



HAL
open science

Impacts of nationally determined contributions on 2030 global greenhouse gas emissions: uncertainty analysis and distribution of emissions

Hélène Benveniste, Olivier Boucher, Céline Guivarch, Hervé Le Treut, Patrick Criqui

► **To cite this version:**

Hélène Benveniste, Olivier Boucher, Céline Guivarch, Hervé Le Treut, Patrick Criqui. Impacts of nationally determined contributions on 2030 global greenhouse gas emissions: uncertainty analysis and distribution of emissions. *Environmental Research Letters*, 2018, 13 (1), pp.1-10. 10.1088/1748-9326/aaa0b9 . hal-01662799

HAL Id: hal-01662799

<https://hal.science/hal-01662799v1>

Submitted on 13 Dec 2017

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

ACCEPTED MANUSCRIPT • OPEN ACCESS

Impacts of nationally determined contributions on 2030 global greenhouse gas emissions: uncertainty analysis and distribution of emissions

To cite this article before publication: H el ene Benveniste *et al* 2017 *Environ. Res. Lett.* in press <https://doi.org/10.1088/1748-9326/aaa0b9>

Manuscript version: Accepted Manuscript

Accepted Manuscript is "the version of the article accepted for publication including all changes made as a result of the peer review process, and which may also include the addition to the article by IOP Publishing of a header, an article ID, a cover sheet and/or an 'Accepted Manuscript' watermark, but excluding any other editing, typesetting or other changes made by IOP Publishing and/or its licensors"

This Accepted Manuscript is  2017 IOP Publishing Ltd.

As the Version of Record of this article is going to be / has been published on a gold open access basis under a CC BY 3.0 licence, this Accepted Manuscript is available for reuse under a CC BY 3.0 licence immediately.

Everyone is permitted to use all or part of the original content in this article, provided that they adhere to all the terms of the licence <https://creativecommons.org/licenses/by/3.0>

Although reasonable endeavours have been taken to obtain all necessary permissions from third parties to include their copyrighted content within this article, their full citation and copyright line may not be present in this Accepted Manuscript version. Before using any content from this article, please refer to the Version of Record on IOPscience once published for full citation and copyright details, as permissions may be required. All third party content is fully copyright protected and is not published on a gold open access basis under a CC BY licence, unless that is specifically stated in the figure caption in the Version of Record.

View the [article online](#) for updates and enhancements.

Impacts of nationally determined contributions on 2030 global greenhouse gas emissions: uncertainty analysis and distribution of emissions

Hélène Benveniste^{1*}, Olivier Boucher¹, Céline Guivarch², Hervé Le Treut^{1,3},
Patrick Criqui⁴

1. Institut Pierre Simon Laplace, Université Pierre et Marie Curie / CNRS, Paris, France
2. Centre International de Recherche sur l'Environnement et le Développement, Ecole des Ponts ParisTech, Nogent-sur-Marne, France
3. Ecole Polytechnique, Palaiseau, France
4. Laboratoire d'Economie Appliquée de Grenoble, Université Grenoble Alpes / CNRS, Grenoble, France

* Now at Princeton University, Email: helene.benveniste@princeton.edu

Abstract

Nationally Determined Contributions (NDCs), submitted by Parties to the United Nations Framework Convention on Climate Change (UNFCCC) before and after the 21st Conference of Parties (COP21), summarize domestic objectives for greenhouse gases (GHG) emissions reductions for the 2025-2030 time horizon. In the absence, for now, of detailed guidelines for NDCs format, ancillary data are needed to interpret some NDCs and project GHG emissions in 2030. Here, we provide an analysis of uncertainty sources and their impacts on 2030 global GHG emissions based on the sole and full achievement of the NDCs. We estimate that NDCs project into 56.8 to 66.5 Gt CO₂eq yr⁻¹ emissions in 2030 (90% confidence interval), which is higher than previous estimates, and with a larger uncertainty range. Despite these uncertainties, NDCs robustly shift GHG emissions towards emerging and developing countries and reduce international inequalities in per capita GHG emissions. Finally, we stress that current NDCs imply larger emissions reduction rates after 2030 than during the 2010-2030 period if long-term temperature goals are to be fulfilled. Our results highlight four requirements for the forthcoming “climate regime”: a clearer framework regarding future NDCs’ design, an increasing participation of emerging and developing countries in the global mitigation effort, an ambitious update mechanism in order to avoid hardly feasible decarbonization rates after 2030 and an anticipation of steep decreases in global emissions after 2030.

1. Introduction

Parties to the UNFCCC have submitted their intentions for mitigating climate change in the run-up to the COP21 that was held in Paris in December 2015. Their Intended Nationally Determined Contributions (INDCs), which cover a range of targets and actions for reducing GHG emissions, have become Nationally Determined Contributions (NDCs) for the Parties that have ratified the Paris Agreement. With a few exceptions, NDCs are generally very close to INDCs for the overarching targets that we consider here and, although they may evolve in future negotiations [1], they reflect the current level of commitment of Parties and represent a legitimate source of information for projecting GHG emissions in 2030.

