E4M-GAIA: Energy-Economy-Environment-Engineering Modelling of Gaia

Dr. Athanasios Dagoumas

Senior Energy Analyst, Hellenic Transmission System Operator S.A.

3rd International Scientific Conference on "Energy and Climate Change", 7-8 October 2010, Athens, Greece

Outline

- **Modelling approaches**
  - **Underlying Theory**
- **Need for Integrated Modelling**
  - **Climate Change, Economics and Energy System**
- **E4M-GAIA Model with Focus on Energy System Modelling**
  - **Energy Demand econometrics modelling**
  - **Energy Supply probabilistic modelling**
- **Conclusions**

Modelling Approaches

- **Modelling approaches**
  - **Top-down (macro-economic models)**
    - **Neoclassical tradition (Computable General Equilibrium (CGE), Agent-based Models…)**
    - **Keynesian tradition (Econometrics, “New Economics”...)**
    - **Others (Behavioural, Evolutionary economics…)**
  - **Bottom Up Models**
    - **Energy System models**
    - **Technology Innovation models…**
  - **Hybrid**
    - **Integration of top-down and bottom-up approaches**

Critical issues in modelling

- **Theoretical approach**
  - **Equilibrium based or open as regards economic policy**
  - **Demand or Supply driven, Consideration of history**
  - **Endogeneity, Assumptions for the future**
    - Endogenous Technological change…
  - **Treatment of Uncertainties and Risks**
    - in parameter estimates
    - in assumptions and policies
- **The level of disaggregation and/or detail of agent representation**
  - regions, economic sectors, energy users, fuels…
  - **Social institutional groups** (heterogeneous not representative agents)
- **Dynamic, static**
- **Modularity**
  - **Level of detail in sectoral modelling**
- **“Scenario” or “target” approach**

Challenges in modelling

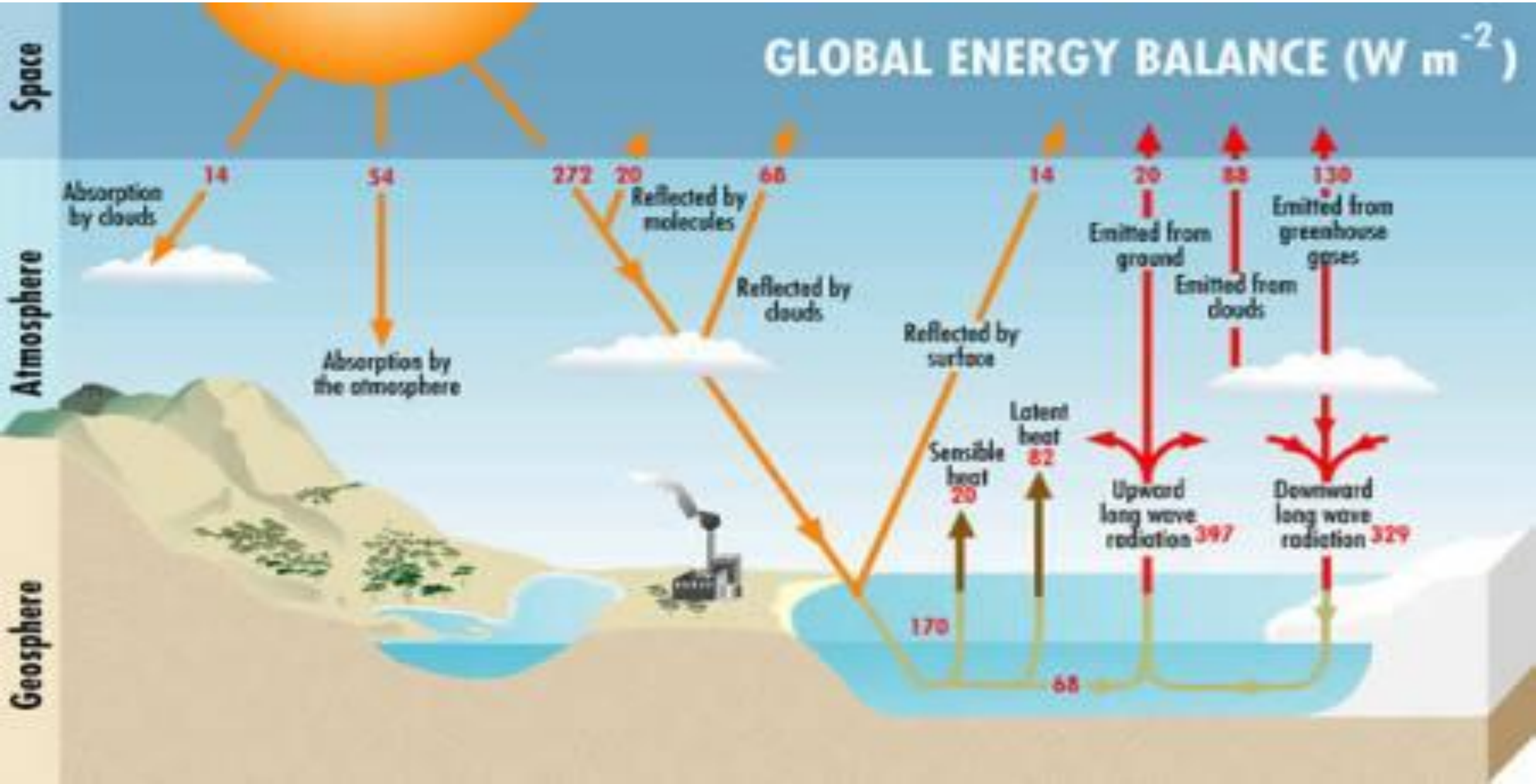
- The Climate Change and the Financial crisis revealed the weaknesses of the neoclassical dominant economic approach
  - Economic System should not be regarded as a closed system
    - Avoiding dangerous climate change (mitigation and adaptation)
  - Economic system is not in equilibrium
    - Financial system is not modelled in detail in any model
  - Assumptions have to be reconsidered e.g. full employment, market perfections, use or resources...
    - All mitigation policies lead to loss in GDP, welfare

