Long-term energy-emission scenarios with the World-TIMES

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Plan (not shown)

- Description of TIMES (From MARKAL)
- Database (SAGE+EFDA)
  - 15 regions, horizon 2100, hydrogen, etc.
- Demand projection method
  - Denise assumptions with GEM-E3, DOE+IPCCB2,
  - Method for generic dm after 2050
- Scenarios
  - 1 Base
  - 1 Alternate base scenario (fuel mix after 2050)
  - 2 Constraint scenarios (CO2 taxes).
- Results (for 5 regions only)
  - 2 Base scenarios
  - 1 Base+ 2 constraints

MARKAL model

- Linear programming model
- Integrated bottom-up energy model
- Prospective analysis on a 50-year horizon
- Partial equilibrium calculation (perfect market)
- Optimal technology selection
- Minimize the total system cost
- Emission constraints
- Energy and emission permits trading

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MARKAL model

- Price-elastic demands
- Stochastic programming
- Endogenous technological learning (MIP)

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MARKAL model

Inputs

- Technology data
- End-use demands
- World crude oil price
- Resource costs
- Emission constraints
- Other parameters
  - Discount rate

Outputs

- Technology investments
- Technology activities
- Demand loss (or gain)
- Fuel prices
- Imports/Exports
- Permit trading
- Total system cost

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TIMES model

- **T**he **I**ntegrated **M**ARKAL-**E**FOM **S**ystem
- Created by ETSAP members - 1997
- Current users: IER, VTT, SA, Italy…

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TIMES model

- **T**he **I**ntegrated **M**ARKAL-**E**FOM **S**ystem
- A new energy/technology model based on technology explicit representation
- Computes a supply-demand equilibrium that maximizes net social surplus
- In policy cases, demands are (own-)price elastic
- Flexibly scalable to local, national, global levels, with endogenous trade

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TIMES Equilibrium Computation

$$Max\left\{\int_{d_0}^{d} p(q)dq \; - c^t \cdot x\right\}$$ objective function : NPV of net surplus

$s.t.\;\; Ax - d \geq 0$ satisfaction of demands

$Ex \leq e$ cap on emissions

$Bx \geq b$ financial, logical, and technical constraints

$UB \geq x \geq LB$ optional bounds

x : decision variables : investments, capacities, activities, of technologies, amounts of commodities produced, consumed, traded

d: variables : demands for products and services

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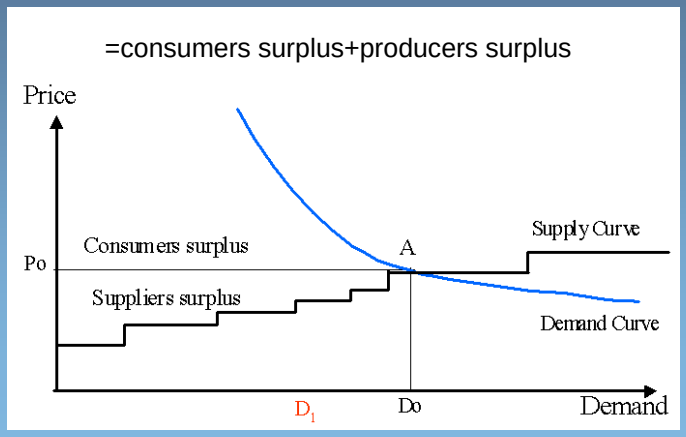
Net Surplus



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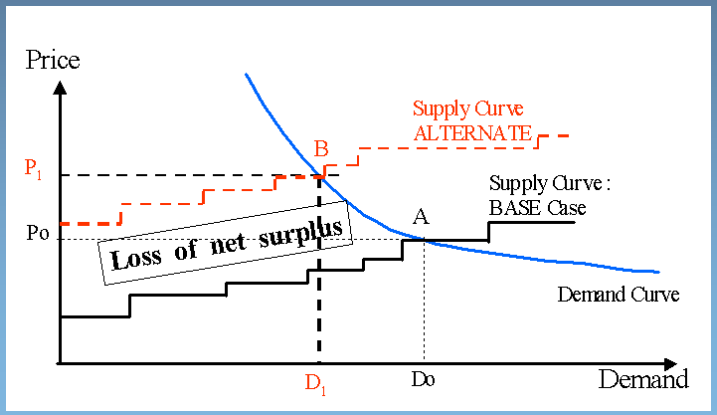
Loss of Net Surplus



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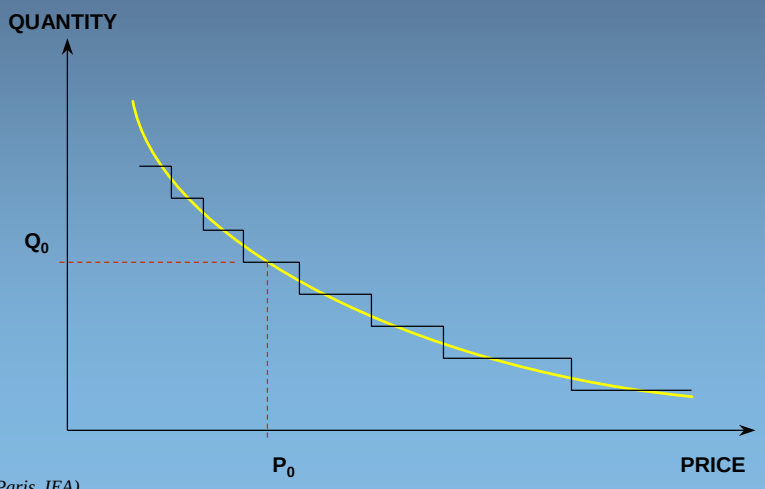
The demand curve



