Modelling Impacts of Energy and Environmental Policies for the EU and the Czech Republic by CGE GEM-E3 model

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Outline

- Typology of models and their respective contributions
- Brief description of GEM-E3
- Policy studies for the EU with GEM-E3
  - Climate change
  - Local pollution
  - Energy taxation
- Linkage/Integration of models

Typology of Economic/Energy and Environmental models

- IAM models: Integrated Assessment models
- Macroeconomic models: CGE models, Macroeconometric models
- Partial Equilibrium Models: energy system models
- Sectoral models: covers only one specific part of the economic/energy/environmental system

For all, there is always a trade-off between time horizon, geographical and sectoral detail

Macroeconomic Models

- Two types:
  - Macroeconometric models, oriented towards short to medium term analysis with the focus on the dynamics of adjustment
  - General equilibrium model, oriented towards long term analysis with the focus on the equilibrium after all the adjustment
- Sectoral and geographical detail depends on the objective of the model.
- Economic theory underlining the model structure can differ between models
- When for environmental/energy policy analysis, include an environmental module for modelling the emissions and abatement possibilities. Sometimes also the feedback on the economy of the environment.
- Those models are what is called 'Top-Down' models.

This type of models integrates the different mechanisms present in the energy models but in a less detailed, less technical and more schematic way (e.g. substitution between technologies is represented with production function).

- **Policy question/analysis**
  - Macroeconomic impact of energy/environmental policies
  - Choice of policy instruments
  - Burdensharing of climate target between regions/countries

Examples of development in macroeconomic models for better integration of energy/environment

- Example of General Equilibrium model
  - GEM-E3:
    - Technology for electricity production
    - Environmental damage linked to energy
    - Feedback from damage to economy
- Example of Macroeconometric model
  - NEMESIS, E3ME
    - Full modelling of demand and supply
    - Energy module with explicit technologies
- Integrated Assessment models
  - RICE
    - Full integration of environment and its feedback on the economy

Partial equilibrium Models of the Energy System

- Cover the energy system, i.e. the demand and supply of energy/energy services, but the macroeconomic background remains exogenous.
- They are generally ‘technology rich’, they are called ‘Bottom-Up’ models in the literature.
- Other possible characteristics:
  - Learning by doing
  - External cost linked to energy
- Representation sometimes limited to supply and cost accounting, the demand being considered as fixed focussing then only on the technological options.
- **Policy question/analysis**
  - Impact on the energy system of energy and environmental policies
  - Role of technological options
  - Impact of resource constraints

Examples of development in energy models

- TIMES/MARKAL
  - Partial equilibrium model of the energy system
  - Perfect competition assumption
  - Integrate environmental damage ex post or in the optimisation
  - Macro component possible
- POLES and PRIMES
  - Partial equilibrium model of the energy system
  - Partly optimisation, partly simulation
  - More adaptive behaviour by economic agents
- All these models are getting more and more detailed

Complementarity of the models

- Partial equilibrium models
  - Detailed analysis of technological choices, inclusive the direct cost
  - Can serve as input for macro models
- General equilibrium/Macro models
  - Evaluation of the total welfare cost of policies with limited technological content but inclusive impact of tax shifting or tax distortions
  - Contribute to consistent exogenous growth assumptions for the partial models

General Identity of GEM-E3

- GEM-E3 is a multi-country computable general equilibrium model built to evaluate the economic impacts of structural policies and mainly the interactions between the economy, the energy system, the environment and the technological progress
- GEM-E3 is a modelling framework providing the user with many modelling options: a European model, a World model, and a series of different modelling options
- GEM-E3 runs on GAMS on a PC and uses MS-Excel for the data and the results

GEM-E3 History

- The model was built in the beginning of the 90s by a collaborative project supported by DG Research and involving mainly NTUA,KUL and ZEW
- Over the last ten years, the modelling framework was considerably extended in terms of coverage, data and modelling options. The data are continuously updated
- A series of major European studies have been carried out by using GEM-E3: Single Market Act, Taxation reform, Double Dividend, Emission Trading, Kyoto targets, R&D policy and budget, Employment, Enlargement of the EU, GHG reduction framework at world level, etc.
- The major modelling developments include endogenous technology progress and innovation, imperfect competition with product differentiation, bottom-up energy system with depletable resources, dynamics and labour market.

