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Evaluación pública de grandes proyectos: teoría y práctica

Examples: Oligopolistic Electricity and General Equilibrium Mixed Complementarity Models

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Contents

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Introduction

Introduction:

- Class objective:
  - Present examples of real world policy evaluations using mathematical operation research instruments.
- Why:
  - Assist decision making process.
  - Necessity for ex-ant assessments of complex policies and agents behavior
- Class focus: mixed complementarity problems.
- Lets start!!!

Nonlinear and mixed complementarity problem

- Special case of Variational Inequality

Mixed complementarity problem:

$$\min_{x} \quad f(x,y)$$
$$\text{s.t.} \quad g(x,y) \leq 0 \quad (\perp \lambda \geq 0)$$
$$H(x,y,\lambda) = 0 \qquad (\perp y \text{ free})$$

$\Rightarrow$

$$\nabla_x f(x,y) + \lambda^T \nabla g(x,y) = 0$$
$$0 \leq -g(x,y) \perp \lambda \geq 0$$
$$H(x,y,\lambda) = 0$$

Karush–Kuhn–Tucker conditions:
Karush–Kuhn–Tucker conditions provides the necessary conditions for a solution in nonlinear programming to be optimal. It is a generalization of the method of Lagrange multipliers to inequality constraints.

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Application 1

Electricity sector oligopolistic model

Application 1:

- How to evaluate the consequences to an electricity company of different CO_2 prices (or a different ETS regime)?
- Which are the consequences of a increase on demand response for the market prices?
- What a nuclear phase-out means to electricity market prices?
- What are the competitors behavior changes if one company changes its strategies?
- How much CO_2 emissions are avoided by implementing a renewable subsidy?
- ...

Application 1:

- Instrument:
  - Electricity operations and expansion planning simulation.

- First step:
  - Simulate a single electricity company optimization problem

- Second step:
  - Introduce oligopolistic competition behavior

Electricity operations and expansion planning optimization model

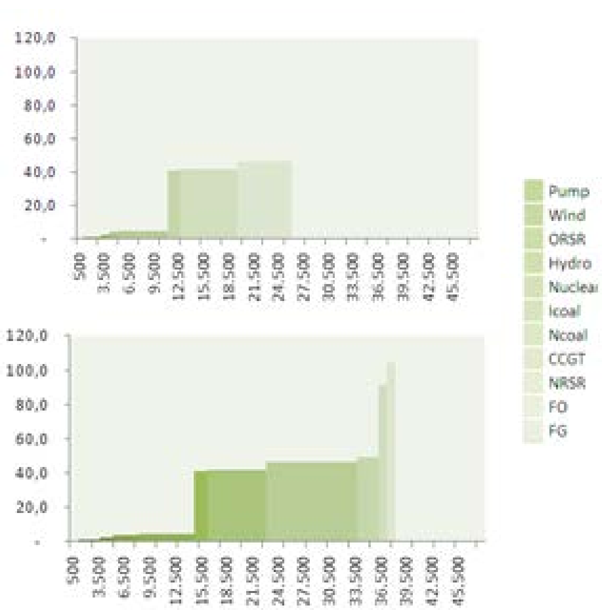
- Company objective
  - Profit maximization
  - Cost minimization
  - Risk aversion
  - Market share
  - ….

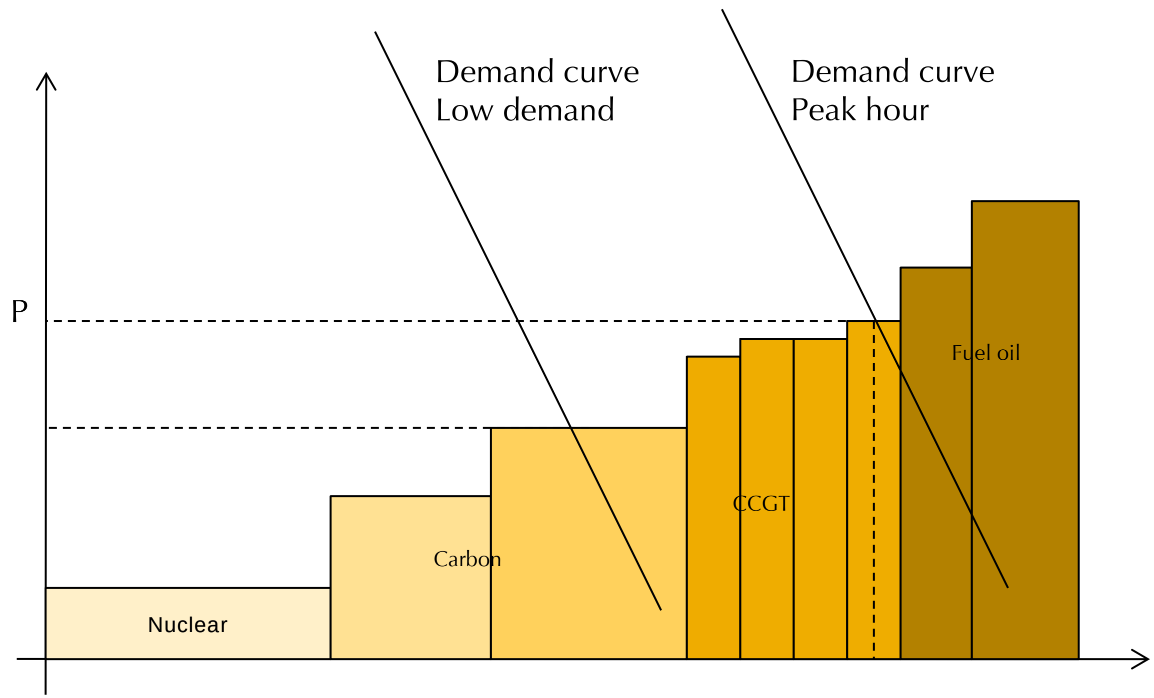
- Time Horizon
  - Long vs short run decisions

- Technology representation
  - Economic production function
  - Engeneering technical constraints

