Sectoral Emission Mitigation Potentials:

Comparing Bottom-Up and Top-Down Approaches

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This study has been performed within the framework of the Netherlands Research Programme on Scientific Assessment and Policy Analysis for Climate Change (WAB). The study results in three products for further reading: a background report describing the Bottom-Up approach, two workshop reports on the comparison of the Bottom-Up and Top-Down approaches for respectively the energy sector and the forestry sector, and a power point with all results and the main conclusions. All products can be downloaded from the WAB website at
http://www.mnp.nl/en/themasites/wab/index.html

1. A Project on Comparing Bottom-Up and Top-Down Assessments

An important question for climate policy making is how much GHG emissions and energy can be saved, in which sectors and at what costs? Traditionally, studies looking at this question are often characterised as either using a **Bottom-Up** or a **Top-Down** approach. The differences between these approaches are far from clear-cut. The first approach tends to focus more on available technologies and their characteristics, while the second approach focuses on the processes within the economy as a whole on the basis of observed historic behaviour. The two approaches have also been used in the IPCC fourth assessment report (AR4) (IPCC, 2007) in order to assess the medium-term (2030) sectoral potentials and costs of GHG emission reduction. AR4 finds that at the global level the total emission mitigation potentials and costs of the two approaches are comparable (and presents both results in the summary for policymakers). However, at a regional and sectoral scale, the results could not be readily compared due to different data formats.

In this report we analyse available data in more detail, by presenting a detailed comparison between the Bottom-Up and Top-Down approaches on a regional and sectoral scale. Using an updated Bottom-Up analysis compared to AR4 and six hybrid or Top-Down energy-environment-economy models, sectoral and regional mitigation potentials are estimated at different cost categories for the year 2030. The aims of this study are to derive improved insights into mitigation potentials, to assess the uncertainties therein and to help bridge the gap in understanding the differences between different assessment approaches.

2. Outline of the Project

The Bottom-Up approach focuses on distinct technologies. Technologies or mitigation options at regional and sectoral level are explicitly identified and related reductions are aggregated. In contrast to this approach, the Top-Down approach focuses on economies or the energy system as a whole. The energy-environment-economy models at the macro-level employed for Top-Down analyses include and use data on historical behaviour to varying degrees, response to prices (elasticity) and changes in economic structures. In addition, various hybrid approaches are developed. Here we use the term Top-Down (or modelling) approach also for the hybrid models.

The Bottom-Up approach used in this study is an extension and update of the AR4 approach and focuses on individual sectoral estimates. The baseline used for the Bottom-Up approaches is the baseline of IEA's World Energy Outlook 2004 for all sectors besides the residential and service sector. For this sector, a baseline is used aggregated from different literature sources. The Bottom-Up results are corrected for double counting of power supply and end use sectors. For a detailed description of the approach, see Hoogwijk et al. (2008).

The AR4 analysis for the (Top-Down) model approach is based on statistical analysis of existing model runs. In order to obtain further insights, in this project results from dedicated model runs of six different energy-environment-economy models were used[1]. These models are based on different approaches, including computable general-equilibrium models (WorldScan, ENV-Linkages and AIM), energy system models (IMAGE/TIMER and MESSAGE) and an i/o model (E3MG). These models differ in technology detail and whether they use a simulation or optimisation approach. Each of the Top-Down models ran seven scenarios: a baseline scenario and six scenarios with a carbon tax of respectively 20, 50 and 100 US$/t$CO_2$. Two carbon trajectories were used: a constant tax applied from 2010 onwards to US$20, US$ 50 and US$100 and an exponentially increasing tax introduced in 2010 and reaching the same levels in 2030.

The lessons of the analysis can be summarized in 4 categories:
- lessons for the use of mitigation potentials;
- main findings on aggregated mitigation potential;
- main findings on detailed mitigation potentials;
- recommendations for AR5.

3. Lessons for Users of Mitigation Potentials

The following lessons can be drawn for the use of mitigation potentials.