A number of analyses, including by the UNFCCC secretariat [2], the UNEP Gap Report [3, updated for COP23 in ref. 4], Fawcett et al. [5], Rogelj et al. [6], den Elzen et al. [7], Vandyck et al. [8] and Rogelj et al. [9] have inferred the 2030 global emissions from INDCs or NDCs. The UNFCCC based its analysis on the content of INDCs, but considered additional information from the IPCC AR5 database and other national data for emissions not covered by INDCs. Their calculations result in global emission

1
2
3 levels of 56.2 (52.0 to 59.3) Gt CO₂eq yr⁻¹ in 2030; their uncertainty ranges indicate 20%-80%
4 percentiles. The four studies by Fawcett et al., den Elzen et al., Vandyck et al. and Rogelj et al. [9]
5 share similar methodologies relying on scenarios from Integrated Assessment Model(s) (IAMs) in
6 which the targets expressed in the INDCs/NDCs are implemented. These studies assess 2030
7 emission levels accounting for current policies and additional targets expressed in the INDCs/NDCs.
8 Economic growth is exogenous to their models and follows either domestic forecasts or a given
9 Shared Socioeconomic Pathway (SSP) scenario [10]. The UNEP Gap Report results from an iterative
10 process with yearly updates since 2010. It draws from the content of the INDCs/NDCs, other
11 documents submitted by countries to the UNFCCC (such as national inventories), estimates from
12 country-specific studies, and ten global analyses (those cited above, and another six not peer-
13 reviewed). Global emission levels in 2030 are predicted to be 55.2 (51.9–56.2) Gt CO₂eq yr⁻¹
14 accounting for unconditional NDCs only and 52.8 (49.5–54.2) Gt CO₂eq yr⁻¹ for conditional NDCs
15 (uncertainty ranges correspond to 10%-90% percentiles). The UNEP report highlights the “gap”
16 between emissions levels resulting from the aggregation of NDCs and those required to achieve the
17 ambitious temperature target “well below 2°C”. Rogelj et al. [6] adopt a similar 10-90% uncertainty
18 range as the 2017 UNEP Gap Report and go one step further to estimate temperature change
19 projections for 2100 assuming some continuation of the mitigation effort after 2030.
20
21
22
23
24
25
26
27
28
29
30
31

32 While the UNEP Gap Report represents a useful meta-analysis of available studies, it also involves
33 some degree of expert judgment. Indeed, interpreting the NDCs is not straightforward. Their format
34 and content vary tremendously and some external information is required for their interpretation.
35 These issues were discussed ahead of COP21 during a workshop organized in Paris by the authors
36 [11]. When available, the uncertainty analysis in individual studies is often semi-quantitative and
37 likely to be dependent on the model used. The UNEP Gap Report derives uncertainties from its meta-
38 analysis, but does not perform a systematic treatment of uncertainties, neither for global emissions,
39 nor for individual countries. Overall, the drivers for uncertainties and their respective contribution to
40 the total uncertainty are unclear. Rogelj et al. [9] provide a quantitative analysis of uncertainty
41 sources, resulting in an extended 2030 emission range of 47-63 GtCO₂eq yr⁻¹ (minimum-maximum
42 range), but leave aside several crucial drivers such as emissions from Land Use, Land Use Change and
43 Forestry (LULUCF), and use a restricted set of socio-economic scenarios. Furthermore, the emission
44 levels for individual countries are not easily traceable to model outputs, although some studies treat
45 some countries more in-depth [5, 7, 8].
46
47
48
49
50
51
52
53
54
55

56 Here, we chose a different methodology from previous analyses. We deliberately step aside from
57 IAMs and take NDCs at face value. We treat countries individually whenever possible and only apply
58
59
60

1
2
3 a generic treatment to countries that published insufficient information. For countries that have
4 expressed their target partly as a reduction in the carbon intensity of their economy without
5 providing a Gross Domestic Product (GDP) binding scenario, we consider twenty GDP growth
6 scenarios stemming from different quantifications of the five SSP [12-15]. We explicitly flag further
7 assumptions made in the study and apportion the total uncertainty among the various drivers. To our
8 knowledge, this study is the first systematic uncertainty analysis of global GHG emissions implied by
9 NDCs. While our approach has intrinsic limitations, it also has advantages in terms of simplicity,
10 flexibility and transparency. Unlike previous studies [2-9], we do not attempt to project 2030 GHG
11 emissions under current policies, we are only interested in interpreting the absolute level of GHG
12 emissions implied literally by the NDCs. It is conceivable that current economic trends and/or current
13 policies result in smaller emissions than implied by the NDCs for some countries and we expect the
14 ambition level of NDCs to be revised upwards in such cases. Conversely, some other countries may
15 experience higher emissions than predicted.

16
17
18
19
20
21
22
23
24
25
26 By monitoring GHG emissions against our model, it will be possible to assess which NDCs are over- or
27 underachieved. Our approach also allows updating the projected emissions when new data become
28 available or when new NDCs are submitted as part of the revision process of the Paris Agreement.
29 This will be facilitated by the release of our python code as Supplementary Material to this article.

30 31 32 33 **2. Methods**

34 35 36 **2.1 Emission datasets**

37
38 We first consider a dataset of emissions for reference years used in the NDCs. For consistency with
39 work from the Intergovernmental Panel on Climate Change (IPCC), we rely on published emission
40 inventories [16, Table S2]. Historical emissions data come from three distinct databases: the
41 Emissions Database for Global Atmospheric Research (EDGAR) for emissions of CO₂ except from
42 LULUCF, CH₄, N₂O, HFC, PFC, and SF₆ [17], and the BLUE (bookkeeping of land use emissions) model
43 [18 and personal communication] for CO₂ emissions from LULUCF. For the United States, Canada and
44 Russia, whose NDCs are expressed in “net-net emissions”, we also consider their CO₂ LULUCF balance
45 (emissions + sinks) reported to the UNFCCC. Since the UNFCCC accounting for LULUCF balance differs
46 from that used in Earth system models [19], we only consider half of these supplemental carbon
47 sinks as anthropogenic (Table S4). Uncertainties in historical emissions, including in Chinese
48 emissions [20, 21], are not accounted for. Rather, in the light of the recent study by Liu et al.
49 considering specific emission factors for Chinese coal types [22], we use average values between
50 Chinese emissions data from EDGAR and those of Liu et al. This results in Chinese CO₂ emissions
51
52
53
54
55
56
57
58
59
60

