The IMACLIM modeling platform
Principles, methodologies and applications

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IMACLIM modeling team
CIRED
The methodologies behind the IMACLIM modeling platform
The threefold hybridization behind the IMACLIM platform

1. Articulating accounting systems: money flows / physical quantities

2. Articulating technical and economic expertises: Bottom-up / Top-down

3. Articulating growth at different time scales: natural growth / real growth
The threefold hybridization behind the IMACLIM platform

1. Articulating accounting systems: money flows/physical quantities
   - Dual and consistent description in monetary flows (input-output tables) and “physical” quantities (energy balances in MToe, transport statistics in pkm)
   - Technical coefficients in physical units to characterize production and consumption processes
Towards dual accounting systems

Recurrent debates about the representation of techniques: Re-establish the conditions of control at the interface between technical systems and the global economy

- Back to Arrow-Debreu axiomatic: Dual description of economic flows, General equilibrium in the large sense
- Simultaneous equilibrium of economic and material flows linked by the price system
- Economic projections rely on plausible technical background / technical systems are coherent with the economic environment

In practice: building accounting tables both in monetary values and physical quantities by combining macroeconomic tables and balances of physical flows

<table>
<thead>
<tr>
<th>Matrix</th>
<th>C</th>
<th>G</th>
<th>I</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>K</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>(FCC/II)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Uses (formal/informal markets)

Resources (cost structure)
Our methodology of Hybridization

Step 1

Available energy statistics

Matrix of quantities (energy unit)

\[
\begin{array}{c|c}
\text{IC} & \text{FC} \\
\hline
Q_{ij} & \\
\end{array}
\]

Matrix of prices (currency/energy unit)

\[
\begin{array}{c|c}
\text{IC} & \text{FC} \\
\hline
P_{ij} & \\
\end{array}
\]

Step 2

Energy bills (currency)

\[
\begin{array}{c|c}
\text{CI} & \text{CF} \\
\hline
V_{ij} = P_{ij} \cdot Q_{ij} & \\
\end{array}
\]

Step 3

‘Hybrid matrix’ for energy

Statistical gaps allocated to non-energy goods
Rationale 1: Using all available information to enrich the picture of the initial economy

Importance of methodologies to combine datasets from different sources (no consistent datasets on quantities/values in official statistics)

Example: Energy-cost shares

- crucial impact on macroeconomic analysis: Energy/GDP ratio, energy bills and CO$_2$ emissions of households and firms

- but important statistical gaps between national accounts and results obtained by combining statistics on physical quantities and prices (gaps in nomenclature)
## Statistical gaps in the economic value of energy flows

<table>
<thead>
<tr>
<th>French national accounts (Input-Output table, 116 products)</th>
<th>Energy statistics, AIE</th>
<th>Statistical gaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal, lignite and peat</td>
<td>1 965</td>
<td>1 558</td>
</tr>
<tr>
<td>Crude oil and hydrocarbons</td>
<td>26 875</td>
<td>17 234</td>
</tr>
<tr>
<td>Refined petroleum products</td>
<td>92 974</td>
<td>67 454</td>
</tr>
<tr>
<td>Gaseous fuels, heat and air conditioning</td>
<td>20 229</td>
<td>15 230</td>
</tr>
<tr>
<td>Mineral chemistry</td>
<td>(11 596)</td>
<td>(-)</td>
</tr>
<tr>
<td><strong>Fossil energies, commercial circuit inc. mineral chemistry</strong></td>
<td>142 043 (153 639)</td>
<td>101 476</td>
</tr>
<tr>
<td><strong>Weight in total value of production inc. mineral chemistry</strong></td>
<td>4,8% (5,2%)</td>
<td>3,4%</td>
</tr>
</tbody>
</table>
Statistical gaps in the allocation of carbon emissions