Both the Bottom-Up and Top-Down approach add Information: Technology Detail versus System Integration.
It may sound obvious, but the two approaches are not exclusive: they add different types of information. The Bottom-Up approach adds technology detail and is therefore also well suited to deal with other policy instruments than financial instruments. It pays relatively little attention to barriers within the system that may limit adoption. In most Top-Down models, technology detail is

[1] **Worldscan** (Lejour, et al., 2006); **MESSAGE-MACRO** (Messner, Schrattenholzer, 2000; Riahi et al., 2007; Rao and Riahi, 2006); **E3MG** (Barker et al., 2007; Barker, et al., 2008; Barker, et al.,2008); **AIM** (Fujino et al., 2006); **IMAGE** (Bouwman et al., 2006; van Vuuren, 2007); **ENV-Linkage** (OECD, 2008).

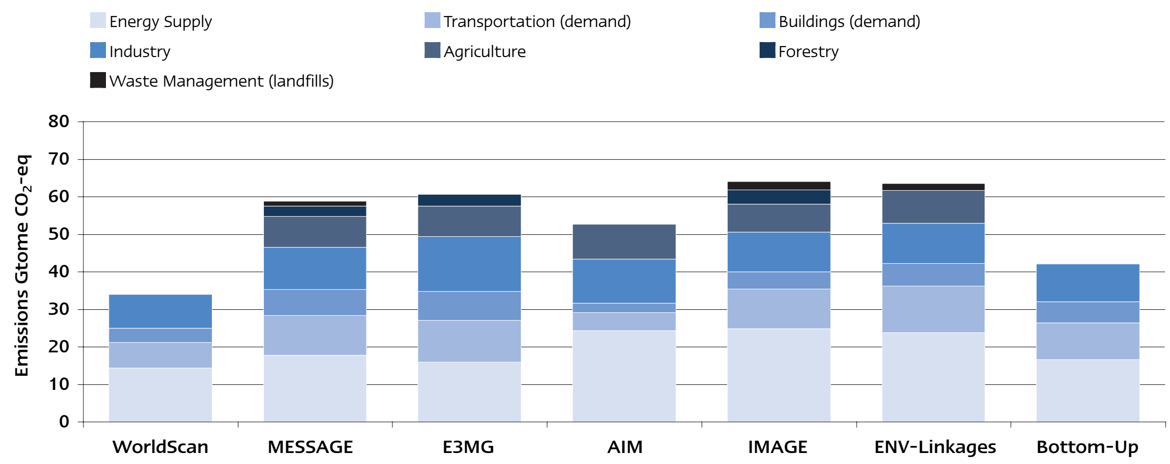

Figure 1: The absolute baseline emissions for the six models (for a medium baseline) and the Bottom-Up approach (WEO2004).

limited, but much more attention is paid to system integration and barriers to adoption. Yet, at the aggregated level no clear bias to lower or higher potentials is found as both approaches are also limited by factors such as the number of technologies taken into account. None of the models included allows for negative costs as they assume technologies with negative costs would either already have been included in the baseline and/or market barriers exists that raise their costs.

Given the wide Uncertainty Ranges: Never focus on a Single Number or Study for Policy Decisions.

The ranges between the different models and studies are significant. The differences are partly because of differences between the type of approach, but also because of different input parameters and assumptions and different starting conditions. There is no best approach or result. For a good understanding of the possible future mitigation potential and related costs, it seems more useful to study the range within the different studies and the reasons for them, than to focus on one single study.

Ensure the Consistency in Allocation of Emissions and the Definition of Sectors when Comparing Data.

Studies can allocate results in different ways. For instance, emissions can be calculated for end-use sectors or at the point-of-emission. There are advantages of both methods (in terms of policy relevance, but also methodology) – but they cannot be directly compared. It should also be noted that studies may use different sectoral definitions. In this study, we have ensured consistency in all definitions as far as possible, while all emissions were allocated to the point of emission.

Be aware of the Role of Baselines.

Even if models implement a similar baseline (i.e. emissions in the absence of climate policy), their results will not be exactly the same (*see Figure 1*). One of the reasons is that the modelling approaches do not always include the same sectors or GHG gasses. Note for instance that for the Bottom-Up approach only the energy sectors are included. Moreover, emission pathways are calculated endogenously in most models, which implies that specific model dynamics can play an important role. Furthermore, the baseline for the base year (2000) already differs as a result from differences in databases (GTAP and IEA) used. Across the models, the baseline emissions in 2030 are around 60 GtCO_2-eq. For the energy related sectors only, the baseline varies from around 35 to 55 GtCO_2-eq. Because of the differences in the baseline, the mitigation potential can best be compared in relative terms: relative (e.g. percentage change) compared to the baseline for each of the models.

