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Comparing Emission Mitigation Effort

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Abstract: A natural outcome of the emerging pledge and review approach to international climate change policy is interest in comparing mitigation effort among countries. Domestic publics and stakeholders will have an interest in knowing if peer countries are undertaking (or planning to undertake) comparable effort in mitigating their greenhouse gas emissions. Moreover, if considered inadequate to address the risks posed by climate change, the aggregate effort will likely prompt broader interest in identifying those countries where greater effort is arguably warranted on the basis of peer comparisons. Both assessments require metrics of effort and comparisons among countries. We propose a framework for such an exercise, drawing from a set of principles for designing and implementing informative metrics. We present a template for organizing metrics on mitigation effort, for both ex-ante and ex-post review. We also provide preliminary assessments of effort along emissions, price, and cost metrics for post–2020 climate policy contributions by China, the European Union, Russia, and the United States. We close with a discussion of the role of academics and civil society in promoting transparency and facilitating the evaluation and comparison of effort.

1. Introduction

Free riding is the primary threat to any international climate change treaty. Any country considering taking domestic actions to mitigate its greenhouse gas emissions has a legitimate concern that other countries will not undertake similar actions to contribute to the global public good of a stable climate. Since the costs of mitigating emissions are local, while the benefits are global, the prospect of free-riding weakens incentives for countries to take serious action against climate change. This is especially the case within the current multilateral framework in which commitments are effectively self-enforced (whether they are so-called legally binding or not).

If one country is proactive in its emission mitigation policy, then it will enjoy fewer benefits if other countries free-ride and fail to deliver own comparable domestic mitigation policies. Moreover, absent such reciprocal action, unilateral mitigation efforts increases the prospect of adverse competitiveness impacts, which could raise the costs borne by the proactive country and provide a political economy context for inhibiting domestic action against climate change. In light of these factors undermining international cooperation and meaningful mitigation effort, a system of transparency and comparability of effort appear necessary for a successful international climate agreement (Aldy, 2014). Indeed, even if the international community does not reach agreement on the design and implementation of a transparency regime and methods for evaluating and comparing effort among countries, the largest economies – in response to domestic political pressures – will develop their own capacity for doing so. Nonetheless, in the long term, a successful pledge and review regime will need a substantive, legitimate review mechanism (Schelling, 1997; Pizer, 2007).

To facilitate the comparison of mitigation effort, we have developed a framework for assessing various metrics of effort, building on the work in Aldy and Pizer (2014). We discuss some of the advantages and shortcomings of various metrics, including the issues requiring resolution to enable comparisons, such as agreement on an appropriate system of exchange rates to compare effort measured in local currency units. We also consider potential facilitative and normative frameworks for using these metrics. We then employ the DNE21+ model to illustrate a suite of metrics for China, the European Union, Russia and the United States based on their announcements for what will likely be their intended nationally determined contributions (INDCs) on the road to the 2015 Paris climate talks and their likely contributions post-Paris. We close with our suggestions for additional work, considerations for the design of ex ante and ex post reviews, and opportunities for academics and civil society to inform the review and comparability processes going forward.

2. UNFCCC Processes and Comparability of Effort

The concept of comparable effort has evolved over the past several decades in international climate change negotiations. The 1992 UN Framework Convention on Climate Change and the 1997 Kyoto Protocol set emission targets for developed countries and established the first and most enduring notion of comparability: quantitative emission limits relative to 1990. Negotiators effectively measured effort through the percentage reductions in emission relative to their 1990 levels as specified in the Kyoto Protocol, a simplistic and potentially misleading approach. For example, Russia's emissions have remained well below 1990 levels since the Kyoto Conference due to the state of its economy, not a broad and effective emission mitigation program.

The term "comparability of effort" first emerged explicitly in the text of the 2007 Bali Action Plan, which noted that the concept should guide consideration of developed countries' emission mitigation efforts. At the 2009 Copenhagen Conference, the European Union and Japan each announced conditional commitments: a willingness to implement more ambitious domestic emission targets if other developed countries committed to comparable reductions. Different countries, however, held different perspectives on how to measure and compare effort, and whether to compare effort among only developed countries or to include the pledges by the fast-growing emerging economies, such as China and India. To promote the transparency of these mitigation pledges and facilitate a better understanding of effort, the 2009 Copenhagen Accord and the 2010 Cancun Agreements included "international consultations and analysis" and "measurement, reporting, and verification" – review mechanisms comprised of reporting, technical analysis, and a period of consultation with other parties. The first of these consultations took place in 2014.

