that are used to improve their energy efficiency. These goods and services accumulate to an energy saving capital stock that provides permanent energy efficiency improvements (with a declining/depreciation rate). The investment of a firm in energy saving equipment/capital increases energy efficiency and reduces its energy bill but it does not increase its productive capacity (i.e. it does not add to the capital stock of the firm). Energy efficiency improvement translates to additional demand for goods and services such as equipment goods, electrical goods, construction, market services (in fixed proportions).

Similarly for households the expenditures on goods and services to improve their energy efficiency do not increase directly their utility, only indirectly through the energy bill reductions. Hence, there are no direct effects on productive capacities or the consumption of other commodities. Of course, indirect effects do exist and are quantified through the model. Finally, it should be noted that the energy efficiency improvements are modeled so as to exhibit decreasing marginal returns (saturation effect).

To enforce the energy saving scheme to be implemented by firms and households the following methodology is adopted: The government raises an energy tax (proportional to the energy consumption of each economic agent). It imposes that rate of taxation to all consumers (firms and households) of energy, which is exactly necessary for collecting revenues equal to the amount of the energy saving expenditure. These revenues are then used by the government to finance the energy saving expenditures, ensuring public budget neutrality. Essentially the Government is used in the model to reallocate firms and households funds from their "optimum" placement in the reference case to the particular energy saving expenditures.

The introduction of energy efficiency cost curves into the GEM-E3 model involves three tasks:

- Specification of the energy efficiency cost curve
- Calibration of the curve
- Implementation within the current GEM-E3 model setup.

4.3.3) Industrial sector - GEM-E3

Industrial sectors demand for energy inputs in their production i.e. electricity, coal, oil, gas. These inputs are provided by the power generation sectors (conventional and RES) and the coal, oil and gas manufacturing and distribution sectors.

4.4) Energy demand - GEM-E3

The GEM-E3 model endogenously computes energy consumption, depending on energy prices, realised energy efficiency expenditures and autonomous energy efficiency improvements. Each agent decides how much energy it will consume in order to optimise its behaviour (i.e. to maximise profits for firms and utility for households) subject to technological constraints (i.e. a production function).

At a sectoral level, energy consumption is derived from profit maximization under a nested CES (Constant Elasticity of Substitution) specification. Energy enters the production function together with other production factors (capital, labour, materials). Substitution of energy and the rest of the production factors is imperfect (energy is considered an essential input to the production process) and it is induced by changes in the relative prices of each input.

Residential energy consumption is derived from the utility maximization problem of households. Households allocate their income between different consumption categories and savings to maximize their utility subject to their budget constraint. Consumption is split between durable (i.e. vehicles, electric appliances) and non-durable goods. For durable goods, stock accumulation depends on new purchases and scrapping. Durable goods consume (non-durable) goods and services, including energy products. The latter are endogenously determined depending on the stock of durable goods and on relative energy prices.

Energy efficiency

Energy efficiency in the GEM-E3 model can result from three factors:

- An increase in the amount agents spend to improve energy intensity in response to regulations, for example, by mirroring energy saving obligations or a minimum performance of energy efficiency (endogenous mechanism based on cost-potential curves for energy efficiency by sector).
- A change in energy prices that triggers the substitution of relatively less expensive inputs for more expensive energy, along the frontiers of substitution possibility.
- A change in the rate of energy-embodied technological progress (based on exogenous projections that reflect technological progress).

Expenditures in energy saving technology are treated as spending that economic agents undertake so as to reduce their energy consumption (e.g. purchases of more energy efficient appliances, insulation of buildings and retrofit etc.). For firms, expenditures in energy saving impact on their energy intensity and do not add to their capital stock (as opposed to investments). As energy saving expenditures do not add to the capital stock of firms, the productive capacity of the firms remains unchanged (i.e. energy saving expenditures of a firm reduce energy consumption per unit produced but they do not affect its productive capacity, that is the number of units that a factory can produce). Energy efficiency expenditures reduce energy consumption one period after they take place and continuously for a period of at least 20 years. Households' expenditures in energy efficiency improvements do not have a direct impact on their utility. The impact is indirect through the reduced energy costs that households have to pay.

Expenditures in energy efficiency improvements generate additional demand for goods and services (ferrous and non-ferrous metals, non-metallic goods, chemical products, electrical goods, construction and market services) which provide inputs to energy efficiency projects (see Table 10).

