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From My Perspective

Critical review of: "Making or breaking climate targets — the AMPERE study on staged accession scenarios for climate policy" (TFSC 17862)

Richard A. Rosen

Tellus Institute, 11 Arlington St., Boston, MA 02116, USA

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ABSTRACT

This critical review of the integrated assessment modeling (IAM) research underlying the AMPERE study is also relevant to many other IAM-based model comparison papers. One of the main symptoms of the serious methodological problems of these studies is that the results produced by different models for what are portrayed as the "same" scenarios differ quite substantially from each other. While the authors of the AMPERE study correctly raise the important question of whether these differences are due primarily to differences in model structures, or to differences in the sets of input assumptions for the "same" scenario used by different research teams, they never address this question in a logically systematic and credible way. In fact, they cannot and do not arrive at an answer, since each modeling team generally relies on a single but different set of most input assumptions for the same scenario. Finally, the research teams involved in the AMPERE project, and other similar projects, fail to understand the fundamental impossibility of forecasting net mitigation costs or benefits over the long run given both the practical and deep uncertainties implicit in both the equations comprising these IAMs, and the input assumptions on which they rely.

1. Introduction

The AMPERE project was a major EU-funded research effort to try to determine the economics and, therefore, the desirability of "staged accession" scenarios to mitigate climate change at the global level through 2100, with a focus on the European Union as the key actor. The results of this research are presented in the TFSC article under review here (Kriegler et al., 2014). Staged accession scenarios appear to involve various regions of the world taking action to mitigate climate change in different ways and at different times, rather than collectively at the same time. This project produced several mitigation scenarios for analysis and comparison to a reference policy case. The details of these mitigation scenarios are not important for our critical analysis here. Instead, what is important is the project's focus on the differences in the long-run economic results for different mitigation scenarios when compared to the reference policy case, especially the results for the EU and China. These economic results include the present value of the GDP and other economic costs and benefits computed by the models, as well as the cost of carbon prices computed in different scenarios.

The purpose of this critical review, which is unusual within the literature on the economics of mitigating climate change, is to try to enumerate the major weaknesses of the AMPERE project in attempting to apply credible methodologies for analyzing the results of this type of modeling study. One goal of this critique is to encourage the various integrated assessment modeling teams around the world to reconsider their research priorities in light of the types of problems identified here. If integrated assessment models of the types utilized in this major EU project are going to be used in the future to assist policy makers, the ways they are used, as well as the models themselves, will require major modifications.[1] And while the issue of TFSC in which this overview of the AMPERE study was published also contains many other articles on related topics, I

[1] This paper will not address the model flaws, some of which are addressed in reference 2, and other papers referenced in that paper.

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will focus attention on this single overview paper as representative of the others. Note that the critique of this overview paper follows directly from the broader critique of many IAM team research efforts to assess the economics of mitigating climate change over the long run as described in much greater detail in my previous TFSC paper (Rosen and Guenther, 2014). Note that there is considerable overlap in these sets of research teams that have published research papers in this field in TFSC and many other journals, as well as between the ones referenced in the Stern Report, the various IPCC assessments, and the AMPERE project. These sets of research teams often publish joint research articles.

2. Methodological claims in the TFSC article

The findings for the AMPERE study were based on a set of "coordinated scenario" runs using eleven global "energy-economy" integrated assessment models, broadly grouped into four different types (Kriegler et al., 2014, page 1). The article also points out that the models differ from one another in "numerous" ways (Kriegler et al., 2014, page 2). Some of the ways in which the models differ include the level of technological detail in the energy sector, the substitutability of energy forms, and the representation of greenhouse gases (Kriegler et al., 2014, page 2). However, the only aspects of the eleven models that were harmonized to each other were the GDP and population growth rate assumptions for the various regions of the world for the scenarios modeled. In spite of the lack of cross-model structural consistency, the article then claims that the numerous differences in model structure and input assumption values that reflect the differences in choices made by the eleven different modeling research groups is "not a drawback, but a feature of model comparisons, since it allows us to explore the associated range of uncertainties" (Kriegler et al., 2014, page 4). On the other hand, the article admits that this does not imply that the range of assumptions implicit or explicit in these model runs "necessarily cover[s] the entire range of [reasonable?] possibilities."