The emerging international climate architecture reflected in decisions at the 2014 Lima climate talks further advanced the concept of pledge and review, building on the Copenhagen model. Many countries are expected to table their mitigation pledges, referred to as "intended nationally determined contributions" (INDCs) in the negotiations, over the course of 2015. Through this pledge process, the Lima Call for Climate Action notes that countries may submit additional information, including data, analysis, methods, and descriptions of implementation policies that may promote the transparency and credibility of countries' INDCs.

This evolution illustrates how economic analysis can inform the implementation of the comparability of mitigation effort concept. In the 2009 Copenhagen Accord and in what is expected for Paris (and beyond), countries' emission mitigation pledges take on many different forms: targets versus 1990 or 2005 base year emissions, percentage improvements in the CO2-to-GDP ratio, percentage abatement versus a no-policy reference case, a peak year for national emissions, renewable power goals, energy efficiency goals, afforestation goals, etc. A negotiator cannot simply do an accounting of tons of emissions as a percentage of countries' 1990 emissions as she could have performed during the 1997 Kyoto talks. The pledges themselves do not facilitate such a comparison and negotiators as well scholars are well aware that such a simplified comparison is not informative. In this emerging international pledge and review architecture, negotiators, stakeholders, and the publics of countries participating in the climate talks would benefit from a characterization of the effort that other countries propose to undertake in the international negotiations. Economic data and analysis can play an important role in providing this information, enhance the credibility of countries' pledges, and lead to stronger pledges in the future. Indeed, an informed consideration of countries' proposed mitigation actions and goals cannot occur in the absence of an assessment of the estimated emission levels, emission abatement, carbon and energy price effects, and costs of implementation.

3. Description of Comparability Metrics

Aldy and Pizer (2014) have compiled a set of metrics for measuring effort in terms of emissions, prices, and costs. *Emissions* correspond to physical outcome measures that are most commonly employed as the form of a mitigation commitment. *Prices* on carbon and of energy reflect market signals designed through mitigation policy and can represent the marginal incentives to reduce energy use and carbon dioxide emissions. *Cost* metrics include measures of economic resources diverted away from current consumption and non-climate investment. These are evaluated in the context of three principles for desirable metrics. First, an ideal metric would be *comprehensive* and thereby characterize the entire effort actively undertaken by a country to achieve its mitigation commitment. Second, a metric should be *measurable* and *replicable*. That is, different analysts making calculations of the metric would come up with the same values. Third, metrics should be *universal* – they should be available for a wide range of parties making mitigation commitments.

Among metrics, annual emission levels of greenhouse gases are perhaps the most logical place to start as they are directly related to the ultimate objective of limiting climate change. Annual measures of national carbon dioxide emissions from fossil fuel combustion exist for nearly all countries. Some types of greenhouse gas emissions, such as those related to land-use change or fugitive emissions, are more difficult to measure. The use of market-based mechanisms – including international emission trading and transfers of offset credits – requires additional accounting regarding a country's net position in international trades.

The metric used in the Kyoto context is a country's emissions relative to a 1990 *base year*. Unless countries are on similar trajectories prior to the commitment, however, emission levels relative to a base year will not comprehensively represent mitigation effort. In fact, it may have little to do with effort as noted with respect to the economic transition in Russia and other former Soviet republics in the 1990s. Emission trends vary from country to country for a number of reasons beyond respective government policies and efforts to mitigate greenhouse gas emissions. While the issue in the former Soviet republics may have been declining economic activity, the larger issue is often concern about rising economic activity particularly in emerging economies.

To avoid penalizing economic growth, some countries prefer an *emission intensity* (tons of carbon dioxide per GDP) metric. In the run-up to the 2009 Copenhagen talks, China and

India each proposed emission goals structured as percentage reductions in the ratio of emissions to GDP. Such metrics can ensure that a country is not penalized as a climate laggard simply because of faster economic growth, nor is it rewarded simply because of economic decline. As a measure of mitigation effort, however, several issues confound emission intensity: emissions will continue to grow unless the reduction in emission intensity exceeds the economic growth rate; growing countries tend to experience a natural decline in emission intensity owing to technology improvement and changing economic structure of the economy; and analysis has shown that emission intensity targets often become more stringent if a country grows slower than expected and less stringent if it grows faster than expected (Aldy, 2004; Newell and Pizer, 2008). Comparing emission intensities among countries at a point in time also involves conversion of local currencies into a single currency.