<table>
<thead>
<tr>
<th></th>
<th>Energy statistics (calculated)</th>
<th>NAMEA accounts* (published)</th>
<th>Statistical gaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total emissions (Mega tons of carbon)</td>
<td>109 107</td>
<td>111 904</td>
<td>-2.5%</td>
</tr>
<tr>
<td>From production</td>
<td>67 846 (41 261)</td>
<td>76 095 (35 809)</td>
<td>-10.8% (+15.2%)</td>
</tr>
<tr>
<td>From households</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Housing / Individual vehicles</td>
<td>16 / 25</td>
<td>17 / 19</td>
<td>-6.0% / 34.8%</td>
</tr>
</tbody>
</table>

* NAMEA: National Accounting Matrix Including Environmental Accounts
Source: Pasquier (2010). Allocation based on national accounts (macro data on expenditures)
Rationale 2: Overcoming the limits of standard models

- **Stylized representation of technical dimensions**
  - A-temporal description of technical possibilities: future technical change deduced from the past (econometrics on monetary and macro statistics)
  - Representation valid only in the short-term (‘small deviations’)
  - Impossibility to use sectoral forecasts of technical change possibilities
  - No control on the technical plausibility of ‘important mutations’

- **Stylized economic behaviours**
  - Minimizing immediate costs
  - Maximizing current profit
  - Two polar options for the dynamics:
    - Simulation under myopic expectations
    - Intertemporal optimization under perfect foresight

- **No ‘second-best’ mechanisms**: oligopolies, labour rigidities, technical inertias...
The threefold hybridization behind the IMACLIM platform

1. Articulating accounting systems: money flows/physical quantities
   - Dual and consistent description in monetary flows (input-output tables) and “physical” quantities (energy balances in MToe, transport statistics in pkm)
   - Technical coefficients in physical units to characterize production and consumption processes

2. Articulating technical and economic expertises: Bottom-up / Top-down
   - The projected economy is supported by a realistic technical background: explicit description of infrastructures, equipments and technologies.
   - Projected technical systems corresponds to realistic economic flows and relative price sets: description of investment costs and microeconomic decisions
The static version IMACLIM-S describes socio-economic interactions at a given time horizon (e.g., 2050)

- Heterogeneous socio-economic groups and High sectoral resolution
- Reduced forms of bottom-up approaches (mimic adjustment possibilities)

The dynamic recursive version IMACLIM-R describes the trajectories of socio-economic interactions over a given time period (e.g., 2010-2050)

- Representative agents and Aggregated description of production
- Explicit dynamic modules describing the reaction of technical systems, resource availability, preferences and location decisions to socio-economic signals
A tool for sensitivity analyses by comparison of various “conceptions” about

- constraints and potentials (parametric uncertainty on techniques, resources...)
- modalities of policy implementation associated to various combination of objectives
- the structure of interactions in the socio-economic system (nature of labor markets, importance of market imperfections, size of the informal sectors)

Exploring the indirect mechanisms triggered by general equilibrium interactions by abstracting from controversies on dynamic effects

- Social and Institutional: poverty, inequalities and redistribution mechanisms
- Investments: financing sources, macroeconomic imbalances
Representative of techniques in IMACLIM-S: reduced forms of bottom-up modules

From detailed bottom-up modules to production possibility frontier as a reduced form

Technical change that is dynamically feasible for different sets of relative prices (Bottom-up information)

Production Frontier (Reduced form)

Production Factor 1

Production Factor 2
Representation of techniques in IMACLIM-S: reduced forms of bottom-up modules

Energy consumption (physical unit, e.g. MTEO)

Quantity of energy at the base year

Price-elasticity

Relative price

Technical asymptote

Relatif price et the base year
Rationale for using the IMACLIM-R version

- A tool for exploring the dynamic effects and investigate the interplay between short-term and long-term mechanisms
  - Short-term inertias and constraints imposed by installed infrastructures
  - Long-term path dependency of trajectories due to cumulative investments decided under imperfect foresight (risk of ‘lock-in’ effects)

