EURASIAN JOURNAL OF ECONOMICS AND FINANCE

www.eurasianpublications.com

FUTURE FOSSIL FUEL PRICE IMPACTS ON NDC ACHIEVEMENT; ESTIMATION OF GHG EMISSIONS AND MITIGATION COSTS*

Yosuke Arino

Corresponding Author: Research Institute of Innovative Technology for the Earth (RITE), Japan
Email: arino@rite.or.jp

Fuminori Sano

Research Institute of Innovative Technology for the Earth (RITE), Japan
Email: sanofumi@rite.or.jp

Keigo Akimoto

Research Institute of Innovative Technology for the Earth (RITE), Japan
Email: aki@rite.or.jp

Abstract

The Shale Revolution in the US, a supply-side innovation in oil and gas production, has been dramatically changing the world's fossil fuel energy markets – leading to a decrease in oil, gas and coal prices. Some projections suggest that low fossil fuel prices might continue at least over the next few decades. Uncertainty in fossil fuel prices might affect the levels of emission reductions expected from submitted nationally determined contributions (NDCs) and/or influence the difficulty of achieving the NDCs. This paper evaluated the impact of different (high, medium, and low) fossil fuel prices, sustained through to 2050, on worldwide GHG emissions reductions and associated costs (mainly marginal abatement costs (MACs)). Total global GHG emissions were estimated to be 57.5-61.5 GtCO₂eq by 2030, with the range shown reflecting uncertainties about fossil fuel prices and the target levels of several NDCs (i.e., whether their upper or lower targets were adopted). It was found that lower fuel prices not only diminished the environmental effectiveness of global NDCs but also widened regional differences of marginal and total abatement costs, thereby generating more room for carbon leakage. One possible policy direction in terms of abatement efficiency, fairness and environmental effectiveness would be to require countries with low marginal and total abatement costs but having a major influence on global GHG emissions (such as China and India) to increase their mitigation efforts, especially in a low-fuel-price world.

Keywords: Paris Agreement, Nationally Determined Contributions, Shale Revolution, Fossil Fuel Prices, Marginal Abatement Cost, Carbon Leakage

JEL Classifications: Q40, Q54

* Earlier versions of this paper were presented at the 6th Congress of the East Asian Association of Environmental and Resource Economics in 2016 and the 23rd Annual Conference of the European Association of Environmental and Resource Economists in 2017. We thank the participants for helpful comments. This research was conducted as part of the Alternative Pathways Toward Sustainable Development and Climate Stabilization Project, which is supported by the Ministry of Economy, Trade and Industry.

1. Introduction

By February 28, 2017, 190 out of the 195 parties to the United Nations Framework Convention on Climate Change (UNFCCC), including the European Union, had already submitted their intended Nationally Determined Contributions (NDCs) to the secretariat, with the remaining five NDCs for the Paris Agreement still in preparation. The greenhouse gas (GHG) emissions of these parties, comprising more than 99.4% of the world total, based on 2012 data (Carbon Brief, 2016; EC, 2016), are expected to be reduced in accordance with the proposed NDCs by 2030.

During the period from 2014 to 2015, oil prices on the global energy market fell dramatically because of the expansion of supply, notably from North America, and the slower than expected growth in demand (IEA, 2015; BP, 2016b). Because of the Shale Revolution, a supply-side technological innovation originating in the US, and a structural shift in the international oil market, some projections now suggest that the prices of fossil fuels (oil, gas and coal) may stay low for a considerable period, at least for a few decades (IEA, 2015; IMF, 2016). BP (2016a) predicts that shale oil and gas production will spread to regions outside North America, most notably in Asia and the Pacific, and particularly in China, by 2035.

If fossil fuel prices continue to stay low for some years, GHG emissions might increase, thereby decreasing the effectiveness of the NDCs that pledge a target of emission reductions compared to business-as-usual (BAU). On the other hand, the oil and gas price (which is linked with the oil price in Asia) might begin to rise under the influence of the coordinated cut in oil production agreed between the Organization of Petroleum Exporting Countries (OPEC) and Russia for the first time in 15 years (Reed, 2016). Hence, at present, it is unclear how global fossil fuel prices will evolve in future years, and what impacts future price trajectories may have on GHG emissions.

Several studies have been carried out on this subject, and these can be grouped into two categories. The first category focuses on the evaluation of GHG emissions expected from NDCs in a scenario where a single set of fossil fuel prices are assumed, while the second involves the evaluation of CO₂ emission changes in scenarios where fossil fuel prices are differentiated. By the time of the 21st Conference of the Parties (COP21), several international bodies and research institutes had already published analyses estimating the impact of the NDCs on 2030 global GHG emissions reduction (e.g., Spencer *et al.* 2015; UNFCCC, 2015; Akimoto *et al.* 2015; Sano *et al.* 2015a; Sano *et al.* 2015b; Rogelj *et al.* 2016; Robiou *et al.* 2017). Most of these studies also evaluated the consistency of the NDCs' GHG emissions with the emission pathways required to achieve long-term goals such as +2°C stabilization. They found that the currently pledged NDCs would not be stringent enough to achieve such long-term goals with climate sensitivity of 3°C (implicitly assumed), but would be adequate in cases with climate sensitivity of 2.5 °C, as shown in Sano *et al.* (2015a) and Sano *et al.* (2015b). Regarding the second category of studies, McCollum *et al.* (2016) found that long-term low oil prices would significantly increase the cumulative CO₂ emissions in the BAU case up to 2050, while the IEA (2015) estimated that low fossil fuel prices would not necessarily have any substantial impacts on CO₂ emissions when the economic growth rate was also assumed to be low.

In this study, we integrate the two categories of studies described above: the evaluations of NDCs and the impacts of fossil fuel prices. We evaluate the global/regional GHG emissions for 2030, based on submitted NDCs and associated mitigation costs, using three fossil fuel price scenarios ranging from "low" to "high". Mitigation costs are evaluated mainly in terms of the marginal abatement cost (MAC). MAC is an important metric for measuring how rigorous mitigation efforts are, by region, in achieving efficient GHG emissions reductions at the global level (Aldy *et al.* 2016a; Aldy *et al.* 2016b). Overall, the efficiency of GHG emissions reductions improves as differences in MACs decrease. However, as Tavoni *et al.* (2015) have shown, an efficient global climate policy (e.g., uniform carbon prices) can place a heavy burden on non-OECD countries such as China, India, economies in transition, Africa, the Middle East and Latin America - higher than the global average. Therefore, total abatement costs per GDP are included as supplementary information in Appendix C. The way in which the impact of NDCs is distributed is an important aspect to consider, when promoting mitigation efforts, worldwide, in a fair and economically sustainable manner.

Uncertainty in fossil fuel prices is one of the risks to be considered when addressing worldwide climate change policy, and hence its impact on NDCs needs to be evaluated carefully. Drouet (2016, pp. 661) has stated that “It is not clear if the level of emission reductions and enforced energy policies implied by the pledges will be stringent enough in the case of a low-oil-price world.” In the following sections, we will keep this question in mind while attempting to gain some useful insights regarding the management of the uncertainty in fossil fuel prices.