- Level of detail – data requirements and problem dimension

Electricity generation company and market problem:





Electricity operations and expansion planning model (1/2):

$$
\begin{aligned}
\text{Min:}\quad & \sum_{t,f,p,b} \overbrace{\frac{PGEN_{y,t,f,l,p,b}\ \bar{\eta}_{y,l,t}\ \bar{p}^{fuel}_{y,p,t,f}\ \overline{dur}_{l,p,b}}{10^6}}^{\text{Fuel cost}} \\
& + \sum_{t,f,p,b} \overbrace{\frac{PGEN_{y,t,f,l,p,b}\ \overline{co2}^{fuel\_content}_{t,f}\ \bar{p}^{CO2}_{y}\overline{dur}_{l,p,b}}{10^6}}^{CO_2\text{ emission costs}} \\
& + \sum_{t,f,p,b} \overbrace{\frac{PGEN_{y,t,f,l,p,b}\overline{oem\_vom}_{y,t}\overline{dur}_{l,p,b}}{10^6}}^{\text{Variable O\&}M\text{ equipament costs}} \\
& - \sum_{t,f,p,b} \overbrace{\frac{PGEN_{y,t,f,l,p,b}\overline{premium}^{renew}_{t,f}\overline{dur}_{l,p,b}}{10^6}}^{\text{Renewable premiun income}} \\
& + \sum_{t} \overbrace{\frac{\left(\overline{oem\_fom}^{labor}_{y,l,t} + \overline{oem\_fom}^{sc}_{y,l,t} + \overline{oem\_fom}^{equip}_{y,l,t}\right) TCAP_{y,l,t}}{10^3}}^{\text{Fixed O\&}M\text{ costs}} \\
& + \sum_{t} \overbrace{\frac{\overline{overn\_costs}_{y,t}\overline{idc}_{t}\overline{crf}_{t}\left(\overline{cap}^{to\_be\_amort}_{y,l,t} + \sum_{y`\geq y-l\_t\ tmeityn\ on}^{y'\leq y} PINS_{y',l,t}\right)}{10^3}}^{\text{Installed capacity amortization costs paid in the year}} \\
& - \sum_{t,f,p,b} \overbrace{\overline{rights}^{CO2}_{y,l,t}\,\bar{p}^{CO2}_{y}}^{\text{Emission rights}} \qquad \forall y, l
\end{aligned}
$$

Electricity operations and expansion planning model (2/2):

Subject to: Demand balance:

$$\overline{demand}_{y,l,p,b} \leq \sum_{t,f} PGEN_{y,t,f,l,p,b} + \overline{pimp}_{y,l,p,b} - PPUMPED_{y,l,p,b} - (\overline{own\_cons}) \sum_{t,f} PGEN_{y,t,f,l,p,b} - \overline{loss}_{y,l,p,b}\left(\sum_{t,f} PGEN_{y,t,f,l,p,b} + \overline{pimp}_{y,l,p,b} + \overline{pexp}_{y,l,p,b} - PPUMPED_{y,l,p,b}\right)$$

Hydro reservoir management level:

$$\overline{inflows}_{y,l,p} \geq \sum_{b} PGEN_{y,Hyd\_Res,na,l,p,b} - RES_{y,l,p} + RES_{y,l,p+1}$$

Hydro run of river production:

$$PGEN_{y,Hyd\_RoR,na,l,p,b}\overline{dur}_{l,p,b} \leq \overline{ror\_inflows}_{y,l,p}$$

Pumping efficiency:

$$PPUMPED_{y,l,p,b}\overline{eff}^{Pump} \geq \sum_{p,b} PGEN_{y,Pump,na,l,p,b}\overline{dur}_{l,p,b}$$

Maximum pumping capacity:

$$\sum_{p,b} PGEN_{y,Pump,na,l,p,b}\overline{dur}_{l,p,b} \leq \overline{res\_max}_{y,l,Pump}$$

Fixed use proportion of combustibles in Fuel-Gas power plants:

$$PGEN_{y,F-G,Fuel-oil,l,p,b} = \overline{pctg}_{y,l}^{foil\_on\_fg} \sum_{f} PGEN_{y,F-G,f,l,p,b}$$

Wind power production at each load block:

$$PGEN_{y,Wind,na,l,p,b} = \overline{pgen\_base\_year}_{l,p,b,Wind} \frac{TCAP_{y,l,Wind}}{\overline{cap}_{Base\ year,l,Wind}}$$

Other special regime renewable production at each load block:

$$PGEN_{y,ORSR,na,l,p,b} = \overline{pgen\_base\_year}_{l,p,b,ORSR} \frac{TCAP_{y,l,ORSR}}{\overline{cap}_{Base\ year,l,ORSR}}$$

Maximum production capacity:

$$PGEN_{y,t,f,l,p,b} \leq \overline{availability}_{y,l,t} TCAP_{y,l,t}$$

Maximum hydro reservoir capacity:

$$RES_{y,l,p} \leq \overline{res\_max}_{y,l,Hyd}$$

Total installed capacity:

$$TCAP_{y,l,t} = \overline{cap}_{y,l,t} + \sum_{\substack{y' \leq y \\ y' \geq y-life\_time}} PINS_{y',l,t}$$

Reserves (firm capacity reserves requirements in non-intermittent technologies):

$$\sum_{t\_non\_intt} TCAP_{y,l,t} \geq \overline{non\_intt\_coverage} \max_{p,b}\left(\overline{demand}_{y,l,p,b}\right)$$

Optimization model characteristics and advantages:

- How to solve it.
  - Simplex algorithm
  - Solvers (matlab, GAMs or even excel for very small problems)

- Formulation:
  - Optimization problem
  - Equivalent mixed complementarity model

- Potentials of optimization problem formulation
  - Easy and fast to solve
  - Suitable to introduce complexities
    - In dimension (time and technology)
    - In variables (integer and binary variables)

Optimization model limitations:

- Restringing assumptions
  - Perfect competition vs. oligopolistic market
  - Single firm modeling
  - Competitors decisions does not reacts to firm decisions
  - Suppliers prices are not changed by firm decisions (small company assumption)

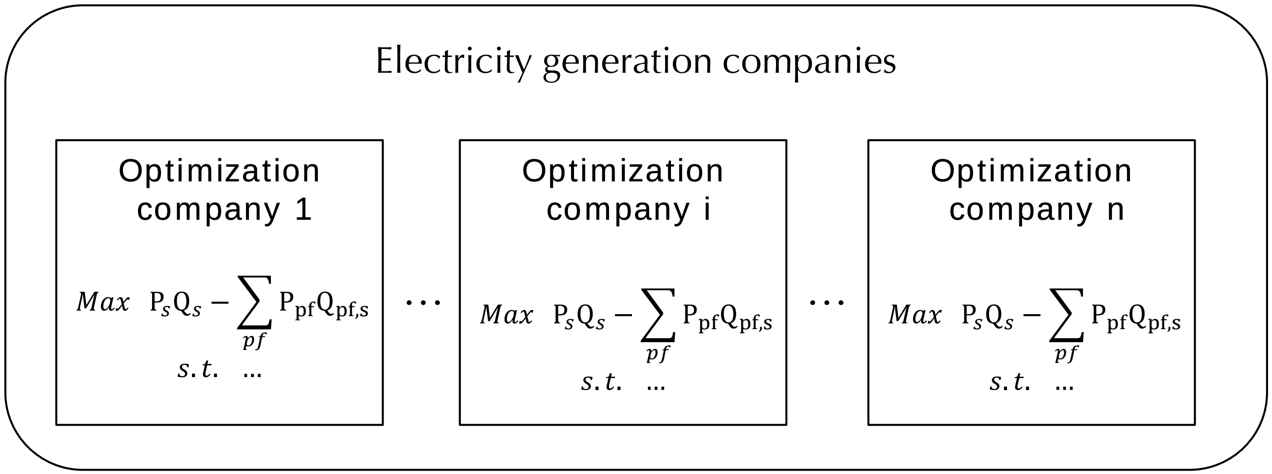
- Single objective function
  - we only consider **one objective function** at time when using an optimization framework.
  - In order to deal with company decisions influences we would need to assume a **conjectural variations** approach, even so this would need to be **exogenously defined** from our model.

- What if we want to evaluate different companies competing and acting together?
  - A iterative approach could be necessary, but not all primal and dual information would be shared between the problems.
- The mixed complementarity formulation alternative allows us to take into account simultaneous optimization problems all together

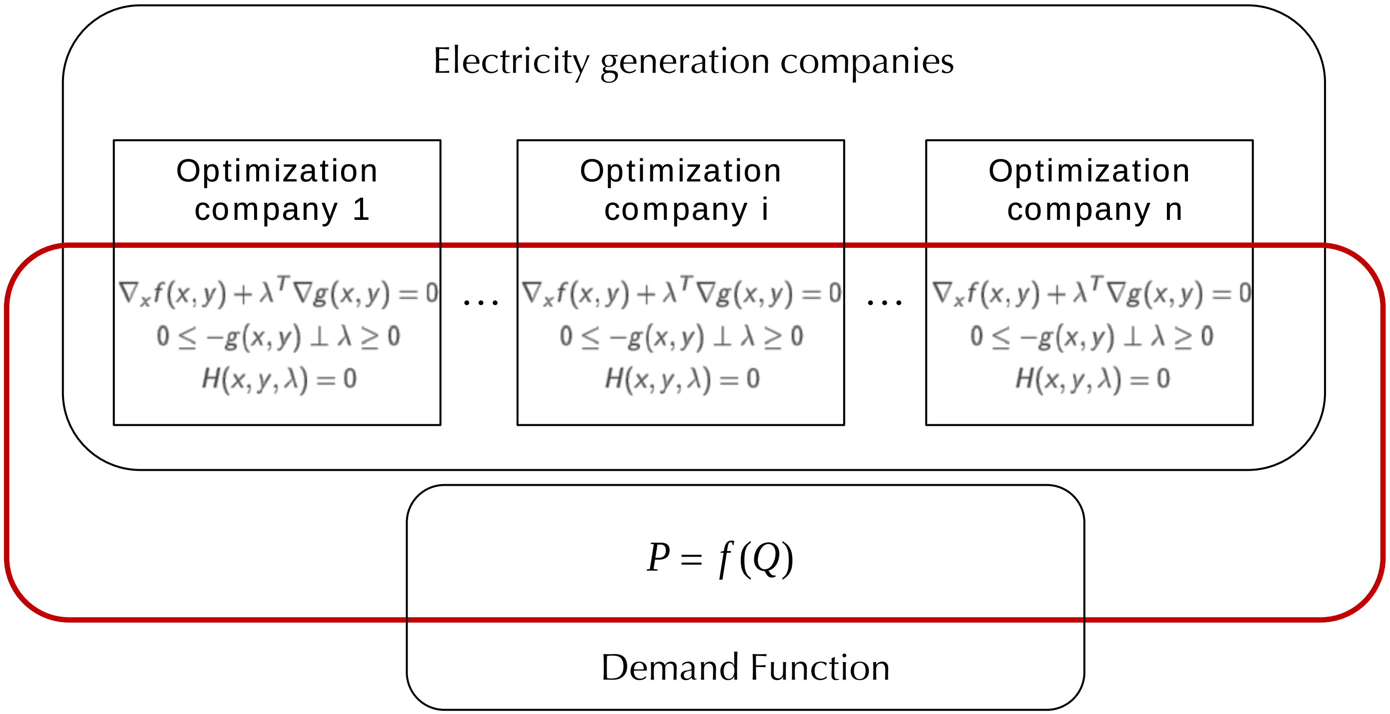
The electricity sector oligopolistic mixed complementarity model :

- The idea behind it is to develop the equivalent mixed complementarity formulation of each company in the market.
- Market clearing and demand conditions are used to link the agents behavior all together.
- We formulate a large equivalent problem with all optimization equilibrium conditions (KKT conditions)
  - we share between all agents the primal and dual information of their respective problems. A different operation from one company directly changes the behavior of their competitors that by meantime could change again the behavior of the first agent.