Of course, saying that a feature of model comparison research projects in the past was that various groups of model outputs which involve sets of very different model structures and input assumptions have been directly compared is not saying much. That something has been done in the past does not mean it is a good idea for the purposes of learning important lessons about the economics of mitigating climate change. Thus, I will focus on the claim that comparing the outputs of many different models of the types used in the AMPERE study allows for a reasonable exploration of the associated range of uncertainties in the results, namely the results which derive from the various models and specific sets of input assumptions included in the study. Unfortunately, however, from the perspective of a reader of this paper, each model is essentially a proverbial "black box". The reader can have little idea as to what is going on inside the "black box" based on the information presented in the TFSC article (Kriegler et al., 2014). To get a somewhat better, but still not complete idea, of how the different models function, one would have to undertake a major research project consisting of trying to find documentation of all the eleven models on the websites of the research teams. However, a reasonably complete set of the important input assumptions, especially cost assumptions, used in this paper cannot be found anywhere, including in the supplementary online material that was published with the paper.

Naturally, running different models with different input assumptions could, in theory, allow one to explore a reasonable range of uncertainties inherent in the model outputs, but, unfortunately, the article under review does not perform any such explorations in a scientifically credible and systematic manner. In fact, no sensitivity analyses based on varying key cost input assumptions are presented at all. To perform a scientifically credible exploration of the uncertainties in results due to the different model structures themselves, one would have to develop a comprehensive research plan to systematically run all the models with the same sets of input assumptions, and one would then need to vary those sets of input assumptions in clever ways to cover the credible range of each type of input assumption.[2] Obviously, since there are dozens, if not hundreds, of key input assumptions for each model, there would be tens of thousands of credible combinations of such input assumptions. This implies that one would need to run a carefully chosen sub-set of input assumptions through the models in order to span a reasonable range of output results for each model, for each scenario. How to reduce the number of combinations of input assumptions to a reasonable sub-set for the research proposed is, itself, a research challenge. Since this type of systematic and comprehensive exploration of uncertainties was not done in this AMPERE study, what did the study accomplish from a scientific perspective? The answer is, as I will show, "not much", but worse still, many key issues were ignored that should have been addressed.

3. Analysis of AMPERE study results

The report on the AMPERE study first presents economic results from the models in the form of CO2 prices in the reference policy case for different regions of the world in the year 2030 (Kriegler et al., 2014, Fig. 1.a.). There, one finds the results for ten of the IAMs plotted for eight regions of the world. Immediately, one can see, as the text acknowledges, that there are "large variations in carbon price projections" between the models (Kriegler et al., 2014, page 6). The authors then address a few possible reasons for these large differences. The first reason given is that the carbon prices depend "on model structures and the availability of mitigation options." This is obviously part of the answer, due to simply considerations of logic. Thus, the authors are not saying anything new in giving this reason that is learned from this research. One key, but unanswered question, is to what extent are these differences in carbon prices due to different model structures and the different assumptions as to mitigation option availability.

One key question that also should have been addressed is what particular *features* of the model structures lead to such big CO2 price differences. Moreover, when the article cites different assumptions about the "availability" of mitigation

[2] An example of a single parameter sensitivity analysis would be to vary the input assumptions for the capital cost of new nuclear plants in order to show how this changes the mix of mitigation technologies implemented in a given scenario, and how it affects the cost of mitigation. A reasonable range for this parameter might go from an extremely optimistic low value of $5000 per kw to a high of $15,000 per kw of capacity, for example. All the models require as input assumptions the capital costs of such mitigation options.

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options, it is not clear if the cost assumptions for each mitigation option also differ between models, though I believe they do. Importantly, different assumptions by different modeling teams regarding the *cost* of mitigation options are very likely to be a key determinant, if not *the* key determinant, of the very different CO2 prices, because input costs generally determine output prices in such models. However, the paper presents no data at all on the cost assumptions for mitigation options by each modeling team, again, even in the supplementary online material. Nor does it even mention the logically obvious point that different assumptions about cost inputs might account for much of the different price results for CO2.

In fact, this seems to be a widespread omission in many papers about the economics of mitigating climate change. This omission of any serious discussion of the role of cost input assumptions in causing the cost and price outputs seems to lead to the general result usually reached in each research paper that in the long run, "emission reductions come at a net cost in most models" (Kriegler et al., 2014, page 9). The authors seem blind to the fact that, certainly, there must be some sets of reasonable technology cost and availability input assumptions for energy supply and demand technologies, and for fossil fuels, that would lead to high net economic *benefits* of mitigating climate change over the long run. In particular, a scenario which has very high fossil fuel prices, and very low renewable energy prices, could easily have large long-run net economic benefits to society. The study participants might not believe that such sets of input assumptions are most likely, but, again, completely ignoring their existence is unscientific, especially if one wants to study a credible range of model outputs.