The structure of this paper is as follows. In section 2, we describe the methods used for evaluating NDCs and scenarios adopted for fossil fuel prices. In section 3, we present assessment results for the impacts of fossil fuel prices on GHG emissions and associated mitigation costs, and then summarize these results in terms of the types of NDCs and the different regions included. Section 4 concludes the study and highlights some relevant policy implications.

2. Methods and Scenarios

2.1. Assessment Model

We used a global energy-environmental model, the Dynamic New Earth 21+ (DNE21+) (Akimoto *et al.* 2010; Akimoto *et al.* 2014: see Appendix A for a more detailed description), and a non-CO₂ GHG assessment model (Akimoto *et al.* 2010) to evaluate NDCs – taking the various types of targets adopted by the parties into consideration (see Section 2.3). The DNE21+ model is an inter-temporal linear programming model capable of assessing global energy systems and global warming mitigation. In this model, the sum of the discounted world total energy systems costs is minimized and the world is divided into 54 regions (See Appendix B, Table B1). The non-CO₂ GHG emissions are calculated outside of the DNE21+ model and then added to the CO₂ emissions derived from the model.

In the DNE21+ model, most final energy demand is responsive to changes in fossil fuel prices. Since, for most energy end-use sectors (energy-intensive industries, road transportation, and several kinds of appliances in the residential and commercial sectors), technology options are explicitly modeled in a bottom-up fashion, incorporating assumptions on costs, energy efficiencies and the lifetimes of facilities, a model run based on cost-minimization algorithms can calculate the final energy demands for these sectors and how they will change in response to varying fossil fuel prices. Accordingly, energy-related CO₂ emissions also change with energy prices (although CO₂ emissions from industrial processes and non-CO₂ GHG emissions are assumed to be independent of energy prices). Therefore, BAU GHG emissions (for a case without any climate policy) will vary as energy-related CO₂ emissions change in response to energy prices.

2.2. Fossil Fuel Price Scenario

Figure 1 show the various cases examined for fossil fuel prices, through to 2050. We used three price levels for crude oil, coal and natural gas, ranging from “low” (blue line) to “high” (red line), to allow for possible price movements after the 2000s. All price projections published by the IEA (2013; 2014; 2015), EIA (2016), and IMF (2016) are included within this range, with the exception of the high price case for crude oil considered by the EIA (2016). We assume the high price case for oil to be consistent with that shown in McCollum *et al.* (2016). Low price cases are based on the low oil price scenario proposed by the IEA (2015). Other combinations of fuel prices, such as the de-coupling of oil and gas prices shown in McCollum *et al.* (2016), could also be included, but we focused on the three price cases including coal price variation on which McCollum *et al.* (2016) did not focus.

We assumed that economic growth rate is independent of energy price, as opposed to IEA (2015) where oil price and economic growth rate are assumed to be positively related. By definition, two-way interactions can take place between these two elements: the economic growth rate affects energy price via change in energy demand, while the energy price also affects the economic growth rate (e.g., Hamilton, 2011; Narayan *et al.* 2014; Terzi and Celik, 2016). However, such interactions between economic growth and energy price are not the main focus of

our paper, and hence we assume the rate of economic growth to be the same across all three of the energy price cases studied.

Figure 1. Price cases for crude oil, coal, and natural gas

Source: IEA (2013; 2014; 2015), EIA (2016)

Note: We deflated nominal price to real price (US\$2000) using the IEEJ (2015) world average GDP deflator.

2.3. Assessment Method used for NDCs

We explicitly evaluated the NDCs of 190 of the parties to the Paris Agreement, while at the same time treating the other 5 parties' BAU emissions as having no set emission reduction targets in terms of the model. Out of the 54 regions included in DNE21+, 47 have already pledged some form of emission reduction target in the form of NDCs and the other 7 regions have no targets (Appendix B, Table B1). In the model, the emission reduction targets for NDCs, by region, were grouped into 5 types (Type 0: No emission target (BAU); Type 1: Emissions reduction ratio from base years; Type 2: GHG intensity (GHG emissions per GDP) improvement; Type 3: Emissions reduction ratio compared to BAU; and Type 4: Others (multiple targets including Types 0-3 because some regions of the model include multiple countries). Figure 2 shows breakdowns of GHG emissions in 2012 according to the type of NDCs. The outer circle represents the 2012 emissions (including land use, land-use change and forestry (LULUCF)) of all 195 parties and the inner circle represents those (excluding LULUCF) of the 54 regions included in the DNE21+ model. As shown in the model, the Type 2 regions (including China and India) produced the largest share of GHG emissions: 39% (green) in 2012.

Note that the NDCs of 9 regions (including 11 countries: the US, Australia, China, India, South Africa, Guatemala, Russia, Kyrgyzstan, Tajikistan, Moldova, and Macedonia) have specified certain target ranges, and hence we evaluated both the upper and lower limits of GHG emissions for these regions.

Several detailed assumptions were made as part of this study. LULUCF emissions were not taken into account when assessing GHG emissions and mitigation efforts for individual countries, because they involve a large degree of uncertainty and are difficult to evaluate accurately. For those countries with emission reduction targets from the base year (Type 1), the emissions in the target year were calculated using historical data, excluding LULUCF, derived from GIO (2016) for Japan, UNFCCC (2016) for other Annex I countries, and from the IEA (2016) for other countries. For those countries with emission intensity improvement targets (Type 2), the emissions in the target year were calculated on the basis of historical emissions and the GDP scenario (medium level) used in Sano *et al.* (2015a; 2015b) and Akimoto *et al.* (2016). For those

countries with emission reduction ratio targets compared to BAU (Type 3), BAU emissions derived by the DNE21+ model were adopted for the calculation of emissions in the target year so that we could investigate the change in BAU GHG emissions in response to energy price. Note that BAU emissions in this study are different from those in the NDCs proposed by the corresponding governments.

Figure 2. Breakdown of 2012 GHG emissions by type of NDCs and representative countries

Source: EC (2016)

Note: See Appendix B, Table B1 for the details of type of NDCs.

For those countries who pledged policies and action without setting any explicit emission targets, BAU emissions were adopted. In the case of developing countries who pledged to meet specific emission targets that were either unconditional or conditional on the receipt of international finance, only the unconditional emission targets were evaluated.

3. Results

3.1. Impact of Fossil Fuel Price Changes on GHG Emissions

3.1.1. Regional GHG Emissions

Figure 3 shows regional GHG emissions during 2010 and 2050 for BAU and climate policy cases. Climate policy here refers to the Cancun pledge for the year 2020, post-2020 (2030 or 2025) NDCs pledged as part of the Paris Agreement and 2030-2050 emission pathways which are necessary for achieving stabilization of the atmospheric GHG concentration at 550 ppm. Carbon prices differ by region until 2030 in accordance with their NDCs, and then these prices are assumed to converge in 2050, reaching a worldwide harmonized carbon price of US\$375/tCO₂eq. This carbon price level in 2050 is arbitrarily selected to derive a representative emission pathway that is consistent with the 550-ppm stabilization. GHG emissions (BAU) from 7 regions (China, the US, EU28, India, Russia, Japan, the Middle East & Africa) are expected to account for 73.8-74.2% of the total world emissions (BAU) in 2030.