Energy efficiency improvements exhibit decreasing marginal returns (saturation effect). Energy savings potential is intertemporally limited (differently by sector) and higher energy saving entails an increase in marginal costs.

Calculating levels of energy efficiency expenditure

Expenditures in energy efficiency imply the accumulation of energy saving stock that is more energy efficient than the benchmark. Thus, specific rates of energy consumption (of equipment) and energy requirements are reduced, which contributes to savings of energy consumption following their installation. The higher upfront expenditures for energy efficiency imply funding requirements that need to be drawn from savings and from other borrowing. The additional funds are drawn from the entire economy (the sum of the economic agents' savings and general financing from financial institutions), eventually stressing capital supply in the economy. Energy efficiency expenditures have no direct impact on the capital stock as they are used by the agents to purchase goods and services that reduce energy consumption and are not used to increase directly productive capacity. The sectors that provide the energy saving goods and services need to increase their productive capacity in order to meet the increased demand for their products and to this end compete for capital resources with all the other sectors in the economy. This leads to a crowding out effect, the magnitude of which depends on the assumptions about capital market flexibility worldwide and financial resources overall. Spending on energy efficiency stimulates demand for sectors that produce the required goods and services, such as construction, industrial materials, equipment and certain market services. The modelling takes into account that the demand for, and expenditure on, energy decreases permanently in the periods that follow energy efficiency expenditures. For the modelling of the energy saving expenditures the basic assumption is that institutional authorities at national, EU or World level define, by sector, obligations that target pre-specified rates of energy efficiency improvements. The amount of energy efficiency expenditure that is required to reach the pre-specified rate of reductions of energy intensity is determined by the energy efficiency cost curves.

Energy efficiency projects generate demand for inputs from several sectors. Technical coefficients are used to determine the share that each sector delivering inputs to the energy efficiency projects has on the final expenditure made, i.e. for every expenditure made on energy efficiency projects what percentage of it is spend on each of the different sectors providing inputs

to energy efficiency projects. Table 10 shows which sectors contribute to the realisation of the energy savings projects and at what shares. These sectors then generate demand for the output of all other sectors through Leontief's Input-Output system, based on technical coefficients that are endogenously projected by the model.

Table 10: Sectoral breakdown of expenditures on energy efficiency projects

Sector	Share of expenditure (in equipment goods and services used to implement energy efficiency investment) as received by production sector, in % of overall expenditure in energy efficiency
Ferrous metals	4
Non-ferrous metals	4
Chemical Products	7
Non-metallic minerals	8
Electric Goods	2
Construction	60
Market Services	15

4.5) Technological change in energy - GEM-E3

Learning curves

The model uses the two factor learning curve approach in order to model the positive feedback between the market adoption of clean energy technologies and their improvement through R&D expenditures.

The endogenisation of technical change is modelled with the learning curve approach. Technological learning is decomposed into two components: learning through experience (learning by doing) and learning by research.

Learning by doing

The learning by doing curves measure how much the costs of a given energy technology will be reduced due to its increased adoption. The learning by doing or experience curve describes the quantitative relationship between output or capacity growth with cost reductions of technologies. The common mathematical formulation used in integrated assessment models to represent the learning curve is by using an exponential function of the form:

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where C is the cost per unit of production, CSales represents the cumulative sales (or cumulative output or cumulative capacity in the case of power generation technologies), C_0 is the cost of the first unit produced and lr is the learning elasticity (or experience parameter) which defines the slope of the learning curve of each technology. The learning effect is then measured in terms of percentage reduction of the cost for each doubling of the cumulative capacity, output or production of the specific technology:

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where LRE represents the learning rate that indicates the cost reduction achieved for every doubling of the cumulative capacity or output. Learning by doing curves have been introduced in GEM-E3-RD for low and zero carbon technologies that have a large potential for cost reductions in the period 2010-2050.

Table 11 presents the values of learning rates used in the GEM-E3 model for the different clean energy producing sectors). The same values are used in all regions identified in the model.