1
2
3 about 5% smaller than EDGAR over the 1990-2010 period (Table S3). We discuss the impact of this
4 correction on our results in the Supplementary Material (Section 10 and Fig. S6). Combining these
5 datasets, we estimate 2010 GHG emissions to be 50.6 Gt CO₂eq yr⁻¹ accounting for an anthropogenic
6 carbon sink due to LULUCF. We are not able to derive a strict uncertainty range for this quantity as
7 neither EDGAR nor BLUE provides an uncertainty analysis for their data. Our estimate is within the
8 range of other estimates: 50.9 GtCO₂eq yr⁻¹ for EDGAR [23]; 47.6 Gt CO₂eq yr⁻¹ for the Climate
9 Action Tracker [24] and 49.3 Gt CO₂eq yr⁻¹ for PRIMAP [25]. While reassuring, this does not mean
10 much as most studies rely on identical or similar sources for emissions. Uncertainties in historical
11 emissions at the country level are also difficult to assess and not considered in this study.
12
13
14
15
16
17
18

19 **2.2 GDP datasets**

20
21 We consider 20 GDP scenarios, illustrating the five Shared Socioeconomic Pathways (SSP) [10] for
22 four quantifications (the marker quantification by OECD [13], and three alternative quantifications by
23 CEPII [12], IIASA [14], and PIK [15]). SSP scenarios aim at facilitating the integrated analysis of future
24 climate impacts, vulnerabilities, adaptation, and mitigation [10] and represent a framework to
25 examine possible future states of the world. Because the GDP scenarios diverge after 2005, we
26 correct them on the basis of the historical 2005-2015 data from the World Bank World Development
27 Indicators database (release from September 15, 2017). We propagate the difference between the
28 SSP and actual GDP growth rates until 2030 with a transition from a purely historical GDP driven
29 trajectory to a purely SSP driven trajectory (see Supplementary Material section 4). This generally
30 results in smaller GDP levels in 2030 than assumed in the SSP scenarios because actual growth rates
31 are lower in the historical data over 2005-2015 than assumed in the SSP scenarios. A noticeable
32 exception is the CEPII scenarios, which show a late rise in GDP growth for some countries, including
33 China (see Supplementary Material section 5). Fig. S1a-b illustrate the 20 economic GDP scenarios
34 before and after correction, respectively, for China. Note that we only use the GDP quantifications of
35 the SSP, not the emissions quantifications (currently not available at the country level). However, we
36 compare our projected emissions with those projected by IAMs for the SSP scenarios for their five
37 usual meta-regions.
38
39
40
41
42
43
44
45
46
47
48
49

50 **2.3 Interpretation of NDCs**

51 Countries used different formats to express their mitigation effort in their NDC [26]. A first set of
52 countries put forward an absolute target, whereby GHG emissions levels for the target year are
53 provided or can be readily inferred from the data provided (reduction with respect to a reference
54 year or a Business As Usual (BAU) scenario which is explicated in the NDC, emission value in target
55
56
57
58
59
60

1
2
3 year). A second set of countries express their target relative to a BAU scenario that is not explicated in
4 the NDC or in terms of a reduction in the carbon intensity of GDP without providing a forecast of the
5 GDP. A third set of countries only provide sectoral indications that do not *per se* allow to infer an
6 emission reduction target (Table S1). Furthermore, China has indicated a CO₂ emission peaking date
7 target before 2030. China and India also provide additional targets in terms of share of non-fossil
8 fuels, of the total primary energy supply for China and of the power generation capacity for India.
9

10 We use the latest updated versions of NDCs, as of November 2017. We treat one by one all 103
11 Parties (among which the European Union represents 28 countries) for which the NDC contains
12 enough information to compute GHG emissions levels for the target year. We lump the remaining 64
13 countries in several groups for which additional assumptions are required. We present results for the
14 23 largest emitting countries (representing 80% of 2010 global GHG emissions), but the results for all
15 countries are presented in a file and code provided as Supplementary Material. The countries other
16 than the 23 largest emitters are separated in four groups (Table S1): Other Annex 1, Other Emerging,
17 Other Oil exporting countries and Rest of World (representing 0.7, 1.7, 0.4 and 14.7% of 2010 global
18 GHG emissions, respectively). A detailed description of our treatment of NDCs is provided in the
19 Supplementary Material (section 1).
20
21
22
23
24
25
26
27
28
29
30

31 **2.4 Treatment of the Chinese and Indian NDCs**

32
33
34 Two of the main elements of the Chinese NDC (i.e., a reduction in the carbon intensity and a peak
35 emission before 2030) refer specifically to CO₂ emissions other than from LULUCF. We take this into
36 account by first estimating CO₂ emissions for 2030 (excluding LULUCF), which are then converted to
37 CO₂eq using a CO₂eq to CO₂ emissions ratio (R). Our derivation of this ratio is described in the
38 Supplementary Material (section 7).
39
40
41
42

43 The Chinese NDC also includes a target to peak CO₂ emissions before 2030. This requires the
44 reduction rate of the carbon intensity in 2030 to exceed the growth rate in the same year. In order to
45 account for this in our analysis, we first interpolate the GDP growth rate in 2030. We then convert
46 the overall carbon intensity reduction target into a time profile and, if necessary, iteratively increase
47 it until the annual rate of carbon intensity reduction in 2030 exceeds the GDP growth rate in the
48 same year. We further describe and justify our approach in the Supplementary Material (section 6),
49 including the reasons and limitations of not considering the non-fossil fuel targets for China and India
50 (section 8). Estimated emissions for China are compared to current trends on Fig. S3.
51
52
53
54
55
56
57

58 **2.5 Treatment of the LULUCF emissions**

Our treatment of LULUCF emissions is indicated in Table S4 and described in the Supplementary Material (section 3). We also account for the LULUCF elements of NDCs when provided.