In principle, the lower fossil fuel prices are, the higher BAU emissions will be, except for India where BAU emissions for the medium price case are expected to be higher than those for the low price case because of the relatively low price of coal compared to oil and gas in the medium price case (Figure 1, Coal, green line).

As shown in Figure 4, the NDCs of the US, EU28, Japan, Russia, the Middle East and Africa result in emissions reductions compared to BAU in 2030, while the NDCs of China and India do not necessarily result in any emissions reduction compared to BAU. China and India can actually generate “hot air” (negative rather than positive reduction amounts) compared to their BAU emissions in the case of the upper (moderate) targets. We do not allow for hot air in the model calculations, but assume that the emissions pathways of climate policy cases follow BAU

emissions pathways. Therefore, the emissions of China and India, in the case of their upper targets, will be influenced by varying fossil fuel prices, thereby affecting the global GHG emissions pathways. At the global level, the lower fuels prices are, the more emissions reductions from BAU are necessary to achieve the NDCs (Figure 4).

Figure 3. GHG emissions by region: BAU and climate policy cases

Figure 4. NDC emission reduction amount relative to BAU in 2030

Note: Negative values represent “hot air”. Error bars show the range of NDC targets: upper limits of error bars are for lower (stringent) targets and lower limits are for upper (moderate) targets. US figures are for 2025.

3.1.2. Global GHG Emissions

Figure 5 shows global GHG emissions during 2010 and 2050 for the BAU and climate policy cases. The BAU emissions in the low price case are the largest because in this case fossil fuel energy makes up the largest share of the primary energy supply (Figure C1 of Appendix C). GHG emissions pathways in climate policy cases begin to decline, relative to BAU emissions, after 2015. The global GHG emissions expected from NDCs range between 57.5-61.5 GtCO₂eq in 2030. This range reflects the magnitude of the uncertainties regarding fossil fuel prices and target levels for NDCs (i.e., upper or lower targets), as shown in Figure 5B.

Figure 5. Global GHG emissions and breakdown of 2030 emissions by regions

Figure 5C shows the regional breakdown for 2030 GHG emissions, highlighting the degree of uncertainty regarding the two target levels (upper and lower) and illustrating how much impact fossil fuel price variation will have on global GHG emissions. Note that emissions for regions with only a single target level were simply summed with those of regions with two target levels, and that hot air results are only generated by China and India, as shown in Figure 4.

Fossil fuel prices have an impact on emissions in regions who have pledged BAU-related targets (including no target) such as Types 0, 3 and 4. This includes the Middle East & Africa, Philippines, Other South America, Chinese Taipei, Korea, Venezuela, Guyana, Suriname, and others. These regions account for 35-79% of the 2030 GHG emissions uncertainty. Note that China and India, having pledged to meet GHG intensity improvement targets (Type 2), also contribute to GHG emissions uncertainty because they have virtually no target (BAU) in the model if their target level is so weak that hot air is generated, i.e., in the upper target case. Note that India has virtually no target even in the lower target case. As a result, the contributions for China and India range between 21-65%, depending on their target levels.

3.2. Impact of Fossil Fuel Price Change on the Cost of Mitigation

First, we will examine how the MACs for major regions are affected by fossil fuel price changes. We will then analyze the mechanisms responsible for these MAC changes, focusing on energy systems transformation brought about by varying fossil fuel prices and the stringency of climate policy (NDCs).

3.2.1. MACs by Region and by Type of NDCs

Figure 6 shows how the MACs of major regions are expected to change, depending on fossil fuel prices. In principle, MACs of Type 1 regions, whose target emission levels are fixed, are expected to increase with a fall in energy price because BAU emissions and the resultant total reduction amount would increase. This also applies for Type 2 regions, because their target emission levels are fixed in the model due to the assumption of uniform GDPs across all price cases. On the contrary, however, the MACs of Type 3 regions would not necessarily increase because their emission levels increase in response to a fall in energy price and an increase in BAU emissions. These interactions are examined in more detail in the following sections.

Figure 6. Marginal abatement costs by region and by type of NDCs across different fossil fuel price cases in 2030

Note: “Upper” or “lower” represent upper or lower emission targets.

MACs of Type 1 regions such as the US, Canada, the EU28 and Japan all increase with a fall in fossil fuel prices. Lower price leads to higher BAU emissions and the emissions reduction amount needed will increase as a result, thereby resulting in higher MACs. In Switzerland, Japan, Canada and the EU28, MAC differences between the various price cases could reach 30-100 \$/tCO₂. However, there are exceptions such as Australia, South Africa and Kazakhstan, where MACs decrease with a fall in prices. As analyzed in section 3.2.2, this is likely to occur because BAU energy systems transition (a rise in carbon intensity) due to a fall in energy price would have a stronger influence on these regions’ MACs than post-NDC energy systems. Noticeably, in these regions, BAU coal consumption is comparatively large (Figure C3).

As for Type 2 regions such as China and India, there are no changes in their MACs due to their relatively weak emissions reduction targets, which in some cases even generate hot air (see Figure 4).

MACs in Type 3 regions do not necessarily increase in the lower price cases because their target emission levels can also increase with a rise in BAU emissions. These countries include Korea, Saudi Arabia and Turkey. Interestingly, BAU coal consumption in Korea and Turkey is relatively large (Figure C3) and this can be associated with lower MACs, even in lower fossil fuel price cases. In Saudi Arabia, a relatively-low gas price compared to coal price decrease its MAC in the low price case.

In absolute terms, MACs can be ranked in order with Type 1 regions highest, then Type 3, then Type 2. Lower prices typically increase the MACs of Type 1 regions, while leaving the MACs of Type 2 regions unchanged (nearly equal to zero). Therefore, at the global level, lower energy prices could make regional differences more pronounced in terms of MACs, and might even cause more “carbon leakage” (an increase in emissions due to the shifting of industry from a region with higher carbon prices to a region with lower carbon prices) than higher prices would.

One way of understanding MAC levels is in terms of their emissions reduction ratio, compared to BAU and NDC carbon intensity (Figure C2). The higher the emission reduction ratio is, the higher the MAC will be. Conversely, the lower the NDC carbon intensity is, the higher the MAC will be. However, such cross-regional data alone cannot fully explain how each region’s MAC will vary with a change in fossil fuel prices. Therefore, we need to examine the energy system transition of representative regions more closely.

3.2.2. Determinants of Fuel Price Impacts on MACs, by Region

In this section, we analyze the impact of fossil fuel price changes on MACs by investigating BAU and NDC energy systems and their respective energy-related CO₂ emissions, because MACs result from the transformation of energy systems in and compared to BAU.

Figure 7 shows how the impact of fossil fuel prices on MAC was assessed. In the model, exogenous fossil fuel price changes, represented by the different scenarios (low, medium and high), influence a region’s BAU energy system and associated emissions in a target year (e. g., 2030). In response to these autonomous changes in energy systems, the transformation of energy systems occurs as a result of climate policy aimed at achieving NDC targets. Both BAU and post-NDC energy systems, and their respective carbon intensities, collectively determine the MAC of a specific region.

