Sufficient or insufficient: Assessment of the Intended Nationally Determined Contributions (INDCs) of the world's major greenhouse gas emitters

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Abstract: The recent Conference of the Parties of the United Nations Framework Convention on Climate Change has resulted in the submission of the Intended Nationally Determined Contributions (INDCs) of 190 countries. This study aims to provide an analysis of the ambitiousness and fairness of the mitigation components of the INDCs submitted by various parties. We use a unified framework to assess 23 INDCs that cover 50 countries, including European Union (EU)-28 countries as parties to the Convention, which represent 87.45% of the global greenhouse gas emissions in 2012. First, we transform initial INDC files into reported reduction targets. Second, we create four schemes and six scenarios to determine the required reduction effort, which considers each nation's reduction responsibility, capacity, and potential, thereby reflecting their historical and current development status. Finally, we combine the reported reduction target and the required reduction effort to assess INDCs. Evaluation results of the 23 emitters indicate that 2 emitters (i.e., EU and Brazil) are rated as "sufficient", 7 emitters (e.g., China, the United States, and Canada) are rated as "moderate", and 14 emitters (e.g., India, Russia, and Japan) are rated as "insufficient". Most pledges exhibit a considerable distance from representing a fair contribution.

Keywords: Intended Nationally Determined Contributions, Mitigation, Responsibility, Capacity, Potential

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1 Introduction

The release of CO_2 and other greenhouse gases (GHGs) as a result of human activities is causing climate change, which controls human development. To avoid the dangers of climate change, the global community of nations reached an agreement in 2015 to keep global average temperature rise considerably below 2 °C above the pre-industry level and to pursue efforts that can further reduce it to 1.5 °C. To accomplish these objectives, 190 countries, including one regional economic integration organization, i.e., the European Union (EU) and its 28 member states, had submitted their voluntary GHG reduction commitments, called Intended Nationally Determined Contributions (INDCs), by November 5, 2016. These INDCs, which account for 98.09% of global GHG emissions, outline the intended post-2020 climate action plans of these countries (UNFCCC, 2016). INDCs undoubtedly represent a breakthrough in the international effort to curb future GHG emissions.

This study compares the reported reduction targets and required reduction efforts of several countries. The assessment conclusion presents the ambitious endeavors of the countries toward decarbonization and whether the submitted INDCs can achieve the global emission reduction objective. The assessment results may help countries formulate better policies. The remainder of this paper is organized as follows. Section 2 provides an overview of the relevant literature on the assessment of INDCs. Section 3 proposes a rating method for the reported reduction targets and required reduction efforts. The data resource is also provided in Section 3. Section 4 presents the results. Finally, Section 5 concludes the study and discusses its uncertainties.

2 Overview of the assessments of INDCs

Several studies have assessed the aggregated efforts of INDCs to reduce global emissions. In particular, the United Nations Framework Convention on Climate Change (UNFCCC), the United Nations Environment Programme (UNEP), and the Climate Action Tracker (CAT) present three essential reports.

UNFCCC released its synthesis report, which includes all INDCs submitted by October 1, 2015 (147 parties, including EU's 28 member states), on October 30, 2015. This report, which covers over 80% of global emissions in 2010 (UNFCCC, 2015), aims to assess the aggregate emission impact of domestic efforts before the 2015 United Nations Climate Change Conference (COP 21). The report provides qualitative and quantitative evaluations of INDCs. It states that all the information provided by INDCs about mitigation actions and the emission growth that will result from these actions is expected to slow down by a third in the period of 2010–2030 compared with that in the period of 1990–2010. Through these mitigation efforts, the world can stride toward its emission reduction target. Despite the extensive and unprecedented involvement of countries in such a global effort, the mitigation actions will not hold the world's temperature below the 2 °C trajectory. The temperature at the end of the century will strongly rely on many factors, including technological development, long-term actions, and the energy structure.

On November 6, 2015, UNEP (2015) released the Emission Gap Report 2015, which provided an update on the assessment of the mitigation effects of INDCs submitted by October 1, 2015. The expert team prepared a preliminary assessment of 38 INDCs among the 59 submissions, accounting for 60% of current global GHG emissions and excluding emissions from land use, land use change and forestry (LULUCF). Assessments of the literature on INDCs are obtained from global and national studies, including estimates from many country-specific studies (e.g., World Resource Institute (WRI), Energy Research Institute, National Center for Climate Change Strategy and International Cooperation), official estimates (documents submitted by countries to UNFCCC), and eight global studies (e.g., CAT, PBL Netherlands Environmental Assessment Agency, International Energy Agency's World Energy Outlook). The results show that the estimated emission level of the most likely scenario cannot limit global average temperature increase to below 3.5 °C (range: 3 °C –4 °C) by 2100 with a probability of over 66%. However, if all INDCs are fully implemented, then the 2030 emission gap will still be 12 Gt CO_2e, thereby placing the world on track to a temperature rise of approximately 3 °C by 2100, with significant climate impacts.

CAT, an independent science-based assessment, has been tracking government emission commitments and actions for years. In preparation for the adoption of the Paris Agreement in December 2015, CAT analyzed the INDCs of 32 parties (CAT, 2016), in which 59 countries (including EU-28 countries as parties to the Convention) covering 81.3% of global emissions in 2010 were analyzed. The CAT methodology for assessing and rating INDCs focuses on CO_2 and other GHG emissions from fossil fuel combustion, industries, agriculture, and waste sources, which account for 93% of global GHG emission in 2012. CO_2 and other GHG emissions from LULUCF, which comprise approximately 7% of global GHG emission, are not included in the effort sharing ranking system. In the assessment of this system, a wide range of literature on what researchers will consider a "fair" contribution to GHG reduction, including over 40 studies used by the Intergovernmental Panel on Climate Change (IPCC) and additional analyses performed by CAT, is compiled to complete the database. The final assessment result depends on a nation's proposal on which part of the emission range is calculated. For example, if a government's proposal is higher than any calculated emissions, then CAT rates it as "inadequate".

Overall, the three aforementioned reports agree that despite the positive contribution of INDCs, a considerable gap remains between the political 2 °C ambition and current intended contributions. The mitigation commitment of all countries should be upgraded to narrow the gap with the temperature target.

Other independent entities have also concluded that despite the reductions, the global GHG emission level is still projected to be higher in 2030 than in 2010 (Höhne et al., 2014; Davide and Vesco, 2016; den Elzen et al., 2016). However, most studies have focused only on the aggregated effect of INDCs and the implication for achieving the temperature goal, which cannot offer comprehensive comparisons on the same basis among countries (Rogelj et al., 2016). To our knowledge, only the report of CAT has ranked countries in terms of the ambitiousness of their individual INDCs. In the current study, we aim to analyze the INDCs submitted by parties and assess the proposed national pledges. First, we calculate each party's reported reduction target, which is represented by the CO_2 emission reduction commitment in 2030 from the initial INDCs files. Second, we calculate each party's required reduction effort according to the reduction factor. Finally, we compare the parties' reported reduction target and required reduction effort and provide an assessment of their INDCs.

3 Method and data

We analyzed and rated all the INDCs of parties with high global CO_2 emission share in 2012 and specific quantifiable goals. Six parties, namely, North Korea, Libya, Syria, Nicaragua, Panama, and Timor-Leste, which account for 0.52% of the global emissions in 2012, have not submitted INDCs (Fig. 1). Meanwhile, the emission share of each of the 147 countries that have submitted INDCs was less than 0.45% in 2012. Their total emission share was 8.78%. Moreover, the emission share of 54 countries (27 parties, EU member states are counted as one party) was each higher than 0.45% in 2012. The INDCs of these 27 parties accounted for 90.56% of the global CO_2 emissions (the sum of the emission shares of the first two lines in Fig. 1). Among the 54 countries, Egypt, Saudi Arabia, Pakistan, and the United Arab Emirates, accounted for 3.11% of the global emissions in 2012. These countries submitted INDCs without specific GHG mitigation target and action, thereby implying that our evaluation objects are 50 countries (23 INDCs), which represent 87.45% of global emissions. Fig. 1 shows the major countries that have submitted INDCs and their global emission shares.