2.6 Monte-Carlo uncertainty analysis

The first part of our study focuses on an uncertainty analysis of the 2030 global GHG emission level. To determine the uncertainty range surrounding the 2030 emission level, a Monte Carlo method ($N=50,000$ runs) is used for each of the 20 GDP scenarios. Uncertainty for each GDP scenario is generated by varying the following parameters: ambition level of the NDC (including the ranges mentioned in some NDCs); our set of assumption for countries with NDCs providing either only sectoral or incomplete information; emissions level for international aviation and shipping; LULUCF emissions reduction for India and the Rest of World; the choice of the intensity reduction profile (parameter λ) for China, and the $\text{CO}_2\text{eq}/\text{CO}_2$ ratio for China (parameter μ). Note that the above-mentioned ambition levels are assumed to be the same for all countries. In other words, they are perfectly correlated in our Monte Carlo simulation. This follows the idea of a virtuous circle between countries as part of the Paris Agreement. Whenever there is a range, whether it is indicated in the NDC, refers to unconditional and conditional statements in the NDC or assumed from our expert judgement, we consider variations within the range and refer in a generic way to the “ambition level” of the NDCs. Note that when only a conditional target is provided, we assume the unconditional target to be no effort compared to BAU emissions, thus generating a range. Unless stated otherwise we assume a uniform probability distribution within the range. This implies in particular that on average half of the additional effort of going from low to high ambition level would be carried out. Finally, a 1,000,000-member ensemble is made by aggregating the 20 ensembles corresponding to the 20 GDP scenarios considered with equal weight. The uncertainty attributable to a particular driver is estimated as the ratio in the variance of the 2030 emissions caused by that driver to the total variance. Covariances between the different drivers are gathered in a residue termed “Interactions of all drivers”. In the second part of this study, where we analyze the evolution in emissions distribution among countries, we do not consider sources of uncertainty other than that of the GDP scenarios, but use average values for all relevant uncertain parameters. Unless otherwise stated, all our confidence intervals represent 5-95% uncertainty ranges.

3. Results and discussion

3.1 GHG emissions in 2030

The GHG emissions levels in 2030 are available at the country level in the Supplementary Material. We find that NDCs imply 2030 global GHG emissions of 61.7 (56.8-66.5) Gt $\text{CO}_2\text{eq yr}^{-1}$ (Figure 1a).

1
2
3 This is higher than in previous studies (see Table 1 for a comparison) with the lower bound of our
4 uncertainty range corresponding to the upper bound of most published estimates. Our uncertainty
5 range is also larger than most of those published so far, which is essentially because we consider a
6 range of GDP scenarios rather than a single scenario. Fig. S5 displays the probability distributions of
7 2030 global emissions grouped by SSP narrative and by GDP data source. For the SSP2 OECD
8 scenario, which is often used as a marker scenario, we find 2030 GHG emissions to be 61.8 (58.4–
9 65.0) GtCO₂eq yr⁻¹. The uncertainty range is then comparable to previous estimates, but it is shifted
10 to higher values, meaning that our mean estimate is still higher than previous estimates. It is
11 unfortunately not possible to gain a full understanding as to where the differences in the median
12 value come from because no single study publishes their emission estimates for all countries.
13
14
15
16
17
18
19

20
21 Nevertheless one likely reason for this difference in emissions is that, unlike previous studies, we do
22 not consider the impact of current policies which are not (yet) reflected into a high-level NDC target.
23 In particular, a large part of the difference appears to come from the Chinese CO₂ emissions. We find
24 a 5-95% uncertainty range of 11.8 to 15.7 Gt CO₂ yr⁻¹ (without LULUCF) in 2030, which accounts for
25 uncertainties in the GDP scenario and the profile of the carbon intensity reduction (see Figs. S2 and
26 S7). For the SSP2 OECD scenario, the range in Chinese CO₂ emissions is 13.3 to 15.0 Gt CO₂ yr⁻¹ in
27 2030. The peak target does or does not constrain the 2030 Chinese emissions depending on the
28 choice of parameters in our Monte Carlo. As expected the peak target is constraining more often
29 when the decrease in the carbon intensity is assumed to be more exponential and less linear. Overall,
30 accounting for the peak target reduces the lower bound of the 2030 Chinese CO₂ emissions by ~0.5
31 Gt CO₂ and the upper bound by ~1.2 Gt CO₂, while the average is reduced by ~0.6 Gt CO₂. For all
32 scenarios and GHG, we find 2030 emissions of 16.4 (14.5-18.2) Gt CO₂eq yr⁻¹. One reason for our
33 larger emissions for China is the occurrence of high, long-lasting GDP growth in many of the scenarios
34 considered (see Fig. S1c for 2030 growth rate descriptions and Fig. S2 for their impact on the peak
35 constraint). For comparison, analyses based on Chinese five-year plans up to 2030 assume GDP
36 growth decreasing from 5.5% yr⁻¹ for 2021-2025 to 4% yr⁻¹ for 2025-2030 and 3.5% yr⁻¹ for 2030-
37 2035, which corresponds to the lower bound of the SSPs scenarios, and find a peak of Chinese
38 emissions between 2025 and 2030 at around 12.7 GtCO₂ yr⁻¹ [27, 28]. The other reason for our larger
39 emissions is that in a number of previous estimates, the carbon intensity reduction target and/or the
40 peaking before 2030 target are overachieved (see section 8 of the Supplementary Material). As
41 Chinese emissions appear to have increased again over the past year following a stagnation for a
42 couple of years [29], it will be important to monitor future trends to confirm whether the Chinese
43 NDC will indeed be overachieved.
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 An equal part of the difference between our estimate and previous estimates comes from Indian
4 emissions. The GHG emissions for India are projected to be 7.6 (5.8–9.1) Gt CO₂eq yr⁻¹ in 2030. It
5 should be noted that the GDP growth projected by India in its NDC is in the higher end of the range
6 of GDP growth of the SSP scenarios. Therefore, here the main reason for our larger estimates comes
7 from the fact the Indian carbon intensity target is overachieved in previous studies.
8
9