- Representing the material content of socio-economic trajectories as a result of the interplay between
  - Techniques: incorporation of information from technology-explicit models on production technologies and end-use equipments
  - Resources: constraints on the extraction of fossil resources
  - Locations: representation of land uses at different territorial scales as from the location of transport and housing infrastructure
Representation of techniques in IMACLIM-R: detailed bottom-up modules

- Primary energy (oil, coal, gas)
  - Geological, technical and geopolitical constraints

- Energy transformation
  - Electricity: 15 explicit technologies, load curve
  - Liquid fuels: tradeoffs between refined oil, biofuels and Coal-To-Liquid

- Final energy demand
  - Residential: stock of m² building shell, standards of living
  - Industry: energy efficiency, fuel switch
  - Transport:
    - 5 explicit types of private vehicles
    - Constrained mobility in function of urban forms
    - Transport infrastructure investments across four modes
    - Freight transport intensity of production
A schematic view of the two versions

- **Annual Equilibrium \((t_0)\) under constraints**
  - Economic signals (prices, quantities, Investments)
  - Representative agent/ N sectors
  - Heterogeneous socio-economic groups/ \(N' > N\) sectors

- **Bottom-up modules**
  - Industry
  - Electricity
  - Coal
  - Transport
  - Technical and structural parameters (i-o coefficients, population, productivity)

- **Annual Equilibrium \((t_0 + 1)\) under updated constraints**

- **Annual Equilibrium \((t_0 + n)\) under updated constraints**

- **Annual Equilibrium \((t_0)\)**

- **Annual Equilibrium \((t_0 + n)\)**

- **Reduced forms of dynamic evolutions**
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3. Articulating growth at different time scales: natural growth / real growth
   - The long-term natural rate of growth is given by demographic and productivity trends
   - Transitory disequilibria happen due to market imperfections and past suboptimal allocation decisions under imperfect foresight
Simulating « non-optimal » economic growth

- An exogenous growth engine defining long-term trends
  - Demography (total and active population)
  - Labor productivity (catch-up)
  - Saving rates (consistent with demographic trends)

- A model of “second best” socio-economic interactions under uncertainty capturing short-term constraints on economic development
  - Imperfect foresight: adaptive anticipations
  - Inertia of capital stocks: past choices constrain future potentials
  - Market imperfections: over- or under-utilization of production factors
  - Physical constraint: availability of natural resources

- A flexibility to represent different beliefs/views about those constraints
The IMACLIM modeling platform
Applications
A variety of questions, A common approach in 5 steps

a) Delineate precisely the policy question(s) under investigation
   (project of reform, objectives, domain of dialogue)

b) Identify the partners to collaborate with
   (« experts », « policymakers », « stakeholders »)

c) Elaborate the structure of the model
   (available data, theoretical issues, controversies)

d) Build a picture of the economy at the initial date
   (hybrid matrix at a base year, statistical synthesis, diagnostic)

e) Represent dynamic interactions
   (modelling economic, social, technical adjustments)
A number of completed or on-going projects

- Global scale with IMACLIM world models
  - Long-term scenarios: development styles, technical change and macroeconomic trajectories
  - Resource depletion and energy markets (Peak Oil)
  - Climate policy analysis: time profiles of costs, sensitivity to technical assumptions, impact of different policy architecture
  - Urban systems and macroeconomic trajectories
  - Energy, land use and food markets (Nexus land-use)

- Local scale with IMACLIM national/regional models
  - Carbon taxation (France) …
    - … and distributive justice
    - … pensions and public finance
    - … labour market and competitiveness
  - Structural change, low carbon and inclusive transition (Brazil)
  - Employment, distribution and green growth strategies (South Africa)
  - Energy transition and low-carbon economy (France)
    - Sectoral policies
    - Co-benefits/cost in the short term?
    - Nuclear power: Impact of different pace of phasing out
  - Energy transition and land use in an insular economy (La Réunion)
Climate policy analysis
## Introducing climate policy

