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RP0286 – Learning from Nationally Determined Contributions

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SUMMARY National governments have submitted emission mitigation pledges under the Paris Agreement that vary considerably in their form, level of required emission mitigation, elaboration of non-emission goals, and implementation strategies. As a result, domestic emission mitigation programs necessary to deliver on the Paris pledges will diverge in the degree to which that mitigation will be achieved at least cost. This paper explores both what we learn from how national determined contributions (NDCs) diverge from least-cost policies and the implications for comparing mitigation effort. The NDCs can reveal a country's preferences over climate policy, economic development, and other priorities. Modeling analysis of the NDCs can highlight opportunities for (i) measuring the revealed cost of institutional and political constraints that limit least cost implementation; (ii) mitigating climate change alongside other policy objectives; and (iii) policy learning over time. We undertake two case studies based on global energy-economic models to illustrate how implementation of NDCs may deviate from least-cost implementation. In the first case study, we employ the WITCH model to assess how the non-emissions goals in NDCs may constrain implementation in a way that increases costs related to cost-effective emissions abatement. In the second case study, we employ the DNE21+ model to assess how countries' stated domestic implementation policies may diverge from a cost-effective domestic mitigation policy. These modelling analyses serve to illustrate how comparing mitigation implementation can then be represented by a bounding exercise that develops both conservative and generous estimates of mitigation effort.

Keywords emissions mitigation, international environmental agreements, modeling analysis, comparability of effort, nationally determined contributions

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1. Introduction

Nearly every country in the world has submitted a pledge to mitigate its greenhouse gas emissions—a so-called nationally determined contribution (NDC)—as a part of the 2015 Paris Agreement. The pledges take on many different forms: targets relative to a historic base year emissions (with heterogeneity in the choice of base year), percentage improvements in the ratio of carbon dioxide to gross domestic product (GDP), percentage abatement versus a "no-policy" reference (or "business-as-usual") case, a specified year by which national emissions will peak, renewable power goals, energy efficiency goals, afforestation goals, and more. In many cases, especially among developing countries, the NDC includes multiple goals, such as a headline emission goal as well as non-emission sub-targets (the renewable power, energy efficiency, and afforestation goals).

The Paris Agreement represents the culmination of a transition toward a pledge-and-review regime initiated in the 2009 Copenhagen climate talks. The near-universal participation in the mitigation pledging exercise in the Paris framework signals an important first step in implementing this new regime.

To build confidence among countries, there needs to be a common understanding of how pledges expressed in different forms stack up against one another. Similar efforts among similar countries would likely be seen as a "fair" deal, likely a necessary condition for countries both to live up to their pledges now and to increase ambition in the future (Ostrom 1998; Barrett 2003; Cazorla and Toman 2003). To the extent that effort is associated with the economic resources diverted to mitigation and the associated reduction in well-being, we face a problem. How does such a measure accommodate proposed policies that clearly diverge from least-cost alternatives? That is, should we value those contributions at their actual cost, as that does represent the realized use of resources? Or, should we avoid valuing those costs that are above the least-cost alternative, as there is no global benefit associated with these additional costs?

This paper does not try to resolve this question—a question that is fundamentally ethical in nature. Instead, we point out that much can be learned for examining how NDCs diverge from least-cost alternatives. As Keohane and Victor (2016) point out, the crafting and communication of a given NDC can reveal a country's preferences over climate change, but also over non-climate outcomes, such as economic development, the evolution of their energy sector, and conventional air pollution issues.

To shed light on these issues, we employ two global energy-economic models, WITCH and DNE21+. Using these tools, we can quantify how much the choice to diverge from least-cost policies will cost. This cost can be expressed either in terms of the additional welfare cost of the more expensive policy, or in terms of the environmental cost of not spending diverted mitigation resources to achieve the most possible mitigation. Just knowing the additional costs and/or benefits could be important to motivate improved policies in the future.

Moreover, the costs of deviating from least-cost implementation may serve as a lower bound on the shadow costs of the institutional and political constraints that explain the deviation. For example, in 2015 the Obama Administration signalled its intent to implement its NDC through an array of sector-specific regulations, including fuel economy standards and the Clean Power Plan. These are more costly than an economy-wide carbon pricing policy, but the failed efforts to secure passage of legislation to create a national cap-and-trade program in 2010 illustrate that the least-cost option may not be politically feasible.

The deviations from least-cost implementation can take two general forms in light of how countries have drafted and described their expected implementation of their Paris pledges. First, countries may impose sub-targets on energy technologies or other objectives on top of the emission goal in its NDC. As a result, delivering on the sub-targets may constrain opportunities for implementing the emission goal and increase the costs relative to a domestic program without the sub-targets. The case study based on the WITCH model will investigate the impacts of such multi-objective NDCS. Second, countries may identify and implement domestic mitigation policies that deviate from least-cost policies. The case study based on the DNE21+ model will investigate the impacts of such implementation strategies.

Transparency about the broader costs and benefits of implemented policy can support not just improved domestic policymaking, but can promote the stability and increase the ambition over time of an international climate policy agreement. Without the means for coercing climate action by other countries, improved information about policies costs and benefits serves to enhance the credibility and likelihood that a country will deliver on its pledge (Schelling 1956). International institutions to facilitate transparency—through the collection, analysis, and dissemination of information on countries' commitments—can lower the costs of international agreements and facilitate their legitimacy (Keohane 1998; Bodansky 2007). As we argue here, however, such analysis should also include analysis of both implemented policies and least-cost alternatives, as well as identifying co-benefits. Such a process, with a more comprehensive analysis, can result in broader participation and greater mitigation benefit than the old Kyoto-style model to international agreements (Victor 2007; Pizer 2007).

The paper is organized as follows. In section two, we highlight the contents of the NDCs, providing a context for the analysis of policies that diverge from least cost. Section three places this research in the context of an academic literature that has rarely addressed how real-world policy implementation deviates from the least-cost carbon pricing assumed in global energy-economic models. In section four, we present two alternative modeling frameworks: DNE21+ and WITCH. Then, we dive into two case studies where the NDCs are compared to least cost alternatives using these two frameworks in section five. One focuses on the added cost burden implied by the non-emission goals in the NDCs, the other focuses on the other outcomes that might be achieved through domestic mitigation policies that several large developed countries have already identified. Both lead to a range of cost outcomes that we discuss. Finally, we conclude with suggestions for how such information could be presented to illustrate the comparability of mitigation effort and to aid in international negotiations.

2. Illustrations of Domestic Mitigation Programs in Countries' Mitigation Pledges

In order to examine something other than efficient, economy-wide carbon pricing, it is necessary to closely examine various national documents, such as INDCs and biennial reports, to understand the implemented and planned implementation of national policies and measures. In this section, we characterize the policies described in those documents for a small set of major developed and developing countries. These implementation policies inform our case study undertaken with the DNE21+ model in Section 5.1. It is also important to recognize that some countries have established technology-specific or sector-specific goals—sub-targets of the national contribution in a country's INDC—that may imply the means of policy implementation but lack such specific details. These sub-targets inform our case study undertaken with the WITCH model in Section 5.2.

2.1. United States

The US INDC commits to an economy-wide reduction of GHG emissions by 26–28% below 2005 levels by 2025.[1] The INDC indicates several policy options that the United States will employ to achieve these targets. The major policy instrument is through a variety of uses of the Clean Air Act (CAA). The first is by using the CAA to regulate emissions from new and existing coal-fired power plants (described below). The Department of Transportation and Environmental Protection Agency (EPA) also intend to promulgate post-2018 fuel economy standards for heavy-duty vehicles under the CAA. Finally, under the CAA, EPA is developing standards to address methane emissions from landfills and the oil and gas sector. These

[1] http://www4.unfccc.int/Submissions/INDC/Published%20Documents/United%20States%20of%20America/1/U.S.%20Cover%20Note%20INDC%20and%20Accompanying%20Information.pdf.

policy actions are motivated in part by the Obama administration's goal to reduce methane emissions 40% below 2005 levels by 2025 (Executive Order 13693).

The US Climate Action Report 2014[2] and the president's Climate Action Plan contain more detailed policy positions on how the United States will reach its emissions reduction targets set out in its INDC. The first point is elaborating on the regulation of new and existing power plants through the use of the Clean Power Plan (CPP). The CPP provides states flexibility to develop and implement plans that ensure the power plants in their state—either individually, together, or in combination with other measures—reduce CO_2 emissions consistent with a nationwide target of a 32% below 2005 levels by 2030.[3] The Obama administration has also set a goal to double renewable electricity generation from wind and solar once again by 2020. To meet this ambitious target, tax credits for renewable power were extended for five years, the president directed the Department of the Interior to permit more renewable energy projects on public lands, and the Obama administration set a new goal to install 100 megawatts (MW) of renewable power in federally assisted housing by 2020. The plan also requested increasing funding for clean energy technology across all government agencies by 30%, to approximately $7.9 billion. This includes investment in a

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[2] https://unfccc.int/files/national_reports/annex_i_natcom/submitted_natcom/application/pdf/2014_u.s._climate_action_report[1]rev.pdf.