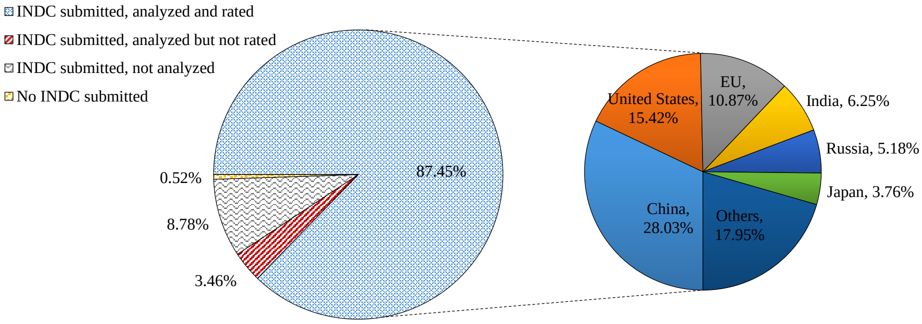

Fig. 1 Major countries that have submitted INDCs and their global emission shares in 2012

3.1 Assessment process

We assess and rate INDCs according to a specific assessment roadmap (Fig. 2), which is divided into two steps. In the first step, we extract the reported reduction target, which is represented by the CO_2 emission reduction commitment in 2030 from initial INDC files. In the second step, we calculate each party's required reduction effort. We set up four schemes and six scenarios. The four schemes are responsibility-oriented, capacity-oriented, potential-oriented, and average weighting schemes. The scenarios limit the amount of emission space that nations can use. We set up six scenarios based on business as usual (BAU) and emission control scenarios. One combination of scheme and scenario results in one required reduction effort. Therefore, we obtain 24 required reductions. Finally, we compare the reported reduction targets of parties with their required reduction efforts and then provide an assessment of their INDCs.

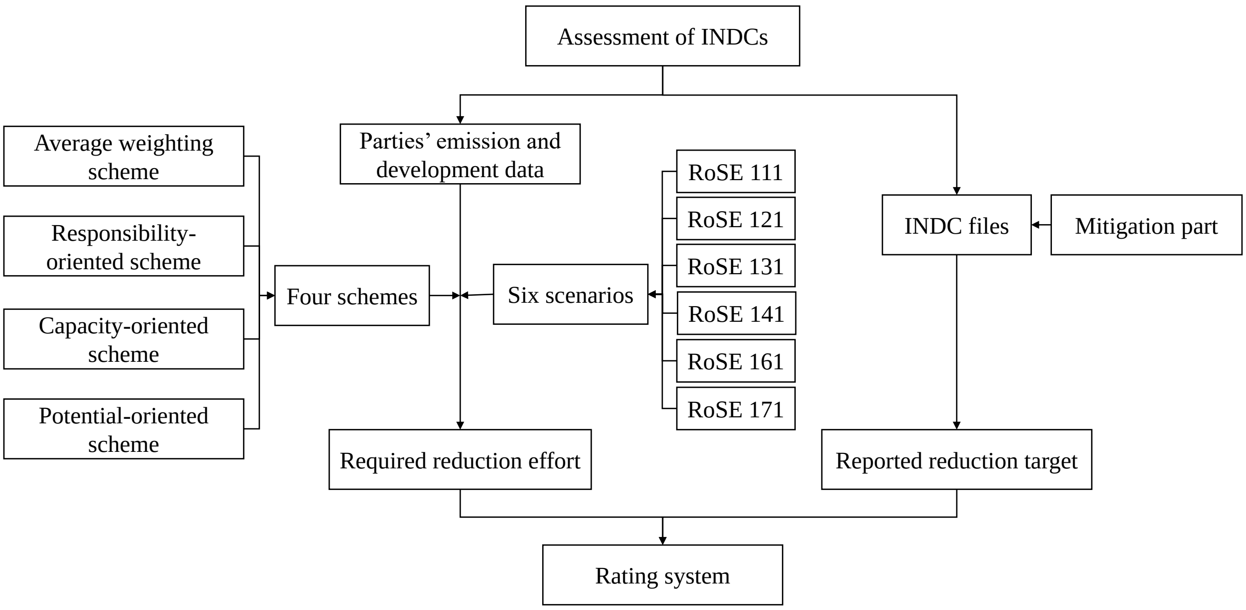

Fig. 2 Assessment process

3.2 Rating method

On the basis of CAT's method, the rating method used in this study is described as follows (Fig. 3). If a country's reported reduction target transformed from its INDC file is below the required reduction effort range, which is composed of 24 combinations of schemes and scenarios, then it is rated as "insufficient" (dark blue in the bar). This country's INDC is considered not in line with the 2 °C pathway limit. If a country's commitment emission reduction from its INDC is higher than any of the required reduction effort, then it is rated as "sufficient" (white in the bar). Such proposal is determined to meet the Paris Agreement goal of limiting temperature change to below 2 °C above the pre-industry level. Furthermore, countries with reported reduction targets that fall in the middle of the required ranges are rated as "moderate" (light blue in the bar). Their efforts are between "inadequate" and "sufficient".

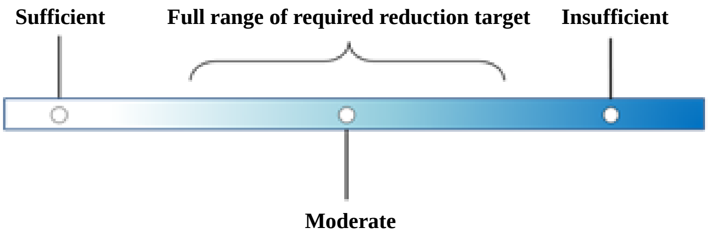

Fig. 3 Rating criteria

3.3 Reported reduction target

The first step is extracting the reported reduction target from the INDCs' mitigation part (Supplementary Table 1). However, the INDCs of parties are heterogametic among submissions, both in terms of GHG coverage and mitigation effort. First, the emission reduction targets of Annex I Parties include six types of Kyoto Protocol gases (excluding NF_3) or all seven types of GHGs (including NF_3). Meanwhile, the GHG coverage of Non-Annex I Parties is different. Most parties listed only two to three types of GHGs. For comparability, we consider only CO_2 in our study because it is the leading GHG. Second, most countries express their contributions in the form of a quantifiable mitigation effort compared with a specific emission level in a reference year or a BAU scenario, from which targets can be transformed. The reference year emissions and BAU scenario emissions are collected from the CAIT Climate Data Explorer database of WRI. By contrast some developing countries (e.g., China and India) formulate their pledges in terms of emission intensity or emission peak year. Further assumptions on the development of the economy and the society are required to obtain the reported target of the two countries, which lead to uncertainties in their emission control efforts. The required emission target is obtained from the CAT report. In addition, four countries (United Arab Emirates, Egypt, Saudi Arabia, and Pakistan) have not specified a quantitative emission reduction commitment but have focused on mitigation action. We have not quantified their reported reduction target. All the reported reduction targets of the parties are projected to 2030 because most parties defined their INDC target year as 2030, except for the United States and Brazil, which adopted 2025 as their target year. We assume that the emission reductions of these two countries are linear in 2025–2030 and transform the target year into 2030.