The AMPERE study article then goes on to state a second reason for why the CO2 prices in even the reference policy case differ so greatly between models in Fig. 1.a., namely that there is a "diversity of baseline assumptions across models". Again, as discussed above, this is very likely to be true, though the major baseline assumptions are not provided. There is no insight here that required the running of models to produce. The key question that the paper should have tried to answer is which differences in key baseline assumptions most accounted for the difference in results. Again, differences in input *cost* assumptions will have likely played a significant role in that regard, but the paper does not discuss this issue. It similarly fails to mention the possible role of differences in input cost assumptions for the various mitigation technologies in the mitigation scenario run by different models labeled the "450 scenario" as a key factor leading to very different CO2 price results (Kriegler et al., 2014, Fig. 1.b.), or the large differences between model results for cumulative CO2 emissions as presented in Table 1 (Kriegler et al., 2014, page 8).[3] If the research teams had even just once run their various models using the same set of input assumptions, including the *same* input cost assumptions for the same scenarios to the extent that the different model structures allowed this to be done, they would have fairly quickly determined the extent to which the results reported in Fig. 1.a. and 1.b. were different because of different model structures, *versus* because of the different sets of input assumptions. But this obvious and necessary step towards adopting a consistent and credible scientific methodology was never taken.

Section 4.3 of the AMPERE project article addresses the study results for net "mitigation costs" for the mitigation scenarios, instead of carbon prices. Note, again, that the term "mitigation benefits" as opposed to mitigation costs is not even mentioned or discussed as a possible outcome of mitigating climate change. Every model run reported in Fig. 3 shows net "consumption losses" and none show net benefits. Furthermore, the authors state that they "expect global direct mitigation costs to rise with mitigation stringency". Why, they never say. Their reason is probably that if there are net costs for less stringent mitigation, then since the marginal costs of more stringent mitigation would be higher than the average costs for less stringent mitigation, the average costs of more stringent mitigation scenarios will increase. But what if there were many scenarios that the modeling teams could have run that would have produced net economic benefits from mitigating climate change? Then more stringent mitigation scenarios might yield even greater net benefits to society. Why weren't those scenarios run and described in this article? Based on my review of many other papers written by the authors of this paper, I suspect that, in fact, each modeling team only made scenario runs with *one set* of most input assumptions, including only one set of input cost assumptions, even though no research team could possibly know which values of such input assumptions were most likely to occur in 20, 50, or 90 years from now. Thus, relying on only one set of input assumptions for most key input parameters under such severe conditions of uncertainty in the medium to long-run is also unscientific.

With respect to the discount rates used in the various IAMs, which strongly affect the magnitude of the reported results, footnote #5 on page 10 states that different models used different discount rates for optimization purposes when computing results, ranging from 3% to 8%. However, Fig. 3 seems to indicate that cost results from every model were discounted at a 5% discount rate for presentation purposes. However, unless the models were actually run using a 5% discount rate for the preparation of Fig. 3, it is totally meaningless, inconsistent, and visually deceptive to take results that were created utilizing one discount rate and then present them (in Fig. 3) based on a different discount rate.

As noted above, even if the models were not run with the same sets of inputs assumptions for the same scenarios, which they should have been for comparison purposes, a paper like this should, at the very least, provide tables of the actual values for a fairly complete set of key input parameters for each model, and for each scenario. Doing so could at least provide the clever reader with some slight glimmer or indication of how to explain some of the differences in results between different models. Doing so would also provide the reader with some sense of whether or not the numerical values for some or all of the key input parameters were themselves credible and up-to-

[3] This is not a minor point, namely the need to consider baseline *vs.* mitigation scenario assumptions separately, since most studies like the AMPERE study fail to discuss the need to create systematically different sets of input assumptions for these qualitatively different kinds of scenarios. This is especially true for energy efficiency assumptions, which should be one of the highest priority mitigation options, but which the article ignores entirely. Clearly, most analysts would assume more energy efficiency in the mitigation case than in the reference or baseline case as an input. Also, the input costs of renewable energy supplies should generally be lower in the mitigation cases than in the reference cases, since more investment in them would occur in the mitigation scenarios, and there would be more cost reductions *via* "learning by doing". Similarly, the cost of fossil fuels should be higher in the reference case, since demand for them would be much higher.

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date. For example, the prices of solar photovoltaic cells have been falling rapidly in recent years, as is well known. Thus, if some or all of the inputs to the models on which the AMPERE project study relied were out-of-date by only a few years, this fact alone could throw all the economic and other results from those model runs off substantially.