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New Features

- Multi-regional by design
- Variable length time-periods
- Flexible technology representation
- Objective function refinements

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Time flexibility

- Variable length periods
- Decoupling of data and model specifications
  - Easy change of horizon & period lengths
  - Improved representation of past investments

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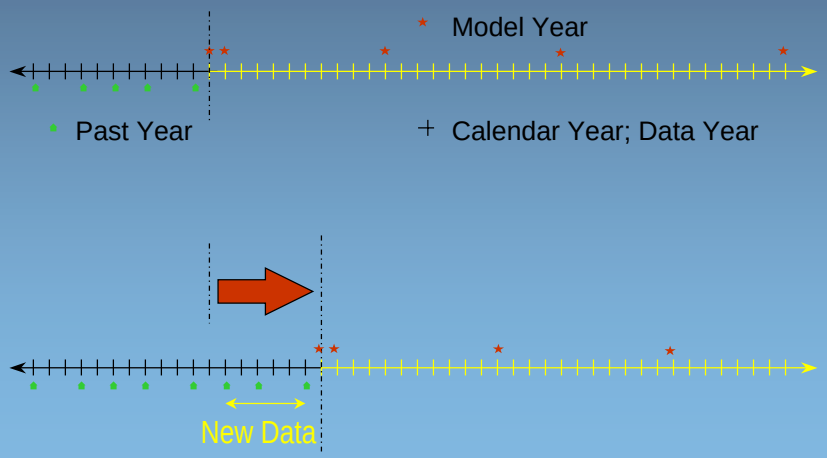
Time periods



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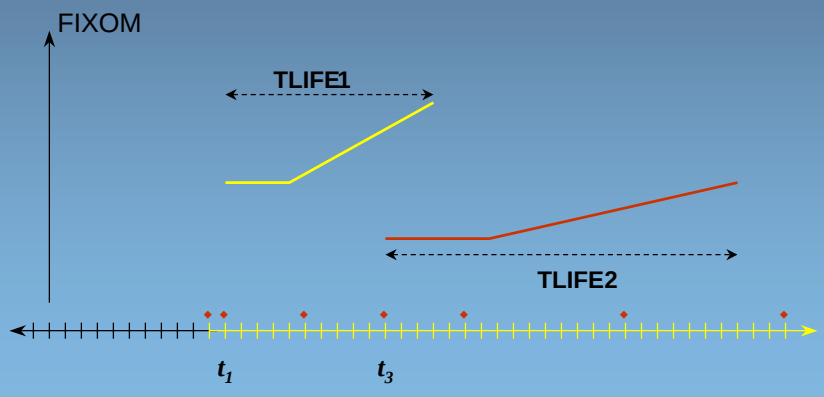
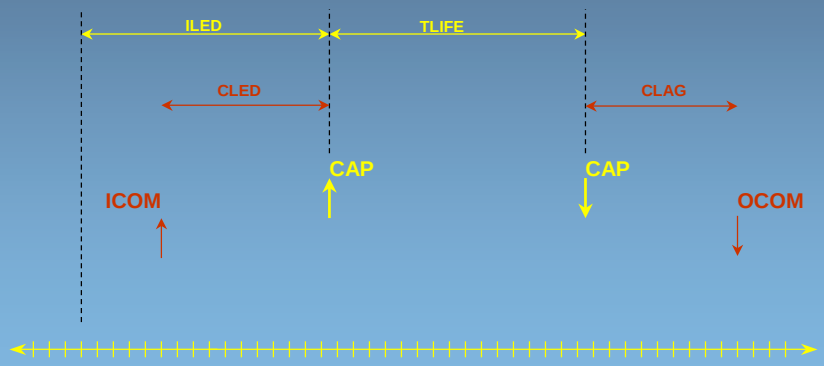
Technological representation

- Flexible (variable input, variable output) processes
- Vintaging and age dependency of processes
- Investment lead-times
- Commodity based attributes
- Unlimited user defined time-slices (any commodity)

Vintaging and age dependency



Leads and lags of stocks and flows



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Objective function refinements

- Sum of discounted annualized costs (year by year)
  - Requires separate reporting of investments
  - Four distinct cases for investments:
    - Lump vs. continuous, Short vs. long life
  - Salvage values replaced by annualized costs
- Refined accounting of investment cash flows within periods (progressive payments)
- Dismantling costs are specifically modeled
- Lead times
- Ready for sector-wise capital constraints

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Database

- SAGE model: System for the Analysis of Global Energy markets
  - Analytical framework for the annual *International Energy Outlook* (US DOE, EIA, 2000-2004)
  - Global 15-regions model, Horizon 2050
- EFDA project: European Fusion Development Agreement
  - Global 15-regions model, Horizon 2100
  - Hydrogen module, Nuclear, etc.