In recent years, interest among some developing countries has turned to emission goals specified as percentage reductions from a forecast level in a future year (e.g., Brazil, Indonesia, and Korea pledged emission mitigation goals of this form through the Copenhagen Accord). In theory, by capturing the emission reduction directly associated with a climate mitigation program, such a metric for all countries represents a more comprehensive indicator of mitigation *effort* than emission levels relative to an historic base year or scaled by GDP. In practice, however, such a metric requires difficult and subjective judgments to calculate the baseline forecasts that define the emission goals. One question is how to address previous or planned mitigation policies—do those go into the baseline? Aside from such conceptual questions, forecasts require subjective assumptions upon which expert opinions will differ and, more importantly, which could be gamed to make a target appear more ambitious then it will likely be in practice. Even when forecasts are unbiased and well-developed, future observed outcomes can deviate from those forecasts for a variety of reasons unrelated to mitigation efforts. In this way, ex post analysis of mitigation effort will likely need to re-evaluate an associated baseline.

In contrast, an observed *carbon price* bears a direct connection to effort, as it measures the marginal incentive levied through a country's mitigation policies. Comparing carbon prices across countries measures the degree to which a country is creating incentives for more or less expensive per ton mitigation efforts. Since countries implement domestic carbon prices in their local currencies, comparisons will require the use of (and raise questions of the appropriate) currency exchange rates. Moreover, *explicit*, observed, carbon prices may not comprehensively reflect mitigation effort. An explicit carbon price may be applied to only a subset of a country's emissions and thus be too narrow a measure of a country's mitigation efforts. It may fail to account for the effect of other, non-price policies – such as efficiency standards and renewable mandates – that reduce greenhouse gas emissions. A country may also undermine the effectiveness of the carbon price by adjusting taxes downward for firms covered by the carbon price, through what is known as so-called fiscal cushioning (Wiener 1999). Alternatively, one could consider *implicit* (or "effective") carbon prices that estimate the average cost of abatement associated with a specific climate policy or collection of policies. Such implicit prices have the advantage of potentially being applied more broadly, but the disadvantage of not being directly observed (i.e., produced by model simulations). They also do not reflect incentives passed down the production chain to end users, and tend to emphasize cost over effectiveness. We return to this latter point below when we discuss costs.

Carbon prices may or may not be part of a country's policy mix and, even when they are, fiscal cushioning can depress their effectiveness. In contrast, *energy prices* are transparent and measurable with high frequency. Energy prices permit a net assessment of all price-based policies, including carbon pricing, and thus can mitigate concerns that a country engages in fiscal cushioning by simultaneously imposing a carbon tax and source-specific tax relief. Energy prices would still fail to capture most effects of non-price policies that mitigate emissions largely without influencing energy prices (which explains why they often attract political support). For countries pursuing such policies to a significant degree, energy prices could be a poor measure of effort. Moreover, not all energy price differences across countries or over time represent policy choices, but instead differences in resource endowments, transportation constraints, and other shifts in supply and demand. This suggests focusing at least in part on the divergence between producer and consumer prices caused by government policies and/or changes in energy prices over time.

The mitigation *costs* of any domestic climate policy are typically most closely aligned with economists' notion of mitigation effort. Ideally, such a metric captures the entirety of resources otherwise available for private consumption and citizen well-being that are diverted towards the public good of mitigating climate change. For that reason, it is intrinsically appealing in terms of being comprehensive. Expressed as a share of national income, or per capita, it could be scaled to be comparable across countries of vastly different sizes. The concern about the costs of combating climate change represents one of, if not the most, significant impediments to serious action by countries around the world. A metric to compare effort based on costs could promote confidence that the international effort is fair by ensuring that comparable countries bear comparable costs from their actions. Coupled with information about emission reductions, it could also highlight the potential advantages of some policies (that reduce more emissions with lower mitigation costs) over others. An assessment of intended (or ex post) policy costs alone runs the risk, however, of rewarding inefficient polices. Such analysis could be coupled with calculations of the least-cost alternative to achieve the same reductions. This would simultaneously emphasize the potential value of cost-effective policies and provide a metric that does not rewards inefficiency. Estimating costs, in any case, requires economic assumptions and detailed modeling frameworks for evaluating economic changes in specific sectors and national economies.

Viewed alone, none of the six types of metrics described here do well against all the principles. Emission levels and intensity do particularly poorly in terms of comprehensiveness, as many factors can influence emissions that are unrelated to mitigation policies. Carbon prices do well on effort per abated ton, but actual effort then depends on tons abatement. Explicit, observed carbon prices are only available where emissions trading or taxes are applied. Energy prices capture the market signals being sent for low-carbon investment and behavioral change, but fail to reflect non-market policies. For many countries, including the United States, non-market policies dominate the climate policy landscape. Emission abatement and abatement costs are jointly the metrics that probably best represent effort, but they are also the most difficult to measure, requiring sophisticated modeling tools for implementation. Credible differences in opinion on modeling assumptions could produce different results for abatement and costs, suggesting that estimated measures may not be replicable. Further, few modeling tools exist to address jurisdictions outside of the largest developed and developing countries.