Integrated Modelling

- The Energy system and Environment modelling should be integrated with economic modelling in a comprehensive approach
  - Complementarity of policy packages for mitigation and/or adaptation of climate change
- New approaches for Modelling the Economy-Energy-Environment system
  - Economics of climate change, Economics of Gaia, “New economics”, Complexity economics, Evolutionary economics, Innovation economics…
- This integrated approach should be linked with the earth system models for an even more integrated approach

Climate Change and the Energy System

- **Climate Change, Economic and Energy System Modelling should be comprehensive, consider uncertanties, and treat the integrated system as a space-time problem**



E4M-GAIA Models

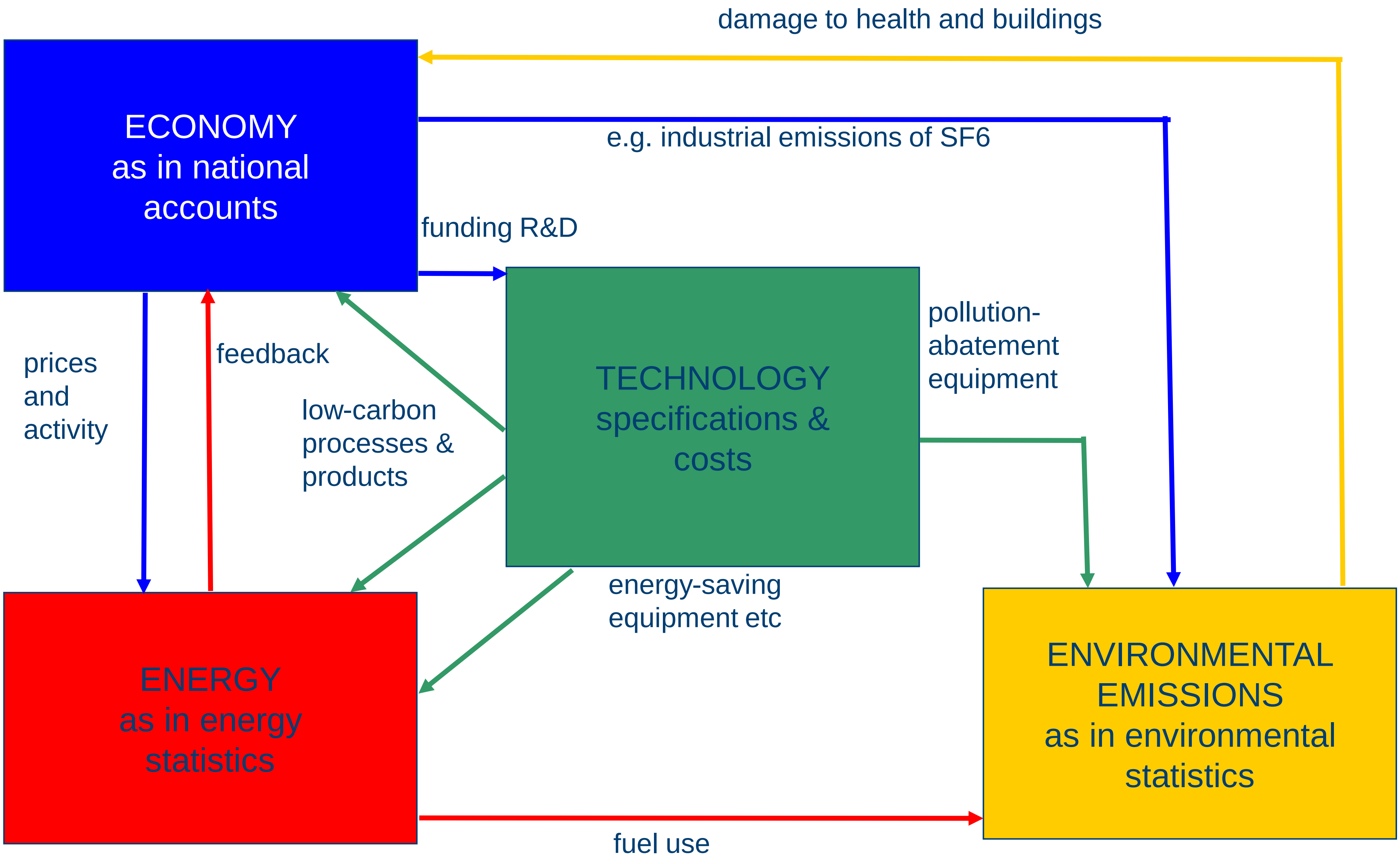
E4M-GAIA: E4 Model of GAIA:

- GAIA represents the Earth, according to the theory introduced by James Lovelock,
  - which postulates that the biosphere is a self regulating entity with the capacity to keep our planet healthy by controlling the chemical and physical environment.

The model shares similar theory with the **“New Economics” approach**, introduced at **the University of Cambridge** and has the following main characteristics: Econometric, Dynamic, Structural, Post-Keynesian, Hybrid

Reference: J. E. Lovelock (1972). "Gaia as seen through the atmosphere”, Atmospheric Environment, Vol. 6, Issue 8, pp. 579–580.

Engineering-Energy-Environment-Economy Interactions



E4M-GAIA main stochastic equations

E4M-GAIA endogenously (aggregate and/or disaggregate by 20 regions/ 42 sectors/ 19 fuel users, 12 fuels …) estimates:

Main economic figures

- **Investment**
- **Government Consumption**
- **Household and Government expenditure**
- **Exports and Imports**
- **Export, Import, Industrial Prices**
- **Industrial output**
- **Industrial employment**
- **Industrial Value Added**

Energy related figures

- **Energy demand**
- **Disaggregated energy demand**
- **Electricity generation, capacity and prices**

E4M-GAIA Classifications

REGIONS	
1	USA
2	Japan
3	Germany
4	UK
5	France
6	Italy
7	Rest EU-15
8	EU-12
9	Canada
10	Australia
11	OECD nes
12	Russia
13	Rest of Annex I
14	China
15	India
16	Mexico
17	Brazil
18	NICs
19	OPEC
20	Rest of world