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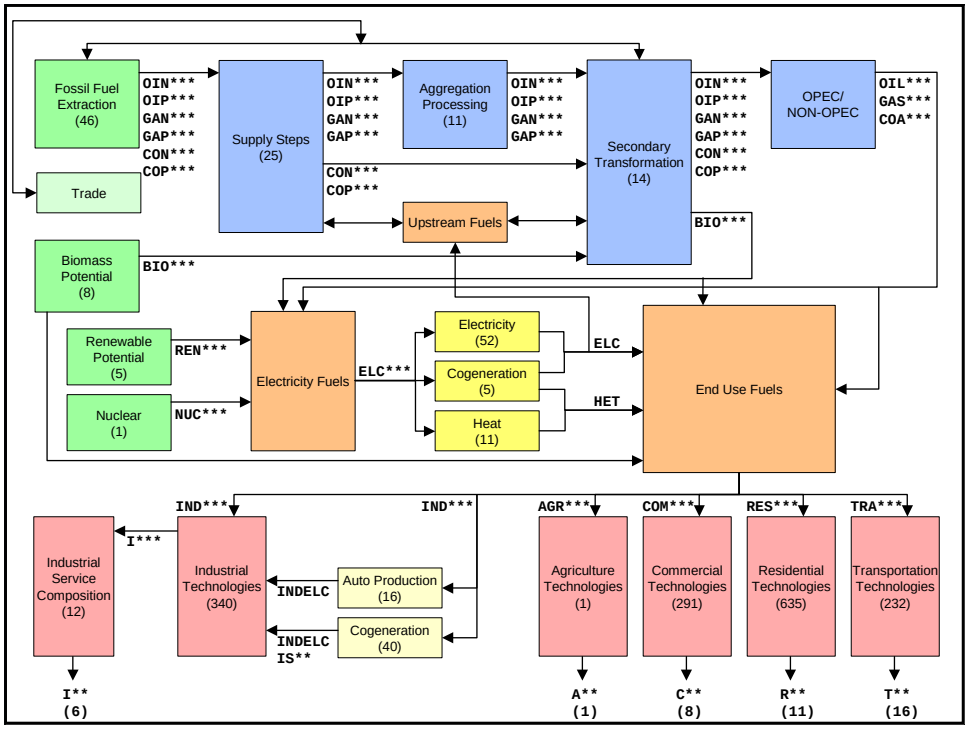

15 World Regions

- AFR: Africa
- AUS: Australia-NZ
- CAN: Canada
- CHI: China
- CSA: Latin America
- EEU: Eastern Europe
- FSU: Former Soviet Union
- IND: India
- JPN: Japan
- MEA: Middle-East
- MEX: Mexico
- ODA: Other Developing Asia
- SKO: South Korea
- USA: United States
- WEU: Western Europe

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Demand segments (42)

- Agriculture (1)
- Commercial (8)
  - Heating, Cooling, Hot water, Cooking, Lighting, Refrigeration, Electric equipments, Others
- Industries (6)
  - Non ferrous, Iron&Steel, Chemicals, Non metals minerals, Pulp&Paper, Others
- Non Energy (2)
  - Industry, Transport
- Residential (11)
  - Heating, Cooling, Hot water, Cooking, Lighting, Refrigeration, Cloth washing, Cloth drying, Dish washing, Electric equipments, Others
- Transportation (14)
  - Autos, Light, Medium, Commercial, Heavy Trucks, Buses, Two and Three Wheelers, Freight and Passenger Rail, Domestic and International Aviation, Domestic and International Navigation

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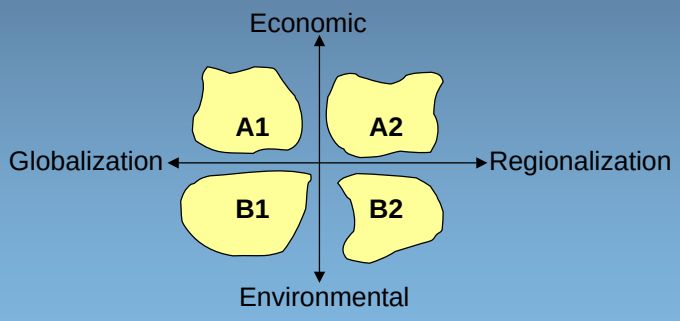
IPCC Emission Scenarios



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Demand drivers

- Population
- GDP (Gross domestic product)
- Households
- GDP per capita
- Agricultural production growth
- Industrial production growth (3 categories)
  - (energy intensives, others, services)

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Demand driver projections

- Population growth
  - US-DOE projections until 2025
  - IPCC B2-Message scenario after 2025
  - Medium growth: decline in the OECD countries from 2050 onwards (but is still growing), though at a very low rate in the rest of the World
  - Slow aging of the population
  - Economic development induce increasing urbanisation in developing countries
  - Decrease in the number of persons per household at 2%/yr in all regions