[3] https://www.epa.gov/cleanpowerplan/fact-sheet-clean-power-plan-overview.

range of energy technologies, from advanced biofuels and emerging nuclear technologies to clean coal.

2.2. India

India proposed to lower its emissions intensity of GDP by 33–35% below 2005 levels by 2030, increase the share of non–fossil based power generation capacity to 40% of installed electric power capacity by 2030 (equivalent to 26–30% of generation in 2030), and create an additional (cumulative) carbon sink of 2.5–3 $GtCO_2e$ through additional forest and tree cover by 2030 in its INDC.[4] This builds on India's Copenhagen pledge to reduce the emissions intensity of GDP by 20–25% below 2005 levels by 2020. With India's continued and forecast economic growth, these targets will translate into an increase in overall emissions but potentially lower than in a no-new-policy counterfactual.

Details on India's INDC implementation appear in its second national communication to the UNFCCC[5] and National Action Plan on Climate Change.[6] These reflect the low-carbon growth strategy in India's 12th Five-Year Plan. To finance clean energy, India imposed a US$1

[4] http://www4.unfccc.int/Submissions/INDC/Published%20Documents/India/1/INDIA%20INDC%20TO%20UNFCCC.pdf.

[5] http://unfccc.int/resource/docs/natc/indnc2.pdf.

[6] http://www.cseindia.org/userfiles/National%20Action%20Plan%20on%20Climate%20Change.pdf.

per ton tax on domestically produced and imported coal. The tax revenues will fund research and innovative projects in clean energy technologies and environmental remediation programs. The tax has been raised several times since its inception in 2010, with a recent budget proposal calling for a tax increase to approximately US$6 per ton of coal in 2017.

India has set several renewable technology–specific goals as part of its plan to increase non–fossil fuel energy generation by 40% by 2030. In 2014, the Indian government announced that it would increase the solar ambition of its National Solar Mission to 100 gigawatts installed capacity by 2022, representing a 30-fold increase over the 2014 level of solar installation. The government also announced its intention to bring solar power to every home by 2019 and invested in 25 solar parks. The 12th Five-Year Plan proposes a National Wind Energy Mission, similar to the National Solar Mission, and the Indian government recently announced plans to boost wind energy production to 50,000–60,000 MW by 2022.

A third major pillar of India climate policy involves changes to the transportation sector. With vehicle ownership expected to continue to rise with per capita income, the transportation sector will continue to be a major source of GHG emissions. In early 2014, India announced a new vehicle fuel-economy standard (Indian Corporate Average Fuel Consumption standard) of 4.8 liters per 100 kilometers (49 miles per gallon) by 2021–2022, a 15% improvement. Additionally, India has established a goal to increase the share of biofuels in gasoline to 20%. Major public mass transportation improvements across Indian cities are also planned.

2.3. China

China's INDC[7] pledges to lower its carbon dioxide emissions per unit of GDP by 60—65% from 2005 levels by 2030. To help achieve this goal, China has also pledged to increase its share of non–fossil fuels in primary energy consumption to 20% and increase forest stock volume by 4.5 billion cubic meters relative to its 2005 level. China's INDC also calls for peaking of CO_2 emissions by 2030, while making the best effort to peak early. Carbon emissions trading pilots have been initiated in 7 provinces and cities and low-carbon development pilots in 42 provinces and cities. These pilot programs will serve as the basis for the rollout of a national cap-and-trade program.

To contribute to its goal of peaking emissions, China has set limits on total coal consumption. The National Development and Reform Commission published the Rules on Implementing the Action Plan on Prevention and Control of Air Pollution in Beijing-Tianjin-Hebei and Neighboring Area, which will reduce coal consumption in Beijing, Tianjin, and Hebei and Shandong Provinces by 83 million tons by the end of 2017. By cutting consumption and identifying clean alternatives, Guangdong Province, Jiangxi Province, and Chongqing have pledged to cut the proportion of coal in their energy consumption to less than 36%, 65%, and 60%, respectively, by 2017.

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[7] http://www4.unfccc.int/Submissions/INDC/Published%20Documents/China/1/China's%20INDC%20-%20on%2030%20June%202015.pdf.

A key to seeing overall emissions peak is by increasing carbon sinks throughout China through the use of various forestry policies. The State Forestry Administration has accelerated the implementation of the Program for National Forestation (2011–2020). In 2013, 91.5 million mu (23,522 square miles) of forest and 2.52 billion trees were planted, surpassing the target for the year. More than 300,000 mu (77 square miles) of carbon sink forestation had been created by 2013. Forest cultivation subsidies, which were being tested in pilot areas, are now being implemented on a nationwide basis. The central fiscal budget allocated 5.8 billion yuan (US$856 million) to cultivating 118 million mu (30,373 square miles) of forest, surpassing the target for that year.[8]

2.4. South Africa

The INDC for South Africa[9] focuses on a transition from business as usual to a peak, then plateau, and eventual decline in its GHG emissions trajectory. South Africa states that its emissions will range between 398 and 614 million metric tons of carbon dioxide equivalent (CO_2e) between 2025 and 2030, conditional on external financing. This would

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[8] http://en.ccchina.gov.cn/archiver/ccchinaen/UpFile/Files/Default/20141126133727751798.pdf.

[9] http://www4.unfccc.int/Submissions/INDC/Published%20Documents/South%20Africa/1/South%20Africa.pdf.

represent a 20–82% increase from 1990 levels of emissions[10] and would presumably be the peak emissions for South Africa.

South Africa has a few policies in place that will help mitigate GHG emissions, including a carbon tax on new vehicles, a tax rebate for energy efficiency, and subsidies to promote solar water heaters. Several policy instruments are also under development, including a carbon tax, desired emissions reduction outcomes for specific sectors, company-level carbon budgets, and regulatory standards and controls for specifically identified GHG pollutants and emitters. In respect to mitigation and adaptation efforts, and as a developing country, the scale and ambition of South Africa's contribution will also be dependent on the extent of international support, such as through funding, capacity building, and technology transfer.[11]

In 2009, the National Energy Regulator of South Africa (NERSA) announced South Africa's first Renewable Electricity Feed-In Tariff (REFIT), which designates Eskom as the single buyer from independent power producers. The key aim of REFIT is to facilitate meeting the 2013 renewable energy target. The technologies included in the REFIT program and tariffs are wind, concentrated solar power, small hydro (1 MW), solid biomass, and biogas. Given the low price of electricity in South Africa, the impact of REFIT on the viability

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[10] www.climateactiontracker.org.

[11] http://unfccc.int/resource/docs/natc/zafnc02.pdf.

of renewables projects could be significant. Regulations are being finalized to implement the REFIT program, and rules for a Cogeneration Feed-In Tariff (COFIT) program to support cogeneration are under development.

2.5. European Union

The European Union set its INDC[12] target of 40% reduction in GHG emissions by 2030 compared with 1990. This comes with pledges to supply 20% of energy, as a share of total EU gross final energy consumption, from renewable energy sources by 2030. This is supplemented by a target to achieve a minimum of 10% renewable energy in transportation. The EU also aims to improve energy efficiency and reduce total energy consumption by 20% by 2020 compared with a business-as-usual baseline.

To achieve its goals, the EU has a wide range of policies, as outlined in the EU's and member states' national communications to the UNFCCC.[13] In the transportation sector, regulations will lower CO_2 emissions of new passenger cars by 40% and emissions of new light commercial vehicles by 28% by 2020 relative to 2007 levels. Fuel suppliers are also

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[12] http://www4.unfccc.int/Submissions/INDC/Published%20Documents/Latvia/1/LV-03-06-EU%20INDC.pdf.

[13] https://unfccc.int/files/national_reports/annex_i_natcom_/application/pdf/eu_nc6.pdf.

required to reduce life-cycle GHG emissions per unit of energy by up to 6% by 2020 compared with 2010.

The EU Emissions Trading System (EU ETS) recently started its third phase (2013–2020). The EU ETS covered on average 41% of total EU-28 GHG emissions during the period 2008–2012. Because of the financial crisis, the significant use of emissions reduction credits from abroad, and member states' ambitious renewable power subsidies, a surplus in allowances has accumulated in recent years that has contributed to a drop in allowance prices.

In addition to the EU ETS, EU member states have taken on binding annual targets for each year from 2013 to 2020 and committed to reducing their GHG emissions from the sectors not covered by the EU ETS, such as housing, agriculture, waste, and transport (excluding aviation). Additional policies in these sectors include the EU's Common Agricultural Policy (CAP). The new CAP, covering the period 2014–2020, will further enhance the existing policy framework for sustainable management of natural resources, both contributing to climate change mitigation and enhancing the resilience of farming to the threats posed by climate change and variability. In the industrial sector, the EU is regulating the emissions of fluorinated gases, and a current proposal would strengthen this regulation.