With this in mind, it is easy to see why a portfolio of metrics is likely necessary, and why considerable work remains to construct more comprehensive metrics estimating emission reductions and cost. We suggest using a collection of metrics to characterize and compare mitigation effort, akin to how analysts describe the health of the macroeconomy with a suite of economic statistics, such as GDP, the unemployment rate, the inflation rate, interest rates, etc..

4. A Template for Comparing INDCs and Potential Uses

To organize the various metrics to facilitate the evaluation of comparable effort, we have developed a template presented in Table 1. This template lists the major categories of metrics with specific examples of each. Each column represents a major economy, with a brief description of a country's mitigation program in the first row. This first table focuses on the ex ante analysis of comparability of effort. For example, this could organize information on the intended nationally determined contributions announced by countries in the lead up to the 2015 Paris talks (and potentially in subsequent rounds of negotiations for the post-2030 period). The first row of the table would list briefly each country's INDC, and the subsequent rows would depict the estimated measure for each of the metrics. As the template notes, some of the metrics will be directly observed, some will require a forecast, and others will require modeling analyses.

In modest contrast, Table 2 presents a template for an ex post analysis, such as the "review" in the pledge and review regime being advanced in the current international climate negotiations. In this case, the summary of a country's climate program is the implemented contribution, as opposed to what it intended to do under the INDC. In addition, some of the metrics have transitioned from being the product of a model prospectively estimating the measure for a given country to being directly observed. Nonetheless, a number of metrics will require counter-factual forecasts and economic modeling even in an ex post exercise—for example, baseline emissions and economic activity absent policy interventions. So long as the review of effort addresses measures beyond physical emission outputs or observed market prices, it is likely that economic tools will need to be employed to quantify effort and organize the heterogeneous contributions in a manner to permit comparisons. In addition, standard economic tools may be employed even for observed metrics, such as aggregating observed energy prices over various fuels over a period of a year or more, to construct a summary of prices. Finally, economic tools may also serve to illustrate the impacts of interactions from the implementation of individual countries' INDCs.

Table 1. Information Sources for Comparability Metrics, Ex Ante Analysis

Table 2. Information Sources for Comparability Metrics, Ex Post Analysis

How could policymakers, stakeholders, and the public interpret these metrics? After constructing and compiling these metrics, a logical next step is benchmarking. That is, given a value for a specific metric, what is the threshold for deciding whether the country's mitigation effort is characterized as satisfactory or not? Let us suggest three ways for addressing this question.

First, the construction of any given quantitative metric creates a natural rank-ordering of countries. Moreover, the measures for a given metric illustrate proximity of any pair of countries. Whether the metric is emission reduction versus a base year, emission intensity, carbon price, or mitigation cost as a share of GDP, those with the lowest emissions or highest price or cost can be identified along with those sharing similar values. Countries could be compared in absolute terms (e.g., the level of emissions per GDP or per capita) or in terms of a rate of improvement (e.g., the percent decline in emissions per GDP per year). Countries could be compared based on each individual metric, or based on a composite suite of measures. This latter approach would require an algorithm for integrating information from the various metrics, perhaps akin to how the human development index aggregates information on various measures of economic, social, and human well-being. Importantly, this does not answer the question of whether a country's performance is satisfactory or not, but it does provide a relative comparison.

Second, countries can be arranged (or self-associate) into peer groups for relative comparisons. Such an approach recognizes that relative comparison among *all* countries is not particularly useful. Countries vary significantly in their emission contribution and capacity to mitigate, an idea reflected in the UNFCCC's concept of "common but differentiated responsibilities and respective capacities." Peer group comparisons are a first step in this direction.

To illustrate this peer group approach, consider the Major Economies Forum on Energy and Climate. As the largest countries and emitters, these countries have the most to gain and lose from leveraging (or failing to leverage) mutual mitigation efforts. The international community might agree on several official metrics, or these countries might themselves select a set of metrics to compare efforts. The MEF countries could then voluntarily agree to present data and analysis regarding their future emission commitments in order to produce these agreed metrics and to demonstrate feasibility and applicability of such a process.

These first two approaches do not directly answer the question of whether a given country is doing "enough," but they provide a means of comparison that can facilitate stronger efforts in the future. Without a normative judgment about the allocation of mitigation effort across countries, analysis of how each country's efforts relate to those of its peers provides the basis for a national government to make its own determinations about others' performance.