Figure 7. Assessment scheme used to explain the impact of fossil fuel price change on MAC

We selected 9 variables (5 BAU variables and 4 NDC variables) to explain the price impact on MAC. A summary of the results is shown in Appendix Table C1. The 5 BAU variables include BAU CO₂ emission ([2] in Table C1), BAU carbon intensity ([3]), BAU renewable energy share ([4]), BAU gas share ([5]), and BAU gas-coal ratio (gas/coal) ([6]). The 4 NDC variables

include the emission reduction ratio relative to BAU ([7]), the renewable energy share change relative to BAU ([8]), the gas-coal ratio change relative to BAU ([9]), and the NDC gas share ([10]). Note that we only evaluated the lower emission targets for regions which had both upper and lower targets.

Table C1 shows that regions can be classified into two subgroups in terms of MAC changes in response to fuel price changes. The first subgroup comprises those regions whose MACs increase in lower price cases (yellow), and the second subgroup comprises those regions whose MACs decrease in lower price cases (blue: Australia, South Africa, Kazakhstan, Korea and Thailand).

In the first subgroup, NDC energy systems rather than BAU energy systems are the main factors explaining MAC changes. For most of these regions, the emission reduction ratio ([7]), the renewable energy share change ([8]) and the gas-coal ratio change ([9]), all defined relative to BAU, increase in lower price cases. In the US, Canada, Norway, New Zealand and Russia, for example, gas shares are larger in the low price case than in any of the other cases. Therefore, their MACs increase. In Japan and Switzerland, whose MACs are extremely high (more than 400 \$/tCO₂), gas share expansion cannot explain the MAC changes but renewable share expansion can.

In the second subgroup (blue), BAU energy system changes matter more than NDC energy system changes in determining how the MAC varies in response to energy price. These regions' BAU gas-coal ratios ([6]) are significantly lower than those regions in the first subgroup (yellow) – the sole exception being Saudi Arabia, whose dominant energy source is oil. This low gas-coal ratio reflects the fact that in these regions, the coal share dominates and carbon intensities ([3]) are also high. In such cases, BAU energy system transitions provide the best explanation for MAC changes, in contrast to the regions in the first subgroup where NDC energy system transformations can provide a better explanation.

In Type 2 regions, notably China and India, these considerations are not a contributing factor because their MACs remain zero across all price cases. However, it can be inferred from the evidence for energy systems that China and India could be included in the second subgroup, where MACs decrease with a fall in fossil fuel prices (but, needless to say, only if China and India submit more stringent NDCs directing positive MACs in the next round of climate negotiations). China's BAU gas-coal ratios ([6]) for low, medium and high price cases are 0.2, 0.1 and 0.1, respectively, and India's are 0.3, 0.1 and 0.1, respectively. These are lower than the averages for regions in the second subgroup: 0.5, 0.2 and 0.2, respectively. This implies that, in China and India, coal remains a dominant energy source and BAU carbon intensity is high. Therefore, BAU energy systems transition in response to fossil fuel price changes may be a potential factor in explaining MAC changes. Moreover, NDC gas shares ([10]) in China and India are at very low levels (China: 14.6%, 10.8% and 7.2% for low, medium and high price cases, and India: 14.4%, 9.0% and 9.9%) compared to the averages for regions in the second subgroup: 27.6%, 15.6% and 14.1%, respectively. Furthermore, their NDCs do not promote a shift from coal to gas (gas-coal ratio change relative to BAU ([9])). These facts suggest that, in China and India, BAU energy systems transition could have a greater influence on MAC changes than NDC energy systems transition. If so, it is possible that low fossil fuel prices would let the MACs of China and India remain at a low level while raising the MACs of Type 1 regions, thereby increasing regional differences.

3.2.3. Total Abatement Cost per GDP

Before summarizing the results of Sections 2 and 3, it is necessary to examine the impact of fuel prices on total abatement costs per GDP. Total abatement costs are defined as the difference between the energy system costs in the NDC and BAU cases. Note that in this study, a single economic growth rate was adopted across the various energy price cases.

Figure C4 (Appendix C) shows the costs of NDCs by region and by type. With regard to the regional costs, total abatement cost per GDP is positively correlated with the NDC emissions reduction amount relative to BAU emissions (See Figure 4), except for China and India which both exhibit negative costs (benefits). These negative costs for China and India could result from

a change in the terms of trade for energy goods (e.g., a fall in the cost of imported coal) or, more fundamentally, from their having significantly weaker NDC targets than other regions. Costs per GDP in the low fossil fuel price case are higher than those in the high price case for most regions, except for China and India. The same result is shown in the costs by type of NDCs: costs per GDP for all regions, other than Type 2 regions, in the low fossil fuel price case are higher than those in the high price case.

In sum, the aggregated world costs (% GDP) in the low price case (blue bar) are larger than those in the high price case (red bar). This is likely because the low price of fossil fuels will increase BAU emissions and require more mitigation efforts in order to achieve the necessary NDCs, especially for Type 1 regions comprising most developed countries. It can also be seen that the regional differences in total abatement costs are greater in the low price case than in the high price case, implying that a low price for fossil fuels makes it more challenging to expand mitigation efforts in a fair manner across all regions.

3.3. Summary of Results

Table 1 summarizes the impact of fossil fuel prices on GHG emissions (quantity) and MAC (price) in relation to the type of NDC targets. As Figure 5C shows, uncertainty in fossil fuel prices does not affect the emissions for Type 1 regions, but does have a large impact on MAC (Figure 6). In the case of Type 2 regions, especially China and India, uncertainty in fossil fuel prices has a negligible effect on MAC (Figure 6) but a much larger effect on emissions, up to 21-65% (Figure 5C). The reason for the very small effect on the MAC is because the NDC mitigation-effort levels measured by the various metrics used are all low (Table C1, [7]-[10]) for these regions due to their extremely weak NDC targets. In the case of Type 3 regions, there are significant impacts on both emissions (Figure 5C) and MAC (Figure 6). In Type 4 regions, impacts are similar to those in Type 3 regions, although explicit MAC evaluations were not conducted for Type 4 regions because the aggregation of multiple targets would make meaningful evaluations too difficult.

The results shown in Figure 6 and Section 3.2.2 suggest that low fossil fuel prices widen the differences between regions in terms of their MACs.

Table 1. Fossil fuel price impact on emissions (quantity) and MAC (price)

Type of NDC target	Fossil fuel price impact on	
	Emissions	MAC
1. Emissions reduction ratio from base years	No	Large
2. GHG intensity (GHG emissions per GDP) improvement	Large	Very small
3. Emissions reduction ratio compared to BAU	Large	Medium

Regarding the impacts of uncertainty in fossil fuel prices on total abatement cost per GDP, the global costs (% GDP) are higher in the low price case than those in the high price case (Figure C4). Moreover, regional differences in total abatement costs are greater in the low price case. Overall, the results suggest that lowering fossil fuel prices would raise total abatement costs at the global level, while also widening the differences between regions.