The electricity sector oligopolistic mixed complementarity model :



The electricity sector oligopolistic mixed complementarity model :



MCP model characteristics and advantages:

- How to solve it.
  - Path solver in GAMs
  - or quadratic equivalent problem
- Formulation
  - Non lineal mixed complementarity model (KKT complementarity slackness)
- Advantages
  - Simulation of oligopolistic behavior
  - Agents interactions
  - Multiple markets (product, allowance, green certificates,…)

MCP model limitations:

- Dimensionality
- Memory requirements
- Complex and less efficient solver method
- Nonlinear
  - Local optimal
- Integer and binary variables if introduced are much more difficult to deal

MCP case study example 1: ETS evaluation

- Linares, P.; Javier Santos, F.; Ventosa, L. ; Lapiedra, L. Incorporating oligopoly, CO2 emissions trading and green certificates into a power generation expansion model, Automatica, Volume 44, Issue 6, June 2008.

- Evaluates the impacts of the European Emissions Trading System and of a tradable green certificate market on the operation and investments of the Spanish electricity sector.

- Proves the feasibility of using such models with realistic information and great data detail

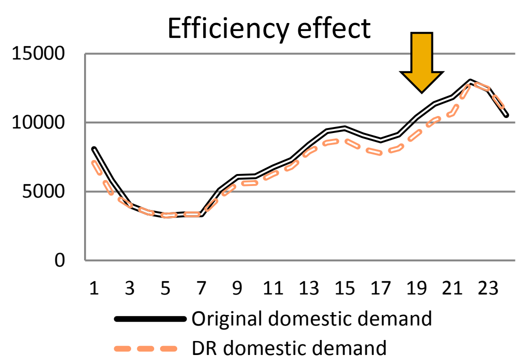
- Models simultaneously the electricity market, the emissions market and the green certificates markets

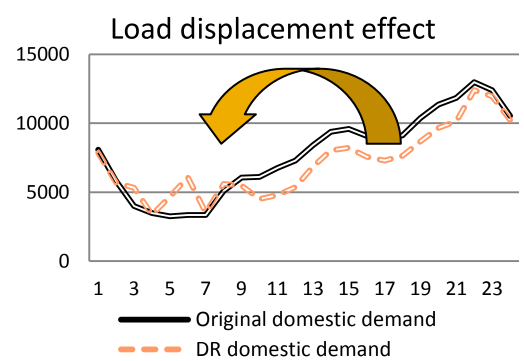
- Presents the oligopolistic formulation, with competition in quantities in the short term (Conjectural variation) and in generation capacity as in a Cornout model.

MCP case study example 2: increase in electricity demand response

- Case study:
  - Active household demand response potential savings in Spain

Consumption variation with ADR			
Appliance	Displacement	Reduction	ADR actions
Washing machine	100%	40%	• Full shutdown
Dishwasher	100%	40%	• ECO program
Dryer	100%	20%	• Limitations
Water heating	50%	30%	• stop / partial shutdown
Heating	-	50%	• Unacceptable shutdown
Air_conditioner	-	50%	• Power limitations, thermostat, time zones …
Others	-	-	Non manageable





MCP case study example 2: increase in electricity demand response

- Demand Response Simulation:

Active demand response demand balance:

$$\overline{\text{demand}}_{\text{y,l,p,b}} + INCREASED\_DR\_LOAD_{y,l,p,b} - DECREASED\_DR\_LOAD_{y,l,p,b} - CONSERVED\_DR\_LOAD_{y,l,p,b} \leq \sum_{\text{t,f}} \text{PGEN}_{\text{y,t,f,l,p,b}} + \overline{\text{pimp}}_{\text{y,l,p,b}} - \text{PPUMPED}_{\text{y,l,p,b}} - (\overline{\text{own\_cons}}) \sum_{\text{t,f}} \text{PGEN}_{\text{y,t,f,l,p,b}} - \overline{\text{loss}}_{\text{y,l,p,b}} \left(\sum_{\text{t,f}} \text{PGEN}_{\text{y,t,f,l,p,b}} + \overline{\text{pimp}}_{\text{y,l,p,b}} + \overline{\text{pexp}}_{\text{y,l,p,b}} - \text{PPUMPED}_{\text{y,l,p,b}} \right)$$

Maximum displacement:

$$DECREASED\_DR\_LOAD_{y,l,p,b} \leq \overline{\text{displaceable\_load}}_{y,l,p,b}$$

Displacement balance:

$$\sum_{b} \left(INCREASED\_DR\_LOAD_{y,l,p,b} \overline{\text{dur}}_{\text{l,p,b}} \right) = \sum_{b} \left(DECREASED\_DR\_LOAD_{y,l,p,b} \overline{\text{dur}}_{\text{l,p,b}} \right)$$

Potency conservation limit:

$$CONSERVED\_DR\_LOAD_{y,l,p,b} \leq \overline{\text{conservable\_load}}_{y,l,p,b}$$

Minimal savings requirement:

$$\sum_{b} \left(DECREASED\_DR\_LOAD_{y,l,p,b} \overline{gad\_price}_{y,l,p,b} \overline{\text{dur}}_{\text{l,p,b}} \right) - \sum_{b} \left(INCREASED\_DR\_LOAD_{y,l,p,b} \overline{gad\_price}_{y,l,p,b} \overline{\text{dur}}_{\text{l,p,b}} \right) \leq (1 - \overline{\min\_sav}) \sum_{b} \left(\overline{displaceable\_load}_{y,l,p,b} \overline{gad\_price}_{y,l,p,b} \overline{\text{dur}}_{\text{l,p,b}} \right)$$

MCP case study example 2: increase in electricity demand response

➤ Results of the simulation:

Benchmark	DR policy	Potential DR policy savings		
Total cost	Total cost	Total savings	Conservation	Load shifting
(10^6 €)	(10^6 €) (%)	(10^6 €) (%)	(10^6 €) (%)	(10^6 €) (%)
10303	10075 -2.21%	243 2.36%	198 1.92%	45 0.43%

Price	Quantity	Emissions	Final consumer savings
%	%	% CO2e % Acid e	10^6 €
-3.26%	-1.44%	-1.88% -0.65%	756.17

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Application 2

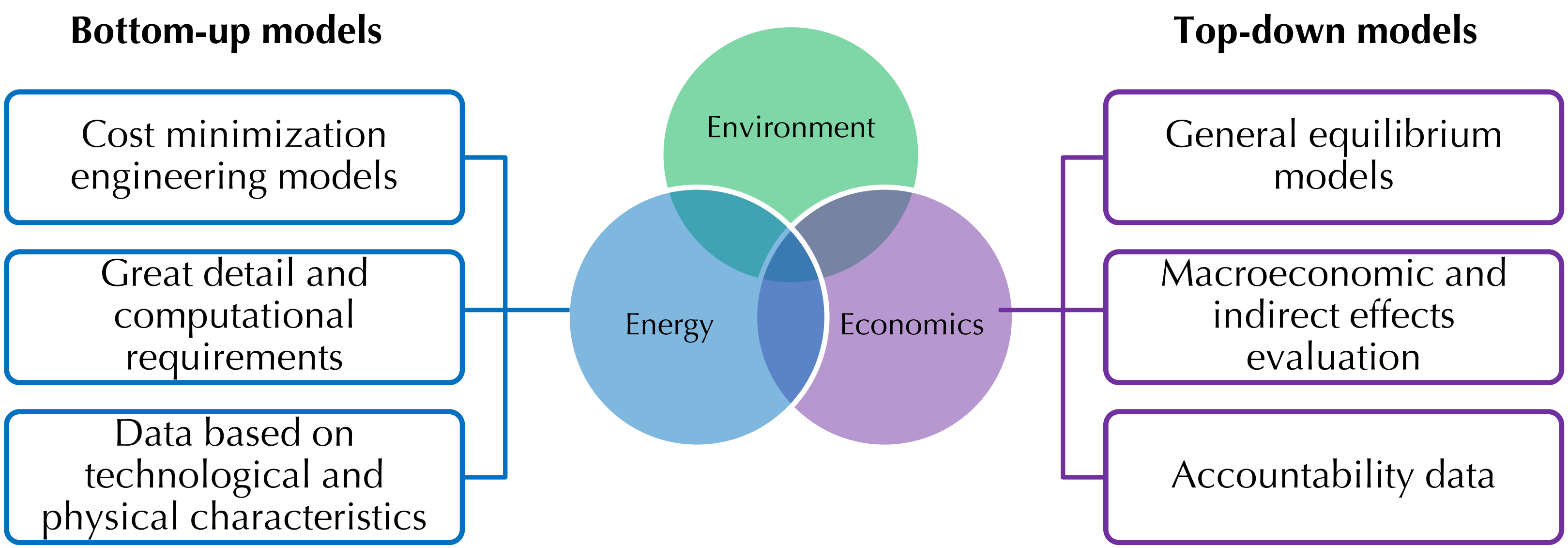
Walrasian general equilibrium models

Computable General Equilibrium Model (CGE):

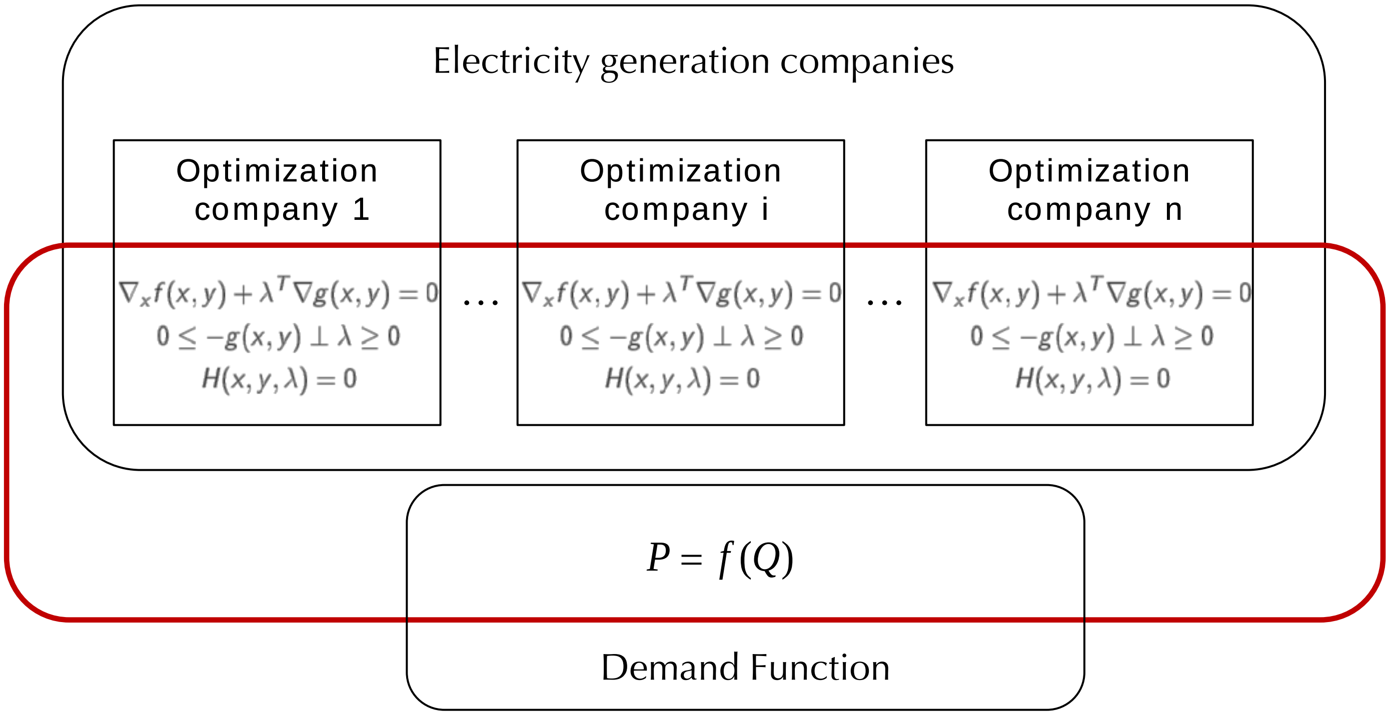
- Models a region, country or world economy
- Based on input output tables and Social accountability matrix
- Describes every economic flow between agents of the economy.
- It is composed by:
  - Equilibrium set of variational equations (mixed complementarity formulation) that represents each economic agent behavior.
  - Market clearing conditions.
  - Macroeconomic closure assumptions.