A third approach, however, is to consider normative, absolute benchmarks for countries' contributions. Such metrics could be derived from a negotiated emission commitment. For example, under the Kyoto Protocol, 1990 emissions served as the reference year for targets that were defined as changes relative to 1990 levels.[1] Countries had individualized targets ranging from -8% (most European countries) to +10% (Iceland) relative to 1990 levels, presumably reflecting their particular circumstances or capacity—but the adjustments were ad hoc. That is, there was no formula to say why some country's targets were -8% and others were +10%. This focused the debate on effort and which country was "doing more" in terms of a larger percentage below 1990 levels (even if, as we note above,

[1] Note that a number of eastern European and former Soviet republics listed in Annex B of the Kyoto Protocol could employ alternative base years for their emission commitments.

emissions in a later year relative to their 1990 level may have nothing to do with emission mitigation effort).

An alternative to such ad hoc adjustments is to develop a formulaic approach to address the normative question of what countries "should" do. A number of papers in the literature have addressed the normative issues of allocating the burden of effort (e.g., Bosetti and Frankel, 2012; den Elzen et al., 2006; Groenenberg et al., 2004; Gupta, 2007; Hof and den Elzen, 2010; Höhne et al., 2006; Michaelowa et al., 2005). Of course, this discussion illustrates the relationship between benchmarks and commitments/contributions, and it is not obvious that negotiators will agree on a set of normative benchmarks in a framework organized around sovereign, voluntary pledges of emission contributions.

We can highlight a few issues that merit consideration in the discussion of potential absolute benchmarks.

First, in light of the Lima Call to Action's provision requiring an assessment of the adequacy of collective effort in the submitted INDCs before the Paris talks, it could be natural to design a benchmark associated with the UNFCCC's long-term objectives. For example, the Copenhagen Accord and Cancun Agreements identify a long-term objective to limit warming to no more than 2°C, which could be linked (with admitted uncertainty) to a trajectory of cumulative emission levels. One way to present this would be to examine the cumulative emissions over the INDC horizon, and compare to the emission budgets associated with various likelihoods of exceeding 2 degrees. Without a formula for sharing a cumulative emission budget, however, this would not measure adequacy at the national level.

Second, one could design a benchmark based on the social cost of carbon, which has been used by a few countries in informing their domestic emission mitigation programs (Pizer et al., 2014). Such a benchmark would work quite well for evaluating and comparing carbon price and carbon tax metrics (as well as average mitigation cost, computed from cost divided by abatement).

Finally, the principle of common but differentiated responsibilities and respective capabilities does suggest that comparisons across countries require us to tailor benchmarks to reflect national circumstances. Whether ad hoc or formulaic, this may raise questions about the appropriateness of any given metric and the arguments for tailoring. For example, large ad hoc adjustments in benchmarks across the UNFCCC membership may undermine the comparability exercise. Formulaic adjustments will necessarily prompt fundamental questions about the validity of various concerns likely to arise in the negotiations. For example, countries like the United States, Canada, and Australia have all faced annual population growth on the order of 1% per year. Europe and Japan have not. China, India, and other emerging economies are not as wealthy on a per capita basis as the United States. Some countries are endowed with plentiful fossil resources; others are not. Some countries have taken significant actions to mitigate actions, while others are regarded as policy laggards. How should decisions about benchmark differentiation (or about the metrics themselves) balance these and other dimensions of national circumstance or past action? The difficulty of these questions—and the possibility that official, negotiated answers may not be forthcoming—suggests a likely continuing role for independent, albeit unofficial, work in this area.

Independent, scholarly analysis of mitigation effort has a long history in climate policy discussions. Since the 1997 Kyoto Conference, scholars have examined the consequences of various climate agreements and proposals and developed tools that could help estimate various metrics. In one early example, the Stanford Energy Modeling Forum organized an exercise with about a dozen modeling teams to evaluate the Kyoto Protocol (Weyant and Hill, 1999). Through this exercise, the modeling teams produced estimates for a variety of metrics, including carbon prices (dollars per ton of carbon dioxide) and abatement costs (expressed as a percent of GDP). Emission levels were implicit in the Kyoto Protocol commitments, and the modeling teams' forecasts of business-as-usual emissions would permit an estimate of emission abatement. Finally, estimated emission intensities (carbon dioxide emissions per unit of GDP) could be produced from the outputs of these analyses.

Evaluations of the emission commitments under the Copenhagen Accord have focused on a similar set of metrics. Employing a global energy-economic model, McKibbin, Morris, and Wilcoxen (2011) compare emissions, emission reductions, carbon prices (\$/ton CO2), and costs (percent changes in GDP and percent changes in consumption) among countries. Dellink and Corfee-Morlot (2010) estimate emission reductions – both relative to baseline and a specified base year, carbon prices ($/ton CO2), fiscal revenues (assuming a carbon tax), production among energy-intensive industries, and costs (changes in GDP and changes in household income). Finally, Houser (2010) also compares emission reductions under Copenhagen Accord emission targets, goals, and policies among participating countries. Most recently, we have seen a number of groups begin to discuss the pledges (or incipient pledges) leading up to Paris (Climate Action Tracker, n.d.; WRI, 2015).