- Rest EU-15 (11 countries): Austria, Belgium, Denmark, Finland, Greece, Ireland, Luxembourg, Netherlands, Portugal, Spain, Sweden
- EU-12: Czech Republic, Cyprus, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovenia, Slovakia, Romania, Bulgaria
- OECD nes (not elsewhere specified - rest of Annex 1 OECD): New Zealand, Norway, Switzerland, Turkey
- Rest of Annex 1 (3 countries): Belarus, Croatia, Ukraine
- NICs (Newly Industrialised Countries: 6 countries): S Korea, Malaysia, Philippines, Singapore, Taiwan, Thailand
- OPEC (11 countries): Algeria, Indonesia, Iran, Iraq, Kuwait, Lybia, Nigeria, Qatar, Saudi Arabia, UAE, Venezuela
- Rest of world (all remaining countries are included, the following being just major 11 economies): South Africa, N Korea, Argentina, Khazakstan, Pakistan, Uzbekistan, Egypt, Israel, Bangladesh, Vietnam, Colombia + all other countries not covered in the above 19 regions

Energy system Modelling

Energy System modelling problems

- Energy Supply
- Transmission and Distribution
- Energy Demand
- Energy Prices
- Funding investments
- Regulation
- Investments’ decision process
- Risks and Uncertainty
- Implementation of policies

Hybrid modelling

The main energy submodel

- Determines **aggregate and disaggregate energy demand** by fuel user and prices of fuel use

Δεν είναι δυνατή η εμφάνιση αυτής της εικόνας.

- Provides **feedback to main economic framework**

In E4M- GAIA this 'top-down' approach is supplemented by a set of 'bottom-up’ submodels

- the **Energy Technology Model (ETM)**
  - provides fuel use for power generation that replaces the econometric estimates.
- the **Transport submodel**
  - provides fuel use for electric vehicles

Energy demand econometrics modelling

- **2-level hierarchy**: aggregate and disaggregate energy demand equations
- **Aggregate demand** affected by:
  - **industrial output of user industry, household spending in total, relative prices, temperature, technical progress indicator**
  - Augmented by time trends and/or **accumulated investment** to represent energy efficiency improvements
  - Some users' aggregate demands are affected by upward movements in relative prices only (ratchet or **asymmetrical price effects**)
  - In some **countries** (mainly **developing**) a **generic stochastic trend** can be created in order to cover the lack of data and/or to catch the effect of temperature, globalization, changes in economic structure, behavioral shift
- **Disaggregate energy demand** equations depend as above on:
  - activity, technology, relative price effects, temperature and generic trend
- Error Correction Model (ECM) - in the econometric equations- distinguishes between **long-term and adjustment parameters**

Disaggregate Energy demand econometrics modelling

- **Depending on the availability of data and focus of the policy**, more detailed disaggregate energy system models can be created
- **E.g. Road Transport econometrics modelling:**
  - **Traditional Energy demand econometric equations**:
    - Activity, fuel prices, technological progress indicator (investment in the Motor Vehicles sector, adjusted by R&D expenditure)
  - **Alternative Energy demand econometric equations**:
    - Demand for passenger travel, disaggregated by vehicle type (eg Cars and taxis, Bus/coach) and transport network (eg Urban A roads and Motorways)
    - Annual purchases of new vehicles, disaggregated by vehicle type and propulsion technology (eg petrol or diesel internal combustion engines)
    - Average fuel efficiency of new vehicles, disaggregated by vehicle type and propulsion technology
    - The above figures catch the effect of: personal disposable income, fuel prices, technology progress, transport vehicle availability, transport network availability, transport vehicle speed, transport vehicle safety, vehicle stock

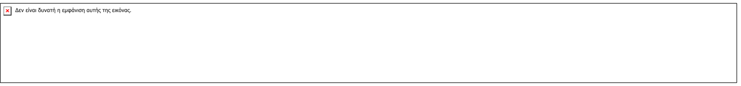
Energy Prices modelling

- **Energy Prices (generally) are determined through:**
  - **a production function or**
  - **detailed energy system submodels (electricity, transport..),** linked to generation, transmission, distribution and supply costs (ETM submodel in E3MG)
  - **assumptions** based on international organizations projections (e.g. IEA, OPEC) on oil, gas and coal production prices
- **Endogeneity in energy prices modelling as:**
  - **Policy measures (**carbon/energy tax, EU ETS etc) affect the prices
  - **Revenue** recycling from any energy tax (e.g. reducing employer taxes, direct/indirect tax burden, not causing inflation) to higher public investments in green policies