In addition, heterogeneity appears in the reported promised conditions of parties. Several parties distinguish between unconditional and conditional targets. Among the 23 INDCs assessed, 9 parties have indicated their need for international financial support. They are requesting for market-based cooperation mechanisms and domestic and international financial assistance, such as emission allowance purchases and capacity-building support, toward their commitment. For assessment uniformity, only unconditional commitment is included in this study. Table 1 presents the CO_2 emission reduction commitment for 2030 under quantifiable unconditional commitment.

Table 1 Reported reduction targets from INDCs (top–down in descending order of emission shares in 2012)

Abbreviation	Country	Projected BAU emissions ($MtCO_2$)	Absolute emission reduction ($MtCO_2$)	Percentage emission reduction with respect to 2030 BAU (%)
CN	China	13457.25	1457.25	10.83
US	United States	6864.83	3002.14	43.73
EU-28	EU-28	5423.99	2910.97	53.67
IN	India	5082.93	−917.07	−18.04
RU	Russian Federation	2011.40	388.74	19.33
JP	Japan	1360.89	428.79	31.51
KR	Korea, Republic of	815.40	279.52	34.28
IR	Iran	784.46	9.74	1.24
CA	Canada	1022.23	630.50	61.68
SA	Saudi Arabia	634.40	-	-
BR	Brazil	870.77	673.26	77.32
MX	Mexico	949.20	170.69	17.98
ID	Indonesia	602.46	−494.22	−82.03
AU	Australia	736.57	237.18	32.20
ZA	South Africa	1127.21	513.21	45.53
TR	Turkey	499.17	174.88	35.03
UA	Ukraine	334.52	−85.30	−25.50
TH	Thailand	360.77	−133.99	−37.14
KZ	Kazakhstan	273.84	69.87	25.51
EG	Egypt	646.55	-	-

MY	Malaysia	274.59	−215.01	−78.30
VN	Venezuela	426.81	299.83	70.25
AR	Argentina	377.44	241.31	63.93
AE	United Arab Emirates	239.50	-	-
VN	Vietnam	387.60	187.98	48.50
DZ	Algeria	228.60	−126.45	−55.31
PK	Pakistan	201.03	-	-
UZ	Uzbekistan	135.58	-	-

3.4 Required reduction effort

The second step is to calculate the required reduction effort for each country. Emission scenarios limit the amount of space that nations can release to the atmosphere. First, we determine six emission scenarios by comparing two scenarios: BAU and emission control. The BAU scenario provides information on how emissions are likely to develop in the absence of mitigation policies. The emission control scenario is represented by the Representative Concentration Pathway (RCP)2.6 scenario, which can limit global mean temperature to approximately or below a 2 °C increase since pre-industrial times (van Vuuren et al., 2007). The difference between the BAU emission scenario without INDC commitment and the emission control scenario results in an "emission gap" in the world, thereby indicating that global reduction effort is required.

3.4.1 Six emission scenarios

Here, we present six scenarios based on diverse gaps.

BAU scenarios

We provide six different scenarios based on the Roadmaps toward Sustainable Energy Futures (RoSE) scheme using the Global Climate Assessment Model (GCAM). GCAM is an RCP-class model (Joint Global Change Research Institute, 2015) that can be used to simulate scenarios, policies, and emission targets from various sources. It is calibrated between 1990 and 2005 and operates in 15-year time steps until 2095. The output includes projections of future energy supply, demand, resulting GHG emissions, radiative force, and the climate effects of 16 GHGs. This model has been widely used in national and international assessment activities, such as the Energy Modeling Forum, the United States Climate Change Technology Program, and IPCC assessment reports.

Six different scenarios (RoSE 111, RoSE 121, RoSE 131, RoSE 141, RoSE 161, and RoSE 171) and their corresponding emissions across the model are attributed to three dimensions: (1) underlying assumptions on future socioeconomic development determined by population and economic growth; (2) reference assumptions on long-term fossil fuel availability with a focus on variations in coal, oil, and gas; and (3) stringency and timing of climate protection targets and framework of an international climate policy. In this study, we set the climate policy regime as the baseline.

The RoSE scenario matrix is presented in Table 2. Each column corresponds to a combination of socioeconomic and fossil resource drivers. The growth speed of each parameter is divided into three levels: Fast (or High), Med, and Slow (or Low). Using the Rose 111 scenario as an example, “Med Growth” indicates that the growth speed of the economy is medium, “Fast Conv” represents fast convergence of economies, and “Med Pop” and “Med Fossils” denote moderate growth rates for population and fossil consumption.

Table 2 RoSE scenario matrix

Scenario	RoSE 111	RoSE 121	RoSE 131	RoSE 141	RoSE 161	RoSE 171
Element	Med Growth	Slow Growth	Fast Growth	Slow Growth	Med Growth	Med Growth
	Fast Conv	Fast Conv	Fast Conv	Slow Conv	Fast Conv	Fast Conv
	Med Pop	Med Pop	Med Pop	High Pop	Med Pop	Med Pop
	Med Fossils	Med Fossils	Med Fossils	Med Fossils	High Fossils	Low Fossils

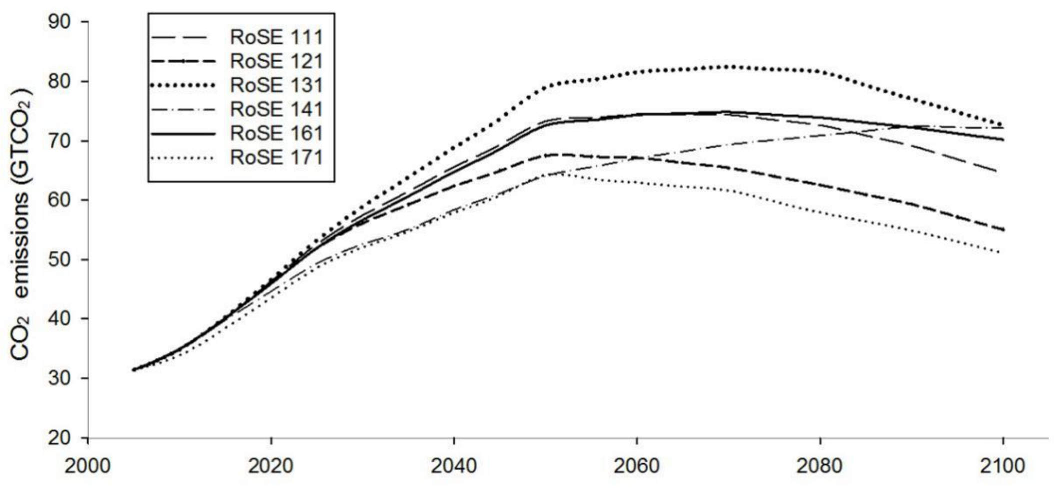

Fig. 4 CO_2 emissions in six global BAU scenarios

Emission control scenarios

The emission control scenario is determined by RCPs (van Vuuren et al., 2011; Meinshausen et al., 2011; Hibbard, 2010), which are scenarios for the possible future evolution of concentrations of various gases that affect climate. Different RCPs are related to varying radiative force levels. RCP2.6 represents strong abatement relative to a no-climate policy reference scenario, with CO_2 concentrations not exceeding approximately 450 ppm. Fig. 4 shows the emission pathways of the world under RCP2.6 compared with those under RCP4.5 and RCP8.5. In RCP2.6, the peak year of CO_2 emissions is approximately 2020, and then emissions will decrease with a high speed compared with the pre-2020 level. In this case, the global CO_2 emission in 2030 will reach 26.24 $GtCO_2$, which is nearly the same level as that in 2003. Eventually, the difference between each BAU emission scenario and emission control scenario will require a global reduction effort. We obtain six global required efforts because we have six BAU scenarios.