CGE application examples:

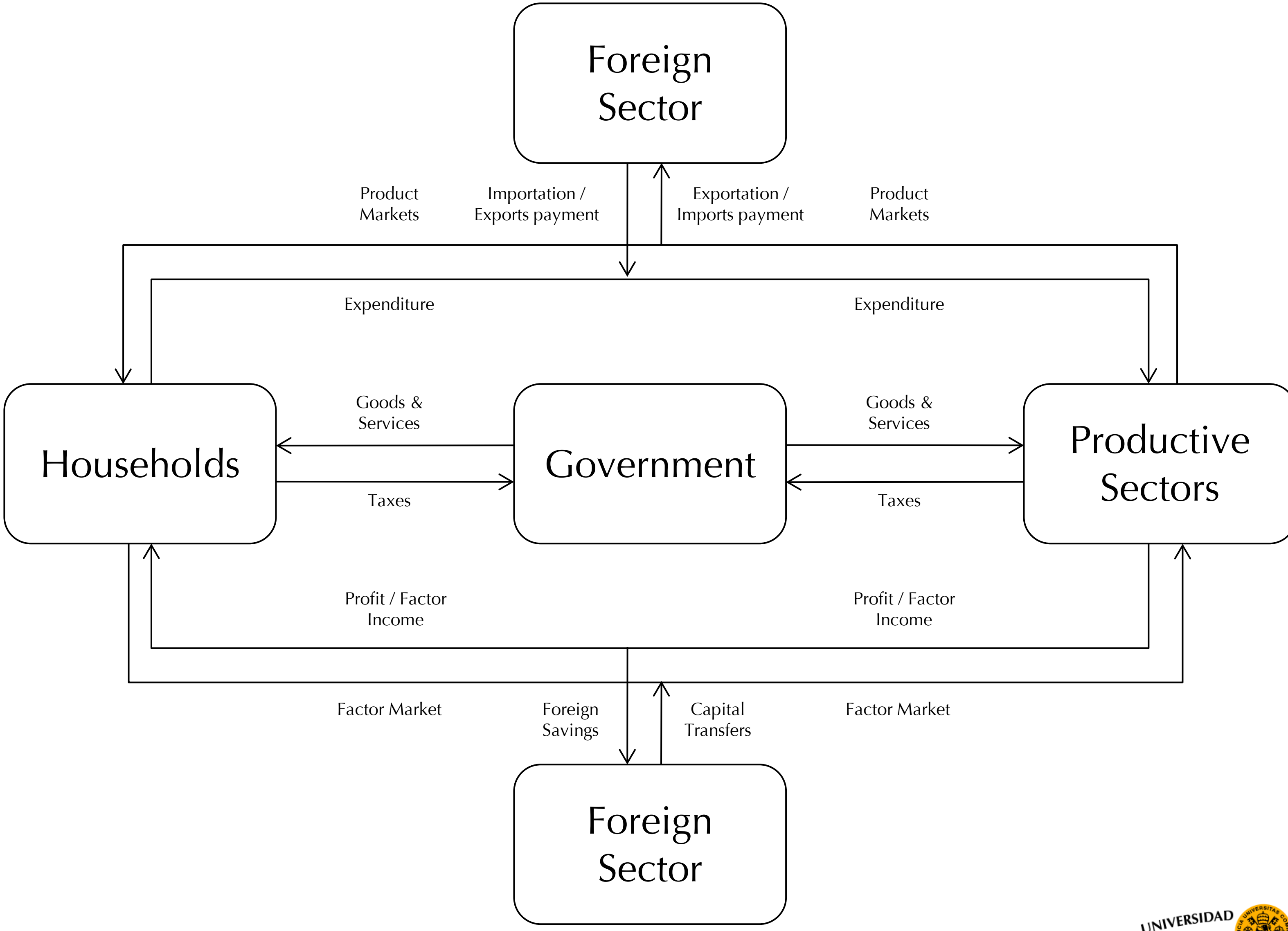
- Main areas:
  - Tax studies
  - Agricultural and land use
  - Capital and labor
  - E3 models



The electricity sector oligopolistic mixed complementarity model :



The economy-wide model (the CGE model):



The economy-wide model (the CGE model):

Households:

Max Welfare

s.t. budget constraint

$$Max \quad U(Q_g^H) = \sum_g \bar{c}_g^H \, ln Q_g^H$$

s.t.

$$\sum_g P_g Q_g^H \leq (1-\bar{s})Y^H$$

Government:

Max Public services

s.t. budget constraint

$$Y^G - E^G = S^G$$

$$Y^G = \sum_{pf} P_{pf}\bar{q}_{pf}^G + \overline{transf}^{Ext-G} + Y^{TAX}$$

$$E^G = \sum_g P_g^Q \bar{q}_g^G + \overline{transf}^{G-H}$$

Integrating Equations Market Clearing:

Final Goods

Production Factors

Capital Formation:

Investments and Savings relationships

$$S = \bar{s}^H Y^H + S^G + S^{Ext}$$

$$S^{Ext} = \sum_g P_g^M Q_g^M - \sum_g P_g^{EX} Q_g^{EX} - \overline{transf}^{Ext}$$

$$I_g = \frac{\bar{\theta}_g}{P_g^Q} I$$

Productive Sectors:

Max Profits

s.t. production function

$$Max \quad P_s Q_s - \sum_{pf} P_{pf} Q_{pf,s}$$

$$s.t. \quad Q_s = \bar{\alpha}_s^{VA}\left(\sum_{pf} \bar{a}_{pf}\left(Q_{pf,s}\right)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$$

Foreign Sector:

Imperfect substitutibility

Imports (Armington Agg.)

$$Max \quad P_g^D Q_g^D - P_g^S Q_g^S - \bar{p}_g^M Q_g^M$$

s.t.

$$Q_g^D = CES(Q_g^S, Q_g^M)$$

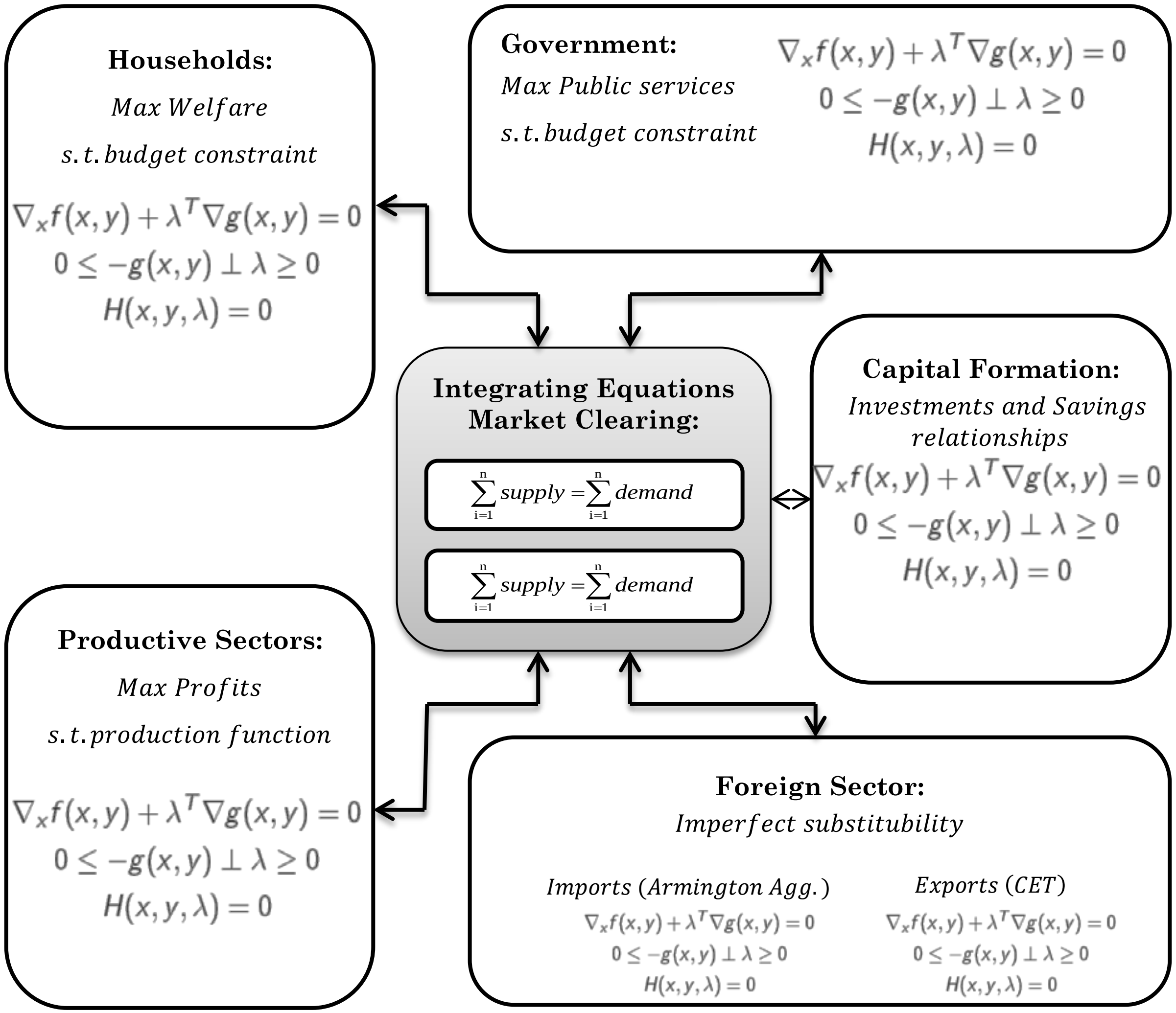
Exports (CET)

$$Max \quad P_g^Q Q_g^Q + \bar{p}_g^{EX} Q_g^{EX} - P_g^D Q_g^D$$

s.t.

$$Q_g^D = CET(Q_g^Q, Q_g^{EX})$$

The economy-wide model (the CGE model):



