Establishing sustainable levels of GHG concentrations

Analysis based on the newly developed hard-link of MERGE & TIMES-MACRO (MTM)

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S. Kypreos, A. Lehtila

Overarching goals for the development of MTM were threefold:

- **Study of global/regional policies under consistent boundary conditions**
- **Use models with macro-economic equilibrium and technology details**
- **Simulate technology dynamics with endogenous learning (LbD and LbS)**

To meet these goals we have established a hard link of TIMES-MACRO (TM) models (with USA as example) and the MERGE model of all other world regions such that we get:

a) **Endogenous technology dynamics** to be scenario and path dependent
b) Endogenous **price** feed-backs due to resource depletion
c) Endogenous **trade** of CO2 permits and other energy products
d) **Macro-economic** feed-backs of energy and environmental policies
e) The macro-economic **cost of policies**

Coordinates of Merge & Times-Macro (MTM)

- **MTM**: consists of a 8 region of MERGE-ETL
  & one region of TIMES-MACRO
- **MTM** is an Integrated Assesment Hybrid Model combining 'bottom-up' & 'top-down' approaches and is solved by maximizing the Negishi weighted global welfare
- Traded **commodities** are: *oil, gas, coal, biomass, synthetic fuels, CO2 permits, and a numeraire good*

We aim to assess the feasibility and implications of the COP17 outcome, i.e., a Post-Kyoto agreement in 2020

Table 1 Probabilities of exceeding 2 °C

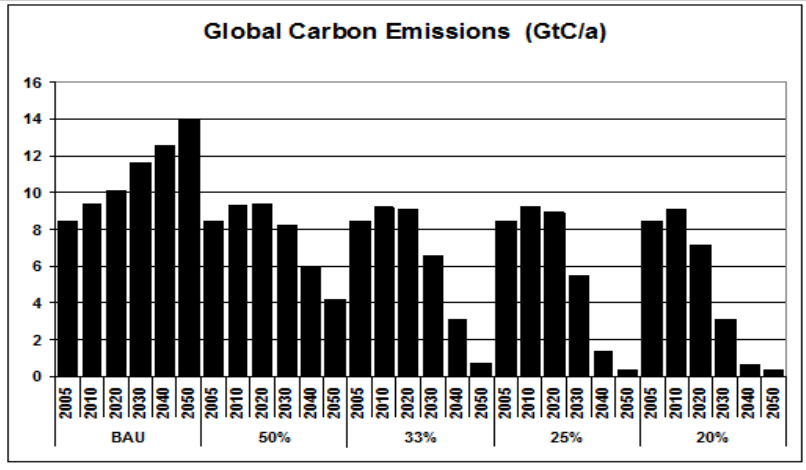
	Indicators	Emissions	Probability of exceeding 2°C	
Scenario Name	Cumulative CO2		Range*	Illustrative Default**
50 percent	Cumulative CO2 emissions 2000-50	1437 GtCO2	29-70%	50%
33 percent	Cumulative CO2 emissions 2000-50	1158 GtCO2	16-51%	33%
25 percent	Cumulative CO2 emissions 2000-50	1000 GtCO2	10-42%	25%
20 percent	Cumulative CO2 emissions 2000-50	886 GtCO2	8-37%	20%

Based on the conclusions of Meinshausen et al. (Nature 2009) shown above, we impose cumulative CO2 emissions constraints between 2020 and 2060, following the Durban agreement, with gradually stringent CO2 budgets fixing the emissions for only 2005 and examine the probability to exceed 2° Celsius.

We also study the necessary structural changes in the energy systems and define the economic impacts globally and by region relative to baseline.

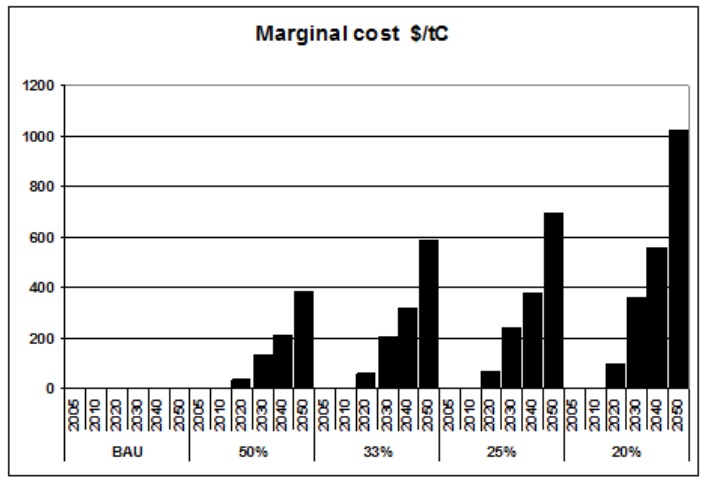
Finally the same information is given for USA in details.

