New developments related to the World TIMES model: EMF-22 Project & Climate Module

Maryse Labriet, Richard Loulou
Group for Research in Decision Analysis (GERAD)
Montreal, Canada

Energy Technology Systems Analysis Programme
Semi-Annual Workshop
Kyoto, July 4, 2005

Outline

1. Progress made in the EMF-22 project

- Stanford meeting, May 25-27, 2005
- Progress accomplished so far in TIMES database and structure
- Current and next work

2. The new “Climate Module” of TIMES

- General equations
- Implementation
- Some results

Introduction

Starting Collaboration started in 2004

EMF-22 Climate Policy Scenarios for Stabilization and Transition
⇒ Focus on comprehensive analyses of long-run climate stabilization policies under uncertainty as well as intermediate-term transition policies (2010-2040)

1st Meeting Brussels, November 2004
- Define the work and the scenarios

2nd Meeting Stanford, May 2005
- Consolidate the original objectives
- Confirm the Study Groups (SG)
- Outline a calendar for future activities

Four Study Groups

- Hedging
- Transition Policies
- Black Carbon
- Land-Use

Rules of participation

Flexibility and freedom each participant has in choosing:
- membership in one or more SG's
- among the several experiments proposed in each SG

No rigid base cases
⇒ each modeler ~ free to define its own reference case
⇒ alternate policy scenarios run by each modeler are relative to that modeler's reference case(s)

1. EMF-22

Hedging SG

Objective
Evaluate hedging policies, i.e. “good” or “optimal” decisions taken while uncertainty prevails

Uncertain parameter
Climate sensitivity
Discrete probability distribution function:
L= 1.5°C (0.30), 2.5°C (0.40), 5°C (0.15), 8°C (0.15)

Three experiments
A: Full resolution of uncertainty in 2050
B: Partial resolution in 2050, full resolution in 2070
C: Partial resolution in 2030, full resolution in 2050

Non-CO_2
CO_2 concentration replaced by the concentration of all GHG gases expressed in CO_2-eq $\Rightarrow$ avoids the modeling of life cycle of non-CO_2 GHGs

1. EMF-22

Transition Policies SG

Objective
Simulate a relatively large range of policies that could be applied in the 2010-2040 period

Target-Driven Policies
A reduction target (not yet defined) is specified in 2040 under a cap-and-trade regime, and the response of the model is analyzed, thus revealing sectoral and regional policies

Policy-Driven Policies
A set of policies* are specified and the effects on climate and costs are analyzed

**Eg: - sectoral caps and trade*
- taxes and/or subsidies on commodities and/or technologies
- technology standards (car efficiency, building shell efficiency)
- portfolio standards (emission per kWh of electricity produced)
- impact of non-GHG policies on climate (local pollution limits, development oriented policies)

Land Use SG

Objective

Provide a detailed inventory and projections to 2050 of land uses and emissions as well as quantitative information on mitigation options

Approach similar to EMF-21, which provided non-CO_2 emissions and marginal cost curves for abating the emissions

Black and Organic Carbon SG

Objective

Study the effects of including black and organic carbon* in a cap-and-trade regime