4. Conclusions

This study estimated the impact of fossil fuel prices on GHG emissions and mitigation costs at the global and regional levels, considering 190 NDCs (out of 195) covering 99.4% of all GHG emissions, worldwide. Major findings are as follows:

- BAU emissions: Based on the different scenarios examined in this study, BAU emissions in the low price case are larger than those in the high price case because more fossil fuels are consumed at each point in time from 2010 to 2050. Global GHG emissions in 2030 range from 65.6-70.5 GtCO₂eq, reflecting the impact of uncertainty in fossil fuel prices on BAU emissions. Ranges of BAU emissions in 2030 and 2050 are predicted to be about 5 GtCO₂eq and 10 GtCO₂eq, respectively.

- NDC (climate policy) emissions: Global GHG emissions in 2030 are predicted to range from 57.5-61.5 GtCO₂eq, with the difference of 4 GtCO₂eq suggesting that future fossil fuel prices could have a significant impact on NDC emissions, depending on price variations. This uncertainty range should be acknowledged in any policy debates focusing on the gap that may develop between the near-term emissions expected from NDCs and the emissions required for achieving long-term targets, such as +2°C relative to preindustrial levels. The emissions from the regions that have pledged BAU-related targets (emissions reduction ratios compared to BAU) or have no target (BAU) account for 35-79% of the uncertainty range for emissions. The emissions from the regions with GHG intensity improvement targets, including China and India, account for the rest of the range, i.e., 21-65%, because their target ranges can generate hot air and they have virtually no set targets to meet (BAU) in the model. By definition, the emissions from regions with emission reduction ratios calculated from base years are not affected by any fossil fuel price uncertainties.
- NDC (climate policy) costs: In terms of MAC, any uncertainty in fossil fuel prices has the most pronounced effect on the MACs of regions pledging emission reduction ratios calculated from base years. This includes developed countries such as the US, EU28, Canada and Japan. Fuel price uncertainty also affects the MACs of regions with other types of targets, but to a lesser extent. The MACs of regions with GHG intensity improvement targets, such as China, India, Malaysia and Singapore, are not visibly affected because of their weak emissions reduction targets. In terms of total abatement costs for achieving NDCs in 2030, the aggregated world costs per GDP in the low price case are larger than those in the high price case because of the increase in the emissions reduction amount/ratio relative to BAU. When fossil fuel prices stay low, differences in the costs per GDP across regions become more pronounced, lowering the level of equity in terms of *capability* (UN, 1992; Robiou et al. 2017).

The estimates derived from the model show that uncertainty in fossil fuel prices would affect NDCs both in terms of emissions and costs, but that the magnitude of this effect is likely to differ by region and by type of NDC. China and India, who have pledged extremely low emissions reduction targets (in some cases even generating “hot air” in the model), and many other countries in Asia, the Middle East and Africa who have pledged BAU-related targets may, therefore, play an important role in increasing worldwide mitigation efforts. Since these countries’ MACs are low, raising their effort levels is a reasonable strategy for ensuring the global efficiency of mitigation. The fact that total predicted abatement costs per GDP in China and India are negative in 2030 can be used as a reason for them to increase their efforts. As Robiou et al. (2017) show, China and India’s NDCs can be considered weak even with other equity principles such as “equal per capita” and “equal cumulative per capita”, etc., taken into account.

Having fossil fuel prices stay low seems to put a greater burden on the global economy in terms of achieving NDCs while at the same time diminishing their effectiveness¹. Moreover, low fuel prices make regional differences more pronounced in terms of both total and marginal economic costs. Widening the spread of marginal abatement costs across regions can also generate more room for carbon leakage, and the wider spread of total abatement costs might harm sustainable efforts for mitigation, overall, making it more difficult to ensure fairness and equity among regions. To achieve efficiency and equity (in terms of *capability* (Robiou et al. 2017)), some kind of redistributive policy perspective at the global level might be necessary in the face of continuing low fossil fuel prices. One possible strategy for policy coordination in terms of abatement efficiency, fairness and environmental effectiveness could be, for example, to require countries with low marginal and total abatement costs but with a large influence on the global GHG emissions (such as China and India) to increase their mitigation efforts, especially in a low-fuel-price world. Considering that the Paris Agreement specifies that the efforts of all Parties will

¹ This parallels the findings of Rout et al. (2008) who stressed the beneficial impact of high fuel prices on climate through reductions in energy consumption and associated emissions.

represent a progression over time, this form of policy coordination could help facilitate efforts by the global community directed towards the long-term goal of deep decarbonization.

Further studies will need to be carried out on how economic growth rates can be differentiated across multiple fuel price scenarios in order to evaluate how the levels of emissions and the costs of mitigation would change if economic growth rates are interlinked with energy prices. Such evaluations would parallel the work of Rogelj *et al.* (2017) in which socio-economic baseline variation, including variation in the economic growth rate, is considered when evaluating the emissions expected from NDCs. Domestic policies affecting the fossil fuel mix, such as China's shutdown of coal-fired power plants as part of their anti-air pollution policy, could also be considered because such domestic policies can work as constraints on BAU emissions that would otherwise increase in response to lowering coal prices.

References

- Akimoto, K., Sano, F., Homma, T., Oda, J., Nagashima, M., and Kii, M., 2010. Estimates of GHG emission reduction potential by country, sector, and cost. *Energy Policy*, 38(7), pp. 3384–3393. <https://doi.org/10.1016/j.enpol.2010.02.012>
- Akimoto, K., Homma, T., Sano, F., Nagashima, M., Tokushige, K., and Tomoda, T., 2014. Assessment of the emission reduction target of halving CO₂ emissions by 2050: Macro-factors analysis and model analysis under newly developed socio-economic scenarios. *Energy Strategy Reviews*, 2(3-4), pp. 246–256.
- Akimoto, K., Shoai, B.T., Sano, F., Oda, J., Kainuma, M., Masui, T., and Oshiro, K., 2015. MILES (Modelling and Informing Low Emissions Strategies) Project –Japan Policy Paper: A joint analysis of Japan's INDC. [pdf]. Available at: <http://www.rite.or.jp/system/global-warming-ouyou/download-data/Energymix_INDCs_MILESreport20151118.pdf> [Accessed on 10 October 2017]
- Akimoto, K., Sano, F., and Shoai, B.T., 2016. The analyses on the economic costs for achieving the nationally determined contributions and the expected global emission pathways. *Evolutionary and Institutional Economics Review*, 14(1), pp.193-206. <https://doi.org/10.1007/s40844-016-0049-y>
- Aldy, J. E., Pizer, W. A., and Akimoto, K., 2016a. Comparing emissions mitigation efforts across countries. *Climate Policy*, 17(4), pp. 501-515.
- Aldy, J., Pizer, W., Tavoni, M., Reis, L. A., Akimoto, K., Blanford, G., Carraro, C., Clarke, L.E., Edmonds, J., Lyer, G.C., McJeon, H.C., Richels, R., Rose, S., and Sano, F., 2016b. Economic tools to promote transparency and comparability in the Paris Agreement. *Nature Climate Change*, 6, pp. 1000–1004. <https://doi.org/10.1080/14693062.2015.1119098>
- BP, 2016a. *BP energy outlook: 2015 edition* [online]. Available at: <<https://www.bp.com/content/dam/bp/pdf/energy-economics/energy-outlook-2016/bp-energy-outlook-2016.pdf>> [Accessed on 10 October 2017].
- BP, 2016b. *BP statistical review of world energy June 2016* [online]. Available at: <<https://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2016/bp-statistical-review-of-world-energy-2016-full-report.pdf>> [Accessed on 10 October 2017]
- Carbon Brief, 2016. *Paris 2015: Tracking country climate pledges* [online]. Available at: <<https://www.carbonbrief.org/paris-2015-tracking-country-climate-pledges>> [Accessed on 10 October 2017]
- Drouet, L., 2016. Cheap oil slows climate mitigation. *Nature Climate Change*, 6, pp. 660-661. <https://doi.org/10.1038/nclimate3064>
- EC, 2016. *EDGAR (Emissions Database for Global Atmospheric Research)* [online]. Available at: <<http://edgar.jrc.ec.europa.eu/overview.php?v=GHGts1990-2012>> [Accessed on 10 October 2017].
- EIA, 2016. *International energy outlook 2016* [online]. Available at: <[https://www.eia.gov/outlooks/ieo/pdf/0484\(2016\).pdf](https://www.eia.gov/outlooks/ieo/pdf/0484(2016).pdf)> [Accessed on 10 October 2017]