Of course, the fact that all input parameters, especially input cost parameters, might change in a similarly substantial way over the next 20 years, not to speak of by 2100, is one of the fundamental types of inherent uncertainties involved in making long-term economic projections for mitigating climate change. As a result, making reasonable projections of discounted net costs and benefits of mitigating climate change over such a long time period that would be useful for policy makers is theoretically impossible, even if the model structures and equations were perfect (Rosen and Guenther, 2014).[4] In addition to the theoretical impossibility of making credible long term economic projections, there are also many types of inherent and deep uncertainties deriving from our inability to predict human behavior and, therefore, economic behavior, that would affect one's ability to model anything like the economics of mitigating climate change over such a long time, making accurate projections scientifically impossible. The unknowable non-linearities of the system being modeled become dominant after some time period, depending on the system being modeled.

For economic systems, the relevant forecastable time horizon might actually be quite short, *e.g.*, a few years, given the possibility of financial and other types of unpredictable emergent developments in the global economy. Yet these critical issues regarding the impact of time-dependent uncertainties and the non-linearities of the IAM forecasting models relied on in the AMPERE project (and many other long-term economic forecasting projects) are never even mentioned as possible limiting factors on the usefulness and credibility of the study's numerical results.

Finally, the study neglects to mention that many possible types of economic benefits of mitigating climate change over the long run have been completely left out of the models used, especially the avoidance of damages from climate change to the world's economy, people, and ecosystems. This is a very important and well-known issue, and no research paper like this AMPERE project paper can be deemed honest and policy-relevant without at least drawing this critical fact to the reader's attention in the very beginning of the article. Clearly, avoiding these global economic and ecological damages could easily overwhelm the net costs of mitigation as calculated by the IAMs relied on in this research, and cause the net costs to become net benefits, even based on the sets of input assumptions utilized by the IAMs in this study.[5] Likewise, higher levels of possible cost-effective investments in energy efficiency than the models allow for in the mitigation scenarios have been totally ignored.[6]

4. Conclusions and recommendations

The AMPERE study, and the TFSC article in which its methodology and results are described, are typical of dozens of similar economics studies that have been published in the "scientific" literature over the past seven years since the IPCC's Fourth Assessment Report of Working Group III, and earlier. Many, if not most, of those studies were carried out by the very same research teams to which the authors of this article belong. Now that the Working Group III report for the IPCC's Fifth Climate Assessment has been released, one can see that this new Working Group III report (especially Chapter 6 on the economics of mitigation) primarily relies on the same integrated assessment models and inter-model comparison projects as the AMPERE study. (Inter-governmental Panel on Climate Change, 2014) Consequently, many of the criticisms enumerated above of the AMPERE study could be validly levied at the research papers that report on these other studies, and at the new Working Group III report itself. Note that even the Working Group III report fails to list the key cost input assumptions that the research papers, on which it relies for its basic conclusions as to the net long-run economics of mitigating climate change, utilize. Unfortunately, this implies that much of the economic analysis of the mitigation of climate change over the long run as reported in the economics literature on climate change is usually quite opaque as to the basis for the conclusions reached. Given that the goal of most integrated assessment models is to educate and inform policy makers, their manner of use in these studies generally lacks credibility, and the research projects usually do not teach us much upon which sound public policy to mitigate climate change can be based.

In fact, the main conclusions reached here can be further illustrated by analyzing the AMPERE study's own statement of conclusions in Section 7 [Kriegler et al., 2014, pages 17–18]. The very first sentence states, "The current climate policy situation is marked by the long-term aspiration of stabilizing climate change at or below 2 °C of global warming, but also by fragmented and moderate short-term action, and by large uncertainty about future national climate policies and the prospect of an international climate agreement."[7] Then, the article points out, "A defining question for the way forward for global climate policy is how to build a bridge between short-term realities and long-term aspirations." Indeed, this is one of the defining questions of our time. The authors then claim that "this study contributes to mapping out the climate policy landscape by exploring how staged accession can constitute such a bridge" (Kriegler et al., 2014, page 17).

Unfortunately, however, this claim is not justified, since this modeling project, like many others, cannot possibly determine to any reasonable degree of scientific credibility the economic costs or benefits of any particular mitigation scenario for the implementation of both new technologies and climate policies, including staged accession scenarios, over the long run. This is true whether the scenario is for a single region like Europe, or for the entire world. Beyond 10 or, perhaps, 20 years into the future (if we are lucky), all the "bridges" that we may try to build towards long-term aspirations disappear into the uncertain fog of the future, and, therefore, the net social cost of one

[4] Of course, all the models could not have been equally "perfect".