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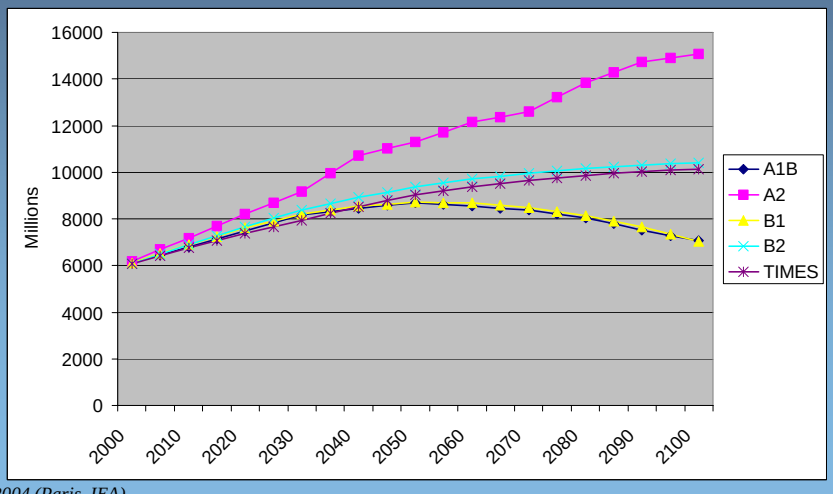
Population



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Demand driver projections

- Technological progress
  - Evolution in line with past trends
  - Labour productivity increasing at 1.5%/yr, slightly accelerating towards 2100, partly compensating for the decline in the population growth.
  - Moderate shift in the production towards services and away from the more energy intensive sectors. More pronounced in the OECD countries.
  - Energy savings proceed at 1%/yr in all regions, reflecting the improvement in energy technology efficiency and change in production technologies.

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Demand driver projections

- Economic growth (GDP)
  - Growths are higher in the non-OECD countries, contributing to a certain convergence of the regional economies by 2100.
  - Shift away from energy intensive industries towards other industries and services (reflecting the evolution in production technologies).
  - More pronounced in the OECD countries, but the same trend appears in the non-OECD countries by 2100.

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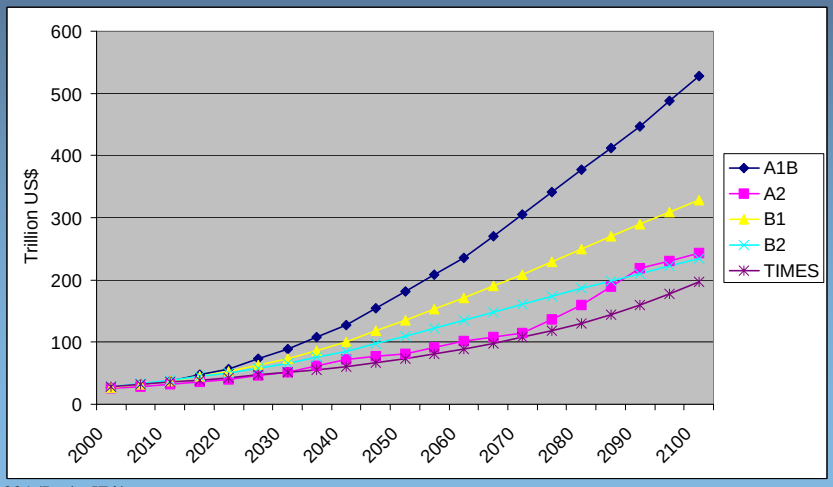
GDP



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Demand driver elasticities

- General: In the long run, the developing regions are approaching the development patterns of the industrialised countries.
- Passenger transport: Shift away from public transport towards private car; saturation level after 2050. Lesser increase in the passenger-km demand with urbanisation.
- Freight transport: Close to the GDP growth. Shift away from road transport before 2050. After, slowdown in the freight transport demand with congestion and limit to globalisation.
- Residential demand: Follows the population or households for the basic needs. The income is the dominant factor for the others. In the long run, a saturation and changes in consumption patterns will weaken this link.
- Commercial demand: Follows the activity of the service sector; decreasing link in all countries after 2050.
- Industrial and agriculture demand: Follows the sectoral production evolution. Decoupling of this link after 2050 due to a greater efficiency in the technologies. Shift towards more elaborated products and global markets maturity.

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Demand projections

- Step 1: Define a set of socio-economic drivers (GDP, Pop,,,)
  - Using the general equilibrium model GEM-E3
- Step 2: Make specific assumptions on which driver to use to project each demand category (region and time dependent)
- Step 3: Obtain projections for each driver of step 1 in each region at each time period
- Step 4: Choose elasticities of each demand to its assigned driver (region and time dependent)
- Step 5: Compute each demand

DM growth= Driver growth*DM elasticity

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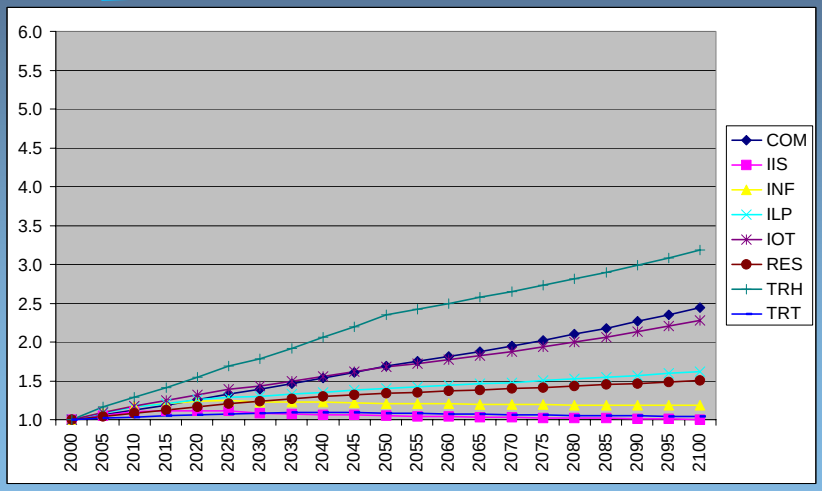
Demand growth: OECD