5. Illustration of Comparability of Effort

To provide an initial illustration of the comparability of effort, we focus on the announcements for post-2020 mitigation contributions by several of the largest economies in the world, including China, the European Union, Russia, and the United States. In particular, China has announced that its emissions will peak by 2030 and that non-fossil energy will represent at least 20% of its fuel share in that year. The European Union has announced that it will reduce economy-wide emissions to 40% below their 1990 levels by 2030. Russia announced that it would limit its emissions to 25% to 30% below their 1990 levels by 2030. The United States has announced that it will reduce economy-wide net emissions to 26% to 28% below their 2005 levels by 2025. The EU and US commitments are part of their recently submitted INDCs, it is unclear whether China's INDC will be more specific than its announced emission peak.

We have employed the RITE DNE21+ model in undertaking this assessment. DNE21+ is a linear programming model that focuses on minimizing the world energy system costs (Akimoto et al., 2008; 2012; RITE, 2015). Given the application of a specific policy, the model searches for the solution that minimizes energy system costs globally. The model can run over 2000-2050, with initial 5-year timesteps that extend to 10-year timesteps in the latter end of the model period. The world is divided into 54 regions, which permits more granularity of analysis than many energy-economic computable general equilibrium models. The model includes 200+ technologies in a bottom-up modeling scheme, including coal, oil, natural gas, hydroelectric, geothermal, wind, solar photovoltaics, biomass, nuclear power, and ocean energy. The model also includes interregional trade in coal, crude oil, natural gas, ethanol, hydrogen, electricity, and carbon dioxide allowances. The model begins with an explicit characterization of existing facility vintages. While this model is quite rich in how it captures the energy economy around the world, it does not cover non-energy related greenhouse gas emissions or land use change. For some countries, such as those with significant agriculture-related methane emissions or substantial deforestation and reforestation activities, alternative analytic frameworks would be recommended. See RITE (2015) for more details.

Table 3 presents the preliminary results for China, the European Union, Russia, and the United States. The table presents metrics for emissions relative to various base years, emissions intensity in levels and changes over time, changes in emission relative to emission forecasts, estimated marginal abatement costs, and total abatement costs scaled by GDP. As suggested earlier, the choice of base year for emissions and emissions intensity matters significantly in the levels and rankings among countries. While there is likely to be disagreement over business-as-usual forecasts, we present our results using our best estimate. The uncertainties associated with the implementation of some contributions, such as China's peak year objective, also require modelers to make important assumptions that merit sensitivity analysis.

Further work will expand the full suite of metrics and models. As additional countries table their INDCs, we may also be able to investigate the emission, price, cost impacts using the DNE21+ (and other) modeling frameworks. Furthermore, future work will also consider alternative analytic frameworks to identify the most robust metrics and measures.

Table 3. The preliminary INDCs of China, the European Union, the United States, and Russia by different metrics

6. Conclusions

Metrics to compare climate change actions across countries are increasingly relevant as we transition to a program of periodic, unilateral pledges of domestic action and policy within international negotiations. The emerging architecture calls for countries to state what they intend to do, review the intended contributions by other countries and (along with various stakeholders) determine their adequacy, and then react accordingly. This reaction may be in the form of new or improved contributions in the formal UN negotiations, in the current round or the subsequent round of talks. The reaction may also be in the form increased domestic activity beyond the level of the current pledge. Moreover, the review process itself may also permit countries to learn how to improve the design of their own policy response over time, promoting cost-effectiveness and environmental ambition (Aldy, 2013).

In considering metrics for comparability, a number of relatively deep differences emerge. First, some metrics are relatively easy to observe and measure—total emissions and explicit emission prices—but may be one or more steps removed from the key concepts of effort and underlying policy implementation. Meanwhile, the concepts that are closer to effort—emission *reductions*, implicit prices, and costs—are harder to observe and measure directly. These will require explicit modeling tools, leading to more subjective and possibly divergent estimates. We have presented one set of preliminary modeling analyses to illustrate the application of this framework for China, the European Union, Russia, and the United States.

Developing metrics for assessing comparability of effort, compiling data and related analysis in light of these metrics, and reporting the results of the assessments will require a serious, transparent, and legitimate process (Aldy and Stavins, 2012; Aldy, 2014). Yet official agreement on specific metrics and a comprehensive policy surveillance mechanism is a tall order. In the meantime, independent researchers need to fill the gap. An array of easily available metrics could be developed and data collected by existing international organizations to facilitate comparisons in the near term—in advance of any official policy surveillance. Unofficial but independent expert analysis could further synthesize these data to create some of the more challenging but informative metrics. In turn, stakeholders and other users could provide feedback on the feasibility, integrity, and precision of various metrics to enable further refinement of metrics and to inform the deliberations over metrics going forward.