Table 11. Learning rates for clean energy technologies assumed in GEME3

Clean energy producing sectors	Learning by Doing rate
Equipment for Wind power generation	0.07
Equipment for Photovoltaic systems	0.17
Equipment for CCS technologies	0.07

(Source: Karkatsoulis P., Kouvaritakis N., Paroussos L., Fragkos P. & Capros P. (2014). Modification of GEM-E3 technological innovation module. SIMPATIC Working Paper No.18. Available at: http://simpatic.eu/wp-content/uploads/2014/05/D9-2- n%C2%BA18 -modification-of-GEM-E3-SG.pdf)

5) Land-use - GEM-E3

GEM-E3 considers land as a separate production factor

6) Emissions - GEM-E3

6.1) GHGs - GEM-E3

The GEM-E3 environment module addresses the following GHGs: CO2, CH4, N2O, HFCs, PFs and SF6. In the model these emissions are linked to the activity level of the relevant sectors. This link is presented in the following table. Data on GHG emissions are extracted from the UNFCCC database and estimates for process related GHG MACCs are taken from "Global mitigation of non-CO2 GHG" EPA report (2006), and IIASA database.

Table 12: GHG emission sources and link with GEM-E3 activities

GHGs	Sources	GEM-E3 activity	% in total GHG emissions of Annex I (2005)	GWP
CO2	Burning of fossil fuels	Coal, Oil, Gas	0.785	1
CO2	Cement production	Non-metallic minerals	0.04	1
СН4	Waste management, Gas and Coal mining, Oil, Animals	Coal, Oil, Gas, Agriculture, Public services	0.12	24
N2O	Burning of fossil fuels, Transport, Production of adipic and nitric acid (nylon), Fertilizers	Coal, Oil, Gas, Transport, Chemical products, Agriculture	0.057	310
HFC	CFC substitute, Production of HCFC-22, refrigerators	Chemical products, Equipment goods	0.0119	2000
PFC	Production of aluminium, semiconductors	Ferrous and non ferrous metals, Equipment goods	0.002	6800
SF6	Magnesium production, power distribution, Production of aluminium	Power supply, Ferrous and non ferrous metals	0.002	22200

There are three mechanisms of emission reduction explicitly specified in the GEM-E3 model:

- End-of-pipe abatement (where appropriate technologies are available): End-of-pipe abatement technologies are formulated explicitly by bottom-up derived abatement cost functions that differ between sectors, durable goods, pollutants and between countries. The marginal costs of abatement are increasing functions of the degree of abatement. These costs differ between sectors and countries according to the country- or sector-specific abatement efforts already done. End-of-pipe abatement technologies refer only to non-CO2 emissions.
- Substitution between fuels and/or between energy and non-energy inputs: In the case of substitution of fuels, as the production of the sectors is specified in nested CES-functions, there is (at least for a substitution elasticity greater than zero) some flexibility on the decision of intermediates. The input demand is linked to the relative prices of these inputs. Hence, if there is an extra cost on energy inputs, there will be a shift in the intermediate demand away from "expensive" energy inputs towards less costly inputs. A politically imposed cost on emissions therefore drives substitution towards less emission intensive inputs, e.g. from coal to gas or from energy to materials, labour or capital.
- Emission reduction due to a decrease of production and/or consumption: in a general system that covers the interdependency of agent's decision, imposing an environmental constraint (through standards, taxes or other instruments) causes additional costs to production (which is linked to the costs of substitution or abatement installation). An increasing selling price decreases demand of these goods even if this demand is inelastic to price changes (which are usually not the case) due to budget constraints. This lowers production and accordingly the demand for intermediates. Hence, there is an emission reduction due to a demand driven decline in production.

The dual formulation of the GEM-E3 model eases the incorporation of changes in economic behaviour due to emission or energy based environmental policy instruments. The costs of environmental policy requirements are added to the input (and consumption) prices. Intermediate demand is derived from the unit cost function which takes these extra costs into account. Similarly the demand of households for consumption categories is derived from the expenditure function, which is the dual of the utility function. Hence, the additional policy constraint is easily reflected in prices and volumes.

The model takes into account the trans-boundary effects of emissions through transport coefficients, relating the emissions in one country to the deposition/ concentration in the other countries. For secondary pollutants as tropospheric ozone, it implies considering the relation between the emissions of primary pollutants (NOx emissions and VOC emissions for ozone) and the level of concentration of the secondary pollutants (ozone).

Damage estimates are computed for each country and for the EU-15 as a whole, making the distinction between global warming, health damages and others. The figures for damage per unit of emission, deposition or concentration and per person and their valuation are based on the ExternE project results.

GHGs reduction policies

In GEM-E3 a GHG reduction policy can be implemented either through exogenous tax enforcement (thereby the level of the exogenous tax is given in advance but the level of emission reductions is unknown and is endogenously estimated), or through an exogenous implementation of an emission cap, namely an endogenous tax enforcement (thereby the level of the tax is originally unknown and endogenously estimated in order to achieve a specific emission reduction target). The estimation of the endogenous tax level ensues as the clearing price of demand and supply for emission permits. The available permits for the club are calculated and allocated according to the reduction target relative to emissions in 2005, set on a country or on a regional level.