- GIO (The Greenhouse Gas Inventory Office of Japan), 2016. *National GHG inventory report of JAPAN, Common Reporting Format (CRF) and the GHG emissions data of Japan (1990-2014)* [online]. Available at: <<http://www-gio.nies.go.jp/index-j.html>> [Accessed on 10 October 2017]
- Hamilton, J. D., 2011. Nonlinearities and the macroeconomic effects of oil prices. *Macroeconomic Dynamics*, 15(S3), pp. 364-378. <https://doi.org/10.1017/S1365100511000307>
- IEA, 2013. *World energy outlook 2013*. Paris: IEA publications.
- IEA, 2014. *World energy outlook 2014*. Paris: IEA publications.
- IEA, 2015. *World energy outlook 2015*. Paris: IEA publications.
- IEA, 2016. *World CO₂ emissions from fuel combustion*. Paris : IEA publications.
- IEEJ, 2015. *EDMC handbook of Japan's & world energy & economic statistics*. Tokyo: The Energy Conservation Center Japan.
- IMF, 2016. *IMF primary commodity prices: Data projections actual prices through 01/20/16*. [online]. Available at: <<https://www.imf.org/external/np/res/commod/index.aspx>> [Accessed on 10 October 2017]
- McCollum, D. L., Jewell, J., Krey, V., Bazilian, M., Fay, M., and Riahi, K., 2016. Quantifying uncertainties influencing the long-term impacts of oil prices on energy markets and carbon emissions. *Nature Energy*, 1, 16077. <https://doi.org/10.1038/nenergy.2016.77>
- Narayan, P. K., Sharma, S., Poon, W. C., and Westerlund, J., 2014. Do oil prices predict economic growth? New global evidence. *Energy Economics*, 41, pp.137-146. <https://doi.org/10.1016/j.eneco.2013.11.003>
- Reed, S., 2016. Russia and others join OPEC in rare, coordinated push to cut oil output. *New York Times*, [online] 10 December. Available at: <<https://www.nytimes.com/2016/12/10/business/russia-opec-saudi-arabia-cut-oil-output.html>> [Accessed on 10 October 2017].
- Robiou, Y., Pont, D., Jeffery, M. L., Gütschow, J., Rogelj, J., Christoff, P., and Meinshausen, M., 2017. Equitable mitigation to achieve the Paris Agreement goals. *Nature Climate Change*, 7(1), pp. 38-43. <http://doi.org/10.1038/NCLIMATE3186>
- Rogelj, J., den Elzen, M., Höhne, N., Fransen, T., Fekete, H., Winkler, H., et al., 2016. Paris Agreement climate proposals need a boost to keep warming well below 2 °C. *Nature*, 534(7609), pp.631–639. <http://doi.org/10.1038/nature18307>
- Rogelj, J., Fricko, O., Meinshausen, M., Krey, V., Zilliacus, J.J.J., and Riahi, K., 2017. Understanding the origin of Paris Agreement emission uncertainties. *Nature Communications*, 8. <https://doi.org/10.1038/ncomms15748>
- Rout, U. K., Akimoto, K., Sano, F., Oda, J., Homma, T., and Tomoda, T., 2008. Impact assessment of the increase in fossil fuel prices on the global energy system, with and without CO₂ concentration stabilization. *Energy Policy* 36(9), pp. 3477-3484. <https://doi.org/10.1016/j.enpol.2008.05.030>
- Sano, F., Akimoto, K., Homma, T., Tokushige, K., and Shoai, T. B., 2015a. Evaluation on the Japan's INDC in comparison with other nations', and in the context of achieving 2°C target. In: The Integrated Assessment Modeling Consortium (IAMC), *Eighth annual meeting of the IAMC 2015*, Potsdam, Germany, 16-18 November 2015.
- Sano, F., Homma, T., Tokushige, K., and Akimoto, K., 2015b. *Evaluations on emission reduction efforts of the INDCs and the expected global emissions*. [pdf]. Available at: <http://www.rite.or.jp/system/latestanalysis/pdf/E-GlobalCO2Emission_INDCs_20151111.pdf> [Accessed on 10 October 2017]
- Spencer, T., Pierfederici, R., Waisman, H., Colombier, M., Bertram, C., Kriegler, E., Luderer, G., Humpenöder, F., Popp, A., Edenhofer, O., Den Elzen, M., van Vuuren, D., van Soest, H., Paroussos, L., Fragkos, P., Kainuma, M., Masui, T., Oshiro, K., Akimoto, K., Shoai Tehrani, B., Sano, F., Oda, J., Clarke, L., Lyer, G., Edmonds, J., Fei, T., Sha, F., Kejun, J., Köberle, A.C., Szklo, A., Lucena, A.F.P., Portugal-Pereira, J., Rochedo, P., Schaeffer, R., Awasthy, A., Kumer Shrivastava, M., Mathur, R., Rogelj, J., Jewell, J., Riahi, K., and Garg, A., 2015. *Beyond the numbers: Understanding the transformation induced by INDCs*. Study N°05/15, IDDRI – MILES Project Consortium. Paris: IDDRI.