GEM-E3 general characteristics (1/3)

- follows the computable general equilibrium methodology,
  - demand and supply functions derived from microeconomic behaviour of economic agents (optimisation of their objective)
  - markets clear through prices and prices are such that at equilibrium all agents optimise their behaviour
  - covers the entire economic activity within a region
- simultaneously multinational and specific for each region, markets clear at regional or World level, where appropriate
- Trade on a global scale is formulated by assuming imperfect substitution between goods and services by country or region of origin

GEM-E3 general characteristics (2/3)

- extensive environmental dimension, inclusive its transfrontier characteristics and possibility of feedback from the environment on the economy
- wide variety of policy instruments (standards, taxes, permits, at World, EU and regional level, different allowance schemes)
- oriented towards medium & long term macroeconomic implications of policies (general, energy, environment)
- follows a time forward path (dynamic recursive over time)

GEM-E3 general characteristics (3/3)

- The European version of GEM-E3 is entirely based on Eurostat statistics: Input-Output tables, National Accounts, Investment Matrix, Consumption Matrix, Bilateral Trade Matrix, Employment and Capital data. Also Energy Balances and emission statistics.
- The World version of GEM-E3 is using the GTAP-7 database.
- Environmental data are derived from GAINS data and from EU RD projects on external cost
- A distinguishing feature of GEM-E3 is the details in representing income distribution, taxation, subsidies, social security and other elements affecting the public budget. The European model can simulate constraints related to public budget.

GEM-E3 Regional aggregation

GEM-E3 World

- EU27
- Other Europe
- CIS
- USA
- Canada
- Japan
- Oceania
- Mexico
- Brazil
- Rest of Latin America
- East Asia
- China
- India
- Rest of Asia
- Middle East
- Mediterranean
- South Africa
- Rest of Africa