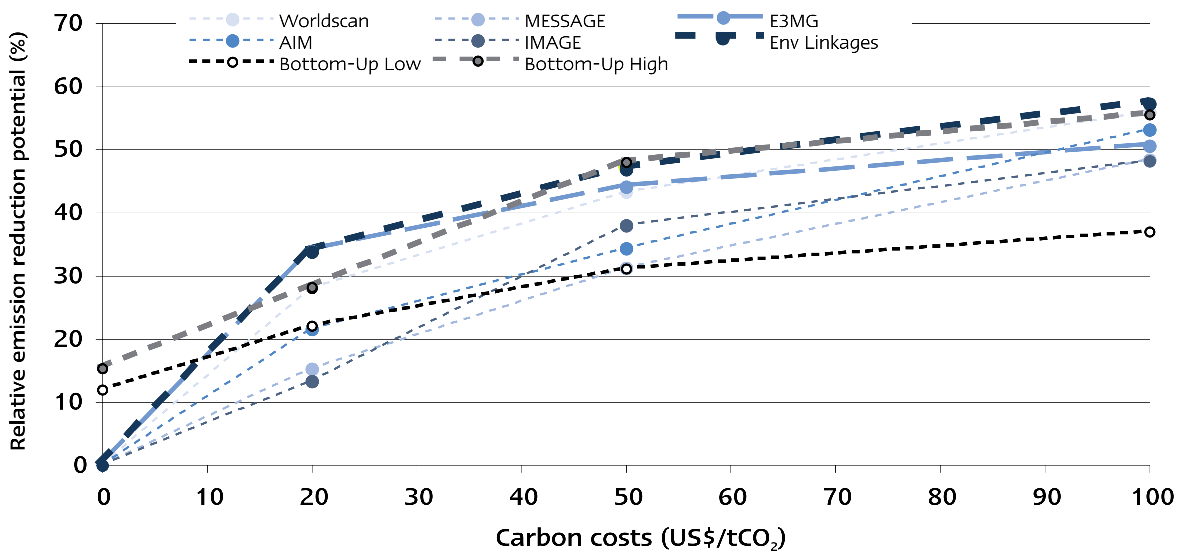

Figure 2: The aggregated relative emission mitigation potential at different cost levels. Figures presented include the energy supply, transport, industry, residential and service sector only.

4. Main Findings on Global Aggregated Mitigation Potential

At the aggregated levels, several conclusions can be drawn (*Figure 2*).

The overall Mitigation Potential is Significant. Together, the different models and assessments methods indicate that in 2030 the total mitigation potential at the global levels ranges from 13 – 36% compared to baseline at 20 US$/t$CO_2$, from 29 – 46% at 50 US$/tCO_2 and from 35 – 56% at 100 US$/t$CO_2$-eq. In relative terms, the spread in mitigation potential seems larger at low carbon prices than at higher carbon prices. Methodological differences across the models and different approaches play a role here.

There seems no Systematic Bias in the overall Mitigation Potential between the Bottom-Up and Top-Down Approach. In the Bottom-Up approach, GHG emission reductions within a certain cost category were defined between a lower and an upper limit. In most cases, the lower estimates of the Bottom-Up results are lower than estimates coming from the modelling approach. However, similarly the higher limit is often higher than the estimates coming from the different models included in the modelling approach. An often used hypothesis is that Bottom-Up analysis results in higher estimates for mitigation potentials as it focuses on technical constraints only. This hypothesis is not confirmed in the results. Reasons include that Bottom-Up approaches often use only a limited technology database. Also at higher carbon prices other market barriers may play a more limited role. Moreover, some of the Top-Down models also capture the effect of output reduction.