10
11
12 The differences about Chinese and Indian estimates represent together about 70% of the difference
13 in global 2030 emissions. The rest of the difference between our estimate and previous estimates
14 may be due to the treatment of other countries, the level of disaggregation for small countries, the
15 choice of global warming potentials to compute carbon dioxide equivalent emissions, the treatment
16 of emissions related to land use, and the treatment of international aviation and maritime shipping.
17
18
19

20
21 Our results in terms of 2030 emissions can also be compared to the IAM quantifications of emissions
22 trajectories for the combinations of the five SSP socioeconomic pathways and various radiative
23 forcing pathways. Section 12 from the Supplementary Material presents such a comparison at the
24 level of five world regions (see Figure S9). We find that our quantification of emissions levels in 2030
25 corresponding to NDC for Asia is at the higher end of IAM quantifications, whereas they are at the
26 lower end for OECD countries and in the middle of the range for other regions.
27
28
29

30
31
32 The uncertainty range for 2030 global emissions results from multiple drivers (Figure 1b). With 44%
33 of the total variance explained, the NDC ambition level is the most important source of uncertainty.
34 Our set of assumptions to interpret NDCs further explains 5 % of the total variance, Future economic
35 growth is also a sizeable source of uncertainty, across SSP scenarios (7%) and especially across GDP
36 data sources within each SSP scenario (20%) (Fig. S7). The relative importance of uncertainty related
37 to economic growth is not surprising given the fact that we consider a large range of GDP values for
38 2030, while a number of key emerging countries have expressed their NDCs with carbon-intensity
39 targets. However the fact that the different GDP interpretations of the SSP are leading to larger
40 differences in global emissions than the different SSP is more unexpected, highlighting the
41 heterogeneity of GDP projections even when following similar narratives. The choice of carbon
42 intensity reduction profile for China explains 7.6% of the total variance. Other identified sources of
43 uncertainty, related to LULUCF or international aviation and shipping, are small. This does not mean
44 the corresponding emissions are not important though, since the share of international aviation and
45 shipping in global emissions increase from 2.3% in 2010 to 3.0 to 3.7% in 2030. The total uncertainty
46 due to LULUCF is more important than shown in the figure, as our estimate only bears on LULUCF
47 emissions from the few countries that have provided separate targets for LULUCF in their NDC; for
48 numerous countries this uncertainty is contained in the NDCs themselves [30]. The term “interaction
49
50
51
52
53
54
55
56
57
58
59
60

of all drivers” arises from covariances between all drivers. In terms of countries, uncertainties on 2030 emissions are largely driven by uncertainties on Chinese, Indian and Rest of World countries emissions (Fig. S7).

3.2 Distribution of GHG emissions in 2030

Notwithstanding the uncertainty surrounding 2030 global emissions, NDCs announce a significant change in the distribution of emissions among countries. This evolution reflects the combination of demographic and economic dynamics with mitigation efforts across the world. As shown in Figure 2a, emissions from the United States, the European Union and LEA countries are all lower in 2030 than in 2010, whereas emissions from China, India, countries from the “World Other” group, international transport and to a lesser extent LENA countries are larger in 2030 than in 2010, whichever GDP scenario is considered.

Emerging and developing countries will represent in 2030 a larger share of global emissions than in 2010 (Fig. 2b). In particular, the combined shares of China and India could reach up to 37 to 41% in 2030, against 28% in 2010. The share of the United States, the European Union and LEA countries would decrease, from 38% in 2010, to a range from 22 to 25% in 2030, depending on the GDP scenario considered.

We also analyse international inequalities in per capita GHG emissions. We find a noticeable reduction in such inequalities (see Supplementary Material section 13, figures S10-12).

3.3 Relation with long-term mitigation goal

Assessing whether current NDCs put countries on track to the long-term goal of “keeping warming well below 2°C and do best efforts to maintain it under 1.5°C” [1] is not a straightforward task. Indeed, it implies building scenarios until the end of the 21st century [31] and judging on how fast emissions can be reduced after 2030. A less questionable way of assessing aggregated NDCs is to compare the implied 2030 global emissions to the worldwide GHG emissions reduction target of 40 to 70% in 2050 compared to 2010 reported in the IPCC Fifth Assessment Report for scenarios aiming at limiting warming to 2°C with a >66% probability [32, 33]. These scenarios correspond to a range of permissible emissions of 15 to 30 Gt CO₂eq yr⁻¹ in 2050. As shown in Figure 3, our interpretation of NDCs results in an average global emissions growth of 1.0% ± 0.7% per year between 2010 and 2030. However, this hides large regional disparities, with e.g. an average emission reduction of 5.1% per year in Brazil, and 5.1% per year emission increase in India. Connecting the NDCs’ 2030 global emission level to the 2°C compatible range in 2050 requires an average annual worldwide reduction

1
2
3 rate in emissions of $4.9\% \pm 2.3\%$. Note that uncertainty for 2030 emissions is mainly due to economic
4 GDP scenarios and NDCs interpretation (Figure 1b), whereas the 2050 range results from uncertainty
5 on achievable emissions trajectories and technology developments during the second half of the 21st
6 century.
7
8
9