GEM-E3 Europe

27 EU countries

Exc. LU,MT,CY

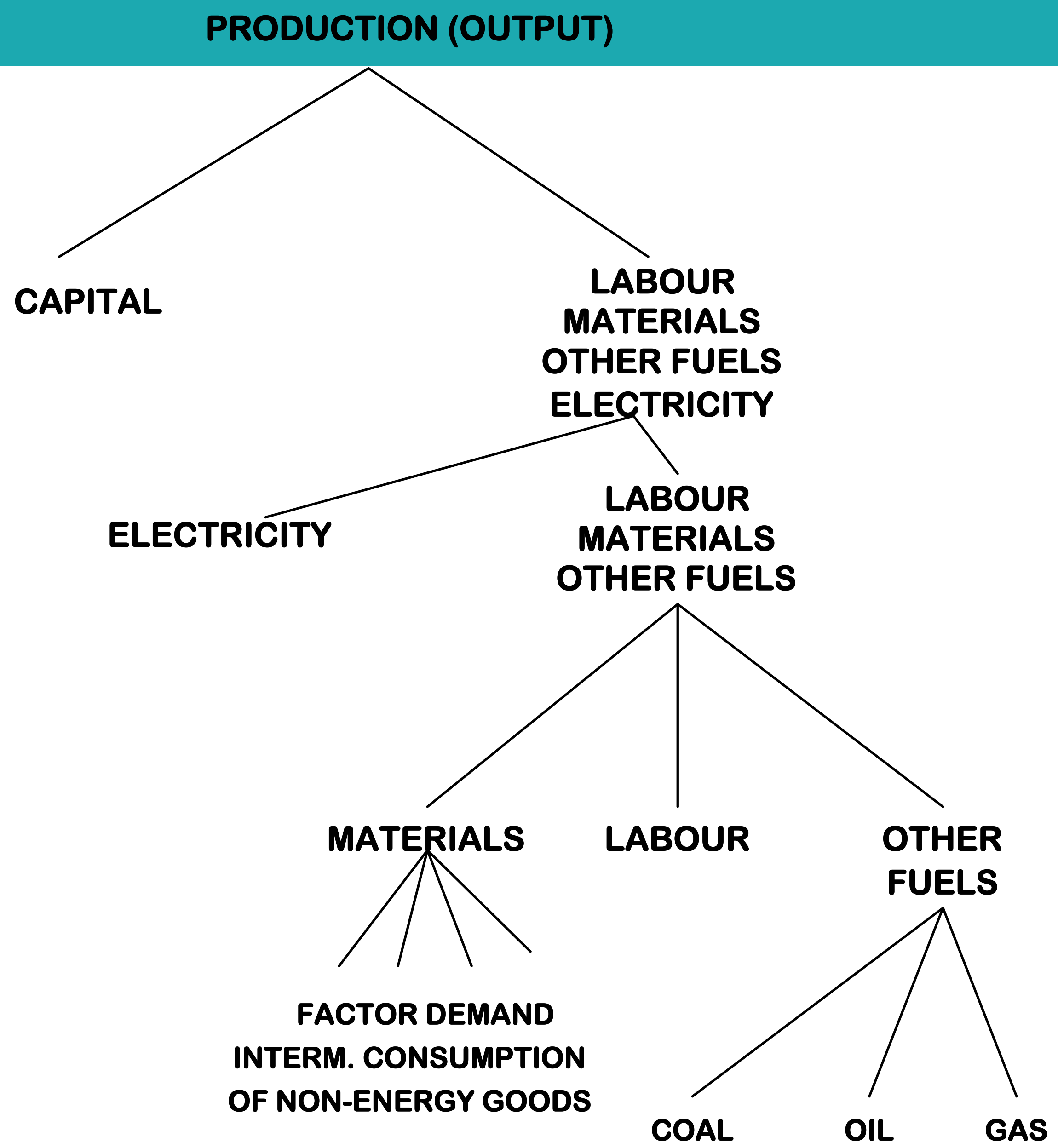
GEM-E3 sectoral aggregation

1. Agriculture
2. Coal
3. Oil
4. Gas
5. Electricity
6. Ferrous and non ferrous metals
7. Chemical Products
8. Other energy intensive
9. Electric Goods
10. Transport equipment
11. Other Equipment Goods
12. Consumer Goods Industries
13. Construction
14. Telecommunication Services
15. Transport
16. Services of credit and insurances
17. Other Market Services
18. Non Market Services

GEM-E3: Producer behaviour

- Maximising behaviour of producers
  - in the short run, constrained by the physical capital stock (fixed within a period)
  - in the long run, change of capital stock over time through investment
- Production scheme, based on nested CES function involving capital, labour, energy and materials
  - demand for production factors, based on demand and prices
  - capital investment decision function has inter-temporal features, uses adaptive expectations to approximate profitability considerations
- Rate of return on capital derived from sectoral, national or multinational closure of capital market