RCPs are meant to serve as input for climate and atmospheric chemistry modeling as part of the preparatory phase for the development of new scenarios for the IPCC's Fifth Assessment Report and beyond. Here, we select RCP2.6, which was developed by the IMAGE modeling team of the Netherlands Environmental Assessment Agency. The emission pathway is representative of scenarios in the literature with very low GHG concentration levels. RCP2.6 is a so-called "peak" scenario: the radiative force level first reaches a value of approximately 3.1 W/m^2 by mid-century and then returns to 2.6 W/m^2 by 2100 (Beltran et al., 2011; Davide and Vesco, 2016). To reach such radiative force levels, GHG emissions (and indirectly, air pollutant emissions) are reduced substantially over time. Emission data are obtained from the Potsdam Institute for Climate Impact Research.

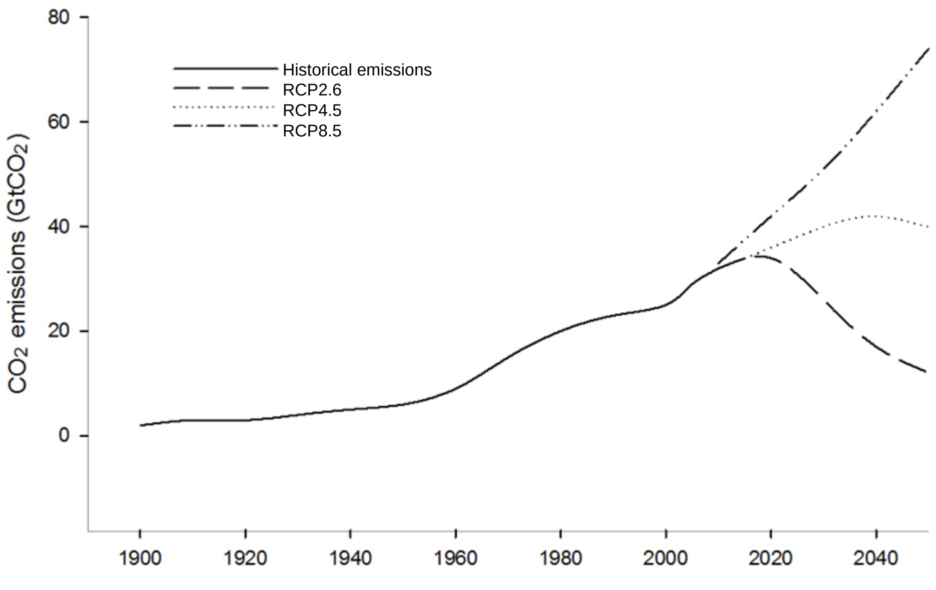

Fig. 5 Global emissions under RCP2.6, RCP4.5, and RCP8.5

3.4.2 Four schemes

We use the emission reduction factor to divide the required global emission reduction effort into parties' reduction efforts. The emission reduction factor is a comprehensive index composed of seven indicators that are grouped into three dimensions: carbon emission reduction responsibility, carbon emission reduction capacity, and carbon emission reduction potential. Countries with higher responsibility, capacity, and potential in CO_2 emission reduction should assume more obligations and implement more reduction efforts. We set two to three indicators in each dimension. Table 3 provides an overview of the seven indicators and three dimensions, along with their explanations.

Table 3 Emission reduction index system of the required reduction effort

Dimension	Indicators	Principle	Interpretation
Carbon emission reduction responsibility	Cumulative CO_2 emissions Per capita CO_2 emissions CO_2 emissions in 2012	Polluter pays	Countries with higher historical emissions should bear more emission reduction effort
Carbon emission reduction capacity	Per capita GDP Human Development Index	Vertical	Rich countries should assume more emission reduction effort
Carbon emission reduction potential	Carbon intensity Proportion of coal consumption to total energy consumption	Development level	Countries with more reduction space should reduce more emissions

Carbon emission reduction responsibility

The required emission reduction effort is determined by the level of historical emissions of a country. This principle was first proposed by Brazil in the Kyoto Protocol negotiation[2] and is perceived as the most significant influence factor, which means that an abatement of burden corresponds with emissions. The indicators include cumulative CO_2 emissions, per capita CO_2 emissions, and CO_2 emissions in 2012, which represent a country's historical emission level and current emission status.

The cumulative CO_2 emission indicator describes the long-term emission level. We select 1990 as the starting year for cumulative emissions because each country should have been aware of the climate problem caused by GHG emissions since 1990 (UNFCCC, 1997). The per capita CO_2 emission indicator reflects a country's per capita carbon emission level at a certain time point; it shows the social fair principle and regional fair principle of reduction, i.e., everyone has equal rights to obtain resources (Baer et al., 2009; Phylipsen et al., 1998). Future emission trend can be reflected from the current emission level. Countries with higher current emissions should assume more responsibility in reducing emissions.

Carbon emission reduction capacity

Several studies have used responsibility and capacity as bases for explicitly distributing emission reduction (Baer et al., 2009; Winkler et al., 2013). The associated principle, "vertical," indicates that rich countries should implement more reduction efforts. Given their diverse abilities, the respective responsibility of countries to protect the climate system varies from one another. Developed countries have higher capabilities compared with developing countries. Here, we select two indicators: gross domestic product (GDP) per capita and the Human Development Index (HDI). GDP per capita represents a nation's economic development level; it characterizes the economic feasibility of emission reduction (Yi et al., 2011; Ott et al., 2004). HDI compensates for the deficiency in measuring society-related state of development, which is a composite statistic that comprises life expectancy, education, and per capita income indicators. A country with longer life expectancy at birth, longer education period, and higher GDP per capita should assume more responsibility toward achieving emission reduction.

Carbon emission reduction potential

Carbon emission reduction potential represents a country's emission reduction space, which determines the amount of reduction that can be implemented domestically and corresponds to the "development level principle". A country with higher potential is obligated to utilize this advantage and reduce more domestic emissions (Winkler et al., 2007). Carbon emission intensity (carbon emission per unit of GDP) describes a country's carbon emission efficiency and reflects its energy development stage. A nation with higher national carbon emission intensity has lower carbon emission efficiency, and thus, has more space and potential to contribute to emission reduction (Wang et al., 2013; Wang et al., 2016). The proportion of coal consumption to total energy consumption represents a country's energy consumption structure. At present, carbon emissions primarily result from the combustion of fossil fuel emissions in most areas of the world. A nation with a higher proportion of coal consumption has greater potential to adjust its energy structure and bear more responsibility (Ringius et al., 1998).

We use the objective information entropy method and the subjective dimension weight set method to determine the emission reduction factor. The information entropy method can determine the information weights of the uncertainty degree of the information source. In the dimension weight set method, we establish four types of scheme: A: average weighting scheme, B: responsibility-oriented scheme, C: capacity-oriented scheme, and D: potential-oriented scheme. Each scheme has its reduction tendency and is distinguished by its weight of dimension. For example, the responsibility-oriented scheme gives more attention to emission reduction responsibility; thus, the indicators for the emission reduction responsibility dimension have higher dimension weights (DWs) compared with those for the other two dimensions. We then set four schemes and obtain four reduction factors to further determine the required reduction effort for each country.

3.4.3 Weights of the four schemes

Dimension weights (DW)

Given the current level of economic development, industrial structure layout and historical emissions are diverse among countries worldwide, and the emission reduction process of countries will emphasize different indicators. For comprehensiveness, we establish four schemes: responsibility-oriented, capacity-oriented, potential-oriented, and average weighting schemes. Different schemes respond to diverse DWs and reflect the emphasis of the carbon emission reduction effort. The specific setting and characteristic of each DW are presented in Table 4.