Results of MTM



Annual Carbon Emissions estimated for the Baseline (BAU) and the imposed global and cumulative budgets with different probabilities of exceeding 2°C

Results of MTM



Marginal cost of carbon under global and cumulative emission budgets from 2020 to 2050 that correspond to the previous emission profiles for different probabilities to exceed 2°C.

Estimated Carbon Emissions in GtCO2/a and the associated probability to exceed 2 °C

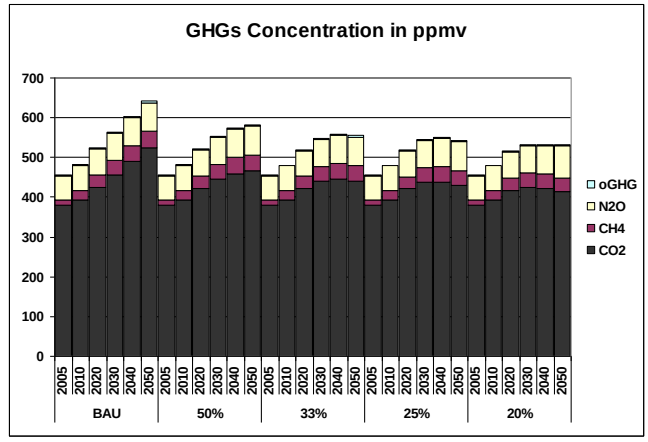
2010 GtCO2/a	2020 GtCO2/a	2030 GtCO2/a	2040 GtCO2/a	2050 GtCO2/a	2000-2050 GtCO2	Probability In %
37.69	41.18	46.93	49.94	54.96	2174	NA
37.40	38.39	34.17	26.03	18.85	1597	60
37.14	37.14	28.38	15.22	5.79	1352	45
37.11	36.67	24.38	8.32	4.58	1232	37
36.74	30.18	15.14	5.79	4.69	1048	28

The cumulative emissions are estimated using the trapezoidal rule for the shown emission levels from 2010 to 2050 adding 330 GtC for the period 2000-2010.

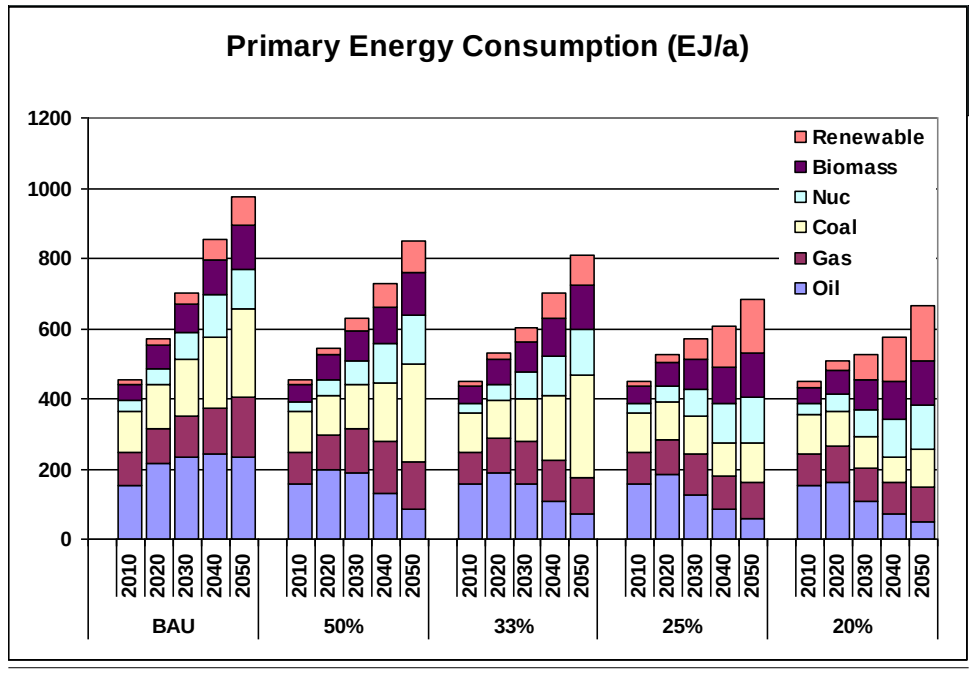
The probabilities in the last column are interpolated values based on the Meinshausen Table