<table>
<thead>
<tr>
<th>Category</th>
<th>Radiative forcing (W/m²)</th>
<th>CO₂ concentration (ppm)</th>
<th>CO₂-equivalent concentration (ppm)</th>
<th>Global mean temperature increase above pre-industrial at equilibrium, using “best estimate” climate sensitivity (°C)</th>
<th>Peaking year for CO₂ emissions</th>
<th>Change in global CO₂ emissions in 2050 (% of 2000 emissions)</th>
<th>No. of assessed scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>2.5-3.0</td>
<td>350-400</td>
<td>445-490</td>
<td>2.0-2.4</td>
<td>2000-2015</td>
<td>-85 to -50</td>
<td>6</td>
</tr>
<tr>
<td>II</td>
<td>3.0-3.5</td>
<td>400-440</td>
<td>490-535</td>
<td>2.4-2.8</td>
<td>2000-2020</td>
<td>-60 to -30</td>
<td>18</td>
</tr>
<tr>
<td>III</td>
<td>3.5-4.0</td>
<td>440-485</td>
<td>535-590</td>
<td>2.8-3.2</td>
<td>2010-2030</td>
<td>-30 to +5</td>
<td>21</td>
</tr>
<tr>
<td>IV</td>
<td>4.0-5.0</td>
<td>485-570</td>
<td>590-710</td>
<td>3.2-4.0</td>
<td>2020-2060</td>
<td>+10 to +60</td>
<td>118</td>
</tr>
<tr>
<td>V</td>
<td>5.0-6.0</td>
<td>570-660</td>
<td>710-855</td>
<td>4.0-4.9</td>
<td>2050-2080</td>
<td>+25 to +85</td>
<td>9</td>
</tr>
<tr>
<td>VI</td>
<td>6.0-7.5</td>
<td>660-790</td>
<td>855-1130</td>
<td>4.9-6.1</td>
<td>2060-2090</td>
<td>+90 to +140</td>
<td>5</td>
</tr>
</tbody>
</table>

*Source: IPCC, 2007

### Carbon emission objective under climate policy (GtCO2)

- Endogenous carbon price to satisfy the emission objective at each date
- Global and Uniform (sectors, households)
- Recycling: lump-sum transfers
- no Cap&Trade
- no When Flexibility
Global costs of climate policy
Time profiles

- High short-term losses
  - carbon price under inertia constraints

- Partial medium-term recovery
  - co-benefit of the climate policy (Peak Oil)

- Long-term effects, a trade-off
  - CP hedges oil depletion (fuel price)
  - …but … steady increase of carbon prices (high carbon cost)

GDP variations

GDP growth rates

Carbon tax

[Graph and chart showing global costs of climate policy time profiles, including GDP variations, GDP growth rates, and carbon tax over time.]
Global costs of climate policy
Regional effects

GDP variations
Global costs of climate policy
Sensitivity to technical assumptions

GDP variations
Global costs of climate policy
Complementary measures to carbon pricing

- Long-term costs: Weak price sensitivity of transport-related emissions to price increases
  - Complementary measures to carbon pricing in order to control mobility: urban form, public transport facilities, logistics organization

- Other measures: Cap&Trade, Fiscal reform, recycling options…
Global costs of climate policy
Complementary measures to carbon pricing
Carbon taxation in France
Policy questions and debates

- Large theoretical consensus among economists
  A carbon tax is the most efficient instrument in the ‘policy tool box’

- But an implementation gap due to a recurrent ‘refusal front’
  - An increase in energy prices will harm activity and employment
  - entails a negative impact on the most vulnerable households and sectors
  - Unilateral policy will create harmful competitiveness distortion
  - Risk to jeopardize other structural objectives (recovery, social protection, deficits)