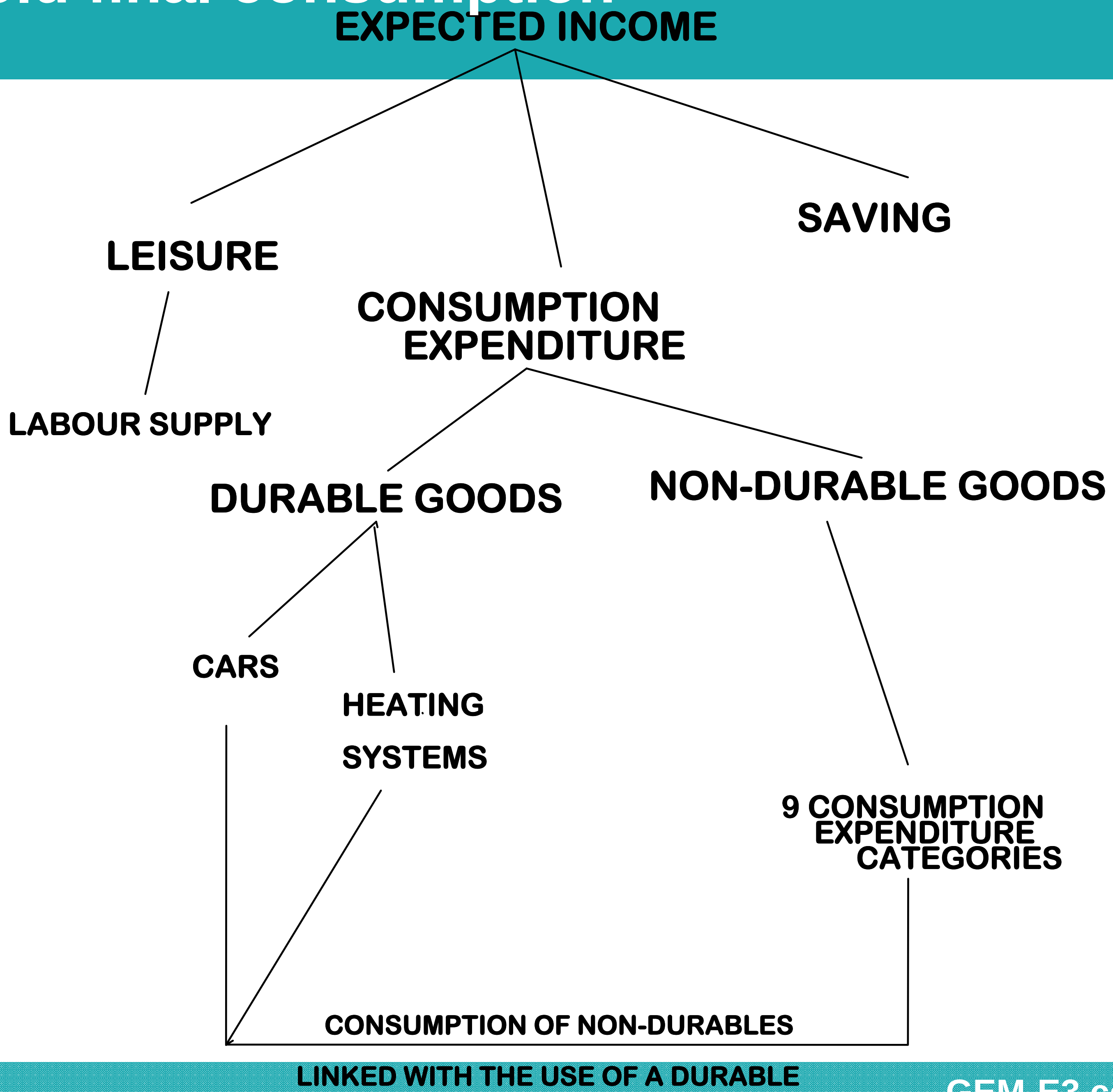
Domestic production scheme



GEM-E3 : Consumer behaviour

- Maximise intertemporal utility under an intertemporal budget constraint (ELES)
- Derived demand for consumption, leisure and savings, assuming myopic expectations
- Allocation of total consumption between consumption goods (LES)
  - durable goods
  - linked non durable goods
  - non linked non durable goods

Household final consumption



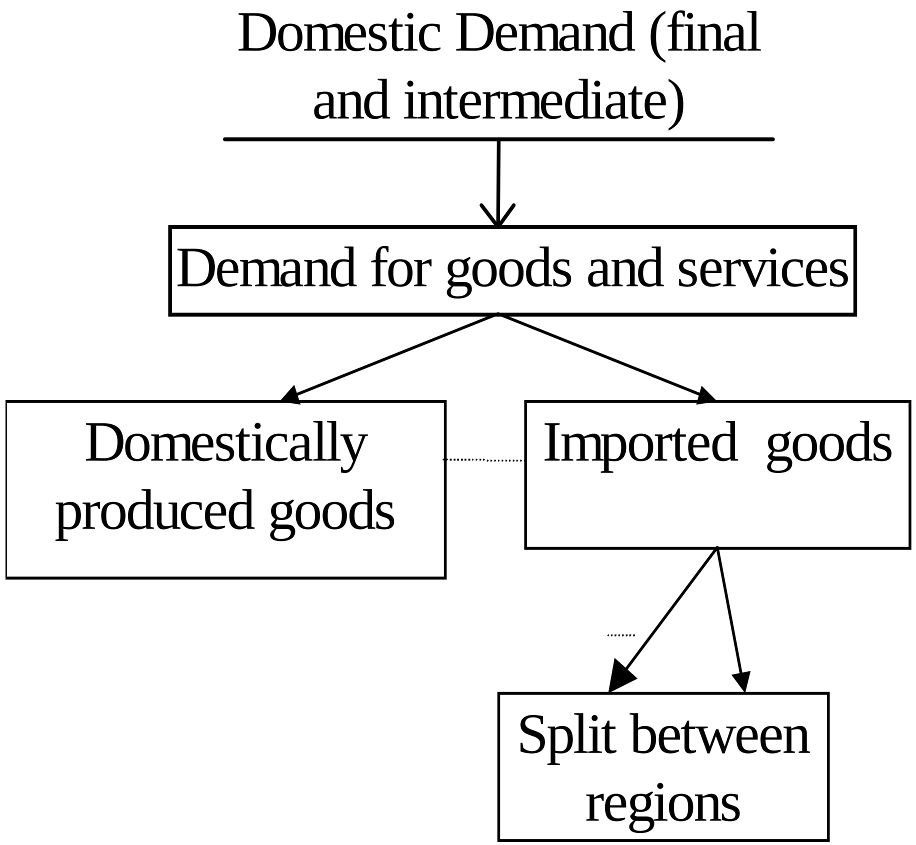
GEM-E3: Public sector

- Behaviour is largely exogenous
  - public consumption and investment
  - taxation and subsidy rates, permit system
  - social policy instruments
- Possibility of endogenous changes of taxation rates to simulate budget neutral policies
- Taxes, permits and environmental targets can be World, regional, country wide and sectorally specified, with either the level of the tax or the target exogenous and different burden sharing possibilities