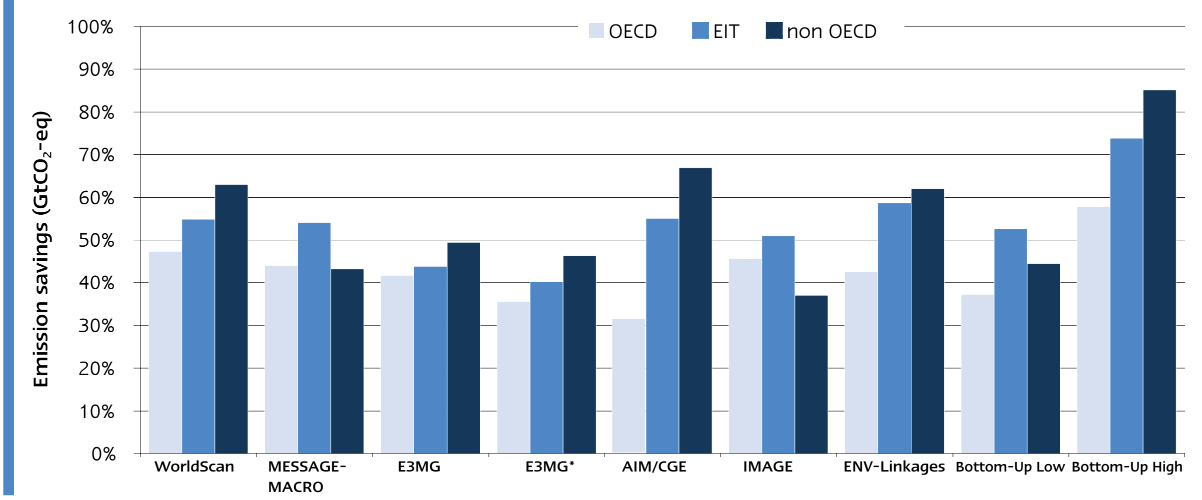

Figure 3: Relative regional mitigation potential at costs below 100 US$/tCO$_2$. The OECD region refers to regions/countries part of the OECD in 1990. The EIT region refers to Central and Eastern Europe and the Former Soviet Union. The Rest of the World region refers to the regions not included in the previous two categories. Figures presented include the energy supply, transport, industry, residential and service sector only. Note that for E3MG two different solutions are included, the regular model result and that of the model without revenue recycling for incentivising low-carbon technologies.

5. Main Findings on Regional and Sectoral Mitigation Potential

More Research is Required for Developing Economies and Countries in Transition.
Figure 3 shows the aggregated mitigation potential compared to the baseline per region. The figure illustrates that the largest mitigation potentials are in non-OECD countries and in the Economies in transition (EIT). However, these are also the regions with the largest variation or uncertainty. More research is required to improve the data for these countries.

The Energy Supply Sector has the Largest Mitigation Potential.
Figure 4 shows the relative emission mitigation potentials per sector. The energy supply sector has the largest mitigation potential. The reductions mainly originate form fuel switch to biomass and renewable energy sources. The different studies indicate that in 2030, the mitigation potential in the the transport sector is relatively limited. This is a result of limited number of technical measures to reduce its emissions and (in most models) a low response to an increase in primary energy prices.

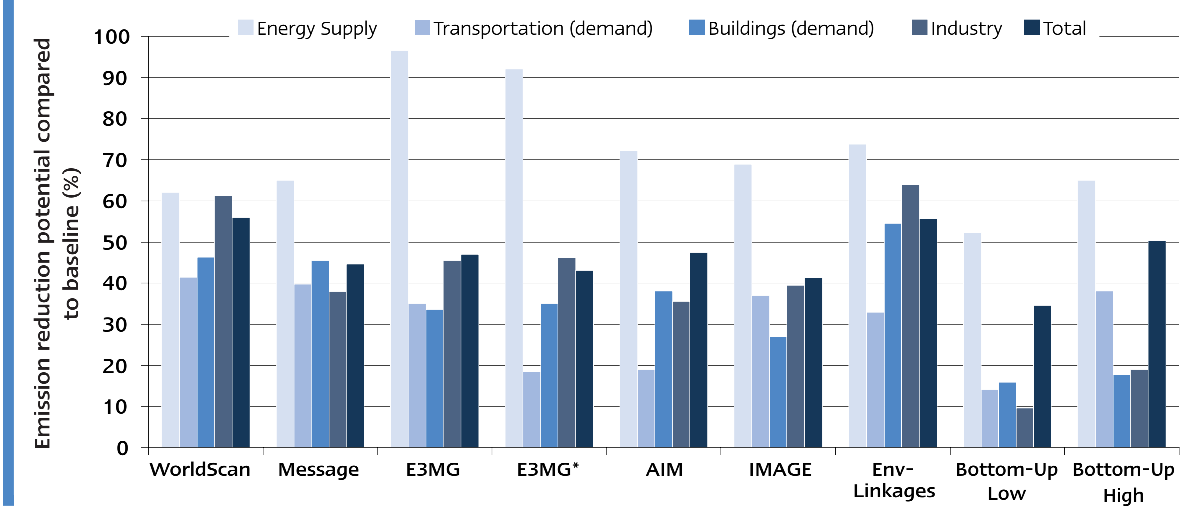

Figure 4: Relative emission mitigation potential at cost below 100 US$/tCO$_2$ per sector.