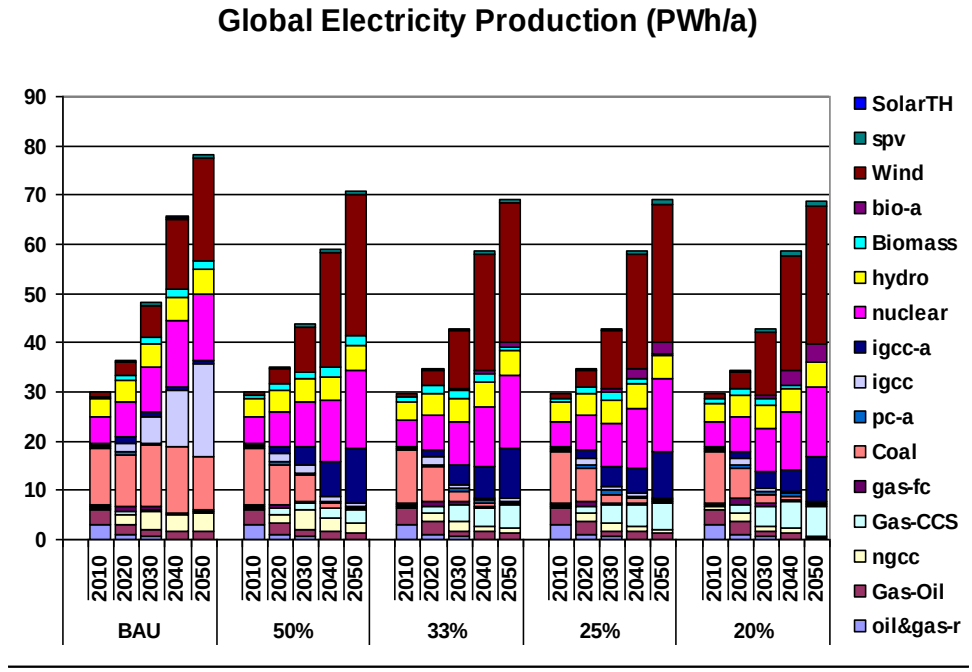
The changed values for 2010 are due to optimization freedom given to MTM for the period around 2010.

Results of MTM

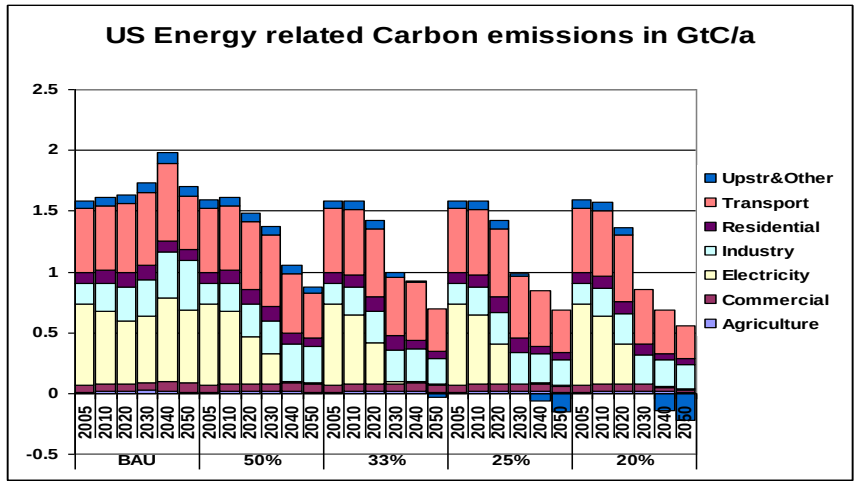


Atmospheric concentrations given in ppmv of Kyoto GHGs in CO2 equivalent as estimated with MTM under global and cumulative emission budgets for different probabilities of exceeding 2°C of warming.