2.6. Japan

Japan committed to reduce its GHG emissions 26% below 2013 levels by 2030.[14] The country plans to cut energy-related CO_2 emissions, which represent approximately 90% of the country's GHG emissions, by 25%. Japan's non-CO_2 GHG reduction targets include methane, 12.3%; N_2O, 6.1%; fluorinated gases, 25%; and removals from land use, land-use change and forestry (LULUCF) activity, 2.6%.

In the transportation sector, Japan aims to increase the share of highly efficient next-generation vehicles—hybrid, electric, plug-in hybrid, clean diesel, and compressed natural gas vehicles—by 50% to 70% by 2030.[15] Japan will employ government procurement of and tax credits for electric vehicle purchases to promote demand for next-generation automobiles. It will also review regulations on fuel-cell vehicles and hydrogen infrastructure.

Additionally, the government of Japan will promote the "greening" of the tax system through energy and vehicle taxes. Japan operates a credit offset scheme called the J-Credit System, which is similar to an emissions trading scheme. This policy creates incentives for

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[14] http://www4.unfccc.int/Submissions/INDC/Published%20Documents/Japan/1/20150717_Japan's%20INDC.pdf.

[15] https://unfccc.int/files/national_reports/annex_i_natcom/submitted_natcom/application/pdf/nc6_jpn_resubmission.pdf.

investment in energy-saving equipment, renewable energy, and carbon sinks through appropriate forest management.

2.7. Russia

Russia pledges to limit its GHG emissions to 25–30% below 1990 levels by 2030 in its INDC.[16] Its mitigation program is briefly outlined in its First Biennial Report[17] and Russian Climate Doctrine.[18] GHG emissions reduction efforts focus on promoting carbon sinks, improving energy efficiency across the economy, and developing renewable and alternative energy sources. Russia plans to employ financial and tax incentives to promote these GHG reductions.

3. Accounting for Domestic Mitigation Programs in INDCs

Aldy et al. (2016b) do not address a key question in their work: what is the *actual* policy implementation used to meet the INDCs? That is, while one approach is to compare the commitment assuming cost-effective implementation, another is to consider the

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[16] http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx.

[17] http://unfccc.int/files/national_reports/biennial_reports_and_iar/submitted_biennial_reports/application/pdf/1br_rus_unoffical_translation_eng.pdf.

[18] http://www.kremlin.ru/events/president/news/6365.

commitment in light of actual policies. This may be important to understand whether, in fact, the commitment will be achieved; to examine costs and impact of actual implementation; or to examine international trade and spillover effects (which will differ depending on implementation). Such analysis, as what we present below, has only rarely been considered in the literature.

Most studies of national-level mitigation policies assume economy-wide prices. The main exceptions would be, in the United States, the use of the EIA's National Energy Modeling System (NEMS) to examine more detailed energy-related policies, as well as various partial-equilibrium sectoral analyses. Indeed, even the EIA NEMS analysis, while economy-wide, does not consider market equilibrium outside of energy markets.

An early effort to bridge this divide was Pizer et al. (2006). This paper uses a collection of sector-based models in conjunction with a computable general equilibrium (CGE) model of the economy to examine and compare sector-based or non-price polices at an aggregate level. The sector-based models are used to calibrate the implementation of non-price policies in the CGE model. The paper examines the relative costs of different policies designed to achieve the same level of emissions reductions. The authors look at different non-price policy tools in different sectors, including renewable portfolio standards (RPS) in the electricity sector, Corporate Average Fuel Economy (CAFE) standards in the transportation sector, and a "uniform percentage rollback" policy in the industrial sector. The CGE model used is a comprehensive representation of the US economy that captures all energy and fossil fuel use. The results show that policies like RPS and CAFE turn out to be considerably more expensive than broad-based market alternatives. At an aggregate reduction of 5%, marginal welfare costs are more than 10 times higher when fuel economy standards and an RPS for power plants are imposed with both sectors facing equal percentage reductions (0.016% of GDP for economy-wide carbon pricing and 0.19% for the latter policies).

More recently, the Energy Modeling Forum 24 study included a set of policy scenarios designed to compare economy-wide market-based and sectoral regulatory approaches of potential US climate policy (Fawcett et al. 2014). Several policy architectures are explored in this study: cap-and-trade scenarios of varying stringency, isolated transportation sector policies, isolated electricity sector policies (separately, renewable portfolio and clean energy standards), combined electricity and transportation regulatory scenarios, and combined electricity and transportation regulatory scenarios plus a cap-and-trade policy. The authors find that for similar levels of abatement, a cap-and-trade policy that places a price on all greenhouse gas emissions is more cost-effective than sectoral or regulatory approaches that are limited in coverage and therefore more prescriptive in how emissions reductions are to be achieved. For example, the approach featuring regulation plus cap and trade is 62% more costly in the US Regional Energy Policy (USREP) model and 230% more costly in the Environment Canada Integrated Assessment Model (EC-IAM) model than with cap and trade alone. Furthermore, when sectoral and regulatory policies are combined with a cap-and-trade policy, the allowance price may be reduced compared with the cap-and-trade policy alone. While prices range from US$67 to US$168 per ton in 2050 for cap and trade alone, that range falls to US$44–US$118 when regulation is imposed on top of a cap-and-trade policy.

This may hold political appeal—by making costs less transparent—but it does so by increasing aggregate costs of mitigation and weakening innovation incentives.

Rausch and Karplus (2014) examine the *distribution* of economic impacts under regulatory versus market-based approaches to climate change in the United States. The authors use the USREP model to model the US economy by region, income category, and sector-specific technology deployment opportunities. They quantify heterogeneity in the national response to regulatory policies, including a fuel economy standard and a clean or renewable electricity standard, and compare these with a cap-and-trade system targeting carbon dioxide or all greenhouse gases. The results show that the regulatory policies substantially exceed the cost of a cap-and-trade system at the national level. That is, welfare loses for the various policies range from 1.1% for policies for coal, RPS, and fuel economy standards to just 0.5% for the cap-and-trade system. They further show that the regulatory policies yield large cost disparities across regions and income groups, which are exaggerated by the difficulty of implementing revenue recycling provisions under regulatory policy designs.

4. Modeling Frameworks

4.1. DNE21+

Dynamic New Earth 21 Plus (DNE21+) is an energy and global-warming mitigation assessment model developed by Research Institute of Innovative Technology for the Earth (RITE) (Akimoto et al. 2010, 2012). The model is an intertemporal linear programming model for assessment of global energy systems and global warming mitigation in which the worldwide costs are to be minimized. The model represents regional differences and assesses detailed energy-related CO_2 emissions reduction technologies up to 2050. When any emissions restriction (e.g., an upper limit of emissions, emissions reduction targets, targets of energy or emissions intensity improvements, or carbon taxes) is applied, the model specifies the energy systems whose costs are minimized, meeting all the assumed requirements, including production for industries such as iron and steel, cement, paper and pulp, transportation by motor vehicle, and other energy demands. The energy supply sectors are hard-linked with the energy end-use sectors, including energy exporting and importing, and the lifetimes of facilities are taken into account so that assessments are made with consistency maintained over the energy systems. Salient features of the model include analysis of regional differences among 54 world regions while maintaining common assumptions and interrelationships, a detailed evaluation of global warming response measures that involves modeling of about 300 specific technologies that help suppress global warming, and explicit facility replacement considerations over the entire time period. The model assumes energy efficiency improvements of several kinds of technologies, cost reductions of renewable energies, and carbon dioxide capture and storage (CCS) for the future within the plausible ranges based on the literature.

4.2. WITCH

The World Induced Technical Change Hybrid Model (WITCH) is an energy-economy-climate model developed within Fondazione Eni Enrico Mattei's (FEEM's) Sustainable Development research program (Bosetti et al. 2006). The model divides the worldwide economy into 13 regions, whose main macroeconomic variables are represented through a top-down intertemporal optimal growth structure. This approach is complemented with a bottom-up description of the energy sector, which details the energy production and provides the energy input for the economic module and the resulting emissions input for the climate module. The endogenous representation of research and development (R&D) diffusion and innovation processes is a distinguishing feature of WITCH, allowing the model to describe how R&D investments in energy efficiency and carbon-free technologies integrate the currently available mitigation options. The model can be used to evaluate the impacts of different climate policies on the optimal economic response over the century for the different regions. These regions can behave as forward-looking agents optimizing their welfare in a non-cooperative, simultaneous, open membership game with full information, or the model can be constrained such that a global social welfare planner finds a cooperative first-best optimal solution. In this game-theoretic setup, regional strategic actions interrelate through GHG emissions, dependence on exhaustible natural resources, trade of oil and carbon permits, and technological R&D spillovers.