Table 4 DWs of the four schemes

$\boldsymbol{DW}$	A: average weighting scheme	B: responsibility-oriented scheme	C: capacity-oriented scheme	D: potential-oriented scheme
$\boldsymbol{DW_1}$	1/3	3/5	1/5	1/5
$\boldsymbol{DW_2}$	1/3	1/5	3/5	1/5
$\boldsymbol{DW_3}$	1/3	1/5	1/5	3/5

Indicator weights (IWs)

IW reflects the importance of each country's responsibility, capacity, and potential in the assessment. In this study, we use the information entropy method to determine the information character of the uncertainty degree of a country's indicator information source. First, we set up the original evaluation matrix as follows:

$$X = \begin{pmatrix} x_{1,1} & \cdots & x_{1,n} \\ \vdots & \ddots & \vdots \\ x_{m,1} & \cdots & x_{m,n} \end{pmatrix}, \qquad (1)$$

where x_{ij} denotes the raw data of the indicator, with *i* representing the serial number of the country, and *j* representing the selected indicator; m=28; and n=7. To avoid the influence of the scale of each indicator, we normalize every indicator of the countries as follows:

$$y_{i,j} = \frac{x_{i,j} - \min_i x_{i,j}}{\max_i x_{i,j} - \min_i x_{i,j}}, \qquad (2)$$

where y_{ij} is the normalized data. The resulting normalize matrix is as follows:

$$Y=\begin{pmatrix} y_{1,1} & \cdots & y_{1,n} \\ \vdots & \ddots & \vdots \\ y_{m,1} & \cdots & y_{m,n} \end{pmatrix}, \qquad (3)$$

Third, in accordance with the basic principle of the entropy weight method, the entropy weight e_j of indicator *j* can be calculated as follows:

$$e_j = -k\sum_{i=1}^{m} p_{i,j} \times \ln p_{i,j} \ , \qquad (4)$$

where k=1/ln$m$, $p_{i,j} = y_{i,j} \Big/ \sum_{i=1}^{m} y_{i,j}$, and *m* is the total number of evaluated countries. In particular, $p_{i\,j} = 0$ and $p_{i,j} \times \ln p_{i,j} = 0$. Each indicator weight under different dimensions can be expressed as follows:

$$IW_j = \frac{1-e_j}{\sum_{j=1}^{n} 1-e_j}\ , \qquad (5)$$

where IW_j is the entropy weight of indicator *j*. The final weight of each indicator is calculated as follows:

$$W_j = IW_j \times DW_j\ , \qquad (6)$$

where $0 \le W_j \le 1$, $\sum_{j=1}^{7} W_j = 1$, and DW_j is the subjective dimension weight, $DW_j \in \left(\frac{1}{3}, \frac{1}{5}, \frac{3}{5}\right)$.

Finally, we can obtain the emission reduction factor K_i of country *i* by linearly aggregating each indicator and the associated final weight as follows:

$$K_i = \sum_{j=1}^{7} W_j \times y_{i,j}\ , \qquad (7)$$

where emission factor K_i reflects a country's contribution toward climate change mitigation and the GHG emission reduction process. A country with a higher emission factor K_i should commit to more emission reduction effort. The required emission reduction effort of each country E_i can be calculated as follows:

$$E_i = E \times K_i \Big/ \sum_{i=1}^{28} K_i\ , \qquad (8)$$

where *E* is the global emission gap between global BAU and the RCP2.6 scenario.

The final required reduction effort is presented in Table 5.

Table 5 Required reduction efforts of 28 nations (Note: A: average weighting scheme, B: responsibility-oriented scheme, C: capacity-oriented scheme, and D: potential-oriented scheme)

Abbreviation	Parties	RoSE 111 (%)				RoSE 121 (%)				RoSE 131 (%)				RoSE 141 (%)				RoSE 161 (%)				RoSE 171 (%)			
		A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
CN	China	15	20	9	15	14	20	9	15	15	21	10	16	12	16	7	12	14	20	9	15	11	16	7	12
US	United States	35	45	40	23	34	43	38	22	37	47	42	24	28	36	32	19	35	44	39	23	27	34	31	18
EU-28	EU-28	30	38	33	20	29	37	31	20	31	40	34	21	24	31	26	16	29	37	32	20	23	29	25	16
IN	India	18	18	11	24	17	17	10	23	18	19	11	25	14	15	9	19	17	18	10	24	13	14	8	18
RU	Russian Federation	40	49	34	40	39	47	33	38	42	51	36	42	32	39	27	32	40	48	34	39	31	37	26	30
JP	Japan	102	95	131	79	98	91	126	76	107	99	137	82	82	76	105	63	100	93	129	77	78	73	100	60
KR	Korea, Republic of	136	120	163	123	131	115	156	118	142	126	170	128	109	97	131	99	134	118	160	120	104	92	124	94
IR	Iran	66	66	58	75	64	63	56	72	69	69	61	78	53	53	47	60	65	64	57	74	51	50	45	57
CA	Canada	101	90	145	65	97	87	138	62	105	94	151	68	81	73	116	52	99	89	142	64	77	69	111	50
SA	Saudi Arabia	122	121	159	86	117	116	152	83	128	127	166	90	98	98	128	69	120	119	156	85	94	93	122	66
BR	Brazil	27	25	33	22	26	24	32	21	28	26	34	23	22	20	27	18	26	25	32	22	21	19	25	17
MX	Mexico	32	30	39	26	30	28	37	25	33	31	41	27	25	24	31	21	31	29	38	26	24	23	30	20
ID	Indonesia	90	74	65	129	87	71	62	123	94	78	68	134	73	60	52	103	89	73	64	126	69	57	50	99
AU	Australia	174	147	220	151	167	141	211	144	182	153	229	157	140	118	177	121	171	144	216	148	133	112	168	115
ZA	South Africa	68	55	50	98	66	53	48	94	71	57	52	102	55	44	40	79	67	54	49	96	52	42	38	75
TR	Turkey	116	93	117	135	112	89	112	130	122	97	122	141	94	75	94	109	114	92	115	133	89	71	89	103
UA	Ukraine	239	195	167	348	229	187	160	333	250	203	175	363	192	157	134	280	235	191	164	342	183	149	128	266
TH	Thailand	120	100	109	147	115	96	105	141	125	104	114	153	96	80	88	118	118	98	107	144	92	76	84	112
KZ	Kazakhstan	409	333	300	580	392	320	287	556	427	348	313	606	328	268	241	466	401	327	294	570	313	255	229	444
EG	Egypt	33	27	28	44	32	26	27	42	35	28	29	46	27	22	22	35	33	26	27	43	25	21	21	34
MY	Malaysia	182	148	152	238	174	142	146	228	189	154	159	249	146	119	122	191	178	145	150	234	139	113	117	182
VN	Venezuela	64	58	75	57	61	55	72	55	67	60	79	60	51	46	61	46	63	57	74	56	49	44	58	44
AR	Argentina	69	58	95	51	66	56	91	49	72	61	99	53	55	47	76	41	67	57	93	50	52	44	72	39
AE	United Arab Emirates	369	342	510	250	354	327	489	240	386	356	533	261	297	274	410	201	363	335	501	246	283	261	390	192
DZ	Algeria	49	40	55	51	47	38	52	49	51	41	57	54	39	32	44	41	48	39	54	50	38	30	42	39
VN	Vietnam	251	180	167	392	240	173	160	376	262	188	174	409	201	145	134	315	246	177	164	385	192	138	128	300
PK	Pakistan	90	66	50	149	86	63	48	142	94	69	52	155	72	53	40	119	88	65	49	146	69	51	38	114
UZ	Uzbekistan	448	335	293	697	429	321	280	668	468	350	305	727	360	269	235	560	440	329	287	684	343	256	224	533

3.5 Assessment data

The second source adopted to develop the analysis is the model data selected from several databases. Considering the availability of all data, we choose 2012 as the base year, thereby establishing a comprehensive index system that reflects national emission characteristics. In the aspect of GHG emission, we only consider CO_2 emitted from fossil fuels. Other non-energy-related emissions (e.g., from land use change and forestry) are not considered. All the emission data are obtained from the CAIT Climate Data Explorer database, namely, the "CO_2 Emission from Fuel Combustion" edition (WRI, 2016). Emission data include domestic cumulative CO_2 emissions for the period of 1990–2012, per capita CO_2 emissions, and CO_2 emissions in 2012. The statistical data of coal and primary energy consumption are provided by British Petroleum (BP, 2016). The global population data are obtained from the publication "World Population Prospects" (2015 edition) of the United Nations Department of Economic and Social Affairs (UN DESA, 2015). The GDP data, which were calculated in 2005 constant dollar, are from the World Bank (2015). The HDI of the countries is from the United Nations Development Programme (UNDP, 2015). Among which, the HDI of EU is obtained from the arithmetic mean of its 28 member states.