10 **4. Conclusion**

11
12
13 We have evaluated the level of global GHG emissions in 2030 if all countries would exactly reach the
14 target stated in their NDCs. We find a 5-95% uncertainty range of 56.8 to 66.5 Gt CO₂eq yr⁻¹, and
15 show that the main sources of uncertainty is the ranges of ambitions given in NDCs, and the
16 uncertainty on the economic growth of countries who expressed their target in terms of intensity.
17 We show that, despite this uncertainty, NDCs provide robust evidence of a shift in GHG emissions
18 towards emerging and developing countries and a reduction in international inequalities in per capita
19 GHG emissions.
20
21
22
23
24
25

26 These results have three main implications:

27
28 First, the large uncertainty surrounding the 2030 global GHG emissions makes a strong case for an
29 improved common framework regarding future NDCs in upcoming negotiation cycles. In particular a
30 growth assumption could be provided in the case of an intensity target and separate national targets
31 for LULUCF emissions could be provided for countries relying significantly on carbon sinks.
32
33
34
35

36 Second, the growing share of emerging and developing countries' emissions in global emissions
37 illustrates the importance of a universal agreement including all countries such as the Paris
38 Agreement.
39
40
41

42 And third, the post-2030 emissions reduction challenge is emphasized: the most ambitious NDC (in
43 terms of emissions reduction) implies an annual minimum reduction rate that should be matched on
44 a global scale after 2030, in order to be on track by mid-century for limiting global warming to 2°C. In
45 particular, this result highlights how efforts needed after 2030 can be reduced if emissions for that
46 year are contained to the lower part of the range (-4.2% yr⁻¹ needed for 2030-2050 when at the
47 bottom of the 2030 range, versus -5.5% yr⁻¹ when at the top). In this framework, any action that can
48 secure a 2030 emission level at the lower part of the range (such as conditional NDCs, e.g. funds and
49 technology transfer between "North" and "South") makes the post-2030 challenge a bit less
50 formidable. Furthermore, this result makes the case for a strong update mechanism, able to raise the
51 NDCs ambition. Finally, even in the most ambitious scenario, a steep decrease in emissions will be
52
53
54
55
56
57
58
59
60

1
2
3 needed for the period 2030-2050. Such a decrease should be prepared as of today [34], at the global,
4 regional, national, and local levels and by all stakeholders.
5

6
7 We conducted this analysis at a highly disaggregated level (103 countries are treated individually)
8 and with a minimal set of assumptions. This methodological choice implies both limitations and
9 strengths.
10
11

12
13 On the limitation side, first, we do not account for uncertainty in historical emissions. Indeed, there is
14 a lack of information on uncertainties in existing emission inventories at the country level. Having
15 only a partial knowledge of 2010 emission uncertainties, we consider it more appropriate to consider
16 a single value (although we do perform a sensitivity analysis on historical Chinese emissions in the
17 Supplementary Material, section 10). Current effort to derive reliable emissions inventories at the
18 country level should be pursued, especially in the land use sector, so that models can be better
19 constrained and emission trends can be detected early on.
20
21
22
23
24

25
26 We also acknowledge that our methodology does not account for the energy component of NDCs
27 that give targets for fossil fuel shares, and further developments should refine the method, or use its
28 complementarity with other methods, in particular those relying on IAMs at the global or national
29 scale, to address this limitation.
30
31

32
33 Furthermore, our methodology neglects feedbacks between emissions reductions and GDP growth:
34 we only use the GDP quantifications of the SSP, not their emissions quantifications. While some IAMs
35 include feedbacks from climate policies onto GDP projections, such a feedback is relatively small
36 compared to both the cumulative economic growth until 2030 for these countries and the
37 uncertainty on economic growth depending on the considered SSP. The effect of NDCs on welfare
38 losses and impact on GDP has been estimated between $\pm 1.6\%$ for China and India, the two countries
39 expressing their targets in terms of carbon intensity of GDP [6, 35, 36].
40
41
42
43
44

45
46 Finally, our approach does not account for a substantial source of uncertainty for 2030 emissions
47 levels, namely which NDCs would be reached, overachieved or missed. It does not give elements on
48 whether current or announced policies, which might result in smaller emissions than implied by the
49 NDCs for some countries, are likely or not to allow reaching or overachieving the target. Therefore, it
50 cannot be used to answer the question of what 2030 emissions are likely to be. Other types of
51 analyses looked into this question. For instance, China presented a rather conservative intensity
52 target in its NDC, and some analysts consider it likely to be overachieved [37]. Our analysis can thus
53 only inform on what would emissions be if NDCs targets are taken “at face value”, i.e. if they would
54
55
56
57
58
59
60

1
2
3 be exactly met. Such information can be used to highlight the need for NDCs update, and to track
4 how updates would reduce 2030 emissions and the associated uncertainty.
5
6

7 Other methodologies, in particular those relying on IAMs, can address these limitations; but currently
8 lack some of the strengths of our methodology, namely its high country resolution, its flexibility, and
9 its transparency. To exploit these strengths, we are making the projections and the code available for
10 other teams to reproduce, improve or update the analysis. In particular, alternative assumptions
11 could be tested with the available code, e.g. growth assumptions different from those in SSPs since
12 our results have shown that they are an important driver of uncertainty. Furthermore, our
13 methodology could be extended to project cumulative emissions from today until 2030, to compare
14 them to allowable budget for the 1.5°C and the 2°C targets. Doing so would require additional
15 assumptions about the time profile of emissions to 2030, which is not directly available in NDCs, and
16 would therefore introduce additional uncertainty. Also, our results could be compared to Business-
17 as-Usual or alternative climate policy scenarios projections at the country levels to allow further
18 analysis, e.g. to answer the questions whether NDCs represent a significant difference relative to
19 these projections or whether NDCs significantly change emissions distribution relative to these
20 projections. Finally, the structure of our model makes it easy to update our results when new data or
21 NDCs become available.
22
23
24
25
26
27
28
29
30
31
32
33
34
35