GEM-E3: import and export

- Domestic demand is allocated between domestic and imported goods and services, following an Armington specification (imperfect substitution)
- export of one region to another are derived from the import demand from the other countries, Armington substitution elasticities crucial for trade effects.
- supply to export market occurs at same price as on domestic markets
- ensures trade matrix with zero trade deficit (in value) at the global level for the World model

GEM-E3: Armington demand structure



GEM-E3: the environmental module (1/2)

- Three important environmental problems
  - global warming
  - problems linked to deposition of acidifying emissions
  - ambient air quality linked to acidifying emissions and ozone concentrations
- Energy related emissions: CO_2, NOx, SO_2, VOC, particulates and the other GHG
- Three explicitly specified emission reduction mechanisms
    - end of pipe abatement (through abatement cost function)
    - substitution between fuels and/or between energetic and non energetic inputs
    - reduction through production/consumption decline

GEM-E3: the environmental module (2/2)

- Policy instruments
  - Permit System
    - at sectoral, national, regional or World level with specific targets
    - possibility of different schemes for burden sharing (great flexibility)
    - limits on import and export of permit
  - Endogenous or exogenous environmental tax (with possibility of neutral budget policy)
  - Energy/emission standards
- Computation of the damage generated by the emissions from one country and linked to a climate module (for the World model) integrated in the welfare evaluation, it follows the bottom-up damage function approach from ExternE

GEM-E3: market equilibrium

- Market clearing condition (equilibrium between demand and supply) serves to compute the market price (explicitly computed)
  - Goods markets: unit cost of production, under perfect competition assumption
  - Labour market: wage rate through equilibrium (full flexibility) or wage rate rule (rigidity of wage and possibility for unemployment)
  - permit market through permit price (at sectoral, national, regional or World level)
- at equilibrium, prices such that all agents optimise their behaviour and fully use their budget
- model designed such that the sum of the agents' surplus or deficit are zero

GEM-E3: policy appraisal

- Social Welfare Function

$$W = \sum_{i=1}^{R} \frac{W_i^{(1-\varepsilon)}}{(1-\varepsilon)}$$

  - where W_i represents the Region i welfare derived from the consumer's utility function, which includes in a separable way the utility from the consumption of goods and leisure and the environmental utility/damage
  - and ε represents the degree of inequality aversion
- Such a function can incorporate two limiting cases: the utilitarian approach and the Rawlsian approach, through ε

GEM-E3 Model Extensions

- Endogenous growth through technology and innovation, modelling endogenously the decision and impact of R&D expenditure
- Imperfect competition in goods and permit market, allowing for the impact of market power and economies of scale
- Energy modelling extension through a bottom up energy system sub-model and the depletable energy resources mechanism
- Imperfect markets for labour (through market negotiation)
- Improvement of the dynamics in the demand for capital

These extensions are currently updated or under further development. The objective is to better represent the objectives on the policy agenda (knowledge society, growth, internal market, environmental sustainability, unemployment)

GEM-E3 endogenous technical change

- Basic modelling idea: combination of two production functions:
  - Knowledge production function: supply, generation of new innovation
  - Output production function: standard KLEM function extended to account for the impact of endogenous technology innovation
- Innovation on products (in the EU mainly the equipment and the chemical goods) to the benefit of the processes used in other sectors, on processes and human capital improvements
- The combination of product, process and human capital improvement augment the quality of all commodities
- Innovation purchasing decision of the firm induces spillovers to other sectors and countries but there benefit are less than for the generator of innovation
- For equal value of two products, the one with better quality sells larger quantity at lower price

GEM-E3 imperfect competition

- Basic modelling idea compared to core version:
  - The selling price of a good results from the unit cost, an endogenous mark-up (due to imperfect competition) and the eventual barriers to trade
  - Economies of scale through fixed factor
  - Product differentiation and love of variety effects on the demand side
- Hypothesis about horizontal product differentiation between firms within the same sector and country; when the number of varieties increase, the consumer (final or intermediate) obtains the sme aggregate quantity more efficiently (i.e. with lower quantities hence lower cost)
- The mark-ups reduce *when enlarging the market*, as a result of more intensive competition, the larger variety of products and the increasing returns to scale (efficient size of company). This further induces growth.