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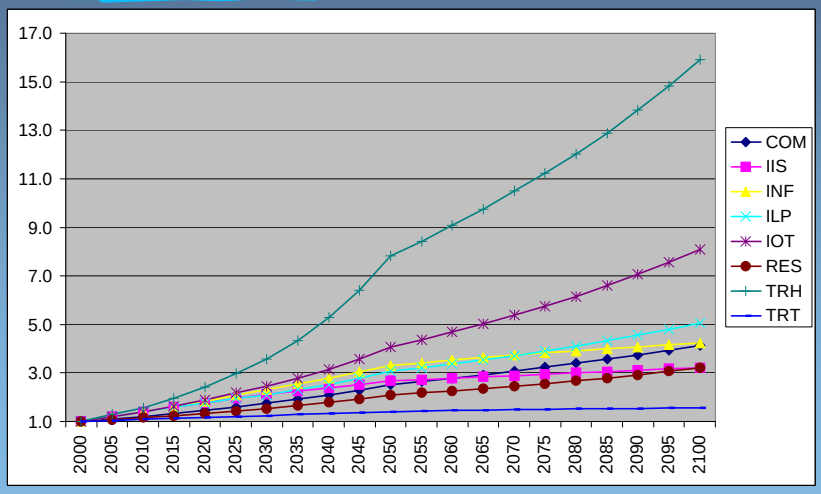
Demand growth: Non-OECD



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Demand projections

- Evolution more contrasted between the OECD countries and the others before 2050 than after, especially in the residential and transport sectors
- After 2050, evolution is more parallel (convergence in growth rates and elasticities).

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Scenarios

- Base case
- CO2 Tax cases
  - Tax1: 40 – 90 $/t CO2
  - Tax2: 40 – 250 $/t CO2
- Alternate base case
  - Fuel demand in industry after 2050

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Preliminary results for 5 regions

- AFR: Africa
- AUS: Australia-NZ
- CAN: Canada
- **CHI: China**
- CSA: Latin America
- EEU: Eastern Europe
- **FSU: Former Soviet Union**
- IND: India
- JPN: Japan
- **MEA: Middle-East**
- MEX: Mexico
- ODA: Other Developing Asia
- SKO: South Korea
- **USA: United States**
- **WEU: Western Europe**

65% of current emissions

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Time horizon: 2100

Before 2050

- 1998-2002: 2000 (5)
- 2003-2007: 2005 (5)
- 2008-2012: 2010 (5)
- 2013-2027: 2020 (15)
- 2028-2032: 2030 (5)
- 2033-2047: 2040 (15)

After 2050

- 2048-2053: 2050 (6)
- 2054-2066: 2060 (13)
- 2067-2074: 2070 (8)
- 2075-2085: 2080 (11)
- 2086-2095: 2090 (10)
- 2096-2104: 2100 (9)

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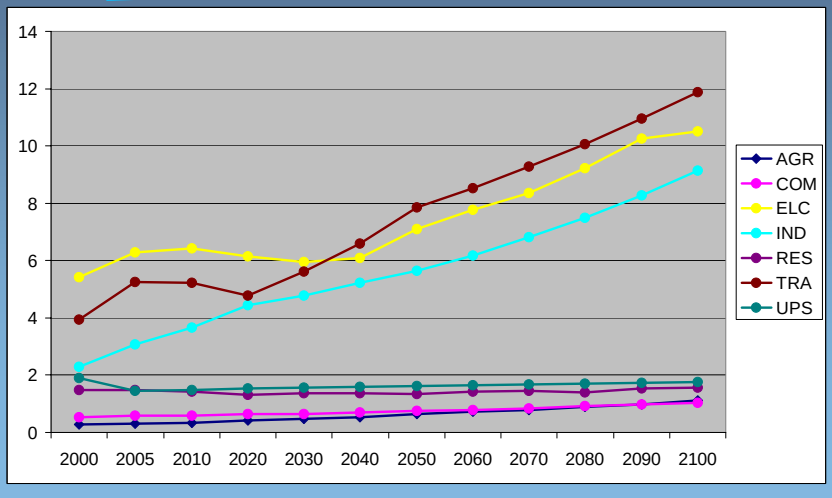
CO2 emissions by sector (Gt): Base



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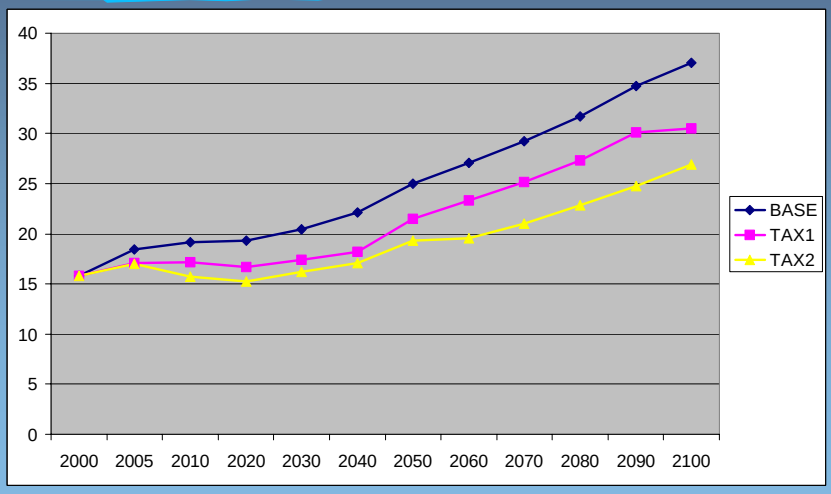
CO2 emissions (Gt): Taxes