References

Akimoto, Keigo, et al. (2008). Global emission reductions through a sectoral intensity target scheme. *Climate Policy,* 8, S46–S59.

Akimoto, Keigo, et al. (2012). Comparison of marginal abatement cost curves for 2020 and 2030: longer perspectives for effective global GHG emission reductions. *Sustainability Science*, 7, 157-168.

Aldy, Joseph E. (2004). Saving the planet cost-effectively: the role of economic analysis in climate change mitigation policy." In: Randall Lutter and Jason F. Shogren, eds., *Painting the White House Green: Rationalizing Environmental Policy inside the Executive Office of the President*, Washington, DC: Resources for the Future Press, 89–118.

Aldy, Joseph E. (2013). Designing a Bretton Woods institution to address global climate change. In: Roger Fouquet, ed., *Handbook of Energy and Climate Change*, Cheltenham, UK: Edward Elgar.

Aldy, Joseph E. (2014). The crucial role of policy surveillance in international climate policy. *Climatic Change,* 126, 279-292.

Aldy, Joseph E. and William A. Pizer. (2014). Comparability of effort in international climate policy. Harvard Project on Climate Agreements Discussion Paper 14-62. January.

Aldy, Joseph E. and Robert N. Stavins. (2012). Climate negotiators create an opportunity for scholars. *Science,* 337, 1043-1044.

Bosetti, Valentina and Jeffrey Frankel. (2012). Politically Feasible Emission Targets to Attain 460ppm CO2 Concentrations. *Review of Environmental Economics and Policy,* 6, 86-109.

Climate Action Tracker. (n.d.). www.climateactiontracker.org.

Dellink, Rob and Jan Corfee-Morlot. (2010). Costs and Effectiveness of the Copenhagen Pledges: Assessing global greenhouse gas emissions targets and actions for 2020. OECD. http://www.oecd.org/environment/cc/45441364.pdf

den Elzen, Michel GJ, et al. (2006). Multi-Stage: a rule-based evolution of future commitments under the Climate Change Convention. *International Environmental Agreements: Politics, Law and Economics,* 6, 1-28.

Groenenberg, Heleen, Kornelis Blok, and Jeroen van der Sluijs. (2004). Global Triptych: a bottom-up approach for the differentiation of commitments under the Climate Convention. *Climate Policy,* 4, 153-175.

Gupta, Joyeeta. (2007). Beyond graduation and deepening: Toward cosmopolitan scholarship. In: Joseph E. Aldy and Robert N. Stavins, eds., *Architectures for Agreement: Addressing Global Climate Change in the Post-Kyoto World*. Cambridge: Cambridge University Press, 116-130.

Hof, Andries F., and Michel GJ den Elzen. (2010). The effect of different historical emissions datasets on emission targets of the sectoral mitigation approach Triptych. *Climate Policy,* 10, 684-704.

Höhne, Niklas, Michel den Elzen, and Martin Weiss. (2006). Common but differentiated convergence (CDC): a new conceptual approach to long-term climate policy. *Climate Policy,* 6, 181-199.

McKibbin, Warwick J., Adele C. Morris, and Peter J. Wilcoxen. (2011). Comparing climate commitments: a model-based analysis of the Copenhagen Accord. *Climate Change Economics,* 2, 79-103.

Michaelowa, Axel, Sonja Butzengeiger, and Martina Jung. (2005). Graduation and deepening: an ambitious post-2012 climate policy scenario. *International Environmental Agreements: Politics, Law and Economics,* 5, 25-46.

Newell, Richard N. and William A. Pizer. (2008). Indexed regulation. *Journal of Environmental Economics and Management,* 56, 221-233.

Organisation of Economic Co-operation and Development. (2013). Effective Carbon Prices. Paris: OECD.

Pizer, William A. (2007). Practical global climate policy. In: Joseph E. Aldy and Robert N. Stavins, eds., *Architectures for Agreement: Addressing Global Climate Change in the Post-Kyoto World.* Cambridge: Cambridge University Press, 280-314.

Pizer, William, Matthew Adler, Joseph Aldy, David Anthoff, Maureen Cropper, Kenneth Gillingham, Michael Greenstone, Brian Murray, Richard Newell, Richard Richels, Arden

Rowell, Stephanie Waldhoff, and Jonathan Wiener. (2014). Using and improving the social cost of carbon. *Science,* 346, 1181-1182.

RITE. (2015). RITE GHG Mitigation Assessment Model DNE21+. http://www.rite.or.jp/Japanese/labo/sysken/about-global-warming/download-data/RITE_GHGMitigationAssessmentModel_20150130.pdf

Schelling, Thomas C. (1997). The cost of combating global warming. *Foreign Affairs,* 76(6), 8-14.