- Tavoni, M., Kriegler, E., Riahi, K., van Vuuren, D. P., Aboumahboub, T., Bowen, A., Calvin, K., Campiglio, E., Kober, T., Jewell, J., Luderer, G., Marangoni, G., McCollum, D., van Sluisveld, M., Zimmer, A., and van der Zwaan, B., 2015. Post-2020 climate agreements in the major economics assessed in the light of global models. *Nature Climate Change*, 5, pp. 119-126. <https://doi.org/10.1038/nclimate2475>
- Terzi, N., and Celik, S., 2016. Oil prices and trade in Turkey: A wavelet continuous transform analysis. *Eurasian Journal of Economics and Finance* 4(4), pp. 29-41. <https://doi.org/10.15604/ejef.2016.04.04.004>
- UN, 1992. United Nations framework convention on climate change [pdf]. Available at: <<https://unfccc.int/resource/docs/convkp/conveng.pdf>> [Accessed on 10 October 2017].
- UNFCCC, 2015. *Synthesis report on the aggregate effect of the intended nationally determined contributions* [pdf]. Available at: <<http://unfccc.int/resource/docs/2015/cop21/eng/07.pdf>> [Accessed on 10 October 2017]
- UNFCCC, 2016. *Greenhouse gas inventory data* [online]. Available at: <http://unfccc.int/ghg_data/items/3800.php> [Accessed on 10 October 2017].
- UNFCCC, 2017. *Intended Nationally Determined Contributions (INDCs)* [online]. Available at: <http://unfccc.int/focus/indc_portal/items/8766.php> [Accessed on 6 November 2017].

Appendix A. The global energy and GHG emission reduction assessment model DNE21+

The DNE21+ model is an inter-temporal linear programming model for the assessment of global energy systems and global warming mitigation in which the worldwide costs are to be minimized. The model represents regional differences (54 regions) and assesses detailed energy-related CO₂ emission reduction technologies (about 300 specific technologies), considering explicit facility replacement over the entire time period up to 2100. When any emission restrictions (e. g., an upper limit on emissions, emission reduction targets, targets for energy or emission intensity improvements, or carbon taxes) are applied, the model specifies the energy systems whose costs are minimized, meeting all the assumed requirements, including assumed production for industries such as iron and steel, cement, paper and pulp, transportation by car, bus, and truck, and other energy demands. The energy supply sectors are directly linked with the energy end-use sectors, including energy exporting/importing, and the lifetimes of facilities are taken into account so that assessments are made with complete consistency regarding the energy systems in question. Based on plausible ranges derived from the relevant literature, the model assumes energy efficiency improvements and cost reductions in several kinds of technologies such as renewable energies and carbon dioxide capture and storage (CCS).

Figure A1. Outline of energy flows in DNE21+

Source: Akimoto et al. (2016)

Appendix B.

Table B1. Type of NDCs for the DNE21+ model's 54 regions

Region No.	Countries	Type No. of NDCs*	Type of NDCs included in each region			
			0. No target (BAU)	1. Emissions reduction ratio from base years	2. GHG intensity (GHG emissions per GDP) improvement	3. Emissions reduction ratio compared to BAU
Reg. 0:	United States	1		○		
Reg. 1:	Canada	1		○		
Reg. 2:	United Kingdom	1		○		
Reg. 3:	France	1		○		
Reg. 4:	Germany	1		○		
Reg. 5:	Italy	1		○		
Reg. 6:	Spain, Portugal	1		○		
Reg. 7:	Belgium, Netherlands, Denmark	1		○		
Reg. 8:	North Europe	1		○		
Reg. 9:	Other EU	1		○		
Reg. 10:	Norway, Iceland	1		○		
Reg. 11:	Greenland (Denmark)	1		○		
Reg. 12:	Switzerland, Liechtenstein	1		○		
Reg. 13:	Japan	1		○		
Reg. 14:	Australia	1		○		
Reg. 15:	New Zealand	1		○		
Reg. 16:	Other Oceania	4	○	○		○
Reg. 17:	China	2			○	
Reg. 18:	North Korea, Mongolia	3	○			○
Reg. 19:	Viet Nam, Cambodia, Laos	3	○			○
Reg. 20:	Korea	3				○
Reg. 21:	Malaysia, Singapore	2	○		○	
Reg. 22:	Indonesia	3	○			○
Reg. 23:	Thailand	3				○
Reg. 24:	Philippines	0	○			
Reg. 25:	Brunei	0	○			
Reg. 26:	Chinese Taipei	0	○			
Reg. 27:	India	2			○	
Reg. 28:	Pakistan, Afghanistan	0	○			
Reg. 29:	Myanmar	0	○			
Reg. 30:	Other Asia	3	○			○
Reg. 31:	Iran	0	○			
Reg. 32:	Saudi Arabia	3				○***
Reg. 33:	Bahrain, Oman, Qatar, UAE, Yemen	3	○			○
Reg. 34:	Other Middle East	4	○	○		○
Reg. 35:	Turkey	3				○
Reg. 36:	North Africa	4	○		○	○
Reg. 37:	South Africa	1		○**		
Reg. 38:	South East Africa	3	○			○
Reg. 39:	Other S.S.Africa	4	○	○		○
Reg. 40:	Mexico	3				○
Reg. 41:	Other Central America	4	○	○		○
Reg. 42:	Brazil	1		○		
Reg. 43:	Venezuela, Guyana, Suriname	0	○			
Reg. 44:	Paraguay, Uruguay, Argentina	3	○			○
Reg. 45:	Other South America	4	○		○	○
Reg. 46:	Russia	1		○		
Reg. 47:	Other Annex I of FUSSR	1		○		
Reg. 48:	Belarus	1		○		
Reg. 49:	Kazakhstan	1		○		
Reg. 50:	Other FUSSR	4	○	○		○
Reg. 51:	OECD E.Europe	1		○		
Reg. 52:	Other Annex I of East Europe	1		○		
Reg. 53:	Other E.Europe	4	○	○		○
	Total number	-	23	29	5	19

*Type number of NDCs: 0. No target (BAU), 1. Emissions reduction ratio from base years, 2. GHG intensity (GHG emissions per GDP) improvement, 3. Emissions reduction ratio compared to BAU, 4. Others (multiple targets including no target).

** Emissions amount without base years is pledged.

*** Emissions reduction amount compared to BAU is pledged.

Source: UNFCCC (2017)

Appendix C.

A Primary energy consumption [Mtoe/yr]

B Electricity generation [TWh/yr]

Figure C1. BAU total primary energy consumption, and BAU electricity generation for three fossil fuel price cases

Figure C2. MACs of regions plotted against emissions reduction ratio and carbon intensity in 2030

Note: For regions whose target has a range, only the lower limits of these targets are displayed. US data are for 2025. MACs of EU28 countries are assumed equal. Brazil's MAC of 700-800\$/tCO₂eq is excluded.

Figure C3. BAU Coal consumption (TPES) in DNE21+ regions in 2030

Figure C4. Total abatement cost (%GDP) by region and by type of NDCs in 2030 for low and high fuel price cases

Note: US data are for 2025.