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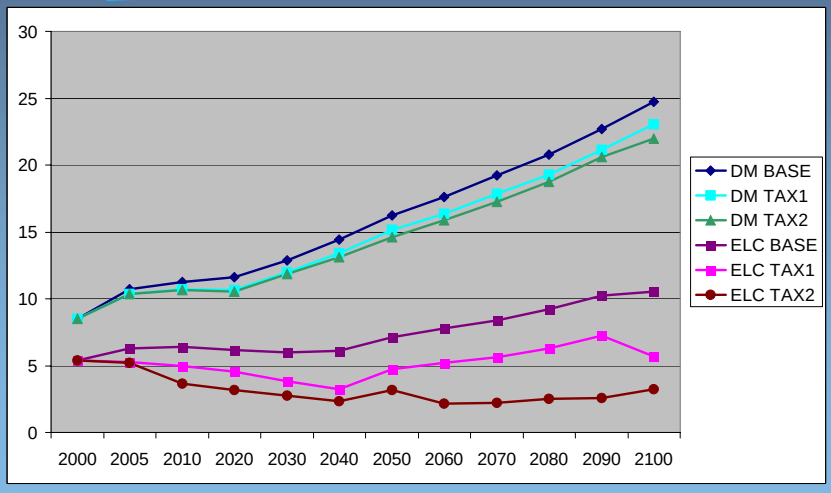
CO2 emission reduction (Gt)



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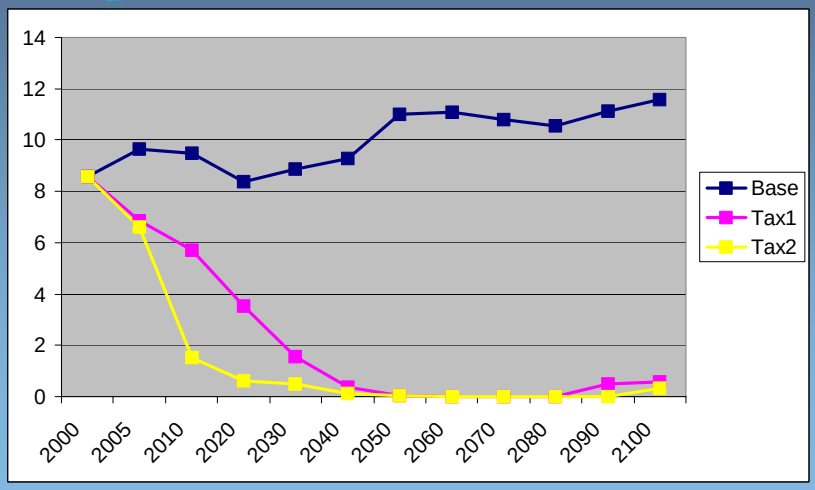
Coal based electricity (EJ)



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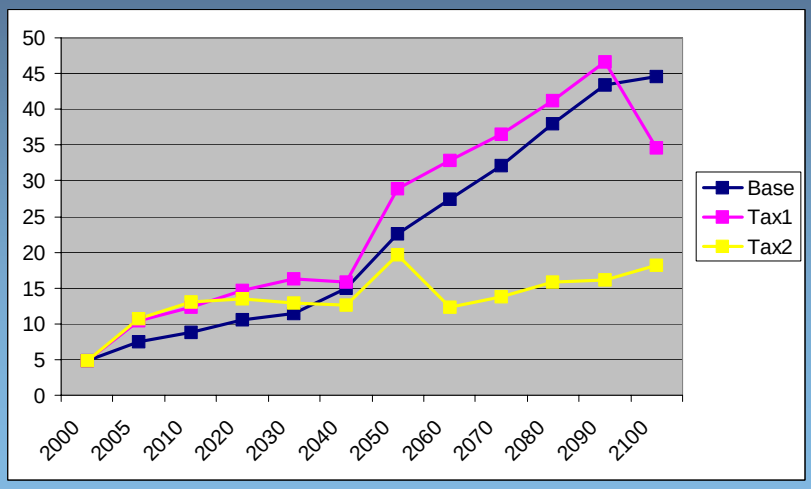
Gas based electricity (EJ)