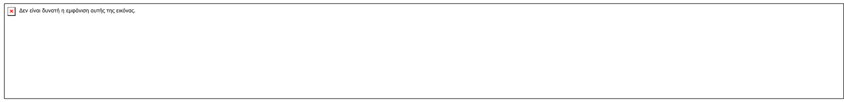
Energy Supply probabilistic modelling

A simulation not optimization model where:

- **Dispatch of electricity generation units** is based on the minimum cost for the system operation considering the history (real market) and the economic, technical and environmental characteristics of the units. Their variable and hourly cost (incorporating the CO2 cost) have the form of:



and



- **Electric system expansion** considers
  - **Investment in new technologies from relative costs**
  - **Learning curves from cumulated *global* investment**

A probabilistic approach (Anderson and Winne) is used to examine the penetration of the energy technologies compared to a marker technology.

- Reference: Anderson, D., Winne, S., 2007. Energy system change and external effects in climate change mitigation. Environment and Development Economics 12, 359–378.

Energy Supply Modelling

The frequency distribution of feasible technologies is represented by the ratio between the cost of all alternatives and the marker technology**.**

$$P_{it} = \frac{C_t^N (1+T_t)}{C_{it}(1+G_t)}$$

P relative price

C present worth of **costs**

N ‘marker’ technology

T taxes on new technology e.g. Carbon tax

G tax/subsidy on new technology

When the ratio C_t^N / C_{it} is greater than unity, the alternative technology costs less than the marker technology**.**

Energy Supply Modelling

Investment shares between the technologies in electricity generation technologies are based on**:**

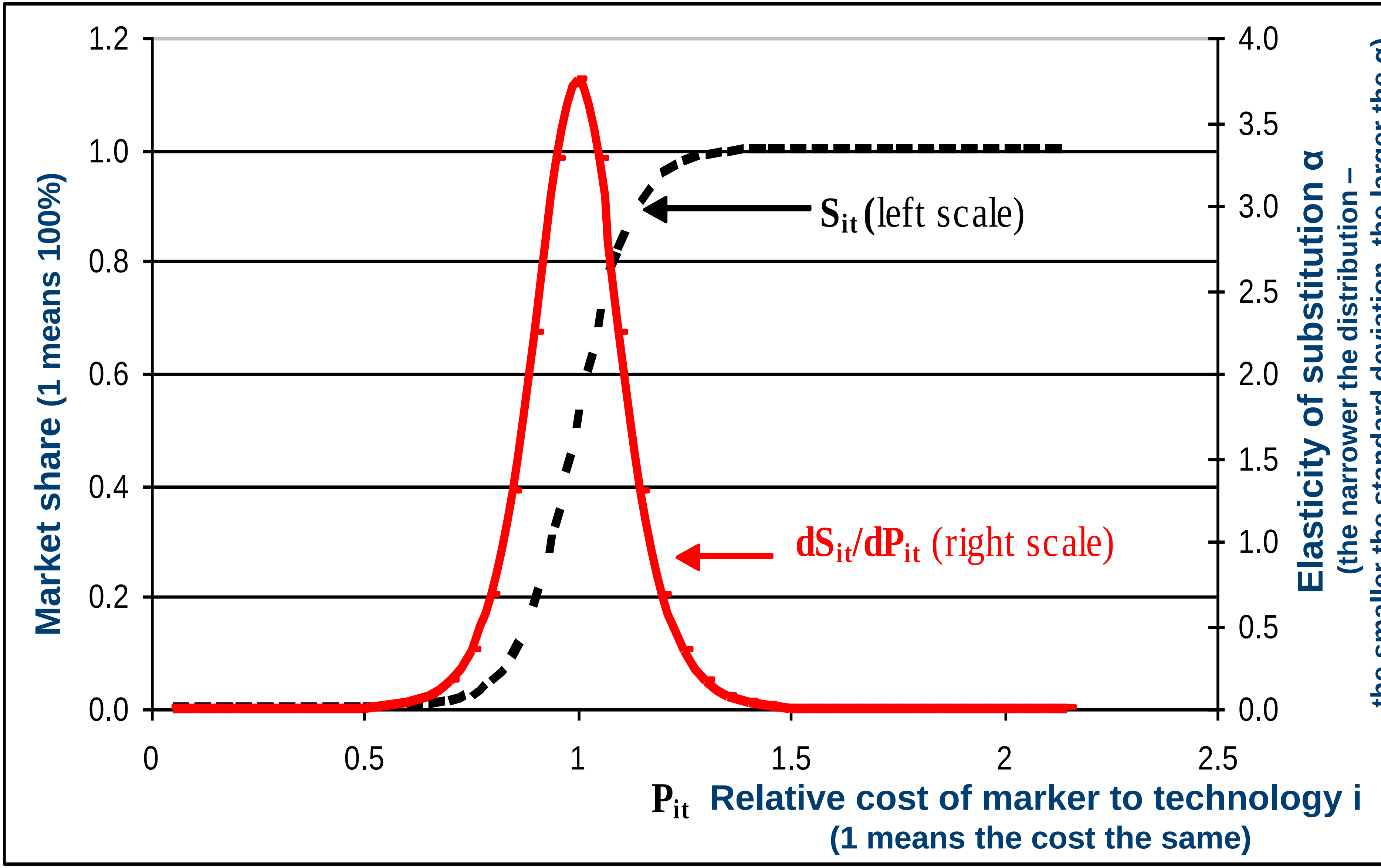
S **share** of new investment in technology i

