



## Comment

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### ABSTRACT

Integrated assessment models are being used to support R&D portfolio decisions, in order to provide a more systems view on the impact of progress for individual technologies. While the model-supported assessment provides a more structured framework for analysis, it should not hide that there are large uncertainties. This paper shows that results are dependent on the model, the ambition of climate policy and other technology assumptions. It is important in R&D investment advice to realize these uncertainties, and assess the robustness of results against results of other models and studies.

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### 1. Comment

Reducing greenhouse gas emissions is arguably the greatest challenge facing the energy sector. It has been shown that advanced technologies can reduce emissions at significantly lower cost than technologies available today (Edmonds et al., 2007; van Vuuren et al., 2004; Weyant, 2004). The question is precisely which mix of advanced and conventional technologies would provide the best opportunity to achieve the required emissions reductions at the lowest overall cost over a long time period. The answer depends on such uncertain factors as the expected development of individual technologies, the effort required to achieve these developments, and the interaction between individual technologies and societal preferences. Despite these uncertainties, governments and businesses alike need to make decisions now about which technologies to invest in. This includes not only investments in actual deployment, but also investments in research and development.

Different forms of portfolio analysis are used to assist in making such decisions. Such analysis can be done in a rather ad hoc manner, by assessing the individual characteristics of different technologies. However, as the paper by Graham Pugh and his coauthors argues, it can also be done more systematically using a model-supported approach. Such an approach allows for a better assessment of the

relevant economic interactions of individual technologies. Pugh et al. present several examples of this kind of analysis, all of which rely on expert judgment both about the relationship between R&D investment and technology performance and about the potential future application of these technologies, as evaluated using the integrated assessment model GCAM. The objective is to provide insight into an optimized R&D investment strategy that would lead to the lowest future energy system costs for a given climate target.

Although the proposed model-supported assessment provides a more structured framework for analysis, it should not hide the fact that enormous uncertainties remain in making such an assessment. These include uncertainty about the accuracy of the expert judgment on the relationship between R&D activity and technology performance and about the wide range of factors determining the application rate of the technology in the integrated assessment model. Pugh et al. acknowledge the role of uncertainty in their analysis. For example, they note that a full understanding of the value of an R&D portfolio requires establishing a linkage between R&D success and full-scale commercialization of technologies, which is made difficult by the influence of various nontechnological and noneconomic factors. Nonetheless, in this comment we would like to point out some fundamental uncertainties that may have implications for the robustness of model-supported R&D portfolio analysis. This is not meant as a criticism of the work that has been performed so far, but rather as an attempt to identify some of the key challenges associated with setting R&D budgets in general, and using the model-supported approach specifically.

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The model-supported R&D portfolio analysis discussed by Pugh et al. allows researchers to evaluate the success of R&D activity not only in terms of the actual advancement of the technology (the extent to which it lowers total costs), but also in terms of its contribution to reducing greenhouse gas emissions at a lower cost. The method is based on a set of energy scenarios, developed using the GCAM integrated assessment model, that differ with respect to the presence of advanced technologies and expert judgment on the costs involved in making these advancements. An obvious uncertainty in this kind of assessment is about the relationship between the investments in R&D and the associated technological advancement. This factor plays a major role in any assessment of priorities in R&D activities. However, the novel factor in Pugh's work, the use of an integrated assessment model, introduces other uncertainties as well, several of which we will discuss here.