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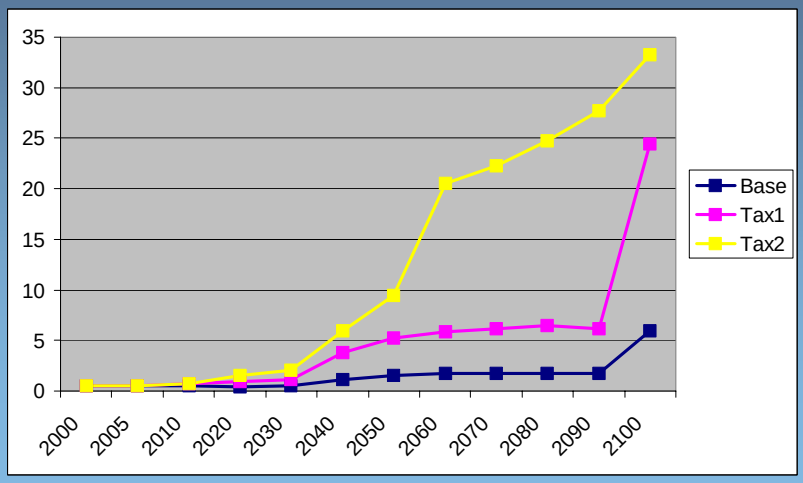
Renewable electricity (EJ)



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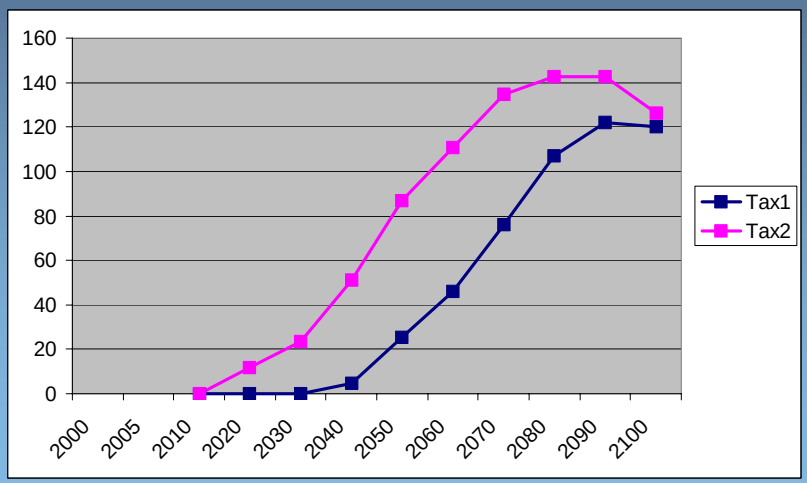
Additional nuclear capacity (GW)



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Alternate base case

- Starting with the fuel consumption in the base case:
  - 5% energy efficiency improvement
  - Share increases
    - Electricity (10%); Gas (10%); Bio (5%)
  - Share reductions
    - Coal (15%); Oil (10%)

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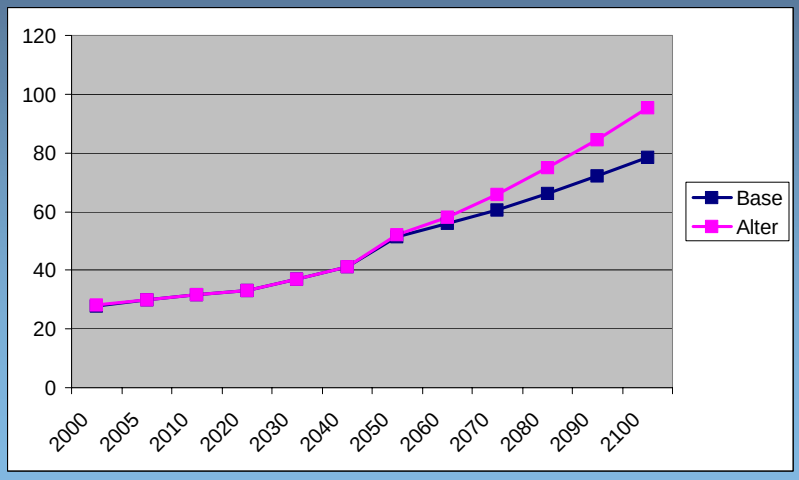
Electricity production (EJ)



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Ongoing work

- Database development
  - Sequestration
  - Renewable electricity potential
  - Technology data review
- Improvements in the TIMES matrix generator
- Explore new features of TIMES
  - Time slices
  - Sensitivity on time period lengths

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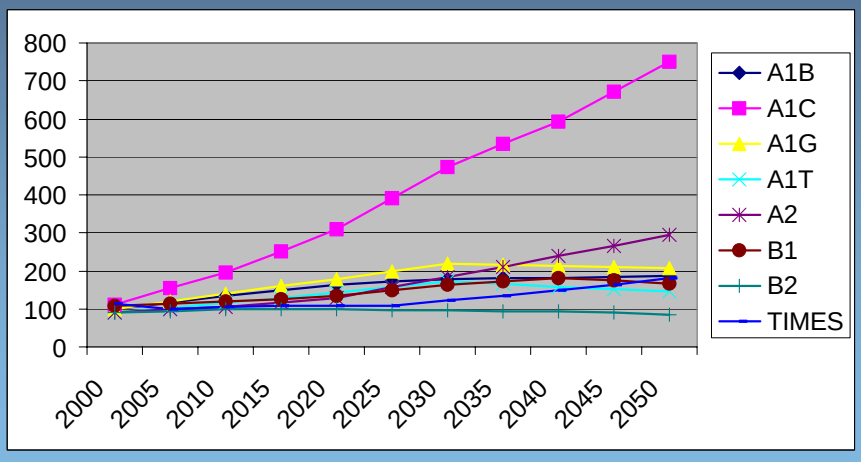
Calibration 2050: Coal (EJ)