4 Results

The pairwise combination of the four schemes and six scenarios provides 24 required reduction efforts for each party in 2030. We calculate the average required reduction effort under each scheme for one party. Fig. 6 shows the average effort with respect to the BAU scenario of main emitters. China, the United States, EU, India, Russia, and Japan will be required to reduce their CO_2 emissions by 9%–19%, 21%–42%, 19%–35%, 10%–22%, 32%–45%, and 73%–121%, respectively, by 2030, compared with their BAU emissions. The required reduction efforts vary because of different schemes. The result illustrates that countries with lower carbon intensity and proportion of coal consumption to total energy consumption have lower emission reduction potential. Thus, these countries do not need to exert considerable required reduction effort in the potential-oriented scheme. This case is applicable to most developed countries, such as the United States, EU, Japan, and Korea. Most developing countries, such as China, India, Russia, Iran, Indonesia, and South Africa, typically have lower emission reduction capacity because they have lower GDP per capita and HDI compared with developed countries. Developing countries will benefit the most from the capacity-oriented scheme. That is, wealthy countries generally mitigate more emissions. For several major emitters, including developing and developed countries, such as China, the United States, EU, India, Russia, and Japan, emission reduction responsibility is greater than those of other emitters. These countries have less emission space in the responsibility-oriented scheme.

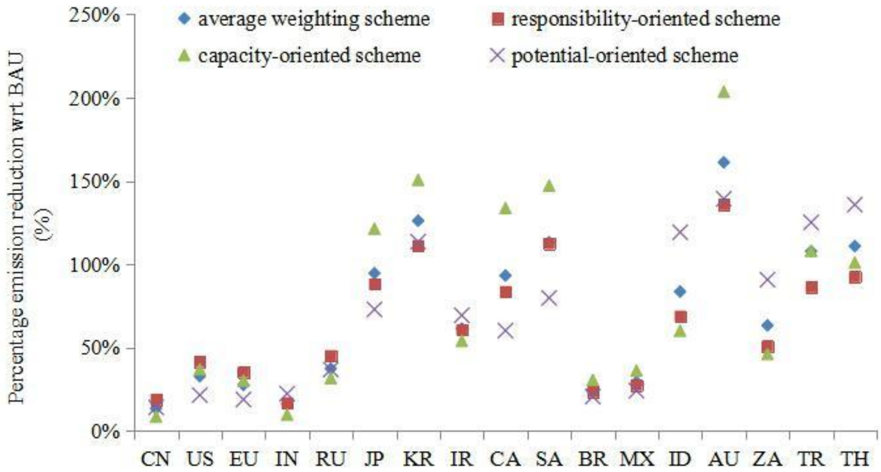

Fig. 6 Percentage emission reduction with respect to BAU (left to right in descending order of emission shares in 2012)

Fig. 7 shows the required reduction effort (histogram) compared with the reported reduction target (boxplot) of 23 parties. The results illustrate that the choice of schemes and scenarios will affect the required reduction effort. The required reduction effort response of different parties varies because of diverse choices. Australia, Kazakhstan, and Vietnam are spread widely in terms of required emission reduction effort. That is, they are considerably affected by emission scenarios and schemes. However, the required reduction effort of China, the United States, EU, India, Russia, Iran, Brazil, and Mexico are relatively stable and less affected by emission scenarios and schemes. These parties are found in the upper half of Fig. 7 (large emitters) and accounted for 70.35% of the global emissions in 2012. Despite the uncertainties in the required effort for small emitters, the global required effort level remains robust by calculating the required reduction effort for each country.

In accordance with the rating method described in Section 3.3, we assess nations as "inadequate" (dark blue), "sufficient" (white), or "medium" (light blue) based on the comparison of the required reduction effort and the reported reduction target. Table 5 provides the assessment result of the 23 parties.

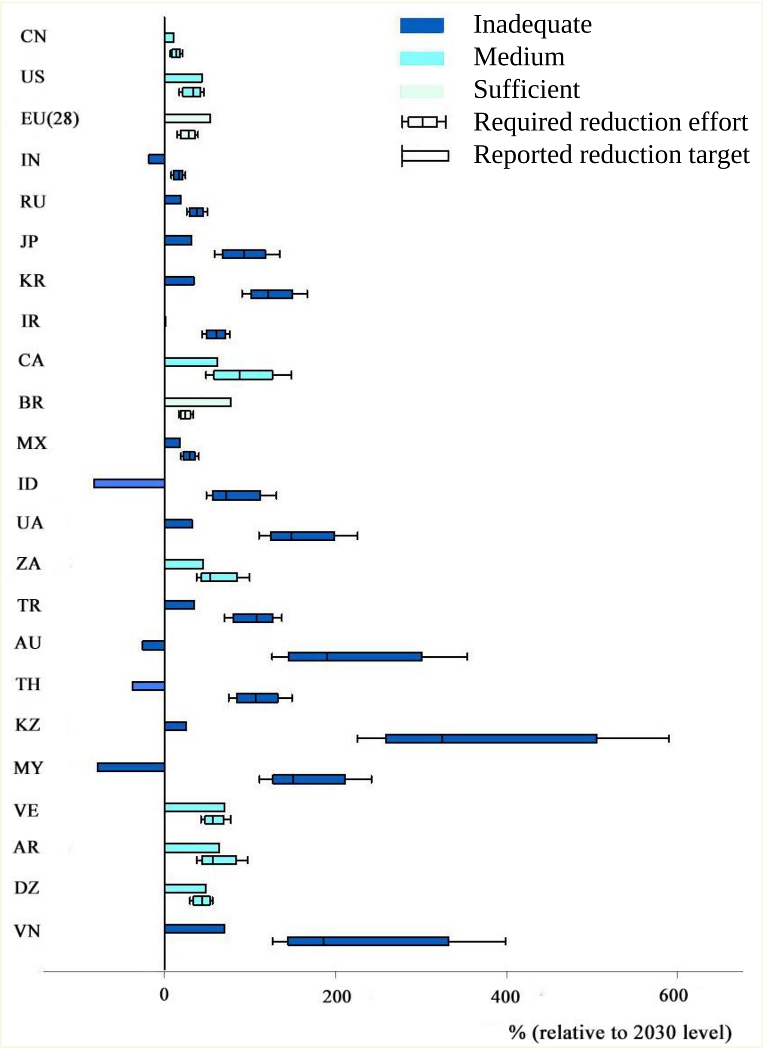

Fig. 7 Assessment result (top–down in descending order of emission shares in 2012)

Table 5 Final rating of the INDCs of the 23 parties

No.	Code	Countries	Rating
1	CN	China	medium
2	US	United States	medium
3	EU-28	EU-28	sufficient
4	IN	India	inadequate
5	RU	Russian Federation	inadequate
6	JP	Japan	inadequate
7	KR	Korea, Republic of	inadequate
8	IR	Iran	inadequate
9	CA	Canada	medium
10	BR	Brazil	sufficient
11	MX	Mexico	inadequate
12	ID	Indonesia	inadequate