Table C1. Fossil fuel price impacts on MACs and potential factors explaining the change (increase/decrease) in MACs

		Explained variable			Explanatory variables																										
Region	Type of NDC target ^a	[1] MAC (NDC) [US\$/tonCO ₂ e]			[2] BAU CO ₂ e emission [MtCO ₂ e]			[3] BAU Carbon Intensity [CO ₂ /1,000 US\$2005]			[4] BAU RE share [%TPES]			[5] BAU Gas share [%TPES]			[6] BAU Gas-Coal ratio (Gas/Coil)[TPES]			[7] Emission reduction ratio relative to BAU [%]			[8] RE share change relative to BAU [%]			[9] Gas-Coal ratio change relative to BAU (Gas/Coil)[TPES]			[10] NDC Gas share [%TPES]		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
United States	1	89	72	62	5907	5670	5541	0.31	0.30	0.29	1.1%	1.5%	2.5%	41.8%	42.6%	36.3%	3.4	3.3	2.4	28.2%	25.4%	23.8%	4.2%	3.8%	3.0%	77.1	29.3	14.6	45.6%	42.2%	39.7
Canada	1	150	135	120	634	575	494	0.48	0.44	0.38	10.4%	13.8%	16.3%	29.2%	25.4%	32.7%	2.6	2.4	4.1	46.2%	40.4%	31.1%	11.0%	7.7%	5.1%	5.7	3.8	2.1	33.0%	28.8%	28.6
EU28	1	240	211	183	4202	4259	3960	0.34	0.34	0.32	2.8%	3.4%	4.0%	33.3%	26.6%	27.5%	2.3	1.3	1.5	38.2%	38.0%	34.4%	4.6%	4.4%	4.6%	5.8	4.7	3.2	33.2%	32.8%	33.2
Norway, Iceland	1	78	72	63	40	40	39	0.14	0.14	0.14	46.3%	48.3%	51.8%	21.1%	20.1%	19.2%	3.0	3.0	3.4	55.3%	55.2%	53.5%	14.1%	9.4%	7.4%	6.8	1.7	3.4	30.4%	16.7%	16.2
Switzerland	1	500	430	400	71	58	49	0.18	0.15	0.13	14.0%	15.8%	17.8%	36.5%	30.3%	19.8%	38.8	29.2	18.3	74.3%	68.6%	63.5%	18.1%	16.0%	14.3%	-32.5	-22.3	-10.5	8.8%	9.5%	10.8
Japan	1	493	487	445	1283	1221	1205	0.18	0.17	0.17	1.6%	2.5%	2.5%	22.9%	25.4%	25.4%	0.8	0.89	0.90	32.2%	28.7%	26.7%	5.8%	5.5%	5.4%	0.0	-0.1	0.0	20.9%	20.8%	22.3
Australia	1	32	34	38	435	425	389	0.50	0.49	0.45	1.3%	2.2%	4.8%	21.9%	16.0%	16.5%	0.6	0.4	0.4	42.2%	41.2%	35.7%	7.8%	7.2%	4.4%	0.0	0.3	0.1	31.1%	21.3%	17.7
New Zealand	1	100	95	90	46	43	38	0.46	0.42	0.37	20.2%	21.8%	28.1%	23.3%	25.6%	25.3%	1.1	1.2	1.6	59.7%	57.1%	52.4%	22.5%	21.9%	17.0%	5.4	4.2	4.4	20.6%	19.7%	18.8
South Africa	1	42	49	49	585	585	562	1.72	1.72	1.65	0.3%	0.6%	0.7%	2.0%	2.0%	2.0%	0.027	0.027	0.028	52.4%	52.1%	50.2%	2.7%	3.3%	6.9%	0.3	0.1	0.0	14.8%	7.6%	2.9
Russia	1	18	5	1	2660	1951	1607	1.73	1.64	1.52	1.3%	2.4%	3.4%	72.6%	68.0%	63.6%	9.0	6.3	5.0	12.4%	7.5%	8.5%	1.0%	0.7%	0.7%	8.9	0.7	0.8	74.7%	67.6%	63.3
Kazakhstan	1	4	3	12	225	257	248	1.96	2.24	2.17	0.9%	1.3%	1.9%	35.2%	14.1%	15.9%	0.8	0.2	0.3	19.9%	19.6%	21.9%	0.20%	0.21%	0.30%	0.19	0.1	0.22	38.0%	18.9%	23.9
China	2	0	0	0	15115	14005	13208	1.15	1.07	1.01	1.8%	2.4%	2.6%	13.3%	8.8%	8.4%	0.2	0.1	0.1	12.7%	5.8%	0.1%	0.6%	0.0%	0.0%	0.0	0.1	0.0	14.6%	10.8%	7.2
Malaysia, Singapore	0	0	0	0	430	406	377	0.65	0.60	0.4%	1.2%	1.9%	47.0%	44.2%	38.8%	4.3	3.8	3.2	0.0%	0.0%	0.0%	1.3%	1.0%	1.6%	-0.1	0.1	0.0	45.1%	43.4%	39.2	
India	2	0	0	0	5092	5231	4760	1.53	1.60	1.43	0.8%	1.5%	2.0%	16.4%	8.1%	6.4%	0.3	0.1	0.1	0.0%	3.9%	0.0%	0.5%	-0.1%	0.0%	0.0	0.1	0.14	9.0%	9.9%	9.9
Korea	3	114	110	163	776	767	677	0.59	0.59	0.52	0.28%	0.31%	0.7%	9.7%	8.2%	8.3%	0.27	0.22	0.26	39.1%	37.7%	38.1%	0.90%	0.86%	3.7%	1.15	0.77	1.17	17.6%	15.1%	14.8
Indonesia	4	46	35	34	744	721	695	1.10	1.06	1.02	3.1%	4.7%	5.5%	42.3%	39.5%	37.2%	4.1	3.4	2.9	29.9%	28.74%	28.70%	4.6%	5.6%	9.5%	7.7	5.4	6.2	41.9%	38.4%	34.7
Thailand	3	1	0	4	608	702	553	1.41	1.63	1.28	2.2%	2.3%	3.7%	25.3%	3.1%	3.6%	0.6	0.0	0.1	24.2%	26.2%	22.3%	0.6%	4.6%	9.4	0.3	0.2	36.7%	14.9%	11.1	
Saudi Arabia	3	29	74	68	1108	1056	1047	1.28	1.21	1.21	0.0%	0.0%	0.0%	18.1%	12.8%	12.2%	18.8	6.6	6.5	10.0%	10.2%	10.3%	0.02%	0.04%	0.04%	-1.3	7.1	6.9	15.3%	12.7%	12.6
Turkey	3	39	64	38	463	410	420	0.60	0.53	0.54	1.9%	5.4%	7.0%	51.1%	44.9%	28.5%	3.3	2.6	6.5	20.0%	19.1%	19.5%	4.1%	2.5%	1.1%	2.0	0.5	1.3	50.3%	39.2%	35.0
Mexico	3	75	30	38	4616	718	649	0.42	0.49	0.45	1.9%	3.3%	4.0%	28.8%	23.2%	20.8%	3.7	0.78	0.80	24.4%	25.7%	25.4%	3.2%	1.7%	2.6%	5.4	2.1	1.1	37.4%	31.5%	24.1

L: Low, M: Medium, H: High, RE: Renewable Energy

*Type number of NDCs: 0. No target (BAU), 1. Emission reduction ratio from base years, 2. GHG intensity (GHG emissions per GDP) improvement, 3. Emission reduction ratio compared to BAU

[1] Explained variable:

- MAC of low price case > MAC of high price case
- MAC of low price case < MAC of high price case
- MACs are zero in all price cases.

[2]~[10] Explanatory variables:

Factors that can fully explain the order of MACs ([1])

Factors that can partially explain the order of MACs ([1])