## 2. Results are model-dependent

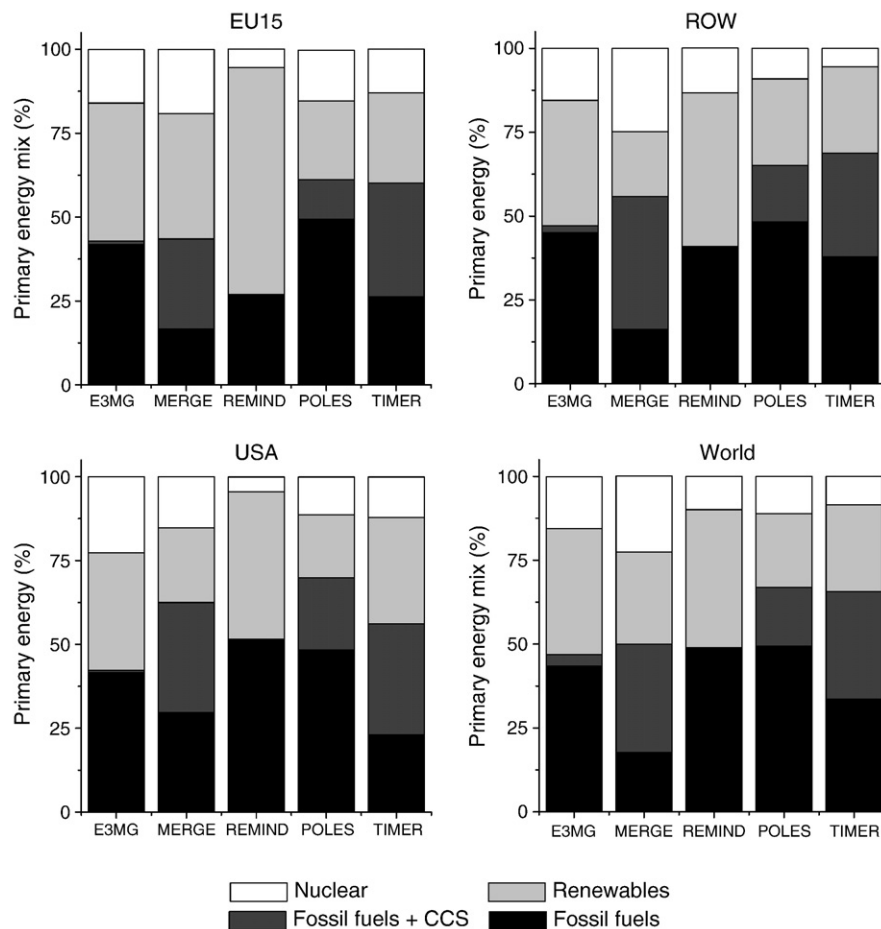
Integrated assessment models are often used to explore which mix of energy technologies can reduce greenhouse gas emissions to meet different climate targets at the lowest cost. Results of the different models are then compared to provide insight into the relevant uncertainties (examples include Clarke et al., 2009; Knopf et al., 2009; van Vuuren et al., 2009; and Weyant et al., 2007). These comparisons reveal some similarities but also significant differences. For instance, although most models agree that improved energy efficiency has a major role to play in any optimal reduction strategy, the models differ with respect to the role of renewables and nuclear power. This model

dependency of the results can be strong, as the results of two independent studies will illustrate.

Knopf et al. (2008) compared the mitigation strategies of five models for a stabilization scenario in which atmospheric concentrations of greenhouse gases are limited to 550 ppm CO<sub>2</sub>-eq. As shown in Fig. 1, the strategies used to achieve this target differ across the models, even for the aggregated categories shown. The E3MG and REMIND models depend heavily on renewables in reducing emissions, while the MERGE and TIMER models include a major role for fossil fuels with CCS; the MERGE model also has a large share of nuclear power. Interestingly, this pattern can be observed not only at the global level but is repeated in every single region, as Fig. 1 also shows. In other words, the model-dependent factors are strong enough to override regional differences (mostly involving resource endowments and fuel preferences) in the models.

The same differences can also be noted in the model comparison undertaken for the IPCC Fourth Assessment Report (Fisher et al., 2007). Here the results show the contributions of various options to emissions reduction. Again there are clear differences, with some models relying much more on increased energy efficiency, while others give more importance to other options such as renewables, nuclear power, or CCS.

What does the model dependency of these model results imply for the use of integrated assessment models in R&D portfolio analysis? Clearly, it is likely that these results are also reflected in the optimal R&D mix. The influence of this factor can be assessed only if several models are used to determine the optimal strategy, or if the model used is calibrated in such a way that it allows the results to reflect a wider range of outcomes.



**Fig. 1.** Model estimates (5 models E3MG, MERGE, REMIND, POLES and TIMER) of the contribution of various categories of technologies to 2050 energy use for a 550 ppm CO<sub>2</sub>-eq stabilisation scenario. Source: Knopf et al., 2008. Some models, such as the REMIND model (which originally did not include Carbon Capture and Storage (CCS)) have been significantly updated since this figure was first published.

### 3. Results depend on the ambitiousness of the climate target

Model comparison studies also show that the results depend on the climate target. Knopf et al. (2009), for instance, find that assuming a low (versus a medium) potential for bioenergy has only a very limited influence on the costs of reaching a 550-ppm CO<sub>2</sub>-eq stabilization target. For a 400 ppm CO<sub>2</sub>-eq target, however, the costs more or less double when a low bioenergy potential is assumed. In terms of the R&D portfolio analysis, the results for the 550-ppm case would likely lead to the conclusion that investments in bioenergy (or in agricultural technologies in general) are not an important part of the portfolio. For the 400-ppm target, in contrast, the same technology might be identified as essential and deserving of large R&D investments.

A similar conclusion can be derived from the work of Azar et al. (2010; Fig. 2). They used three different models to explore the costs of reaching increasingly tight concentration targets using three different sets of technologies. These sets differ with respect to the use of carbon capture and storage (CCS) techniques: no CCS use, CCS for fossil fuels only, and CCS for both fossil fuels and bioenergy (BECCS). For high concentration targets, the difference in costs between these technology sets is minimal, because the BECCS and possibly even the CCS technologies are not (or only minimally) used when the emissions target is less ambitious. For low concentration targets, however, the differences in costs are very clear: in each of the models, CCS and BECCS allow the more ambitious targets to be met at significantly lower cost.

The implication is that technologies may be evaluated differently in terms of their role in a R&D portfolio as a function of the stabilization target. This implies that any choice of investment portfolio is dependent on the situation. If there is uncertainty about climate goals (as is currently the case), the results automatically become more arbitrary.