GEM-E3 energy modelling

- Bottom up modelling of the power generation sector:
  - Engineering oriented modelling of the electricity sector for a more explicit representation of the decision process in the sector.
  - explicit representation of a variety of old and new technologies of power generation with possibility for semi-endogenous learning;
  - Short-term: least-cost dispatching of existing power plants under capacity constraints, for different load segments, placed at the bottom of the electricity sector CES nesting
  - Long-term: investment into new power generation plants based on expected demand, unit costs (capital and fuels) and relative risks
- Modelling of the supply of depletable resources (GEM-E3 World)
  - Extraction rate, discovery rate and their effect on the cost of resources
  - The price of energy resources (e.g. oil, gas) is endogenous at world or regional scales, as a function of
    - The rate of extraction r from proven reserves and d the rate of discovery of new reserves which are function of d and yet-to-find-reserves
    - The accumulated use of the resources

Case studies with GEM-E3

- Contribution to EU impact assessment of
  - Climate policy: impact of different allocation of reduction target and differentiated participation for world climate agreement
  - EU target of -20% GHG reduction in 2020
  - Clean air for Europe: macroeconomic impact of the EU strategy (with targets derived from RAINS/GAINS
- Case studies for DG TAXUD on energy taxation reforms
- Economic impact of climate change in Europe

Case study: post 2012 climate strategies

- Overall target allowing not more than 2° temperature increase in the long term
- Allocation of the targets between countries/regions and intermediate targets for implementation in GEM-E3
  - Relative greater effort by Annex B countries
  - Gradual participation of the other regions in the reduction effort
- Grouping of the countries/regions:
  - Group 1: AUZ, JPN, CAN, USA, EU27, OEU, FSU
  - Group 2: MEV, MED, MEA, EAS

    Both groups with a target from 2020 onwards of -22.5 for 2020 and -38% versus 1990 in 2030
  - Group 3: BRA, LAM, IND, CHN, RAS, SAFR with a gradually increasing target from 2030 onwards, + 135% versus 1990 in 2030.

Case study: post 2012 climate strategies

- Allocation of the target between countries and sectors:
  - Allocation within group by grandfathering
  - Allocation between energy intensive sectors within region on a cost efficiency basis
- Policy instrument: emission trading
  - Energy intensive sectors: a World ETS, i.e. an international emission trading system for these sectors between all groups contributing to the target
  - Other sectors: a domestic trading system for household and sectors not included in the WETS
  - Use of flexible mechanisms is possible depending on the scenarios but limited to the energy intensive sectors
- The Kyoto target are respected for participating countries

Case study: post 2012 climate strategies

- **Scenario 1**: the countries Brazil, other Latin America, South Africa and China are participating in the World ETS from 2020 onwards;
  - Endowment for 2020 and 2025 before having a reduction target equal to the reference emissions of the sectors in the country participating in the WETS.
  - no domestic target before having a reduction target.
- **Scenario 2**: all countries participate in the World ETS only when they have a reduction target

Case study: post 2012 climate strategies

- Reduction targets for 2020 are already stringent for the developed world and are further increasing in 2030.
  - the cost in terms of welfare remains limited but increases with the stringency of the target.
  - regions without target suffers from the decrease in the other regions
- Early participation has a positive effect:
  - less loss of competitiveness for energy intensive sectors
  - reduces the welfare cost for group I and II before 2030
  - It is also positive for the regions providing most of the emission reduction such as China, but more neutral for the other early participants such as Brazil
  - Countries not participating do not gain from the early participation as they are losing some possible market gain in the energy intensive sectors.