4.3. Description of INDCs and Their Implementation in the Models

The modeling teams reviewed each country's mitigation pledge in its INDC submission (http://www4.unfccc.int/submissions/INDC/), and modeling runs assume simultaneous implementation of all INDCs. Replicating the analyses in Aldy et al. (2016b), one set of scenarios is implemented assuming all countries minimize the costs necessary to achieve the emissions goal established in a particular country's INDC—that is, an economy-wide carbon price (tax). Many of the INDCs require economic forecasts to translate into emissions levels as countries such as China and India have submitted mitigation pledges in terms of reductions in emissions intensity. The effective emissions levels for these INDCs are estimated using the models' GDP forecasts coupled with the INDCs' specified emissions intensity reductions. Using an internally consistent set of economic and emissions forecasts can circumvent the potential problem in both comparing mitigation efforts and assessing aggregate effects that arise when countries use different economic and energy price assumptions in their forecasts. For models representing the land use sector, the emissions reductions are implemented by applying the same tax as for the energy system.

In the first case study, the WITCH model targets are augmented by energy policy objectives elaborated in countries' NDCs and major planning documents. Table 1 illustrates these targets for several major economies. These targets inform the second set of analyses run with the WITCH model that account for the NDC emission targets and these energy policy sub-targets. As Table 2 notes, this set of analyses is referred to as "INDC_ALL." Two additional sets of model runs permit an assessment of this mix of emission targets and energy policy sub-targets. The INDC_smac runs realize the emissions of INDC_ALL but implements a least-cost carbon price across all sources within a country to deliver that emissions level. The difference in costs between INDC_smac and INDC_ALL can illustrate the potential economic gains for learning about the deviation from least-cost implementation. It could also serve to illustrate the shadow costs of the political and institutional factors explaining the deviation from least-cost implementation. Finally, the WITCH model employs INDC_sGDPloss scenarios, which takes the GDP loss of the INDC_ALL scenario but realizes that through least-cost implementation. This scenario shows the incremental emissions abatement potential if that country transitioned from the emission targets plus energy policy sub-targets to cost-effective implementation that accepts that GDP loss of the former as politically acceptable. The reported results below focus on the largest economies represented in WITCH, including China, the European Union, and the United States.

In the second case study, DNE21+ focuses on the implementation of the NDCs of Japan and the United States. Tables 3 and 4 highlight the details of the implementation of the Japanese emission mitigation pledge and a variety of scenarios that account for energy-sector specific policy goals. In total, seven scenarios with alternative energy mix outcomes are modeled to characterize the marginal and total costs of domestic mitigation programs in Japan that deviate from least-cost implementation. Likewise, Table 5 shows the possible implementation assumptions associated with the U.S. Clean Power Plan, a sector-specific emission policy. For the United States, seven scenarios are run to illustrate the impacts of constrained domestic implementation on marginal and total costs of delivering on the nation’s emission mitigation pledge.

5. Case Study Results

5.1. WITCH

The WITCH modeling results are presented in figures 1 through 5. In Figure 1, the emission reduction percentages relative to forecast business as usual in 2020 and 2030 are presented for China, the EU, the United States, and the world aggregate. These show considerable variation across the major economies. For example, the emission reductions for the United States under its NDC (INDC_EMI) is nearly identical to what it is estimated to be after augmenting the Paris emission mitigation pledge with national energy policy goals (INDC_ALL). The EU stands in sharp contrast, in which the percentage reductions from business as usual in 2020 are doubled when moving from emission-only goals to including energy policy sub-targets. This effect becomes more muted by 2030, with the more ambitious emission goals of Paris kicking in. Likewise, the modeling for China shows modestly greater emission reductions when accounting for non-emissions energy targets. These deviations, especially in 2020, are quite costly – in terms of foregone emission abatement opportunities. Cost-effective deployment of the resources required to satisfy the emission and energy policy sub–targets could deliver dramatically larger emission reductions in 2020 (compare the INDC_sGDPloss cases with INDC_ALL).

Figure 2 illustrates further the costs in GDP loss of the INDC_ALL scenario compared with least-cost implementation scenarios. The energy policy sub-targets impose quite substantial near-term costs – effectively doubling the costs globally relative to least-cost implementation. This suggests both large gains through policy learning that could transition to least-cost implementation. It also suggests that such policy mixes, to the extent that they reflect political and institutional constraints, reveal large shadow costs to overcoming such constraints.

The substantially greater costs of the INDC_ALL scenario reflects in large part the aggressive solar targets (or solar component of renewable targets) in major economies and around the world. Figure 3 shows the much higher solar capacity in the INDC_ALL scenario for all regions when compared to the other scenarios. The INDC_ALL scenario also requires substantial biomass-based power capacity investment in China that would not be cost-effective under a simple carbon-pricing policy for implementing its Paris pledge.

Finally, these runs of the WITCH model have been integrated with the FASSTR model to characterize the impacts on local air quality. FASSTR is an R version of the FASST-TM5 model developed at JRC Ispra. It estimates the number of premature mortalities associated with ozone and particulate matter based on the air pollutant emissions of the WITCH model.

In order to assess the air pollution implication of the different scenarios, we have looked at different legislations for air pollution, contrasting a case of failed legislation (AP FLE) as well as a case of continued air quality legislation consistent with the SSP2 story line (AP SSP2). We have added an additional climate policy scenario (INDC smac) where the emission caps are as in INDC ALL but in this case regions are allowed to freely trade emission permits in a global market. This is a scenario we had considered in the first phase of the project to highlight the possible economic efficiency gains from carbon trading. However, this scenario is important also in terms of air pollution impacts, given its redistribution of the mitigation effort towards highly pollutant countries, with weak air pollution policies.

While there may be differences in emission outcomes – and certainly economic costs – between cost-effective implementation of the NDCs and the mitigation pledges plus energy policy sub-targets, there is less variation between these scenarios in terms of premature mortality avoided. Figure 4 shows comparable mortality reduction benefits across scenarios, except for INDC_fmac. This scenario redeploys the high costs of the INDC_ALL scenario in a cost-effective manner, which delivers greater greenhouse gas and conventional air pollutant reductions. Figure 5 illustrates the implications of pursuing cost-effective implementation globally through policies that deliver globally common carbon prices (a harmonized carbon tax or a global cap-and-trade program) on premature mortality. Such policies would increase the greenhouse gas mitigation effort in countries like India, which would deliver remarkably higher benefits in terms of reduced premature mortality.

5.2. DNE21+

The DNE21+ modeling results are presented in tables 6 and 7 and figures 6 through 9. These modeling analyses focus on Japan and the United States. Figure 6 details the energy savings and role of renewable power, among other power generating technologies, in Japan's electricity mix in 2013 and expected in 2030. Figure 7 reveals how Japan's electricity mix could evolve under various domestic implementation programs. Table 6 shows how the costs of some strategies for domestic implementation of Japan's Nationally Determined Contribution could be considerably more costly than the least-cost alternative. Indeed, each of the six options yield marginal abatement costs at least three times and as much as eight times greater than the least-cost strategy. This translates into resource costs that differ by as much as a factor of ten. Again, this illustrates considerable gains to policy learning – to the extent that Japan and transition to a least-cost implementation strategy – as well as reveal the shadow costs associated with the barriers to doing so.

For the case of U.S. policy implementation, Figures 8 and 9 show the emissions and power generation associated with various domestic policy implementation scenarios. These permit some variation in the emissions target to reflect the range in the U.S. NDC: 26 to 28 percent below 2005 levels in 2025. It becomes immediately evident in these modeling runs that the Obama Administration's Clean Power Plan would require less power-sector emissions abatement activity in the United States than would be delivered under an economy-wide cost-effective implementation policy.

Table 7 also shows dramatically higher mitigation costs under the less than cost-effective domestic program scenarios. The marginal costs could be five to six times higher under potential domestic implementation than under a least-cost (economy-wide carbon pricing) policy. As a result, the total abatement costs could be an order of magnitude higher. Just as in the case of the modeling analyses of Japan, these results show the large potential gains of policy learning – if that learning results in more cost-effective polices – and highlights the high shadow costs of political barriers to designing and implementing cost-effective emission mitigation in the United States.

6. Comparability Analysis: Extending Modeling Tools to Assess Domestic Programs

The limited literature to date highlights the difficulty of trying to represent a somewhat realistic implementation of national policies under the Paris Agreement. Yet that is precisely what is necessary to provide countries and stakeholders with the necessary feedback to enable increasingly stronger national commitments going forward. Countries need to understand the consequences of the actual policies implemented, not just a stylized representation of the pledged targets.