- Lessons from a modeling exercise applied to France
  Evaluation of the mid term impacts of a unilateral CT without border adjustment, on the CO₂ content of all consumptions, and reaching high levels (200-300€/tCO₂)
  2 periods: 1984-2004 (retrospective) and 2004-2020 (prospective)
Simultaneous equilibria in monetary and physical units (MTOE)

- 20 income classes
  - Prices, Incomes
  - Final demand
- 4 productions (3E + 1 ‘Composite’)
  - Transfers
  - Payroll & other taxes
- Public administrations
- Limited adaptation capacity (technical constraints & basic needs for energy)
- Rest of the world
  - Flows of products & funds
- International trade competitiveness function of the production costs

Public finance modalities (informational constraint and multiplicity of objectives)

France in open-economy
A prerequisite: an integrated accountability

« Physical » data (i.e. energy balance)

Description of material flows

Hybridation

Disaggregation

SYSTÈME COHERENT DE COMPTABILITE

Monetary aggregates

Distribution of economic wealth

Households’ surveys (i.e. income and expenditure)

Distribution of aggregates

Physical aggregates

Disaggregation

Distribution of natural and produced services

MACROECONOMY

ENVIRONMENT

DISTRIBUTION
Recycling the tax revenue: lessons from two polar cases

<table>
<thead>
<tr>
<th>300€ / tCO₂ and</th>
<th>Repayment of the public debt</th>
<th>Lower social security contributions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions</td>
<td>-38.5%</td>
<td>-34.1%</td>
</tr>
<tr>
<td>Real GDP</td>
<td>-6.5%</td>
<td>+1.9%</td>
</tr>
<tr>
<td>Employment</td>
<td>-5.7%</td>
<td>+3.5%</td>
</tr>
<tr>
<td>Poverty</td>
<td>+10.1%</td>
<td>-1.1%</td>
</tr>
<tr>
<td>Inequalities</td>
<td>+1.3%</td>
<td>+2.0%</td>
</tr>
<tr>
<td>Public debt</td>
<td>-92.0%</td>
<td>id.</td>
</tr>
</tbody>
</table>

- A ‘consensus’ among economists -> limit the cost of climate action
- A controversy: weak or strong ‘double-dividend’?
A Potential Virtuous Cycle for Activity and Employment

If the sharing of the payroll tax cuts actually reduces the relative labour costs

If part of the reallocated tax burden does not ultimately fall back on production costs (rents, transfers)

Structural change
Increase in employment intensity

Carbon Tax - Lower Social Contributions

Oil bill alleviation
Reduced levies on national incomes

Tax burden transfer
Decrease in production price

Higher domestic consumption

Higher employment

Higher production

Higher competitiveness

A Potential Virtuous Cycle for Activity and Employment

If the sharing of the payroll tax cuts actually reduces the relative labour costs

If part of the reallocated tax burden does not ultimately fall back on production costs (rents, transfers)
Conditions for a net employment gain

Le sign of the net impact depends on 2 controversial parameters

Sensitivity of net exports to domestic prices

Sensitivity of net wages to unemployment

I et II : Gains

III : Losses
## Conditions for a net employment gain

<table>
<thead>
<tr>
<th>Domaines</th>
<th>Unemployment</th>
<th>Production</th>
<th>Wages</th>
<th>Price</th>
<th>Consumption</th>
<th>Exports</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>II</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>III</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

**I**: The positive impact on real trade is stronger

**II**: The positive impact on wage growth is stronger

**III**: The negative impact on energy bills is stronger
Conditions for a net employment gain

- The initial state of the economy is also important
- The domain III (activity and employment losses) is reduced with:
  - A high level of unemployment
  - A low level of net wages
  - A high level of energy consumption by households and higher than the energy consumption by productive systems
- Other sensitivity tests hardly change the diagnosis:
  - To energy-savings potentials
  - To higher margins (‘deadweight effect’ of SSC reductions)
When the «details» of policy design matter

3 types of tested ‘variables’

- Alternative recycling options
  - Lower VAT
  - Lump sum transfers to households

- Restrictions of the tax base
  - Various exemption devices

- Parameters of public finances
  - Various options of budgetary management
  - Various rules determining public expenditures
  - Various indexation rules of social transfers

leads to robust conclusions and are not superior to the option of lower social contributions. Does not solve the issues of purchasing power & competitiveness.