### 4. Results depend on other technology assumptions

Technologies act within a larger system. As a result, the specification of the energy system plays an important role in how different technologies are evaluated. Van Vuuren et al. (2007) evaluated the impact of excluding different technologies on the overall abatement cost of meeting a climate target. Excluding individual technologies increased costs only to a limited extent. But excluding a combination of technologies, such as CCS and nuclear power, had a much stronger impact, because these technologies act as substitutes buffering the costs impact (if only one is excluded, the other takes its place; if they are both

excluded a much more costly, third alternative has to be found). Another example is that the role of renewables in future energy systems critically depends on the ability of the system to deal with the inherent intermittency of most renewable resources. This ability can be significantly enhanced if flexible power options (such as hydropower) are present, but also if the system includes large-scale (e.g., continental) grid connections and the ability to manage power demand.

The implications of these considerations are similar to those drawn above: the results do depend on a wide range of other assumptions, and at the very least considerable sensitivity analysis may be needed to ensure that the results are robust.

### 5. Other factors

Several other factors could further contribute to different outcomes. For instance, in the GCAM representation, the technology characteristics are exogenously prescribed (and thus assumed to be mainly driven by the R&D choices). Alternative theories attribute technology development also to increasing cumulative knowledge in application (learning by doing) (e.g. van Vuuren et al., 2004). This is likely to lead to different results in optimization of R&D budgets. Another factor that is not considered in detail in GCAM is the interaction of different technology assumptions. As in most such studies, technologies have been looked at individually, and the possible impact of technology clusters has only partly been addressed. Finally, a crucial question is the interaction of different world regions: How, for example, does technological progress in the United States affect R&D portfolios elsewhere? How do R&D portfolio decisions in the United States impact the rest of the world? Obviously, no one tool can answer all questions, but these factors do contribute to uncertainty.

### 6. Conclusions

The use of models in making decisions about an R&D portfolio (or about the deployment of technologies) allows for a more systematic consideration of the complex relationships in the energy system than more ad hoc methods. Still, various uncertainties and various assumptions of the model will inevitably impact the results. To better assess the robustness of the results, it might be useful to undertake a comparison study of the results of several models that apply the method proposed by Pugh et al.

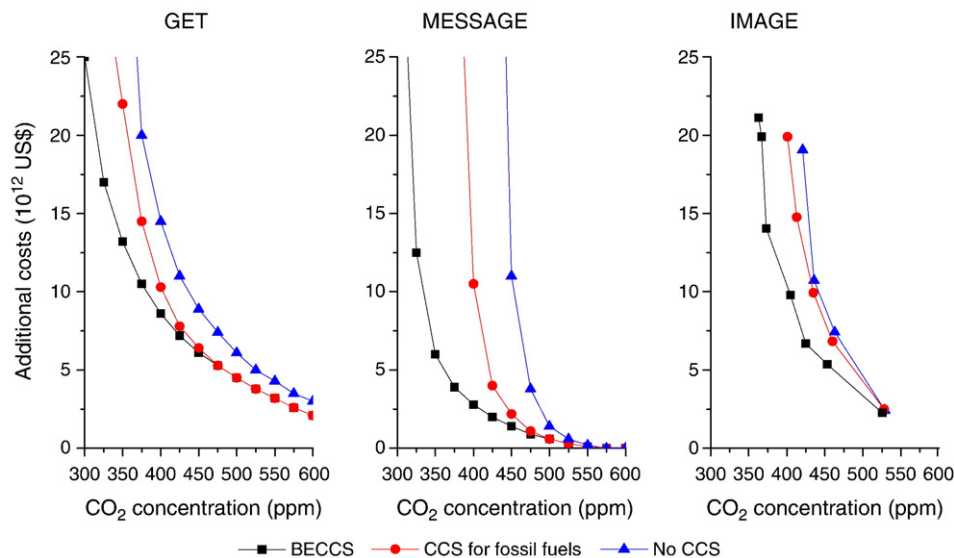


Fig. 2. Abatement costs for various CO<sub>2</sub> stabilization targets under different assumptions regarding use of Carbon Capture and Storage (CCS) for 3 different models: GET, MESSAGE and IMAGE (BECCS = bio-energy and carbon capture and storage; CCS = carbon-capture and storage). Source: Azar et al., 2010. In the "BECCS" case, CCS is used for bioenergy as well as for fossil-fuel combustion. In the "CCS for fossil fuels" case, it is used for fossil fuels only.

Another important question is whether the way in which technologies are treated influences the results. Here it should be noted that not all the factors considered by Pugh et al. are real uncertainties. The availability of nuclear power or CCS is a function not only of technological availability but also of social acceptance. The decision to vary wind power between “standard wind” and “advanced wind,” but nuclear power from “no nuclear” to “advanced nuclear,” itself implies that a mixture of social and technology factors come into play, which could bias the results. It might therefore be worthwhile to more clearly distinguish between the two sets of factors.

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