Thompson, Alexander. (2006). Management under anarchy: the international politics of climate change. *Climatic Change,* 78, 7-29.

Weyant, John P. and Jennifer Hill. (1999). The costs of the Kyoto Protocol: a multi-model evaluation, introduction and overview. *Energy Journal,* Special issue on the costs of the Kyoto Protocol: a multi-model evaluation, vii-xiiv.

Wiener, Jonathan. (1999). Global environmental regulation: instrument choice in legal context. *Yale Law Journal,* 108, 677-800.

World Resources Institute. (2015). CAIT Paris Contributions Map. http://cait.wri.org/indc/.

Tables

Table 1. Information Sources for Comparability Metrics, Ex Ante Analysis

	US	**EU**	**China**
INDC Description	2005 -26 to -28% by 2025	1990 -40% by 2030	Peaking by 2030, 20% non-fossil fuel share
Emissions			
Versus 1990	<directly observed>	<directly observed>	<requires modeling>
Versus 2005	<directly observed>	<directly observed>	<requires modeling>
Versus 2025 BAU	<requires forecast>	<requires forecast>	<requires modeling>
Versus 2030 BAU	<requires forecast>	<requires forecast>	<requires modeling>
Target year CO2/GDP	<requires forecast>	<requires forecast>	<requires modeling>
Δ (CO2/GDP) 2015-25	<requires forecast>	<requires forecast>	<requires modeling>
Δ (CO2/GDP) 2015-30	<requires forecast>	<requires forecast>	<requires modeling>
Price			
CO2	<requires modeling>	<requires modeling>	<requires modeling>
Fossil energy	<requires modeling>	<requires modeling>	<requires modeling>
Electricity	<requires modeling>	<requires modeling>	<requires modeling>
Cost			
$ cost v. BAU	<requires modeling>	<requires modeling>	<requires modeling>
$ cost / GDP	<requires modeling>	<requires modeling>	<requires modeling>

Table 2. Information Sources for Comparability Metrics, Ex Post Analysis

	US	**EU**	**China**
Implemented Contribution	TBD	TBD	TBD
Emissions			
Versus 1990	<directly observed>	<directly observed>	<directly observed>
Versus 2005	<directly observed>	<directly observed>	<directly observed>
Versus 2025 BAU	<requires modeling>	<requires modeling>	<requires modeling>
Versus 2030 BAU	<requires modeling>	<requires modeling>	<requires modeling>
Target year CO2/GDP	<directly observed>	<directly observed>	<directly observed>
Δ (CO2/GDP) 2015-25	<directly observed>	<directly observed>	<directly observed>
Δ (CO2/GDP) 2015-30	<directly observed>	<directly observed>	<directly observed>
Price			
CO2	<requires modeling>	<requires modeling>	<requires modeling>
Fossil energy	<directly observed>	<directly observed>	<directly observed>
Electricity	<directly observed>	<directly observed>	<directly observed>
Cost			
$ cost v. BAU	<requires modeling>	<requires modeling>	<requires modeling>
$ cost / GDP	<requires modeling>	<requires modeling>	<requires modeling>

Table 3. The preliminary INDCs of China, the European Union, the United States, and Russia by different metrics

	US (2025): -26 to 28% relative to 2005	EU (2030): -40% relative to 1990	Russia (2030): -25 to -30% relative to 1990	China (2030): Peak-out (emissions estimated by authors)
GHG emissions [$MtCO_2eq/yr$]	5277	3380	2438	14956
Relative to 1990 [%]	-15%	-40%	-28%	+276%
Relative to 2005 [%]	-27%	-35%	+14%	+82%
GHG/GDP [$kgCO_2eq/US\$$]	0.27	0.18	0.94	0.97
Δ(GHG/GDP)				
2015-2025 (%/year)	-4.3	-3.1	-5.4	-5.4
2015-2030 (%/year)	-3.5	-3.4	-5.8	-5.3
Electricity (household) Price 2025 [US cent/kWh]	14.6	29.9	0.9	9.9
Gasoline Price 2025 [US$/L]	0.8	1.9	0.7	1.2
Natural Gas Price 2025 [US$/GJ]	12.5	29.1	2.2	n.a.
GHG emission reduction from baseline in 2025 [%]	31%	30%	-5%	7%
GHG emission reduction from baseline in 2030 [%]	36%	42%	6%	12%
Marginal abatement costs [$US\$/tCO_2eq$]	64	166	3	5
Mitigation costs per GDP [%]	0.39	0.82	~0	~0

* Baseline: Business as Usual (BaU) scenario estimated by using DNE21+ model developed by RITE