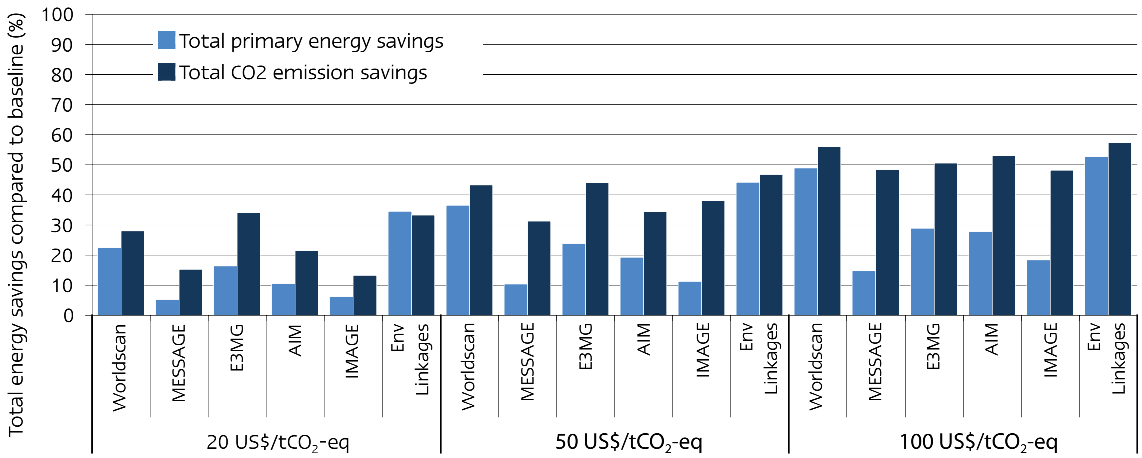

Figure 5: The relative energy savings and the relative savings in GHG emissions for the six Top-Down models. Figures presented include the energy supply, transport, industry, residential and service sector only.

The Bottom-Up and Top-Down Approaches are Most Comparable for the Energy and the Transport Sector.

There are various reasons why the Top-Down and Bottom-Up approach result in the most comparable results for the energy and transport sector. The energy supply sector (mostly power sector) is relatively well-defined, for which models have considerable technology detail. Moreover, in this sector implementation barriers are relatively low. As a result, technical options and market responses could be more similar than in other sectors. For the transport sector, there are relatively few technical measures (Bottom-Up) and the response to higher fuel prices is low (Top-Down). Both factors lead to a low potential.

The industrial and the residential and service sectors have the largest range of variability between the two approaches. Contrary to expectations, the Bottom-Up results are much lower than the model results. Different factors may play a role here. An important reason is the limited number of options included in the Bottom-Up analyses.

Reduction in Carbon Intensity seems to have a larger contribution in the Mitigation Potential than Energy Savings.

The Top-Down models provided data on energy consumption for the baseline and the mitigation potentials. Figure 5 shows the relative contribution of energy savings vis-à-vis the contribution of using lower or zero carbon emission technologies (fuel switch) (e.g. increased use of renewables or nuclear). The reduction of the carbon intensity contributes in most models around or above 50% of the total GHG emission savings in the energy sectors.

More Technical Detail on Energy Supply Side Results in Higher Reductions for Renewables and Biomass.

The models with more detailed technological information show the largest contributions from fuel switching options. In the macroeconomic models, energy savings contribute mostly to the overall emission reductions. This is a mix of efficiency improvement, output reduction and material savings.

Implementing these potentials imply much less coal and more bio-energy use.

As part of the mitigation potential in all studies, the use of fossil fuel decreases. In particular the use of coal is shown to decrease. The contribution of other fuel types such as biomass, renewables and nuclear increases in most models (*Figure 6*) – but again, this is smaller or even non-existent in the macro-economic models. The largest increase is simulated for bio-energy.