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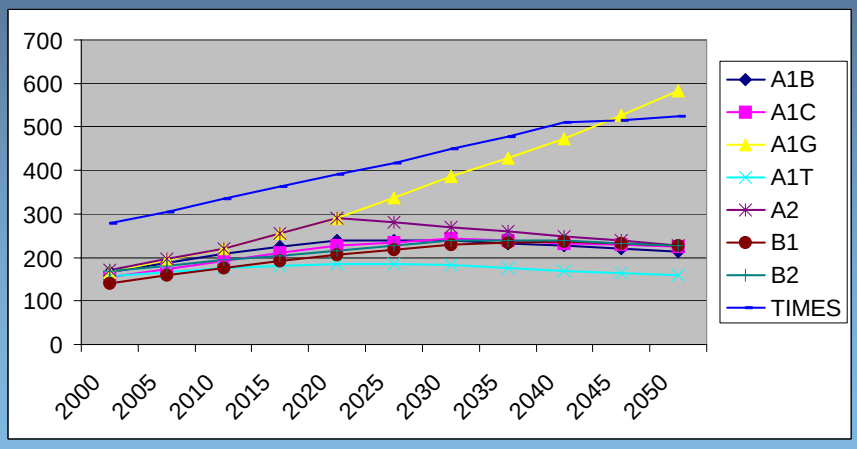
Calibration 2050: Oil (EJ)



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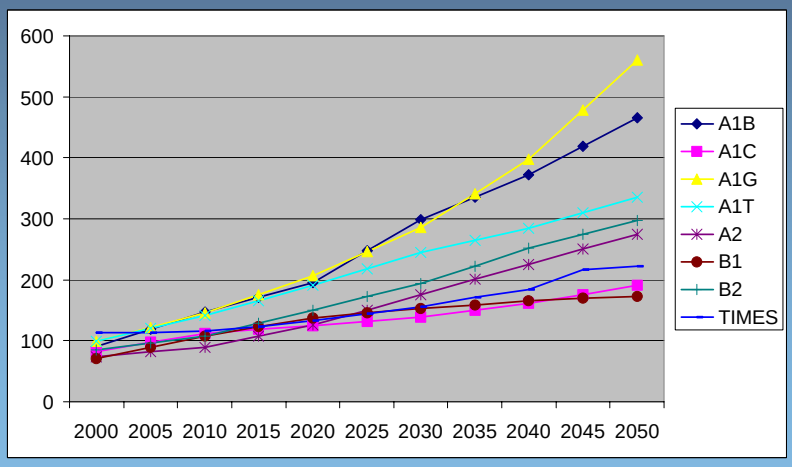
Calibration 2050: Gas (EJ)



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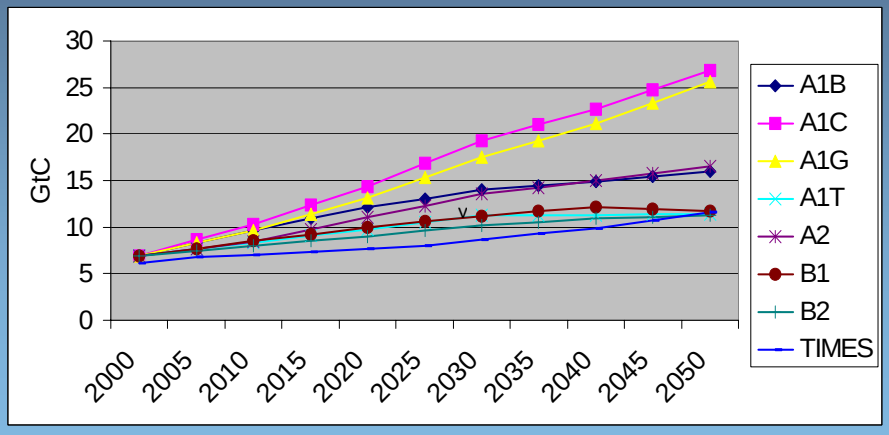
Calibration 2050: Emissions



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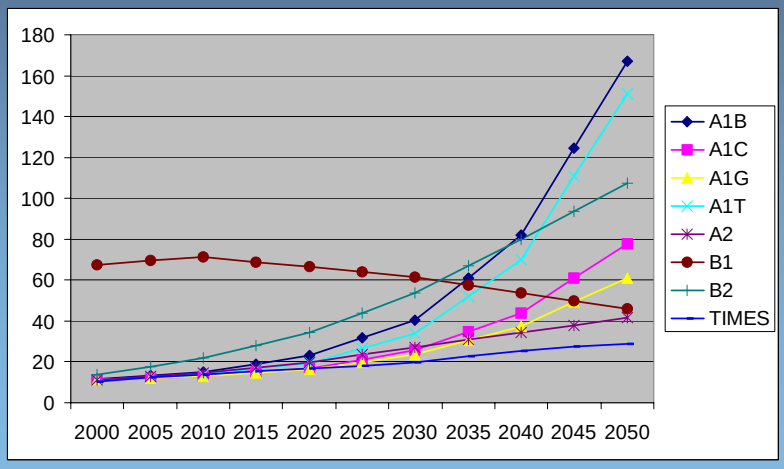
Calibration 2050: Renewables (EJ)



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