36 **Acknowledgements:** The authors would like to acknowledge grants from ADEME on the analysis of
37 Intended Nationally Determined Contributions in relation to COP21 and the French Ministère de la
38 Transition Ecologique et Solidaire (MTES) on climatic services.
39
40

41 **Author contributions:** HB, OB, CG and PC designed the study. HB performed the analysis. All authors
42 contributed to writing the article.
43
44

45 **Competing financial interests:** The authors have no competing interest.
46
47
48

49 **References**

- 50 1. UNFCCC 2015 Draft decision -/CP.21, FCCC/CP/2015/L.9/Rev.1
51 (<http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf>)
- 52 2. UNFCCC 2016 Aggregate effect of the intended nationally determined contributions: an update
53 FCCC/CP/2016/2. Conference of the Parties, Twenty-Second Session
54 (<http://unfccc.int/resource/docs/2016/cop22/eng/02.pdf>)
- 55 3. UNEP 2015 The emission gap report, A UNEP synthesis report. ISBN: 978-92-807-3491-1
56
57
58
59
60

4. UNEP 2017 The emission gap report, A UNEP synthesis report. ISBN: 978-92-807-3673-1
5. Fawcett A A, *et al.* 2015. Can Paris pledges avert severe climate change? *Science* 350 1168-1169
(doi: 10.1126/science.aad5761)
6. Rogelj J, den Elzen M, Höhne N, Fransen T, Fekete H, Winkler H, Schaeffer R, Fu S, Riahi K and
Meinshausen M 2016 Paris Agreement climate proposals need a boost to keep warming well below
2°C *Nature* 534 631-639 (doi: 10.1038/nature18307)
7. den Elzen M, Admiraal A, Roelfsema M, van Soest H, Hof AF and Forsell N 2016 Contribution of the
G20 economies to the global impact of the Paris agreement climate proposals *Climatic Change* 137
655-665 (doi:10.1007/s10584-016-1700-7)
8. Vandyck T, Keramidas K, Saveyn B, Kitous A and Vrontisi Z 2016 A global stocktake of the Paris
pledges: Implications for energy systems and economy *Global Environmental Change* 41 46-63 (doi:
10.1016/j.gloenvcha.2016.08.006)
9. Rogelj J, Fricko O, Meinshausen M, Jrey V, Zilliacus J J J, and Riahi K 2017 Understanding the origin
of Paris Agreement emission uncertainties *Nature Communications* 8 (doi:10.1038/ncomms15748)
10. O'Neill BC *et al.* 2014 A new scenario framework for climate change research: the concept of
shared socioeconomic pathways *Climatic Change* 122 387-400 (doi: 10.1007/s10584-013-0905-2)
11. Boucher O, Benveniste H and Guivarch C 2016 Nations' pledges to reduce emissions and the 2°C
objective *EOS* 97 (doi:10.1029/2016EO052397)
12. Fouré J, Bénassy-Quéré A and Fontagné L 2013 Modelling the world economy at the 2050 horizon
Economics of Transition 21 617-654 (doi: 10.1111/ecot.12023)
13. Dellink R, Chateau J, Lanzi E and Magné B 2015 Long-term economic growth projections in the
Shared Socioeconomic Pathways *Global Environ. Change* 42 200-214 (doi:
10.1016/j.gloenvcha.2015.06.004)
14. Crespo J 2015 Income projections for climate change research: A framework based on human
capital dynamics *Global Environ. Change* 42 226-236 (doi: 10.1016/j.gloenvcha.2015.02.012)
15. Leimbach M, Kriegler E, Roming N and Schwanitz J 2015 Future growth patterns of world regions
– A GDP scenario approach *Global Environ. Change* 42 215-225 (doi:
10.1016/j.gloenvcha.2015.02.005)
16. Ciais P *et al.* 2015 *Towards a European Operational Observing System to Monitor Fossil CO₂
emissions, Final Report from the Expert Group, European Commission*
(http://edgar.jrc.ec.europa.eu/news_docs/CO2_report_22-10-2015.pdf)
17. Olivier JGJ, Janssens-Maenhout G, Muntean M and Peters JAHW 2015 *Trends in global CO₂
emissions: 2015 Report* PBL 1803 JRC98184. (http://edgar.jrc.ec.europa.eu/news_docs/jrc-2015-trends-in-global-co2-emissions-2015-report-98184.pdf)