** Produced during combustion of fossil fuels (RPP, coal) and biomass, warming (BC) / cooling (OC) potential*

Progress accomplished so far

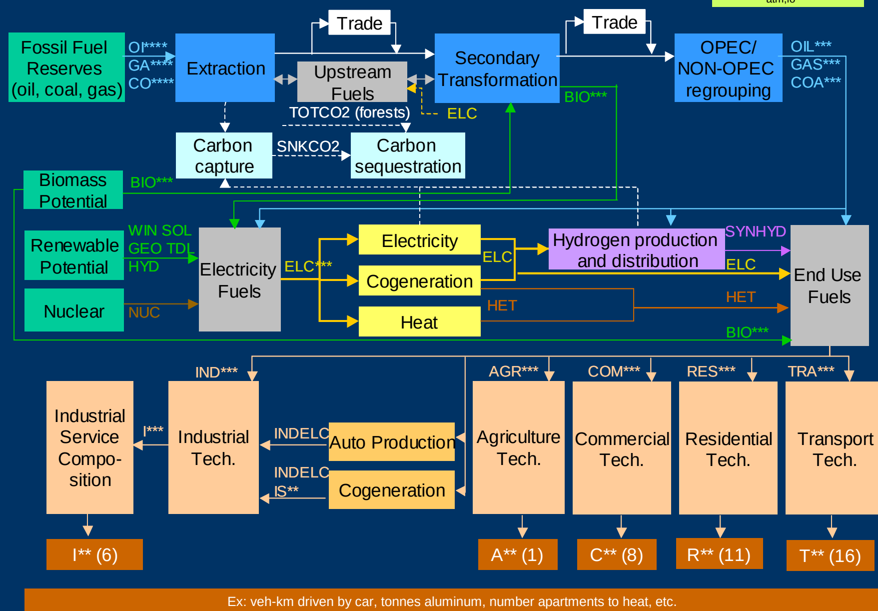
Transition of the database from the world multi-regional MARKAL to TIMES and testing the model

- Same structure
- New assumptions about input data : long-term energy service demands (based on POP and GDP projections), resources availability, specific energy policies & behaviors, future technologies (cost, efficiency), etc.

1. EMF-22

Reference Energy System (RES)

Climate module
$CO2CONC_{atm,up,lo}$
RADFORCING
$TEMP_{atm,lo}$



1. EMF-22

Progress accomplished so far

International trade

- Endogenous trading of natural gas, LNG, crude oil (and CO_2 permits) ⇒ endogenous quantities & prices
- Particularly challenging task for crude oil: control of oil annual production quantities by OPEC, so as to approximate the oil production decisions of the cartel ⇒ oil price from 3.8 to 8.7 \$/GJ (22 to 55 \$/bbl)

Climate module

- Integrated in the structure of the model
- Scenarios with bounded CO_2 concentration tested

Data handling tools (VEDA_FE, VEDA_BE): upgraded

Sequestration

(Can be activated or not)

CO_2

Capture

Power plants (pre- or post-combustion)
Hydrogen plants
Industry not incl

+50% elc price

Transportation
From 3 to 55$/tC

Geological, ocean & advanced storage
CUM=4157 GtC (1)
From 4 to 12$/tC

Depleted oil/gas fields
Coal beds
Saline aquifers *(cheapest)*
Deep ocean
+ *Mineralization (expensive)*

Terrestrial sinks
CUM=163 GtC (2)
From 20 to 70$/tC

Forestry, soils

(1) Calibrated to literature (Kauppi and Sedjo, 2001; Herzog et al., 1997)
(2) In the range proposed by IPCC, but very uncertain
Barriers : Needs for more R&D about CCS technologies, reservoirs and biological processes, risk of leakage, permanence

Available Resources

CRUDE OIL (21)
Conventional (9)
Bitumen (very heavy) (6)
Oil sands (3)
Oil shales (3)
NATURAL GAS (11)
Conventional (9)
Not connected (1)
Not conventional (1)
COAL (4)
Brown (2)
Hardcoal (2)

			US geological survey				
COMPARISON	TIMES	IPCC	*MEAN*	*F95*	*F50*	*F5*	MERGE
TOTAL COAL (EJ)	168298	212193					261518
TOTAL GAS (EJ)	33061	36020					35294
Conventional	*18997*	*17179*	*14395*	*9001*	*13111*	*20258*	*10086*
Unconv. / Undiscov.	*16913*	*18841*					*25208*
TOTAL OIL EJ	42315	35576					20027
Conventional	*15202*	*13562*	*15768*	*9954*	*14454*	*21900*	*8828*
Unconventional	*27113*	*22014*					*11199*

Different types of reserves
- Located reserves (known & recoverable)
- Reserves growth (to be developed)
- New discovery (probabilistic)
- Up to 3 steps for each type of reserves (cost)

Potential
- Gas and coal reserves of TIMES are consistent with other sources
- Oil reserves of TIMES are too high (non-conventional)
  BUT based on reference case results, cumulative consumption of oil up to 2100 is ~ 25000 EJ $\Rightarrow$ OK

➡ ***Potential of renewables also updated***

1. EMF-22

Current and future work

Non-CO_2 gases (2005)