On the one hand, this will require the enhanced use of multisector, multiregional models, if not the enhancement of the models themselves. As Pizer et al. (2006) highlight, it is possible to represent complex policies in more simplified models, but the parameters of that representation may need to be calibrated from an analysis using a more detailed model. It will be important to model such policies in global multiregional, multisector frameworks in order to implement sectoral policies in multiple countries simultaneously and to assess net-of-trade impacts on national well-being.

On the other hand, this will require more sophisticated thinking about how to construct and interpret comparability metrics. When a country chooses to implement a non-price policy with higher societal costs, it may be doing so for a variety of reasons related to other economic concerns, political interests, or bad policymaking. Is that important from a comparability standpoint? For example, a country might prefer to avoid a high carbon price for trade reasons or to avoid redistribution from high energy using consumers and firms. Does that matter? Can we relate such concerns and choices to observable metrics? Also, while measuring trade effects is important, how do we interpret them? Should we consider stand-alone implementation of national policies without trade effects alongside global implementation with trade effects? What would that tell us? Addressing these questions satisfactorily will require additional work.

7. Conclusions

Analyses that compare climate change pledges and actions across countries are increasingly relevant as we transition to unilateral pledges of domestic action and policy within international negotiations. The emerging architecture calls for countries to state what they intend to do, form views about the adequacy of each other's efforts, and react accordingly as they implement policies and make further pledges in the future. This is increasingly complicated as we confront the actual policies countries intend to use, rather than stylized and idealized policies.

No single metric comprehensively measures effort, is easily measured, and is universally available for all countries. Moreover, each country will prefer to emphasise measures that improve its own appearance. This makes it unlikely that an official metric will emerge. Instead, countries will advertise and utilize the metrics they prefer. Analysis is necessary to translate among metrics, particularly harder-to-measure metrics.

Compiling data and conducting this analysis of metrics will require a serious, transparent, and legitimate process (Aldy 2013, 2014). As negotiators attempt to elaborate such a process under the Paris Framework, independent researchers can fill in the gap. An array of easily available metrics could be developed and data collected by existing international organizations to facilitate comparisons.

Unofficial but independent expert analysis could further synthesize these data to estimate metrics that require forecasts and modeling. In turn, stakeholders and other users could provide feedback on the feasibility, integrity, and precision of available metrics and estimates. This enables further refinement and improved estimates going forward. In addition, the work on developing metrics for ex ante comparisons of effort can inform the data collection and analysis needs for ex post reviews. The retrospective review of pledges will be more informative and more effective if countries plan in advance for such reviews by implementing data collection and dissemination protocols. Given that Paris is just the beginning of an ongoing process of policy commitments, these refinements and improvements can ultimately feed into greater confidence and stronger ambition among all countries.

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Figures and Tables.

Table 1. Energy Policies in Major Economies

	Capacity [GW]		Share	
China	2015	Hydro: 270 Solar: 10 Wind :100	2020	Gas in total primary energy 10% Non-fossil fuels in primary demand 15%
	2020	Nuclear: 55 Wind: 200 Solar:100	2030	Non-fossil fuels in primary consumption 20%
Europe			2020	Renewables in power generation 10% Renewables in final demand 20%
			2030	Renewables in total primary energy 27%
USA			2020	Renewables in power generation 14%

Table 2. WITCH Modeling Scenarios

Scenario name	Scenario description
bau	Business as usual
INDC_EMI	Implementation of the INDC emissions pledges
INDC_ALL	Implementation of the INDC emissions and energy pledges
INDC_smac	Same **emissions** as INDC ALL but equalizes the MAC for all sources within a country
INDC_sGDPloss	Same **cost** (GDP loss) as INDC ALL but equalizes the mac for all sources within a country

Table 3. Implementing Japan's 2030 Emission Target

	2030; Compared to 2013（compared to 2005）
Energy-related CO2	**-21.9%（-20.9%）**
Other GHGs	-1.5%（-1.8%）
Reduction by absorption	-2.6%（-2.6%）
Total GHGs	**-26.0%（-25.4%）**

	2005	2013	2030
Industry	457	429	**401**
Commercial and other	239	279	**168**
Residential	180	201	**122**
Transport	240	225	**163**
Energy conversion	104	101	**73**
Energy-related CO2 Total	1219	1235	**927**

Table 4. The Analysis Scenarios for Japan's NDC

	GHG emis. target	Energy related CO2 emission target	Electricity share			w./w.o. CCS option	Electricity saving
			Fossil fuel	Nuclear power	Renewables		
[A0] NDC GHG target (-26%) + Level 2 energy mix	-26%	Cost min.	Coal: 26% LNG: 27% Oil: 3%	20%	24% (cost min. within renewable sources)	Cost min.	Cost min.
[B0] Energy-related CO_2 target (-21.9%) + Level 2 energy mix	-	-21.9%	Coal: 26% LNG: 27% Oil: 3%	20%	24% (cost min. within renewable sources)	Cost min.	Cost min.
[B1] Energy-related CO_2 target (-21.9%) + Level 0 energy mix (the highest consistency with the specific measures listed in the Japan's NDC)	-	-21.9%	Coal: 26% LNG: 27% Oil: 3%	20%	24% (PV: 7%, wind: 1.7% etc.)	w.o. CCS	1065 TWh/yr
[B2] Energy-related CO_2 target (-21.9%) + Level 1 energy mix	-	-21.9%	Coal: 26% LNG: 27% Oil: 3%	20%	24% (cost min. within renewable sources)	w.o. CCS	Cost min.
[B3] Level 3 energy mix (coal 26% + nuclear 20%)	-	-21.9%	Coal: 26% LNG: cost min. Oil: cost min.	20%	Cost min.	Cost min.	Cost min.
[B4] Level 4 energy mix (nuclear 20%)	-	-21.9%	Cost min.	20%	Cost min.	Cost min.	Cost min.
[B5] Cost min. energy mix (Level 5)	-	-21.9%	Cost min.	Cost min.	Cost min.	Cost min.	Cost min.

Table 5. The Analysis Scenarios for U.S.'s NDC

GHG target (%)		**CPP intensity target in electricity sector?**	**Additional electricity savings from EPA analysis?**	**CCS included?**
-28%	**[A1] Carbon intensity of CPP (w.o. CCS) w.o. additional elec. saving**	**Yes**	**No**	**No**
	[A2] Carbon intensity of CPP (with CCS) w.o. additional elec. saving	**Yes**	**No**	**Yes**
	[A3] Carbon intensity of CPP with additional elec. saving	Yes	Yes	Yes
	[A4] The least cost measures (but w.o. CCS)	No	No	No
	[A5] The least cost measures	**No**	**No**	**Yes**
-26%	**[B1] Carbon intensity of CPP (w.o. CCS) w.o. additional elec. saving**	Yes	No	No
	[B5] The least cost measures	No	No	Yes

Table 6. Evaluations of Japan's NDC in Mitigation Cost in 2030

	Marginal abatement cost of CO2 ($2000/tCO2)	Mitigation cost increase (billion $2000/yr)	Mitigation cost increase per reference GDP (%)
[A0] NDC GHG target (-26%) + Level 2 energy mix	378	99	1.41
[B0] Energy-related CO_2 target (-21.9%) + Level 2 energy mix	227	28	0.40
[B1] Energy-related CO_2 target (-21.9%) + Level 0 energy mix	242	38	0.55
[B2] Energy-related CO_2 target (-21.9%) + Level 1 energy mix	272	32	0.46
[B3] Level 3 energy mix (coal 26% + nuclear 20%)	277	24	0.34
[B4] Level 4 energy mix (nuclear 20%)	165	20	0.28
[B5] Cost min. energy mix	50	10	0.15

Table 7. Evaluations of the US NDC in Mitigation Cost in 2025

GHG target (%)		Marginal abatement cost of CO2 ($2000/tCO2)	Mitigation cost increase (billion $2000/yr)	Mitigation cost increase per reference GDP (%)
-28%	[A1] Carbon intensity of CPP (w.o. CCS) w.o. additional elec. saving	**605**	**545**	**3.16**
	[A2] Carbon intensity of CPP (with CCS) w.o. additional elec. saving	**558**	**520**	**3.02**
	[A3] Carbon intensity of CPP with additional elec. saving	379	301	1.75
	[A4] The least cost measures (but w.o. CCS)	134	90	0.52
	[A5] The least cost measures	**94**	**65**	**0.37**
-26%	[B1] Carbon intensity of CPP (w.o. CCS) w.o. additional elec. saving	427	426	2.47
	[B5] The least cost measures	76	56	0.33