According to the environmental policy under analysis, GEM-E3 features a selective activation of equations and respective variables that enable the appropriate simulation of policies. In this way, detailed alternative policies can be assessed as regards, for example, the allocation of emission allowances, the participation of country clusters in common emission reduction clubs, the recycling of government revenues from the sale of emission allowances and other detailed policy features. The activation of the appropriate equations is undertaken by means of specified "switch" parameters.

One method of permit allocation is the supply of free allowances through grandfathering (allocation of permits based on base year emissions) or other type of sectoral distribution. In the GEM-E3 this simulation allows for transfer of the value of emission permits to the firms and/or households by a respective reduction of the production cost or increase of the capital income for firms and by a transfer of value from the government to households.

The case of "hot air" permit supply is treated specifically in GEM-E3 model. If there is "hot air" permit supply, i.e. larger permit supply than actual baseline emissions, then half of the respective value is transferred from the government to the household (lump-sum transfer) and the rest is transferred from the government to the world. In this way, the government has no additional revenues due to "hot air" permit supply.

Recycling options

In microeconomic theory, the distortionary effect of taxes in the economy can be reduced by the recycling of revenues occurring from a second tax (carbon permits) with growth-enhancing effects on the longer-run. Such efficiency gains could lead to the double dividend effect if addressed optimally. A simple application of this "efficiency value" of the carbon permits is the "employment dividend" according to which the distortions created by taxes on labour can be reduced. The economic impacts of climate policies rely on the choice of the revenue recycling options.

In the GEM-E3 model, the following recycling options can be implemented:

- Lump-sum transfer to the household income
- Reduction of the social security contribution of employees
- Direct taxation reduction for households: Government revenues are redistributed back to households by lowering income taxes
- Tax cut for firms: Government revenues are used to reduce firms' costs by lowering indirect taxes
- Revenues from permit sales are used to reduce VAT rate for all goods to stimulate households final consumption
- Revenues from permit sales are used to subsidy private R&D.

6.2) Pollutants and non-GHG forcing agents - GEM-E3

GEM-E3 addresses the following non-GHGs: NOx, SOx.

7) Climate - GEM-E3

8) Non-climate sustainability dimension - GEM-E3

The GEM-E3 model quantifies several indicators relevant to the sustainable development dimensions. Such dimensions include macroeconomic performance, labour market, innovation related factors, air pollution and health, water, food security, energy security and Global partnership issues.

8.1) Air pollution and health - GEM-E3

In the GEM-E3 model emissions are calculated endogenously using emission coefficients per fuel use or economic activity as well as abatement technologies per pollutant. Hence, several indicators relevant to air pollution and health are quantified. Such indicators include emissions and concentration of air pollutants, health impacts, crop impacts, VOLY, DALY, health expenditure, labour productivity loss.

8.2) Water - GEM-E3

The GEM-E3 model quantifies indicators relevant to water, as regards its use by the energy sector, such as fresh - and seawater withdrawal/consumption from electricity sector, thermal water pollution, electricity requirements of cooling technologies, water prices.

8.4) Other sustainability dimensions - GEM-E3

The GEM-E3 model quantifies several indicators relevant to the sustainable development dimensions such as:

- Economic indicators (GDP, GDP per capita, sectoral production, net exports per country, amount of investments in infrastructure as a share of GDP, percentage share of manufacturing Value Added in total VA, Manufacturing employment),
- Labor market indicators (levels of employment per sector and per skill, total unemployment, level of wages),
- Innovation indicators (labour, capital, material, energy productivities),
- Food security indicators (food prices, domestic food production, percentage household expenditure on food),
- Energy security indicators (net energy imports, the energy security price index (ESPI), the composite energy security index (CESI), Jansen's index, oil vulnerability index, import dependence indicators, diversity indices, demand side indicators, share of zero carbon, energy prices) and
- Global partnership indicators (total tax revenue as % GDP, export share in GDP, import/export tariffs).

9) Appendices - GEM-E3

9.1) Mathematical model description - GEM-E3

The documentation of the GEM-E3 model equations can be found at http://www.e3mlab.eu/e3mlab/index.php? option=com_content&view=article&id=56%3Amanual-of-gem-e3-model&catid=36%3Agem-e3&Itemid=71&lang=en.

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