Case study: post 2012 climate strategies

	Scenario 1: early participation				Scenario 2: participation when target			
	2020		2030		2020		2030	
	Economic Welfare	GHG Emissions	Economic Welfare	GHG Emissions	Economic Welfare	GHG Emissions	Economic Welfare	GHG Emissions
USA	-1.4%	-39.5%	-3.4%	-52.1%	-1.4%	-46.6%	-3.4%	-52.1%
EU27	-2.3%	-28.1%	-5.7%	-41.6%	-2.4%	-33.6%	-5.8%	-41.6%
Brazil	-0.3%	-4.8%	-1.5%	-15.0%	-0.3%	3.6%	-1.5%	-15.0%
India	-0.9%	0.5%	-1.6%	-23.3%	-0.7%	0.7%	-1.6%	-23.3%
China	0.3%	-29.5%	-0.8%	-32.8%	-0.8%	1.8%	-0.8%	-32.7%
World inequality aversion=0	-1.2%	-25.9%	-3.4%	-37.2%	-1.3%	-23.6%	-3.4%	-37.2%
World inequality aversion=1	-0.4%		-1.4%		-0.5%		-1.4%	
GHG permit price (US$2001/ton CO2eq)		40.9		83.4		73.5		83.3

Case study: the climate energy package for 2020

- Macroeconomic impact of the climate energy packet for 2020 with GEM-E3 (the impact on the energy system derived with PRIMES), with the overall target of 20% reduction (in GEM-E3 without specific target for renewables/biofuels)
- Focus on the distributional impact of different schemes for the allocation of permits and of the auctioning revenues
- Scenarios
  - Scenario with a cost efficient allocation of the permit through a EU wide permit system with free distribution of permits (fixes the allocation at EU level of the reduction target between the energy intensive sectors and the other sectors, based on equal marginal abatement cost.
  - Scenarios with EU ETS for the energy intensive sectors (with auctioning) and domestic policy for the others (tax or command and control)
  - Scenarios with different allocation between countries for the domestic targets and for the revenue from the auctioning of the ETS permits in function of GDP per head
  - Scenarios with the possibility of JI/CDM

Case study: the climate energy package for 2020 (2)

- Possible to reduce the CO_2 emissions unilaterally with 20% at a reasonable cost.
- The distribution of the cost between the EU countries can be rather differentiated depending on
  - the initial allocation,
  - the CO_2 reduction cost,
  - the share of the energy intensive sectors in the country economy and
  - the distribution of the revenue of the permits' sales.
- Using cost efficient instruments such as permit markets can limit the overall cost in GDP of the policy measure.
- Implementing a cross country ETS and a domestic policy for non ETS sectors can have a cost in terms of efficiency when the targets in the non ETS sectors are reallocated but it is beneficial in terms of distribution of the cost between countries.
- Using revenue generating policy instruments associated with a lumpsum transfer to household favours the household consumption and contributes to the overall welfare increase

Case Study: Macroeconomic effect of CAFE

- Study for evaluation of macro economic impact of the NEC strategy for the European Commission with GEM-E3 (2006/8):
  - Data/Results from GAINS integrated in GEM-E3:
    - emission coefficient and evolution over time
    - marginal abatement cost for local pollutants
  - Evaluation of the macroeconomic impact of the reduction target obtained by RAINS
    - Overall cost, with and without a climate policy
    - Policy instruments at national level and sectoral level depending on the pollutant (standard/permit system)

Case Study: Macroeconomic effect of CAFE (2)

- The macroeconomic cost of air pollution reduction remains limited compared to the benefits obtained in terms of air quality, health and ecosystem
- The benefits return mainly to the EU citizens.
- The effect on the competitiveness of the sectors remains small because the price effect is limited and all EU countries participate in the abatement effort.
- The overall cost depends on the climate/energy policy associated with the air quality policy, the climate policy contributing already to the reduction of the local pollutant.

Case Study: Macroeconomic effect of CAFE (3)