Primary Energy Consumption (EJ/a)
1200
1000
800
600
400
200
0
Renewable
Biomass
Nuc
Coal
Gas
Oil
2010
2020
2030
2040
2050
BAU
50%
33%
25%
20%

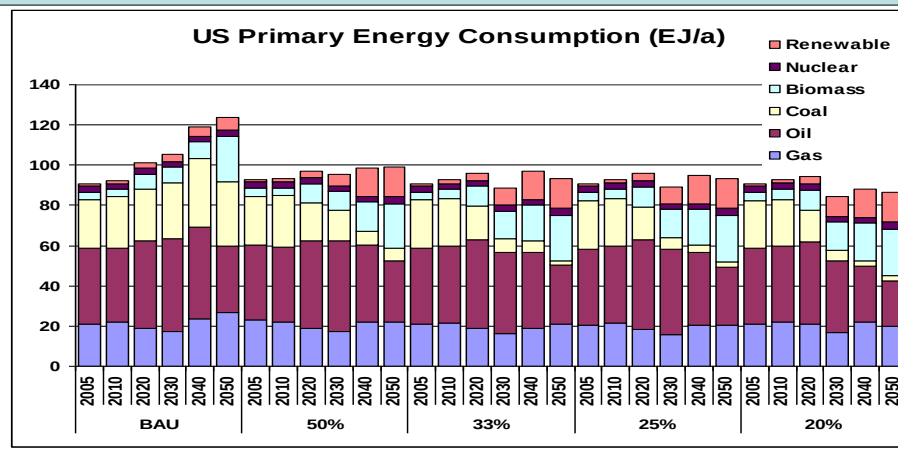

Global Electricity Production (PWh/a)
90
80
70
60
50
40
30
20
10
0
SolarTH
spv
Wind
bio-a
Biomass
hydro
nuclear
igcc-a
igcc
pc-a
Coal
gas-fc
Gas-CCS
ngcc
Gas-Oil
oil&gas-r
2010
2020
2030
2040
2050
BAU
50%
33%
25%
20%

Specific results for USA



The flexibility to reduce emissions for USA is given with remaining emissions Industry and Transport