13	AU	Australia	inadequate
14	ZA	South Africa	medium
15	TR	Turkey	inadequate
16	UA	Ukraine	inadequate
17	TH	Thailand	inadequate
18	KZ	Kazakhstan	inadequate
19	MY	Malaysia	inadequate
20	VE	Venezuela	medium
21	AR	Argentina	medium
22	DZ	Algeria	medium
23	VN	Vietnam	inadequate

The evaluation results of the 23 parties indicate that EU and Brazil are rated as “sufficient”. That is, they are exerting the most ambitious effort. Seven countries are rated as “medium”, namely, China, the United States, Canada, South Africa, Venezuela, Argentina, and Algeria. Finally, 14 countries are rated as “inadequate”, namely, Australia, Iran, India, Indonesia, Japan, Republic of Korea, Mexico, Ukraine, Thailand, Russian Federation, Turkey, Kazakhstan, Vietnam, and Malaysia. Their targets provide considerable opportunity for emission growth until 2030.

Among the world’s top 10 emitters, five are rated as “inadequate” (India, Russian Federation, Japan, Korea, and Iran), three parties (China, the United States, and Canada) are rated as “medium”, and EU (28 members) is rated as “sufficient”. The remaining country in the list, i.e., Saudi Arabia, is not included in the evaluation because it lacks specific and quantifiable INDC goals. Most current pledges are “inadequate” because of the unconditional quantizable mitigation aspects of INDCs, which indicates a considerable distance from representing a fair contribution. Therefore, we assume that the global emission reduction objective will be difficult to achieve through the submitted INDCs. The motivation of short-term contributions must be strengthened in future negotiations.

5 Conclusion and discussions

Undoubtedly, INDCs represent a breakthrough in terms of international effort to curb future GHG emissions. The number of participating countries is 189, which is considerably more than those of previous international efforts, such as the Kyoto Protocol and the Cancun pledges. Since the establishment of INDCs, positive consequences that go beyond benefits to the climate have been achieved. INDCs should provide the first step toward the formation of an ambitious global climate action. At present, however, the number of parties whose pledges are rated as medium is 7, whereas 14 have pledges that are rated as “inadequate”. Most countries have presented mediocre endeavors toward decarbonization.

First, INDCs do not only reflect a country's strength and attitude, but also its responsibility. Each party should work to implement a new transparent mechanism and fulfill its promise. Second, the mitigation commitment of all countries should be upgraded to close the gap toward the temperature target. Further actions and initiatives for narrowing this gap are necessary, such as enhancing energy efficiency with emphasis on industries, buildings, and transport; expanding the use of renewable energy technologies; and strengthening international cooperation and coherence.

This research exhibits many limitations and uncertainties. First, we consider only fossil fuel-related CO_2 emissions exclude the effect of LULUCF because of considerable uncertainties in sector statistics. Moreover, specific LULUCF emission projections are frequently lacking. In general, considering emissions from LULUCF will weaken mitigation effort. Second, in terms of this study's comparability, we consider only CO_2 and disregarded other GHGs. Although CO_2 is the most abundant GHG, six or seven kinds of GHGs identified in the Kyoto protocol are included in the INDCs of most Annex I parties. When all types of GHG emissions are considered simultaneously with LULUCF, the emission space will continuously narrow, thereby resulting in stressful situations. Third, we have not considered the impact from other countries when assessing the required reduction effort for each country. A frequent occurrence is observed in which one country obtains financial support from other countries or is restricted because of various factors. Thus, the required reduction effort of these countries will be affected. However, the quantification of these indicators is difficult; hence, we have not included it in our evaluation. Finally, emission reduction indicators for calculating the required reduction effort are selected based on a country's emission reduction responsibility, potential, and capacity, which comprehensively consider various factors that influence reduction effort. The index system can still be improved. Indicators that can present extensive characteristics will render our index system faultless. Continued effort is required to boost the chances of success of the Paris Agreement, and an adequate assessment of parties' pledges is indispensable to provide feature-for-feature and comprehensive comparisons.

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Appendix

Supplementary A Mitigation aspect of INDCs (in order of emission shares in 2012)

Country	2012 emission share	Included in the analysis	Emission reduction target		
			Base year	Reduction form	Target year
China	28.03%	A	2005	Emission peak 60%–65% (carbon intensity)	2030 (or before)
United States	15.42%	A	2005	26%–28%	2025
EU	10.87%	A	1990	40%	2030
India	6.25%	A	2005	33%–55% (emission intensity)	2030
Russia	5.18%	A	1990	25%–30%	2030
Japan	3.76%	A	2005	25.40%	2030
Korea	1.86%	A	BAU	37%	2030
Iran	1.79%	A	BAU	4% 12% (c)	2030
Canada	1.63%	A	2005	30%	2030
Saudi Arabia	1.45%	B	Mitigation actions only		
Brazil	1.44%	A	2005	37%	2025
Mexico	1.39%	A	BAU	25% 40% (c)	2030
Indonesia	1.37%	A	BAU	29% 41% (c)	2030
Australia	1.18%	A	2005	26%–28%	2030
South Africa	1.15%	A	Emission peak (398–614 Mt CO_2e)		2025
Turkey	1.00%	A	BAU	21%	2030
Ukraine	0.86%	A	1990	40%	2030
Thailand	0.82%	A	BAU	20% 25% (c)	2030
Kazakhstan	0.71%	A	1990	15% 25% (c)	2030
Egypt	0.66%	B	Mitigation actions only		
Malaysia	0.63%	A	2005	35% (emission intensity) 45% (c)	2030
Venezuela	0.62%	A	BAU	20% (c)	2030
Argentina	0.59%	A	BAU	15% 30% (c)	2030
United Arab Emirates	0.55%	B	Mitigation actions only		
Vietnam	0.52%	A	BAU	8% 25% (c)	2030
Pakistan	0.46%	B	Mitigation actions only		
Algeria	0.40%	A	BAU	7 % Up to 22% (c)	2030
Uzbekistan	0.35%	B	Mitigation actions only		
Philippines	0.26%	C	BAU	70%	2030
Chile	0.24%	C	2007	30% (carbon intensity) 35%–45% (c) (carbon intensity)	2030
Qatar	0.24%	C	Mitigation actions only		
Israel	0.23%	C	2005	8.8t CO_2e per capita 7.7t CO_2e per capita	2025 2030
Belarus	0.22%	C	1990	28%	2030
Oman	0.21%	C	Mitigation actions only		