	Impact compared to BL w/o climate policy					Impact compared to BL with climate policy				
	Emission	Emission	Emission	PM	Emission	Emission	Emission	Emission	PM	Emission
EU	-11.4%	-28.3%	-3.9%	-21.6%	-15.7%	-9.1%	-20.6%	-3.5%	-20.1%	-14.2%
Germany	-12.7%	-6.9%	-0.5%	-8.7%	-21.0%	-9.9%	-4.4%	-0.2%	-8.7%	-20.5%
France	-7.1%	-18.9%	-2.5%	-12.4%	-18.7%	-6.3%	-13.5%	-1.3%	-11.8%	-16.9%
UK	-13.1%	-25.1%	-1.4%	-16.9%	-13.7%	-9.9%	-16.5%	-0.5%	-13.6%	-10.7%
Czech Republic	-17.9%	-24.8%	-2.4%	-9.1%	-14.5%	-13.5%	-19.8%	-3.4%	-7.9%	-10.6%
Poland	-13.6%	-38.7%	-8.4%	-29.9%	-19.7%	-7.9%	-34.2%	-9.6%	-27.1%	-14.2%
	Economic Welfare	Gross Domestic Product	Employment	Exports	Final Energy Consumption	Economic Welfare	Gross Domestic Product	Employment	Exports	Final Energy Consumption
EU	-0.04%	-0.07%	-0.05%	-0.11%	-0.79%	-0.03%	-0.02%	-0.02%	0.01%	-0.23%
Germany	0.00%	-0.03%	-0.02%	-0.14%	-0.60%	0.00%	-0.01%	-0.01%	-0.03%	-0.10%
France	0.00%	-0.05%	-0.03%	-0.15%	-0.62%	-0.01%	-0.01%	-0.02%	-0.03%	-0.30%
UK	-0.02%	-0.05%	-0.03%	-0.04%	-0.88%	0.00%	-0.02%	-0.01%	-0.01%	-0.19%
Czech Republic	-0.26%	-0.14%	-0.06%	-0.17%	-1.75%	-0.15%	-0.02%	-0.01%	0.02%	-1.07%
Poland	-0.78%	-0.41%	-0.10%	-0.21%	-6.00%	-0.38%	-0.10%	-0.01%	0.15%	-5.32%

Case study: Harmonisation of Energy Taxation

- Study for DG TAXUD on the harmonisation of the energy taxation in the EU
- Scenarios
  - Implementation of the harmonised tax level, with compensation by employers social security contribution
  - With and without climate policy
  - Current account relative to GDP same as in the reference

Case Study: Economic Impact of Climate Change in Europe

- Study within the PESETA project of IPTS
- Evaluation of the macroeconomic cost of climate change in Europe for different climate scenarios through the implementation of the results of detailed bottom up models for the following components:
  - Agriculture
  - Sea level rise
  - River floods
  - Tourism
- Without adaptation, cost can become high but there are regional differentiation depending on the vulnerability for each component (e.g. agriculture in Southern Europe)

What questions can GEM-E3 answer?

- What are the overall implications/cost of an energy/ environmental policy (on growth, employment, trade balance, sectoral evolution, on environment, etc), how are the cost distributed between EU countries
- Integrated analysis of environmental and energy objectives on an European scale, e.g. energy security versus clean air, simultaneous analysis of global warming and acid rain policy: trade off and synergy between policies
- Evaluation of choice of policy instrument/tax recycling strategy for a given an economy/ energy/environmental target and at which level (EU or country, sectoral)
- It can also contribute to consistent exogenous growth assumptions for the partial models

Complementarity with the other types of models

- Partial equilibrium models (energy and environmental)
  - Gives a more detailed analysis of technological choices, inclusive the direct cost
  - Can serve as input for macro models
- Linkage experiences:
  - No real full integration/linkage: only the IAM models but then all parts are very simplified, other experience not very successful
  - only with one part simplified and the other detailed.
    - MARKAL/TIMES-MACRO: a simplified macro part is added to the full energy model, it allows consistency between macroeconomic evolution and evolution in the energy system (e.g. saving will be consistent with the need of investment in the energy system
    - Technology modelling in general equilibrium models: experience with GEM-E3 and other CGE with technology based modelling of the electricity sector

Is Linkage needed?

- The different models do not answer the same type of policy questions:
  - therefore linkage not necessary needed but results of some models can be an input for the others
- Important however
  - For macroeconomic models to integrate, though in a simplified way, the different possible responses of the energy system to the policy which is analysed.
  - For partial equilibrium models to integrate price mechanism to reflect partly the possible interaction outside the energy system.
  - To calibrate the two types of model to same type of behavioural or technological assumptions when used for joint policy analysis to ensure consistency
    - substitution elasticity of production function in macro model should reflect the technological substitution in energy model
- Examples of joint policy analysis
  - distributional issues between economic agents or countries are better addressed with macroeconomic models
  - technological opportunities, interaction between demand and supply in energy markets, better addressed with energy models

Conclusion

- There has been a real acceleration in the use of models for medium term policy evaluation at EU level
- Macroeconomic models: contribute to the analyse of the direct and indirect cost (incl. its the feedback) of a policy on the rest of the economy, distributional impact, differentiated impact by policy instrument
- Were complemented by more technico-economic model which are fully detailed for the direct cost and choice of technology with sectoral disaggregation and in some cases contribute to the input for GEM-E3
- There are complementarities between the different types of models: a consistent combination of models (not necessarily linked) can contribute to the evaluation of a policy in its various aspects, because the different models do not answer the same questions, both are needed