Specific results for USA



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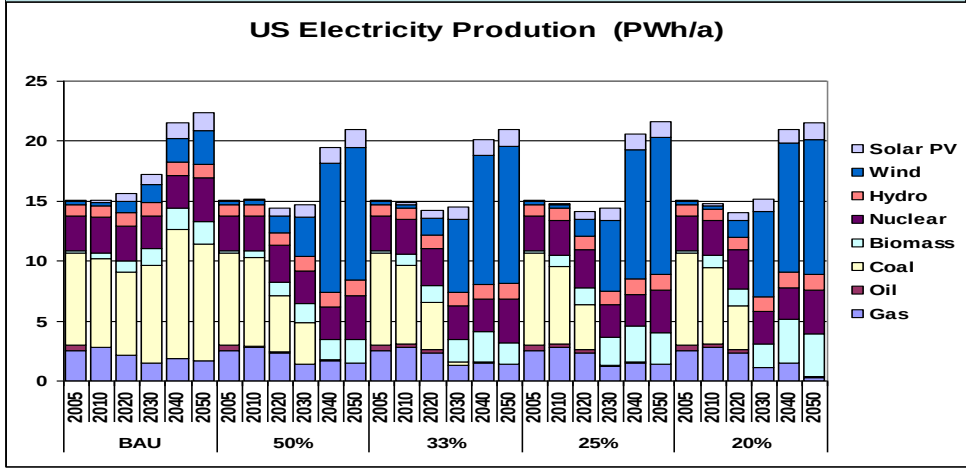
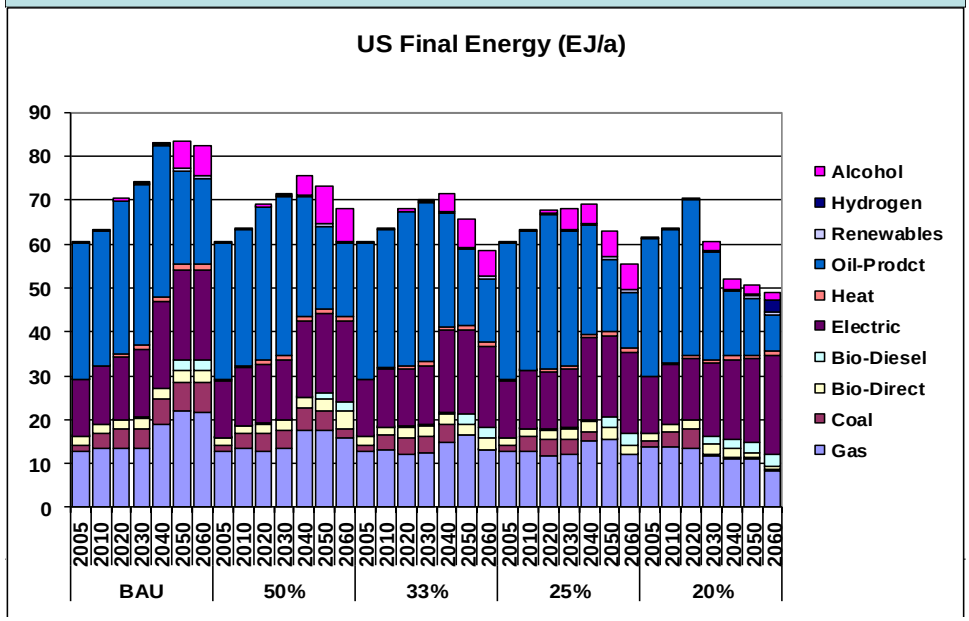
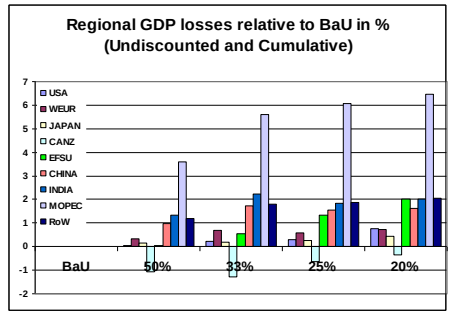
Specific results for USA

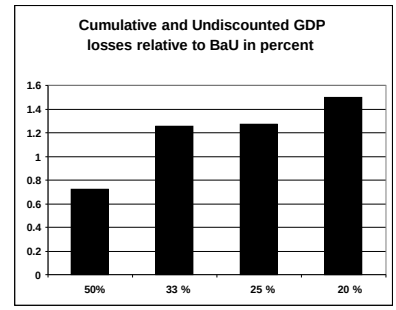


Specific results for USA



Results of MTM; Cost of Policies





Although the global (undiscounted) economic impacts are below 1.5 % of GDP the regional (undiscounted) impacts are significant for DCs and severe for oil producing regions as quantity of exports and prices are reduced.

No compensation via trade of permits and no environmental benefits are estimated here.

Conclusions-1

The study concludes that following Durban it will be feasible but more difficult to sustain global warming below 2°C. However, the associated probabilities to sustain temperature change below 2 °C are becoming worse, due to time delays while the window of opportunity narrows. Actually, I was biased in favor of a positive outcome as the model was constrained for 2005 and not for 2010.

Although some carbon-free technologies like wind and advanced nuclear systems are competitive and contribute to the reduction of carbon emissions already in the baseline, other systems like advanced carbon capture and sequestration options based on coal and natural gas for power generation and solar PV need the introduction of policy instruments to become competitive.

Synthetic fuel production and advanced power generation based on biomass with CCS options have negative carbon emissions and become one of the key future technological options to mitigate carbon emissions but for the moment they need policy support to become mature.

Conclusions-2

Conservation options in the building sector and the transportation together with efficiency improving end-use options are key contributing to the reduction of carbon emissions. This is indicated by the stabilization & reduction of final energy use for USA although the economic activity assumes a significant growth.

Finally, although the net GDP reduction on the global level remains below 1.5% the impact of the carbon constraint is DCs and oil/gas exporting regions is severe asking for compensation measures.

This could be obtained by Cap & Trade policies, the carbon transfer fund for renewable and by regional differentiation of carbon emission policies in the early decades based on the expected economic developments and the potential mitigation options across world regions.