- Calibration of CH_4 and N_2O emissions in the reference case
- Integration of the abatement options for
  - *energy*
    - coal mining (7)
    - oil and natural gas sectors (4+15)
  - *non-energy*
    - waste management (8)
    - manure management (2)
    - adipic & nitric acid industry (8)
- Use of cost curves provided by EMF-21

Hedging and climate sensitivity (2005-2006)

- Implementation of Stochastic Programming
- Simulations of uncertain long term stabilization targets using the climate module

Transition Policies (2006)

- Simulation of Transition Policies

1. EMF-22

Role of ETSAP in EMF-22

Interest by EMF-22 in the active participation of ETSAP

- High degree of development of the TIMES model

(integrated assessment with the Climate module)

- Technology oriented modeling approach

(becoming a necessity for representing detailed policies)

- High visibility of ETSAP and its multi-country membership

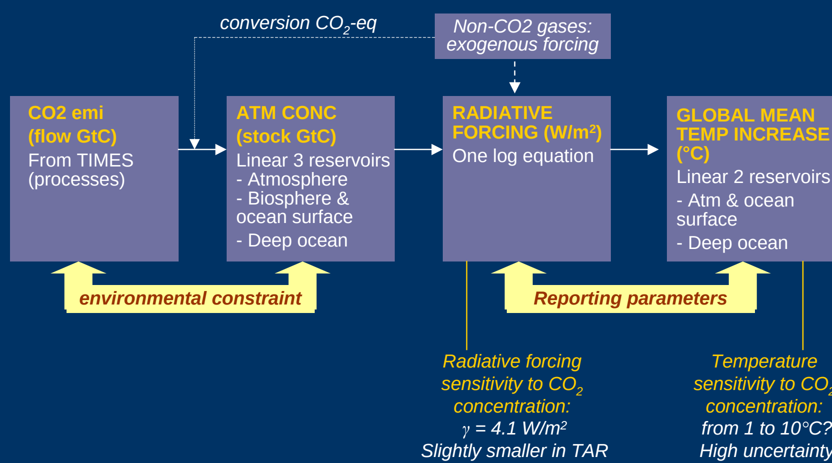
Participation of ETSAP in Study groups

- Hedging
- Transition Policies

Benefit for ETSAP

- Data: other gases (EMF-21), latest knowledge on climate
- Visibility (publications)
- Reinforce collaboration with other BU and TD modelers

Approach: 3-step climate module



Equations

Adapted from the model proposed by Nordhaus and Boyer (1999)
Well documented + simple
Good approximation of those obtained from more complex climate models

Equations: concentration

Accumulation of CO_2 results from the transfer of carbon between:
- the atmosphere
- the quickly mixing upper ocean + biosphere
- the deep ocean (low mixing)

$\Rightarrow$ CO_2 flows in both directions between adjacent reservoirs

Linear

$$M_{atm}(y) = E(y) + (1 - \varphi_{atm\text{-}up})\, M_{atm}(y\text{-}1) + \varphi_{up\text{-}atm}\, M_{up}(y\text{-}1) \quad (1)$$

$$M_{up}(y) = (1 - \varphi_{up\text{-}atm} - \varphi_{up\text{-}lo})\, M_{up}(y\text{-}1) + \varphi_{atm\text{-}up}\, M_{atm}(y\text{-}1) + \varphi_{lo\text{-}up}\, M_{lo}(y\text{-}1) \quad (2)$$

$$M_{lo}(y) = (1 - \varphi_{lo\text{-}up})\, M_{lo}(y\text{-}1) + \varphi_{up\text{-}lo}\, M_{up}(y\text{-}1) \quad (3)$$

with

- $M_{atm}(y)$, $M_{up}(y)$, $M_{lo}(y)$: masses of CO_2 in atmosphere, in a quicly mixing reservoir representing the upper level of the ocean and the biosphere, and in deep oceans (GtC), respectively (GtC)
- $E(y)$ = CO_2 emissions (GtC)
- φ_{ij}, transport rate from reservoir i to reservoir j ($i, j = atm, up, lo$) from year y-1 to y