[5] These economic damages are already probably costing hundreds of billions of dollars per year worldwide, but while different analysts could easily differ in their estimates of these damages, they should not be omitted entirely if the results of an analysis are intended for policy makers, as this paper clearly is.

[6] In fact, no discussion at all of enhanced energy efficiency as a technological mitigation strategy is even mentioned in the article.

[7] Note that uncertainty regarding policies is mentioned, but the uncertainties inherent in IAM modeling work are not mentioned.

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technology/policy bridge cannot validly be compared to the net cost of any other bridge after that time period. We cannot even see the outlines of any bridge from now to 2050, not to speak of to 2100, for which the 2 °C target has been proposed, given all the types of uncertainties involved. Furthermore, the AMPERE project does not even reveal to policy makers the numerous assumptions upon which its analysis is based, for their review. It would be irresponsible, then, for policy makers to act on the basis of the research article, as published. Thus, the AMPERE project has nothing helpful to say about either the long-run impacts of climate policies that might be adopted today, nor about any possible impacts of future climate policies that might be adopted after 2030. This means that this study cannot say anything useful about "how to bridge the current climate policy situation and long term aspirations", as claimed.

If most climate policy actors believed now, as may be the case, that aggressive action to mitigate climate change would have large net economic *benefits* over the long run, then it would be much less likely that we would have to worry about the issue of staged accession scenarios at all, since all regions, if rational, would become "front runners", and would probably move forward aggressively with mitigation now. Thus, in the case of mitigation scenarios with large net economic benefits, the entire "front runner" issue that appears to have been one of the major motivations for Kriegler et al. (2014), to write this article in the first place, would completely disappear, making inaction to mitigate climate change totally irrational. Unfortunately, the impossibility of knowing that any of the scenarios modeled would likely have long-run net economic benefits or net costs should preclude this strictly economic-based motivation from driving the decision going forward to mitigate climate change.

Finally, it is clear from the critique above that the peer review process for articles in this area of research needs to change. As far as I can see, there is no point in having a peer review process if the reviewers are unable, or unwilling, to assess the scientific merit of the models relied on, and the methodologies and input data that determines the scenario results. The peer reviewers also have to be willing and able to criticize and potentially reject the faulty logic in the way conclusions of such research papers are derived from the modeling results. Unfortunately, the peer reviewers of this paper seemed to have missed some key lapses in logic of just this sort. Even if some of the models on which the AMPERE project, or other similar projects, relied were subject to careful peer review in the distant past, many modifications and updates have probably been made to each model in the meantime, especially since their use prior to the IPCC's Fourth Assessment in 2007. In addition, one hopes that, in the meantime, the theoretical underpinnings of developing integrated assessment models would have improved, and would merit describing to policy makers. Furthermore, the research community's collective understanding of the proper use and misuse of such models should also have advanced since any prior peer review of the individual models was conducted.[8] Thus, either first or more up-to-date publicly available peer reviews are needed for all the current crop of IAMs used for evaluating the economics of mitigating climate change. "Secret" (behind the scenes) peer reviews requested by journal editors are not sufficient if the basis for policy making for mitigating climate change is to become transparent to the educated public.

Finally, the research teams involved in cooperative research projects involving many models, such as the AMPERE project, never seem willing to publicly criticize each other's models in order to try to determine which of the models is best for various purposes, as though criticism would be perceived as inappropriate and unnecessary in that research community. Needless to say, in other research communities, cross-model criticism is standard, and is how the scientific content of the field advances. Thus, I recommend that journals such as TFSC that publish articles on integrated assessment modeling of the mitigation of climate change require IAM research teams who want to publish in their journals in the future to go back to the basics of science and logic, and zero-base all justifications of the reasonableness of their models, input assumptions, and modeling approaches given the very important public policy uses to which they are being put. If this were done, then the peer review process would have even more important material to review in the future.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.techfore.2015.01.019.

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Richard A. Rosen received his physics doctorate from Columbia University (1974) and is a Senior Fellow and founder of the Tellus Institute (Boston). He has researched energy system, climate, and electric utility policy issues since 1976. He has testified as an expert witness in numerous public utility commission hearings and Clean Air Act court cases throughout the United States on behalf of the US Department of Justice and state attorneys general. He specializes in reviewing energy system planning and forecasting methodologies and has written reports on these issues for the US Department of Energy and the US Environmental Protection Agency.

[8] Personally, I know of no public peer reviews that have ever been done, *per se*, of the eleven models utilized in the AMPERE study, but I would be happy to stand corrected if I am wrong, and some reviews had been done. A staff member at the Potsdam Climate Institute, the home of one of the research teams that participated in this project, has agreed with this judgment.

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