Colombia	0.22%	C	BAU	20% 30% (c)	2030
Nigeria	0.28%	C	BAU	20% 45% (c)	2030
Turkmenistan	0.20%	C	Mitigation actions only		
Bangladesh	0.19%	C	BAU	5% 15% (c)	2030
Morocco	0.16%	C	BAU	13% 32% (c)	2030
Singapore	0.15%	C	2005	Emission peak 36% (emission intensity)	2030
Peru	0.15%	C	BAU	20% 30% (c)	2030
Serbia	0.13%	C	1990	9.80%	2030
Switzerland	0.13%	C	1990	35% 50%	2025 2030
Trinidad and Tobago	0.12%	C	BAU	30% (public transport only) 15% (c) (total GHG emissions)	2030
Norway	0.12%	C	1990	At least 40%	2030
Ecuador	0.11%	C	BAU	20.4%–25% 37.5%–45.8% (c)	2025
New Zealand	0.10%	C	2005	30%	2030
Azerbaijan	0.10%	C	1990	35%	2030
Cuba	0.09%	C	Mitigation actions only		
Bahrain	0.09%	C	List of actions		
Tunisia	0.07%	C	2010	13% (carbon intensity) 41% (c) (carbon intensity)	2030
Jordan	0.07%	C	BAU	1.5% 14% (c)	2030
Bosnia and Herzegovina	0.00%	C	BAU	2% 23% (c)	2030
Lebanon	0.06%	C	BAU	15% 30% (c)	2030
Yemen	0.06%	C	BAU	1% 14% (c)	2030
Dominican Republic	0.06%	C	2010	25%	2030
Angola	0.06%	C	BAU	20% and 35% (c) 27% and 50% (c)	2025 2030
Bolivia	0.05%	C	Mitigation actions only		
Afghanistan	0.03%	C	BAU	13.6% (c)	2030
Albania	0.01%	C	BAU	11.50%	2030
Andorra	0.01%	C	BAU	37%	2030
Antigua and Barbuda	0.01%	C	Mitigation actions only		
Armenia	0.00%	C	Mitigation actions only		
Bahamas	0.00%	C	Mitigation actions only		
Barbados	0.00%	C	BAU	37% (interim) 44%	2025 2030
Benin	0.01%	C	BAU	3.5%	2030

				21.4% (c)	
Belize	0.00%	C	Mitigation actions only		
Bhutan	0.00%	C	Mitigation actions only		
Botswana	0.00%	C	2010	15%	2030
Brunei	0.03%	C	Energy, transport, and forestry sector emission reduction targets		
Burkina Faso		C	BAU	6.6%	2030
Burundi	0.00%	C	BAU	18.2% (c)	2030
				3%	
Cabo Verde	0.00%	C	Mitigation actions only		
Cambodia	0.00%	C	Mitigation actions only		
Cameroon	0.00%	C	BAU	32%	2035
Central African Republic	0.00%	C	BAU	5% (c)	2030
Chad	0.00%	C	BAU	18.2%	2030
				71% (c)	
Comoros	0.00%	C	BAU	84% (c)	2030
Congo	0.00%	C	BAU	48%	2025
				55%	2035
Cook Islands	0.00%	C	2006	38%	2020
				81% (c)	
Costa Rica	0.00%	C	Net emission limit	9.374 $MtCO_2e$	2030
			BAU	44%	
			2012	25%	
Côte D'Ivoire	0.00%	C	BAU	28%	2030
Democratic Republic of Congo (DRC)	0.00%	C	2000	17% (c)	2030
Djibouti	0.00%	C	BAU	40%	2030
				60% (c)	
Dominica	0.00%	C	2014	39.2% (c)	2025
				44.7% (c)	2030
El Salvador	0.00%	C	Mitigation actions only		
Equatorial Guinea	0.00%	C	2010	20% (c)	2030
Eritrea	0.00%	C	2010	39.2%	2030
				80.6% (c)	
Ethiopia	0.00%	C	BAU	64% (c)	2030
Fiji	0.00%	C	Mitigation actions only		
FYROM (Macedonia)	0.00%	C	BAU	30%–36 %	2030
Gabon	0.00%	C	BAU	50%	2025
Gambia	0.00%	C	BAU	44.40%	2025
Georgia	0.00%	C	BAU	15%	2030
Ghana	0.00%	C	BAU	15%	2030
Grenada	0.00%	C	2010	30%	2025
				40% (indicative)	2030
Guatemala	0.00%	C	BAU	11.2% (c)	2030
				22.6%	
Guinea	0.00%	C	Mitigation actions only, energy target of 30 %		
Guinea-Bissau	0.00%	C	Mitigation actions only		
Guyana	0.00%	C	Mitigation actions only		
Haiti	0.00%	C	BAU	5%	2030
				26% (c)	
Honduras	0.00%	C	BAU	15% (c)	2030
Iceland	0.00%	C	1990	40%	2030
Kenya	0.00%	C	BAU	30% (c)	2030
Kiribati	0.00%	C	BAU	13.70%	2025
				12.80%	2030

Kyrgyz Republic	0.00%	C	BAU	11.49%–13.75% 29%–30.89% (c)	2030
				12.67%–15.69% 35.06%–36.75% (c)	2050
Lao	0.00%	C	Mitigation actions only		
Lesotho	0.00%	C	BAU	10%	2030
				35% (c)	
Liberia	0.00%	C	Mitigation actions only		
Liechtenstein	0.00%	C	1990	40%	2030
Madagascar	0.00%	C	BAU	14%	2030
Malawi	0.00%	C	Mitigation actions only		
Maldives	0.00%	C	BAU	10%	2030
				24% (c)	
Mali	0.00%	C	BAU	29% (agriculture)	2030
				31% (energy)	
				21% (forestry)	
Marshall Islands	0.00%	C	2010	32%	2025
Mauritania	0.00%	C	BAU	2.7%	2030
				22.3% (c)	
Mauritius	0.00%	C	BAU	30%	2030
Micronesia	0.00%	C	2000	28%	2025
Moldova	0.00%	C	1990	64%–67%	2030
				78% (c)	
Monaco	0.00%	C	1990	40% (optional)	2025
				50%	2030
Mongolia	0.00%	C	Mitigation actions only		
Montenegro	0.00%	C	1990	30%	2030
Mozambique	0.00%	C	−76.5 Mt CO_2e		2020–2030
Myanmar	0.00%	C	Conditional actions only		
Namibia	0.00%	C	BAU	89%	2030
Nauru	0.00%	C	Energy target; mitigation actions		
Niue	0.00%	C	At least 80% (c)		2050
Niger	0.00%	C	BAU	2.5%	2030
Paraguay	0.00%	C	BAU	10%	2030
Papua New Guinea	0.00%	C	100% renewable energy target by 2030		
Rwanda	0.00%	C	Mitigation actions only		
Samoa	0.00%	C	Mitigation actions only		
San Marino	0.00%	C	2005	20%	2030
Sao Tome and Principe	0.00%	C	BAU	24%	2030
Senegal	0.00%	C	BAU	3% or 7%(c)	2020
				4% or 15%(c)	2025
				5% or 21% (c)	2030
Seychelles	0.00%	C	BAU	21.40%	2025
				29%	2030
Sierra Leone	0.00%	C	Mitigation actions only		
Solomon Islands	0.00%	C	2015	12% or 27% (c)	2025
			30% or 45% (c)		2030
Somalia	0.00%	C	Mitigation actions only		
South Sudan	0.00%	C	List of actions		
Sri Lanka	0.00%	C	BAU	7%	2030
				23% (c)	
St. Kitts and Nevis	0.00%	C	BAU	22%	2025
St. Lucia	0.00%	C	BAU	16%	2025
St. Vincent and the Grenadines	0.00%	C	BAU	22%	2025
Sudan	0.00%	C	List of actions		

Suriname	0.00%	C	Mitigation actions only		
Swaziland	0.00%	C	Mitigation actions only		
Tajikistan	0.00%	C	1990	10%–20%	2030
				25%–35% (c)	
Tanzania	0.00%	C	BAU	10%–20%	2030
Togo	0.00%	C	BAU	11.14%	2030
				31.14% (c)	
Tonga	0.00%	C	Energy goals		2030
Uganda	0.00%	C	Mitigation actions only		
Uruguay	0.00%	C	Mitigation actions only		
Zambia	0.00%	C	BAU	25 or 47% (c)	2030
Zimbabwe	0.00%	C	BAU	33% (per capita) (c)	2030

Note: Countries marked “A” are analyzed and rated in this study; countries marked “B” are analyzed but not rated (non-GHG targets and actions; cannot be quantified); countries marked C are not analyzed because their 2012 emission share is less than 0.1% each. Targets without remarks indicate an unconditional promise, whereas the mark “(c)” indicates that a country’s promises are conditional.