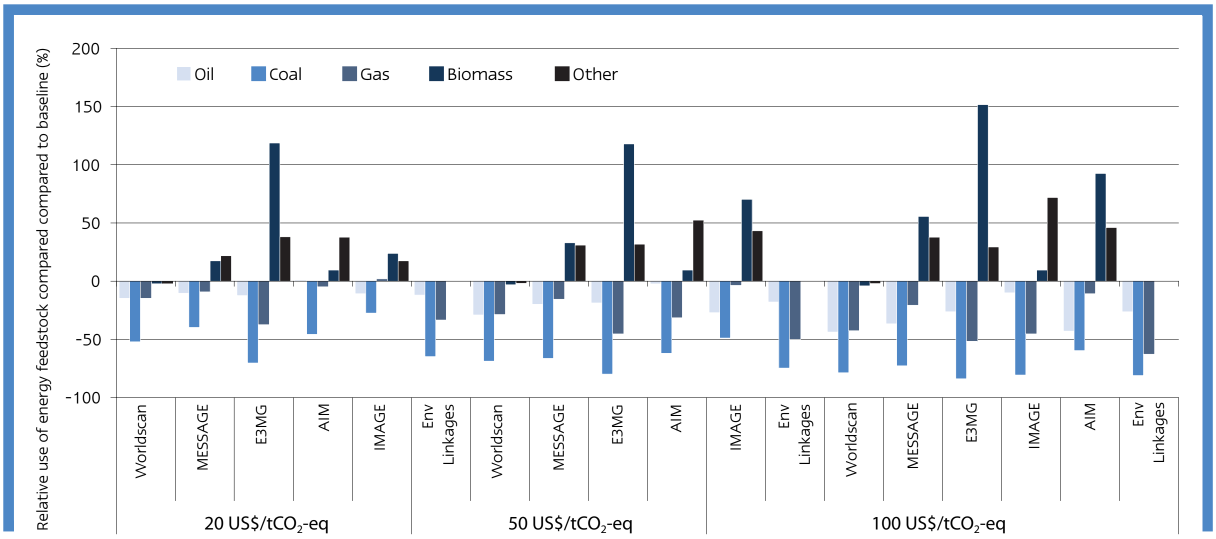

Figure 6: The relative differences in primary fuel use based on higher carbon prices. Please note that ENV-Linkage does report non fossil fuels in physical terms. So for this model the use of biomass or others as renewables and nuclear are not included. Figures presented include the energy supply, transport, industry, residential and service sector only.

6. Recommendations for the Coming AR5

Provide in an Early Stage a Set of Guidelines on Reporting Bottom-Up and Top-Down Studies.
In AR4, the options to analyse the aggregated Bottom-Up mitigation potential and also to compare the outcomes of different approaches were severely limited by the fact that quantitative results were only available by the end of the assessment period and large methodological differences remained. Assuming that in AR5 again an attempt will be made to link short- or medium-term analyses on sectoral mitigation potentials and policies and long term emission pathways, there is a need for a set of guidelines on reporting Bottom-Up and Top-Down studies. These guidelines should include:

- the type of baseline used;
- the sectoral definitions (where are mining, refineries, district heating, etc. included);
- the emission and energy allocation principles used;
- a description of the mitigation options included.

Disaggregate the Emission Scenarios used for Long Term Assessments Early in the Process.
Bottom-Up analyses use exogenous baselines with physical activity data and detailed technical information. When linking long-term and short-term policy analyses a similar baseline is needed. The best way is to disaggregate the long term scenarios for use of Bottom-Up assessments. As this takes time, coordination is needed early in the assessment process.

Both Bottom-Up and Top-Down Studies can be Improved.
The Bottom-Up estimates can be further improved by:

- harmonizing the methodology of the residential and service sector;
- identifying reduction measures that have not been included in AR4 (Combined Heat and Power (CHP), use of recycling material in the industry sector, non CO_2);
- a better representation of developing countries;
- including studies on behavioural changes.

The estimates of the Top-Down models can be improved by:

- additional studies to improve use of panel data in Top-Down models;
- a consistent use of the different databases GTAP and IEA;
- including physical parameters in economic models to improve comparability;
- better representation of dynamics and institutional structure of taxes and expenditures.

The trend towards integration of Top-Down and Bottom-Up models in hybrid approaches is welcome and encouraged:

- the technological options of the Bottom-Up models can allow for economy-wide effects;
- the stylistic treatment of alternative energy technologies in Top-Down models can be supplemented or replaced by technological detail.

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