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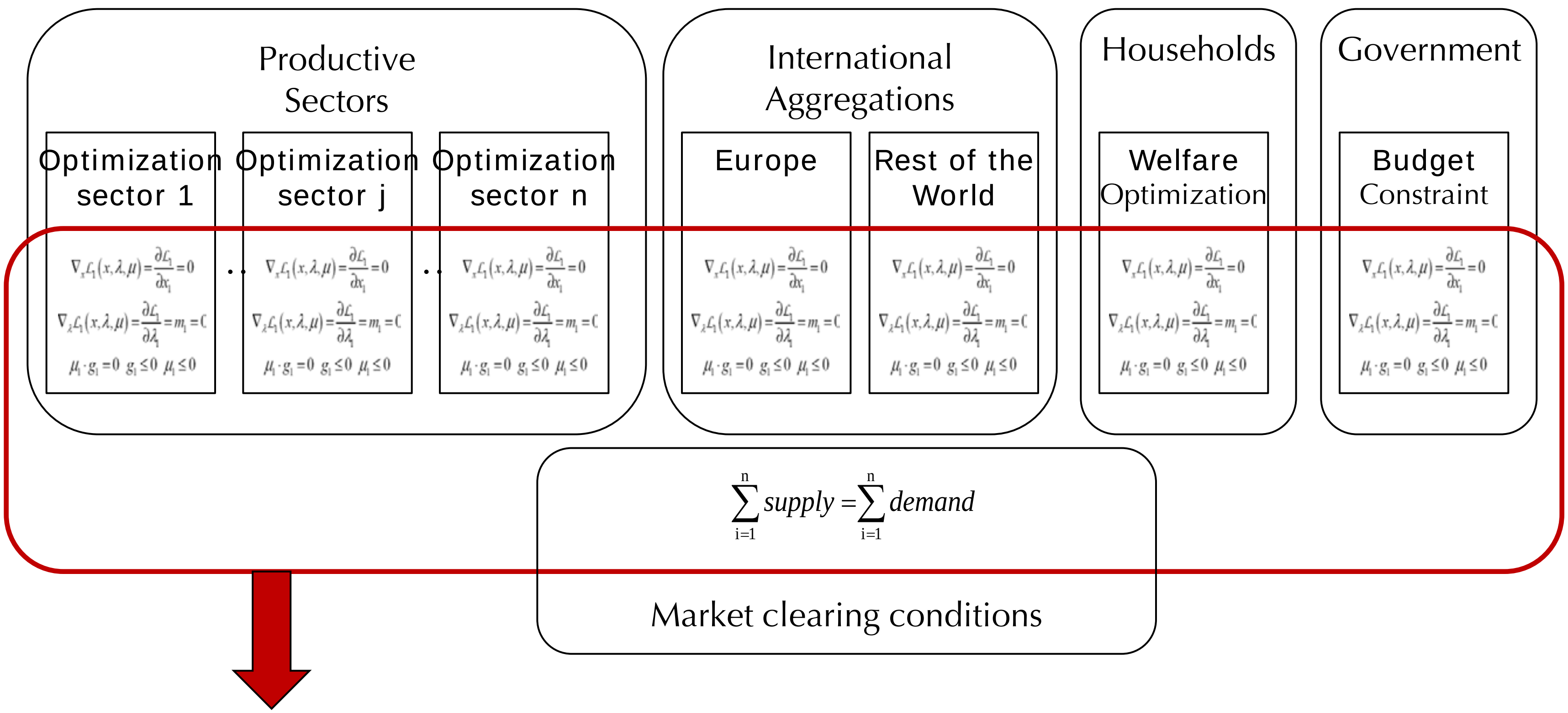

Non-lineal system of simultaneous equations
Mixed Complementary Problem (MCP)

Advantages and limitations of CGE models:

- Advantages:
  - Evaluates rebound effects
  - Indirect effects evaluations
  - Economy wide effects

- Limitations:
  - Highly Non lineal (sensitivity analysis needed)
  - Dimensionality issues in memory and time requirements
  - follows neoclassical efficient frontier assumptions
  - Deterministic model that disregards uncertainty

Revisiting the Demand Response Case study

- Case study:
  - Active household demand response potential savings in Spain

Consumption variation with ADR			
Appliance	Displacement	Reduction	ADR actions
Washing machine	100%	40%	• Full shutdown
Dishwasher	100%	40%	• ECO program
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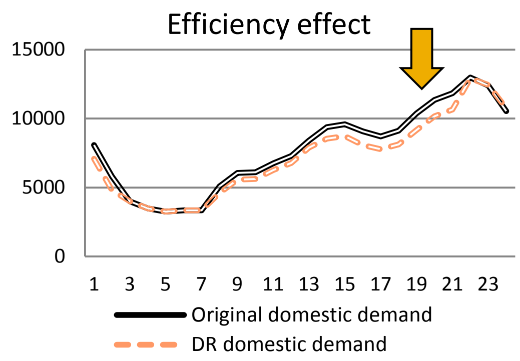

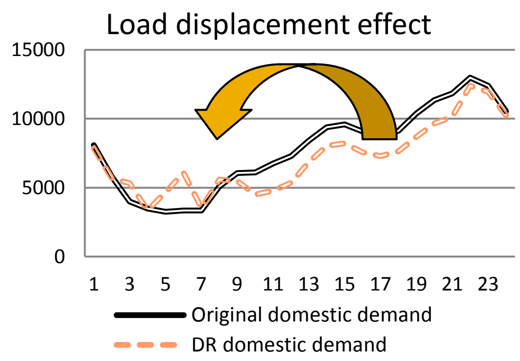

Revisiting the Demand Response Case study

- CGE simulation results
  - Rebound effect of 8% on total quantities.
  - Changes from 1.44% to 1.01% on quantity retraction for the electricity generation.

		Prices		Quantities		Emissions
		Benchm.	DR	Benchm.	DR	
		p.u.	p.u. %	p.u.	p.u. %	% CO2e % Acid e
Products	Electricity GEN	53.64	53,74 0.1885%	247	245 -1.0133%	-1.11% -0.32%
	Electricity TD&O	1.00	1,02 -0.0051%	14826	14825 -0.0019%	-
	Manufacturing	1.00	1,00 -0.0161%	778107	778089 -0.0022%	0.01% 0.01%
	Coal	1.00	1,00 -0.0018%	2413	2397 -0.6711%	-0.67% -0.67%
	Oil/Nuclear	1.00	1,00 -0.0169%	32156	32156 0.0001%	0.02% 0.02%
	Gas	1.00	1,00 -0.0207%	7641	7613 -0.3748%	-0.37% -0.37%
	Transport	1.00	1,00 -0.0209%	75496	75503 0.0090%	0.02% 0.02%
	Other Services	1.00	1,00 -0.0183%	842818	842817 -0.0002%	0.00% 0.00%
Prod. Factors						
	Labor	1.00	1,00 -0.0060%	334314	334314 0.0000%	-
	Capital	1.00	1,00 -0.0368%	376643	376642 -0.0002%	-

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Thank you for your attention!

Questions are more than welcome!

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