Figure 1. WITCH Emission Reduction vs. BAU

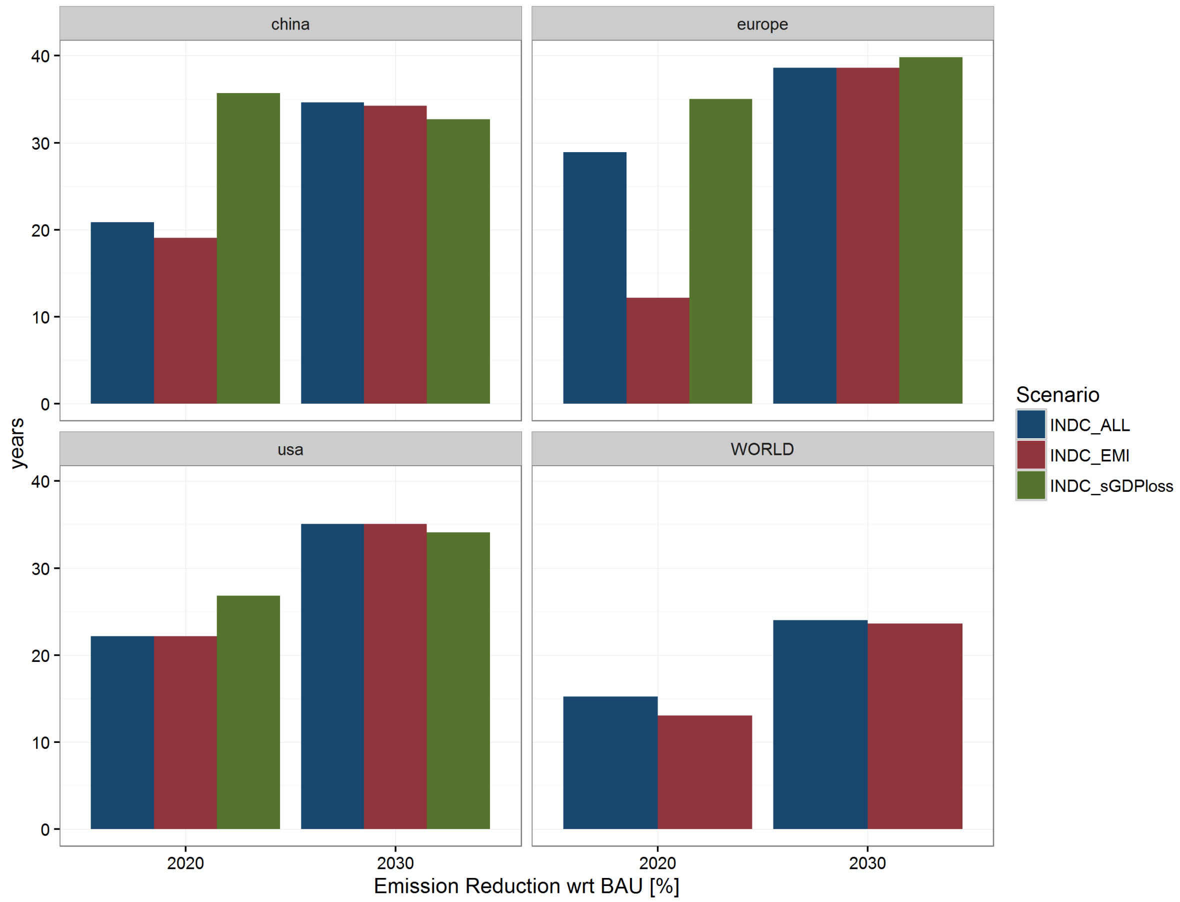


Figure 2. GDP Loss with respect to BAU

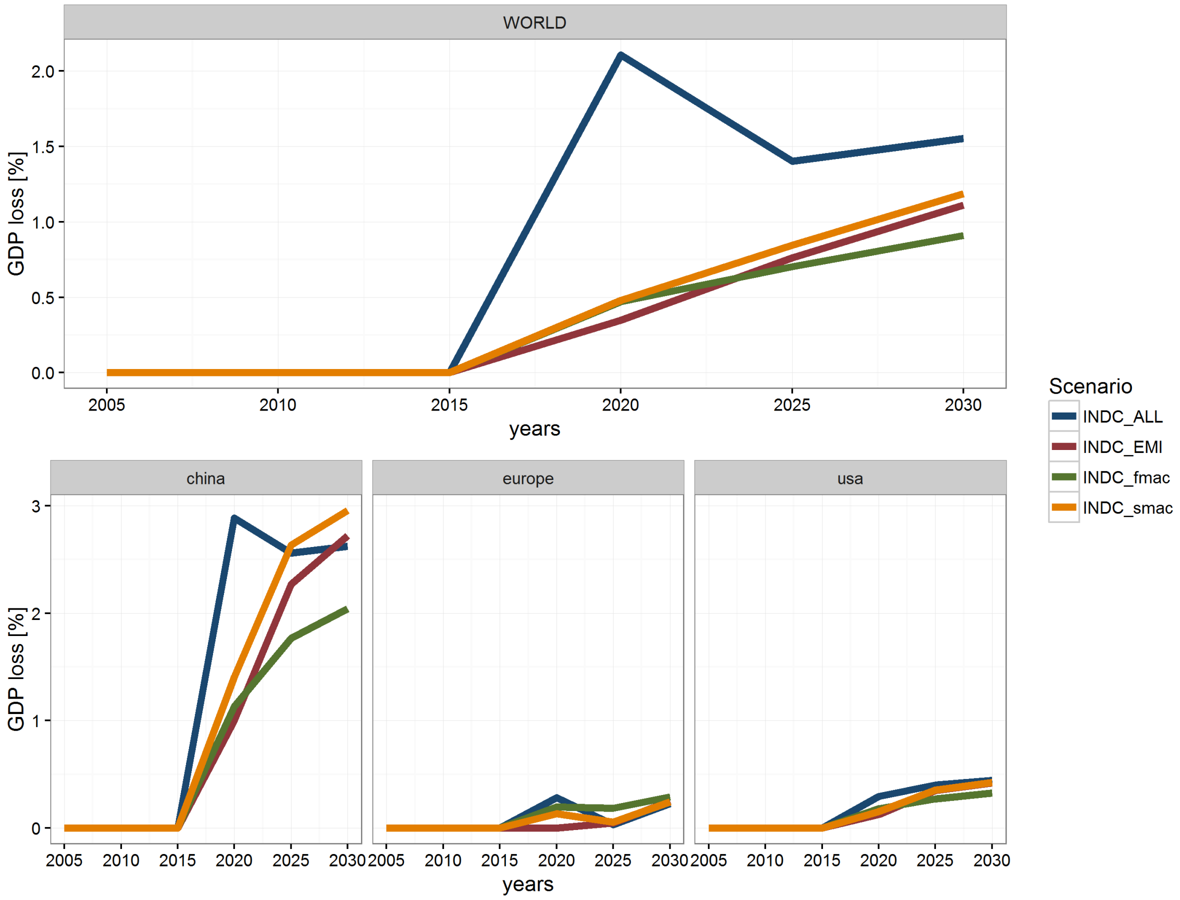


Figure 3. WITCH Installed Capacity

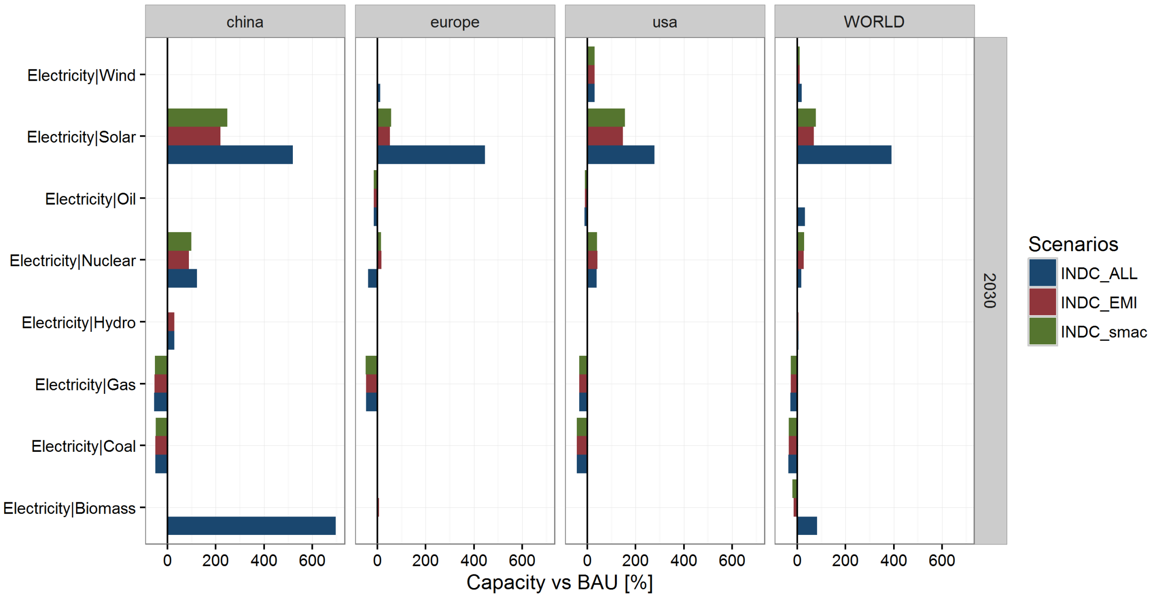


Figure 4. WITCH Mortality due to Air Pollution