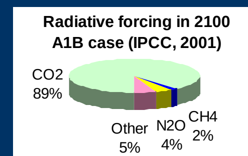
Equations: radiative forcing

Accumulation of GHGs leads to an increased radiative forcing at the surface of the earth

Not controversial equation derived from empirical measurements and climate models

Value of γ (sensitivity to CO_2 concentration doubling)
4.1 W/m^2, 3.7 W/m^2 in IPCC (2001)

Exogenous forcing:
- All non-CO_2
- Only non-CO_2 not included in the CO_2-eq.
- Uncertainties: aerosols (cooling/warming)



$$\Delta F(t) = \gamma * \frac{\ln(M_{atm}(t)/M_0)}{\ln 2} + O(t)$$

where:

- M_0 (i.e.CO2ATM_PRE_IND) is the pre-industrial (circa 1750) reference atmospheric concentration of CO2 = 596.4 GtC
- γ is the radiative forcing sensitivity to atmospheric CO_2 concentration doubling = 4.1 W/m^2
- *O(t)* (i.e. EXOFORCING(t)), is the increase in total radiative forcing at period *t* relative to pre-industrial level due to anthropogenic GHG's not accounted for in the computation of CO2 emissions. Units = W/m^2.

Equations: temperature increase

Higher radiative forcing warms the atmospheric layer, which then warms the upper ocean, gradually warming the deep oceans

Two reservoirs: atmospheric + upper level of the ocean, deep ocean

Temperature change = globally and seasonally averaged temperature in the atmosphere and the upper level of the ocean

Not considered: regional and seasonal variability, precipitations, speed of change

Value of C_s (sensitivity to CO_2 concentration doubling: 1.5 to 4.5 °C, up to 10°C?

$$\Delta T_{up}(y) = \Delta T_{up}(y-1) + \sigma_1\{ F(y) - \lambda \Delta T_{up}(y-1) - \sigma_2 [\Delta T_{up}(y-1) - \Delta T_{low}(y-1)]\} \quad (5)$$

$$\Delta T_{low}(y) = \Delta T_{low}(y-1) + \sigma_3 [\Delta T_{up}(y-1) - \Delta T_{low}(y-1)] \quad (6)$$

with

- ΔT_{up} = globally averaged surface temperature increase above pre-industrial level,
- ΔT_{low} = deep-ocean temperature increase above pre-industrial level,
- σ_1 = 1-year speed of adjustment parameter for atmospheric temperature,
- σ_2 = coefficient of heat loss from atmosphere to deep oceans,
- σ_3 = 1-year coefficient of heat gain by deep oceans,
- λ = feedback parameter (climatic retroaction) ($\lambda = 4.1/C_s$, C_s being the temperature sensitivity to CO_2 concentration doubling).

Variables and parameters

True variables
Three concentrations: atm, upper level of ocean+biosphere, deep ocean
Constraint is possible on atm concentration

Reporting parameters
Radiative forcing
Temperature changes: mean surface, deep ocean
Constraint on temp would result in non-linear non-convex optimisation pb

Input parameters (default values are included)
{ CO_2 transfer rates between reservoirs
{ Sensitivity of radiative forcing to the atm CO_2 concentration doubling
Forcing of non-CO_2 GHGs ?
{ Heat transfer parameters
Sensitivity of temperature to the atm CO_2 concentration doubling
{ Historic (initial) values of concentrations and temperature increases
Pre-industrial atmospheric concentration
{ *Maximal CO_2 concentration*

GAMS Implementation and Reporting

- All required GAMS modules added to the code
- Climate Module implemented as a TIMES extension module
- *Rem:* CO2ATM is interpolated on an annual basis
  ⇒ FORC, TATM and TLOW are calculated on an annual basis
  ⇒ Improvement in precision

- For reporting purpose, attributes have been added in the VEDA_BE report generator:

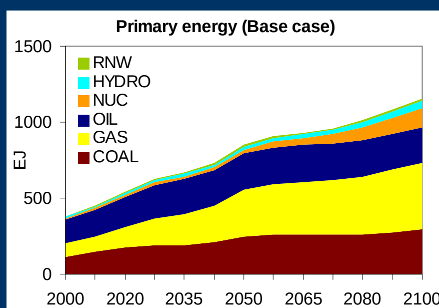
CM_dt_forc:	Delta forcing
CM_dt_tatm:	Temperature change in surface
CM_dt_tlow:	Temperature change in deep layer
VAR_co2tot:	Total CO2 emissions by milestone year (in GtC)
VAR_co2atm:	Mass of CO2 in the atmosphere (in GtC)
VAR_co2up:	Mass of CO2 in the upper ocean layer (in GtC)
VAR_co2lo:	Mass of CO2 in the deep ocean layer (in GtC)
EQ_co2concM:	Undiscounted annual shadow price of maximum CO2 concentration constraint

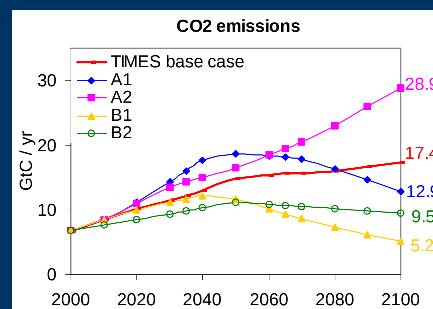
See www.etsap.org/documentation.asp

2. Climate Module

Some illustrative results: Base case

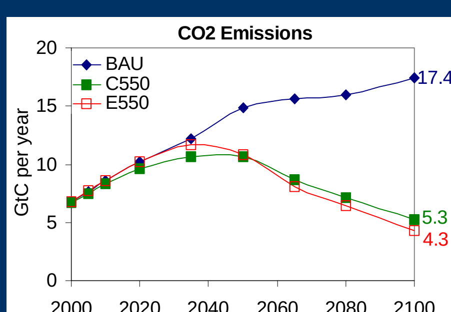
- Inspired by the Common POLES-IMAGE (CPI)
- Moderate POP and GDP growth + technology progress
- Primary energy use continues to grow
- Gas & coal become the dominant energy carriers after 2050 (power plants and industry sector)
- Intermediate range of emissions (IPCC-SRES)

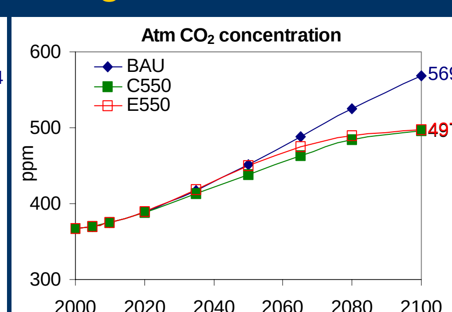




2. Climate Module

Emission vs concentration target



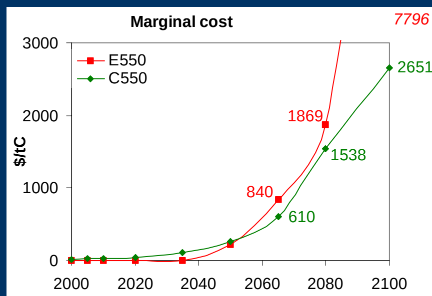


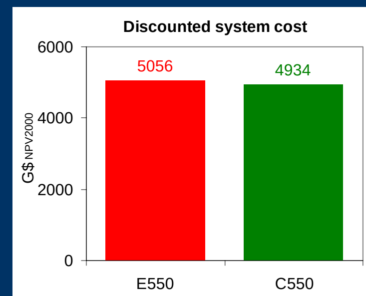
E550 = World Emission Limit from 2005 to 2100. Exogenous path.
C550 = Single CO_2 concentration limit in 2100. Defined by E550.
Sequestration not allowed here.

Higher long-term emissions and e**arlier action**
Faster transition from fossil power plants to hydro and nuclear power plants
Less renewable in LT
Lower substitution to elc in end-use sectors in LT

Higher flexibility of concentration climate policies

Mitigation cost





Remarks

Value in 2080:
- 1538 $/tC with LT concentration limit
- 1869 $/tC with emission limit

Jump & high 2100 values: end-use constraints?

More results available (not shown): 450ppm, sequestration

TIMES documentation
www.etsap.org/documentation.asp