P **relative cost** (cost ratio to a marker technology)

a **acceleration parameter**

$\hat{S}_{it}$ **maximum share** attainable by any given technology

Market share & Frequency distribution of relative costs

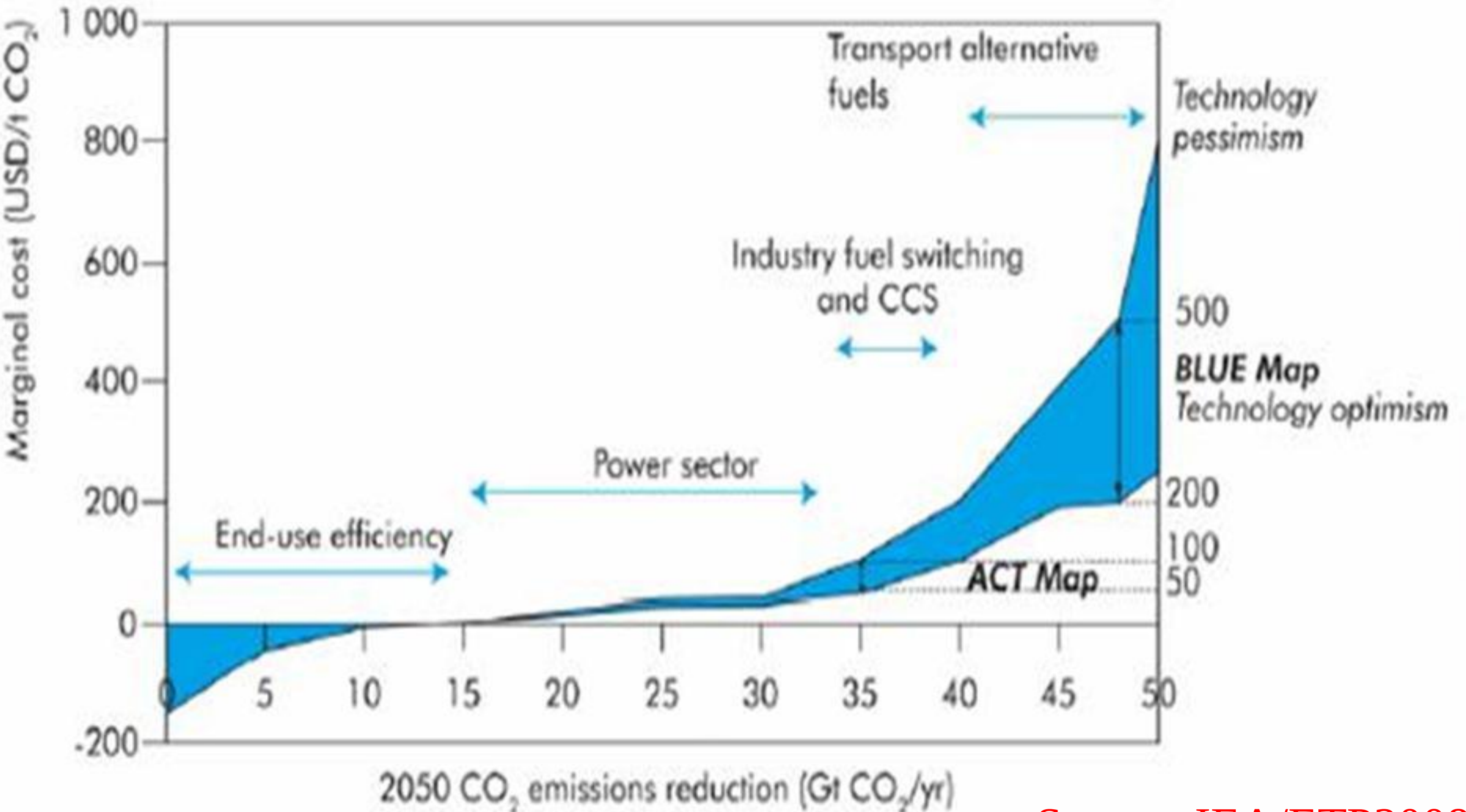


Implementation of Policies -

“Scenario” modelling approach

Neoclassical approach in energy system modelling

Estimation of the marginal cost of alternative policies implemented independently



Source: IEA/ETP2008

“Scenario” modelling approach

- Emission reduction and stabilization targets are considered as part of an international effort and are achieved through a **portfolio of policies**:
  - **Carbon pricing** (Carbon trading for ETS sectors / Carbon Tax for rest of the economy).
  - **Revenue recycling** (e.g. through auctioning carbon permits) to:
    - Incentives for electricity technologies.
    - Accelerated diffusion of electric plug-in vehicles through technological agreements and behavioural shift in transport.
    - Incentives to energy-intensive industries to low-carbon production methods.
    - Incentives for investments in energy efficiency in households, (by improving the energy efficiency of domestic dwellings and appliances and for introducing new ones such as low-emission dwellings and solar appliances).
  - **Accelerated carbon price** increase at an earlier year e.g. 2030

Treating uncertainties

Uncertainties are due to:

- **Climate** (wind, temperature…)
- **Consumers behaviour**
- **Technology progress**
- **Political issues**
- **Resources availability**
- **Prices evolution**
- **Missing data …**

Those uncertainties are **endogenized in modelling** through the parameters estimation, assumptions…

Modellers should provide a **range of solutions to catch those uncertainties**