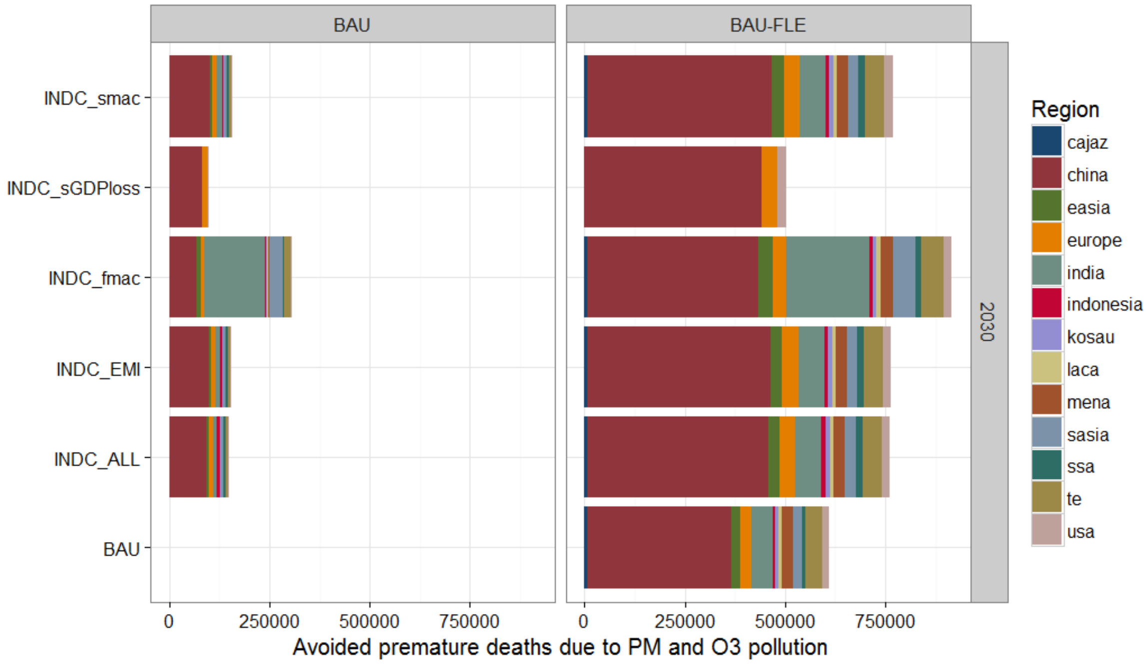


Figure 5. WITCH Mortality due to Air Pollution – Effects of Global Trade

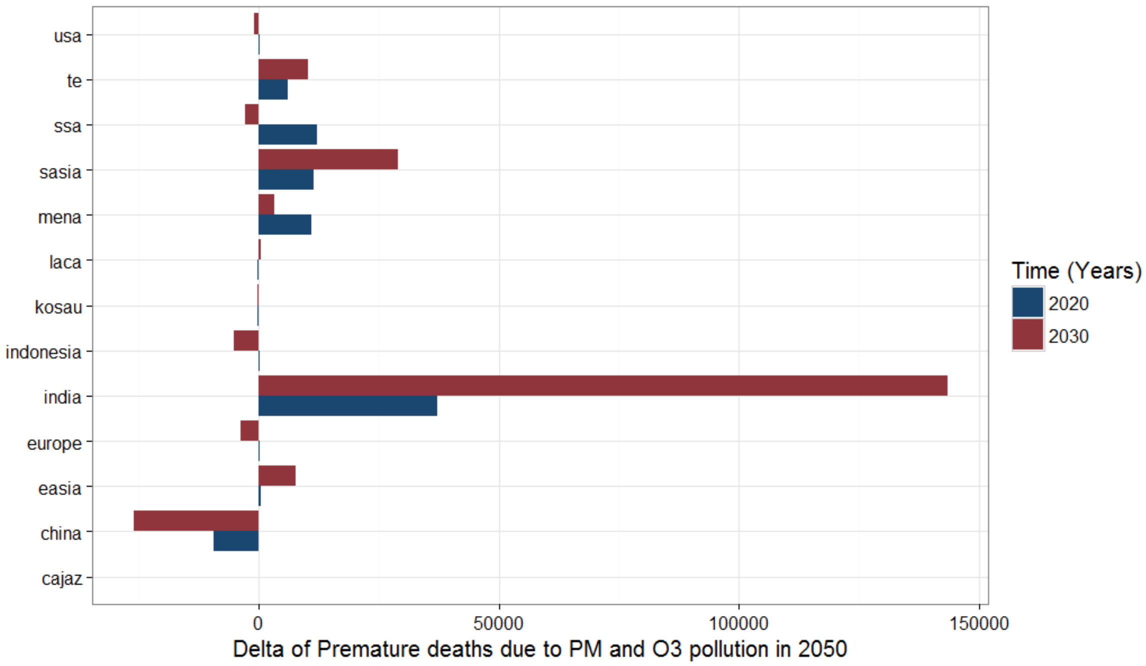


Figure 6. Japan's Electricity Mix in 2030

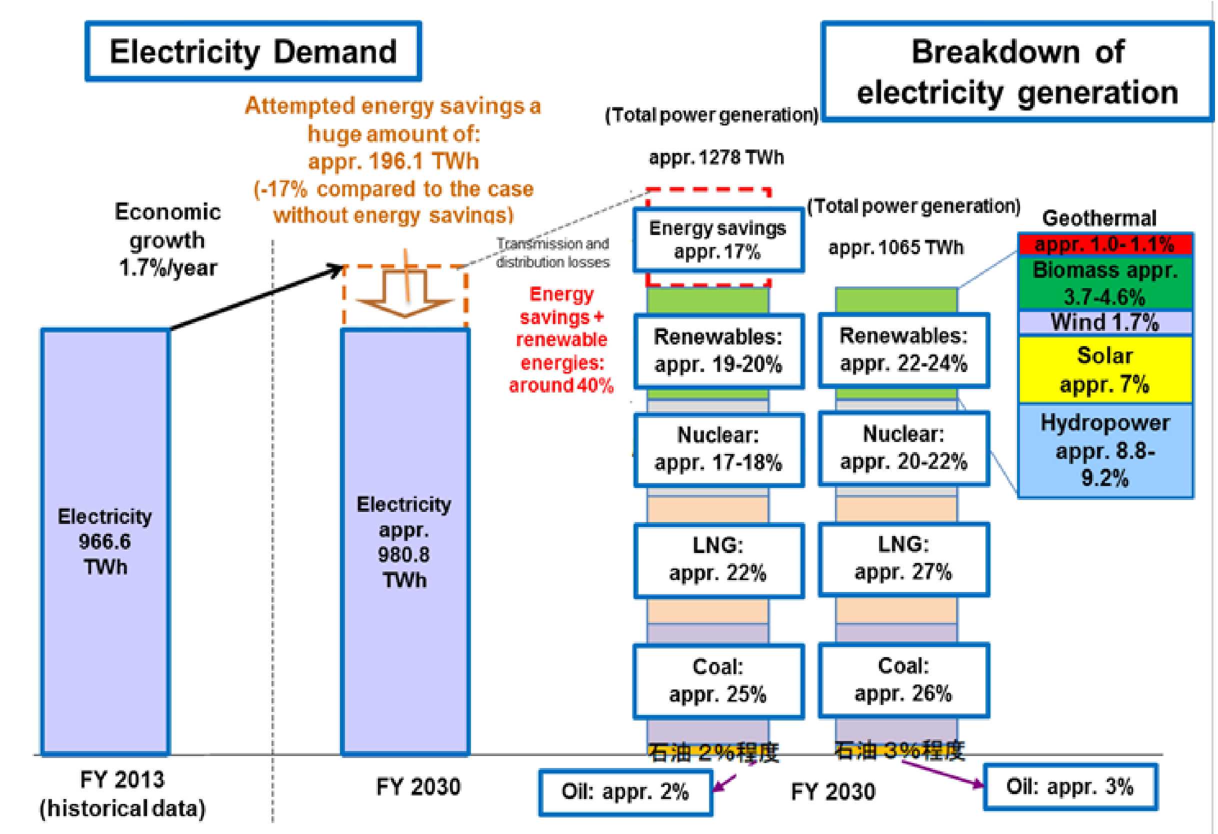


Figure 7. Evaluations of Japan’s NDC in Electricity in 2030