Involves trade-offs between priorities (public debt, current consumption, production, and employment).
And the argument of fairness?
## Poverty alleviation... at cost of higher disparities

<table>
<thead>
<tr>
<th>€300/tCO2 &amp; Lower SSC</th>
<th>Direct impact on the energy bill</th>
<th>Unemployment (% points)</th>
<th>Disposable Income</th>
<th>Gini inequality index</th>
</tr>
</thead>
<tbody>
<tr>
<td>5% poorest</td>
<td>+78.3%</td>
<td>-12.2</td>
<td>+5.4%</td>
<td>+0.3 pts</td>
</tr>
<tr>
<td>5% richest</td>
<td>+72.0%</td>
<td>-0.9</td>
<td>+7.3%</td>
<td></td>
</tr>
</tbody>
</table>

**Main determinants:**

1) Budget share devoted to energy, energy saving potential

2) Initial unemployment rates, jobseeker’s allowance-wage gap

3) Relative weights of income sources (activity, property, transfers, etc.)
The 2 schemes reduce CO$_2$ emissions by 34% over the period 1985-2004.
## Contrasted impacts on the production costs

<table>
<thead>
<tr>
<th></th>
<th>€300/tCO₂ and</th>
<th>Green Check</th>
<th>Lower social security contribution (SSC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total variation</td>
<td>+3.7%</td>
<td></td>
<td>-1.0%</td>
</tr>
<tr>
<td>Energy costs variation</td>
<td>+1.6%</td>
<td>+1.6%</td>
<td></td>
</tr>
<tr>
<td>Net wages variation</td>
<td>+0.1%</td>
<td>+1.5%</td>
<td></td>
</tr>
<tr>
<td>Payroll tax variation</td>
<td>id.</td>
<td></td>
<td>-3.6%</td>
</tr>
</tbody>
</table>

- **Same direct impact** on the energy bill
- **BUT** when social contributions tax are lowered:
  - **Limited propagation** of the costs increases
  - **Slight alleviation of the tax burden** on production
  - **Higher progression of nominal net wages**
But there is room for compromises

This compromise scheme also reduces CO₂ emissions by 34% over the period 1985-2004.
But energy vulnerability is ill-explained by ‘income’

A variety of technical, geographic and socioeconomic factors
Four main constraints for public policies (2020)

1. Higher competition on resources and markets
   - AIE: a barrel of oil at 81-92€ (77€ in 2011)

2. Ageing of the population
   - COR: funding needs for pensions 41-48 billions (11 en 2008)
   - CEPII: important decrease in the households’ saving rate

3. Control of public deficits

4. Ambitious objective of the « facteur 4 »
   - Reducing CO₂ emissions by 17% over less than 10 years
Reconnecting climate, pensions and deficits issues

Consider: 1) A 2020 France ‘COR compatible’ 2) an objective: funding pensions over 2004-2020

Three structural reforms
- Higher legal retirement age (>3 yrs)
- Higher social contributions (+7 pts)
- €200/tCO₂ - Lower SSC & Higher Income Tax (+2 pts)

Graph showing:
- CO₂ emissions
- GDP
- Employment
- Net wages
Conclusion

Economic analysis can contribute to:

- verify the consistency in arguments
- define viable compromises despite of current controversies

Three ‘parameters’ seems crucial:

1. The principle of lowering social cotisations and their sharing
   -> trade-offs between the wage progression and the control of costs

2. The coherence between public policies
   -> trade-offs between objectives and search for synergies

3. Identification of the most vulnerables to high energy prices
   -> solving of the equity/efficiency dilemma