- Those solutions represent the probability of the outcomes a policy or a portfolio of polices can have (e.g. the IPCC provides probability for the different scenarios)

Modelling Challenges

The E4M-GAIA model so far has developed a more robust energy system, considered most of the above uncertainties, and is in trace towards the following challenges:

- **Treating uncertainties** (resources availability, geopolitics…)
- **Developing robust techniques in data mining** (developing countries)
- **Incorporating new Indices** (e.g. Human Development and Energy Poverty Indices for developing countries by IEA and UN)
- **Considering interactions with the earth system (GAIA approach)**
    - **Developing energy supply model**
    - **Carbon Capture and Storage** (storing CO2 -part of the biosphere- enables the control of the earth temperature – self regulating system)
    - **Linking with earth system models** (e.g. NASA GISS model)

Overall Conclusions

Modelling:

- Climate change and the Financial Crisis revealed some of the weaknesses of the dominant neoclassical economic modelling approach
- The energy-environment-economy system is to be understood as a complex system with multiple, indeterminate causes and outcomes
  - highly uncertain to emergent properties (e.g. the global oil price)
  - sudden rapid changes to new growth paths
- Econometrics and probabilistic approaches are alternative modelling approaches
  - Modularity and Endogeneity captures the interactions between the different systems, Treating uncertainties and risks…

Policy implementation:

- Mitigation targets should consider the complementarity of different policies.
  - Carbon pricing accompanied with other policies (e.g. auctioning, revenue recycling, incentives, regulation, behavioural shift…).

E4M-GAIA model is an alternative approach towards facing those challenges