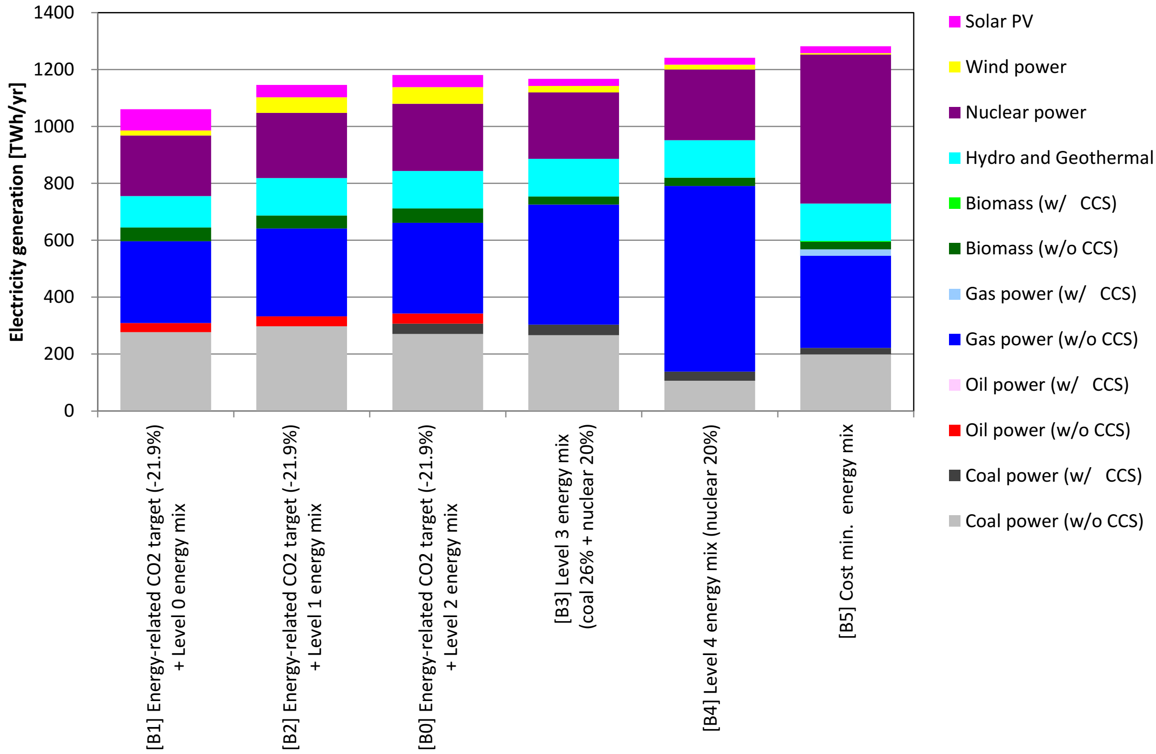


Figure 8. CO2 Emissions by Sector in 2025 (-28% Case)

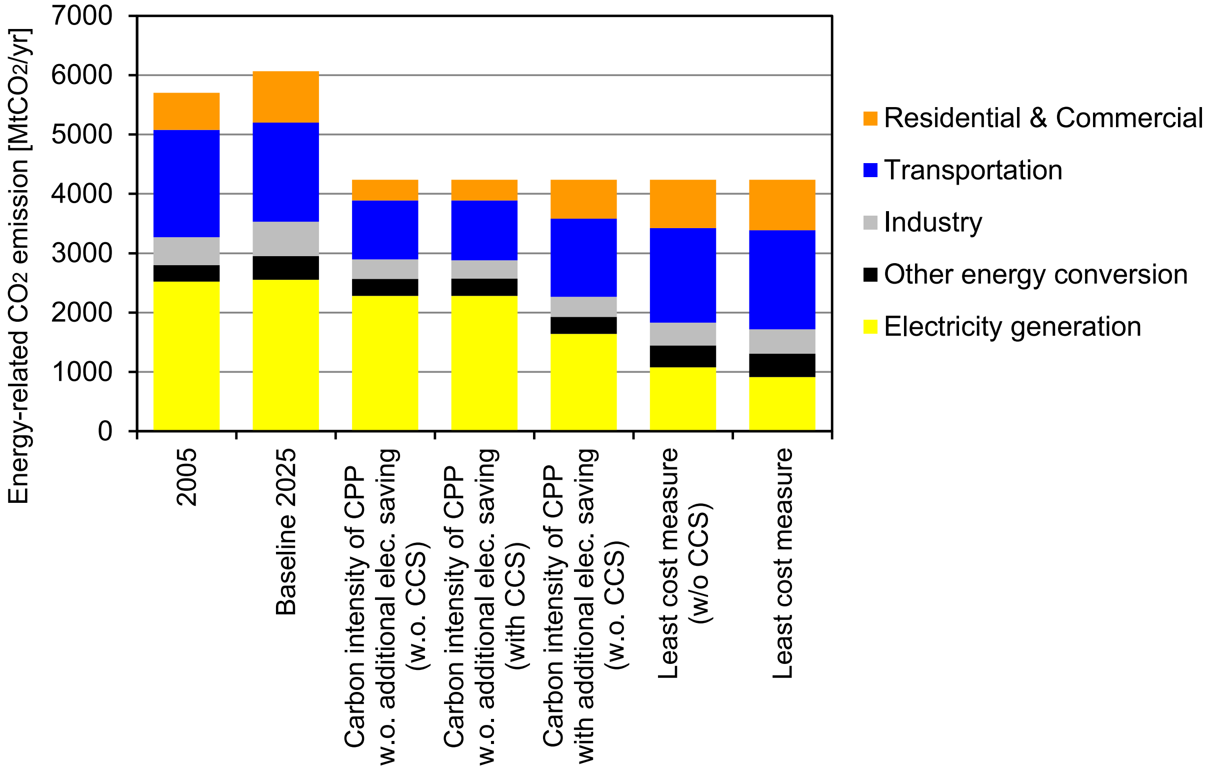
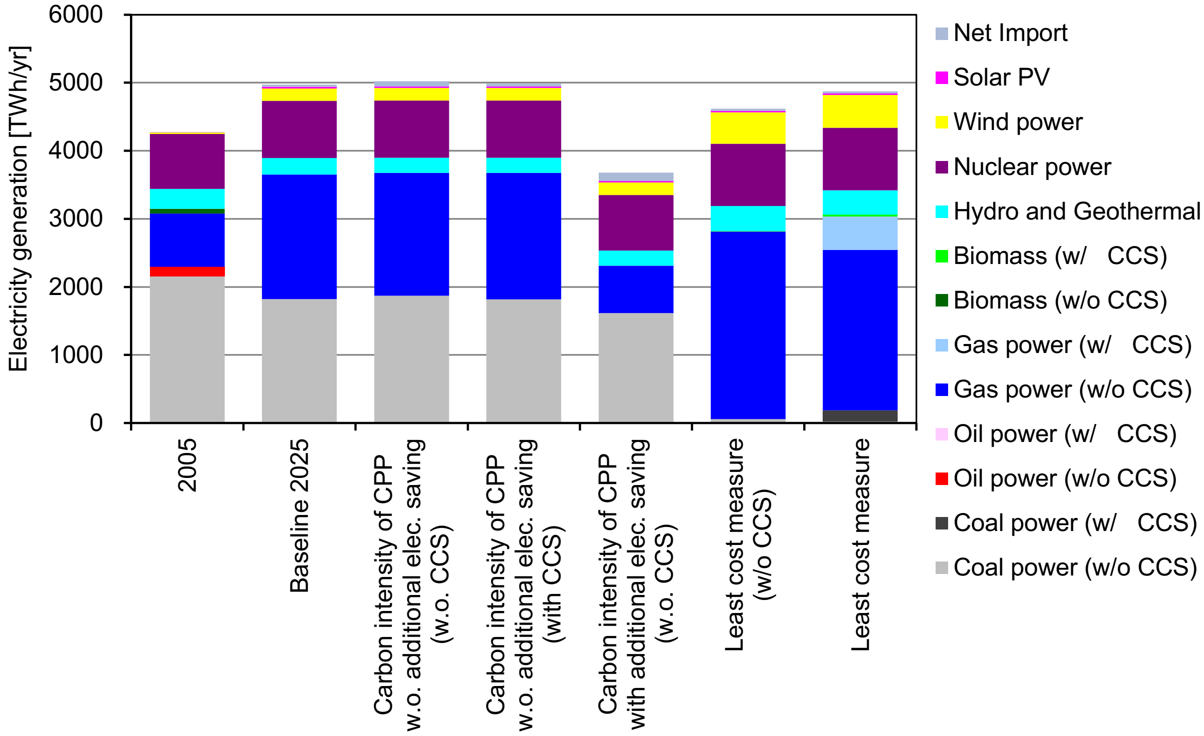


Figure 9. U.S. Electricity Generation in 2025 (-28% Case)



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