- 1
2
3 18. Hansis E, Davis SJ and Pongratz J 2015 Relevance of methodological choices for accounting of land
4 use change carbon fluxes *Glob. Biogeochem. Cycles* 29 1230–1246 (doi: 10.1002/2014GB004997)
- 5
6 19. Pacala S *et al.* 2010 *Verifying Greenhouse Gas Emissions: Methods to Support International*
7
8 *Climate Agreements Committee on Methods for Estimating Greenhouse Gas Emissions, National*
9
10 *Research Council Report National Academy of Sciences USA* 110 p.
11 ([http://www.nap.edu/catalog/12883/verifying-greenhouse-gas-emissions-methods-to-support-](http://www.nap.edu/catalog/12883/verifying-greenhouse-gas-emissions-methods-to-support-international-climate-agreements)
12 [international-climate-agreements](http://www.nap.edu/catalog/12883/verifying-greenhouse-gas-emissions-methods-to-support-international-climate-agreements))
13
14
- 15 20. Korsbakken JI, Peters GP and Andrew RM 2016 Uncertainties around reductions in China's coal
16 use and CO₂ emissions *Nature Climate Change* 6 687-690 (doi: 10.1038/nclimate2963)
- 17
18 21. Andres R J, Boden T A and Higdon D 2014 A new evaluation of the uncertainty associated with
19 CDIAC estimates of fossil fuel carbon dioxide emission *Tellus B* 66, 23616 (doi:
20 10.3402/tellusb.v66.23616)
- 21
22
23 22. Liu Z *et al.* 2015 Reduced carbon emission estimates from fossil fuel combustion and cement
24 production in China *Nature* 524 335-338 (doi: 10.1038/nature14677)
- 25
26 23. European Commission Joint Research Centre (JRC) and PBL Netherlands Environmental
27 Assessment Agency 2011 *Emission Database for Global Atmospheric Research (EDGAR) release*
28 *version 4.2* (<http://edgar.jrc.ec.europa.eu>, accessed 22 November 2016)
- 29
30 24. Climate Action Tracker, Accessed 22 November 2016
31 (<http://climateactiontracker.org/global.html>)
32
33
- 34 25. Gütschow J, Jeffery L, Gieseke R, Gebel R, Stevens D, Krapp M and Rocha M 2016 The PRIMAP-
35 hist national historical emissions time series (1850-2014) *GFZ Data Services*
36 (doi.org/10.5880/PIK.2016.003)
- 37
38 26. UNFCCC Accessed November 2017 NDCs as communicated by Parties
39 (<http://www4.unfccc.int/ndcregistry/Pages/Home.aspx>)
40
41
- 42 27. He J-K 2014 An analysis of China's CO₂ emission peaking target and pathways *Advances in Climate*
43 *Change Research* 5 155-161 (doi: 10.1016/j.accre.2015.04.002)
- 44
45 28. Chai Q-M, and Xu H-Q 2014 Modeling an emissions peak in China around 2030: Synergies or
46 trade-offs between economy, energy and climate security *Advances in Climate Change Research* 5
47 169-180 (doi: 10.1016/j.accre.2015.06.001)
- 48
49 29. Le Quéré C, Andrew R M, Friedlingstein P, Sitch S, Pongratz J, Manning A C, Korsbakken J I, Peters
50 G P, Canadell J G, Jackson R B, Boden T A, Tans P P, Andrews O D, Arora V K, Bakker D C E, Barbero L,
51 Becker M, Betts R A, Bopp L, Chevallier F, Chini L P, Ciais P, Cosca C E, Cross J, Currie K, Gasser T,
52 Harris I, Hauck J, Haverd V, Houghton R A, Hunt C W, Hurtt G, Ilyina T, Jain A K, Kato E, Kautz M,
53 Keeling R F, Klein Goldewijk K, Körtzinger A, Landschützer P, Lefèvre N, Lenton A, Lienert S, Lima I,
54
55
56
57
58
59
60

- 1
2
3 Lombardozi D, Metz N, Millero F, Monteiro P M S, Munro D R, Nabel J E M S, Nakaoka S-I, Nojiri Y,
4 Padin X A, Peregon A, Pfeil B, Pierrot D, Poulter B, Rehder G, Reimer J, Rödenbeck C, Schwinger J,
5 Séférian R, Skjelvan I, Stocker B D, Tian H, Tilbrook B, van der Laan-Luijkx I T, van der Werf G R, van
6 Heuven S, Viovy N, Vuichard N, Walker A P, Watson A J, Wiltshire A J, Zaehle S, and Zhu D 2017
7 Global Carbon Budget 2017 *Earth Syst. Sci. Data* under review (doi: 10.5194/essd-2017-123)
8
9
10
11 30.Grassi G, House J, Dentener F, Federici S, den Elzen M and Penman J 2017 The key role of forests
12 in meeting climate targets requires science for credible mitigation *Nature Climate Change* 7 220–226
13 (doi:10.1038/nclimate3227)
14
15
16 31. Sanderson BM, O'Neill BC and Tebaldi C 2016 What would it take to achieve the Paris
17 temperature targets? *Geophys. Res. Lett.* 43 7133-7142 (doi: 10.1002/2016GL069563)
18
19
20 32. Robiou du Pont Y, Jeffery ML, Gütschow J, Christoff P and Meinshausen M 2016 National
21 contributions for decarbonizing the world economy in line with the G7 agreement *Environ. Res. Lett.*
22 11 054005 (doi: 10.1088/1748-9326/11/5/054005)
23
24
25 33. IPCC 2014 Summary for Policymakers *Climate Change 2014: Mitigation of Climate Change.*
26 *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on*
27 *Climate Change* [Edenhofer O *et al.*]. Cambridge University Press, Cambridge, United Kingdom and
28 New York, NY, USA.
29
30
31 34. Boucher O *et al.* 2016 In the wake of the Paris Agreement, new directions for climate change
32 research *Proc. Nat. Acad. Sci. USA* 113 7287-7290 (doi: 10.1073/pnas.1607739113)
33
34
35 35. Fujimori S, Kubota I, Dai H, Takahashi K, Hasegawa T, Liu JY, Hijioka Y, Masui T and Takimi M 2016
36 Will international emissions trading help achieve the objectives of the Paris Agreement?
37 *Environmental Research Letters* 11 104001 (doi: 10.1088/1748-9326/11/10/104001)
38
39
40 36. Aldy J, Pizer W, Tavoni M, Reis LA, Akimoto K, Blanford G, Carraro C, *et al.* 2016 Economic tools to
41 promote transparency and comparability in the Paris Agreement *Nature Climate Change* 6 1000-
42 1004 (doi:10.1038/nclimate3106)
43
44
45 37. Green F and Stern N 2017 China's changing economy: implications for its carbon dioxide
46 emissions *Climate Policy* 4 423-442 (doi:10.1080/14693062.2016.1156515)
47
48
49
50
51
52
53
54
55
56
57
58
59
60

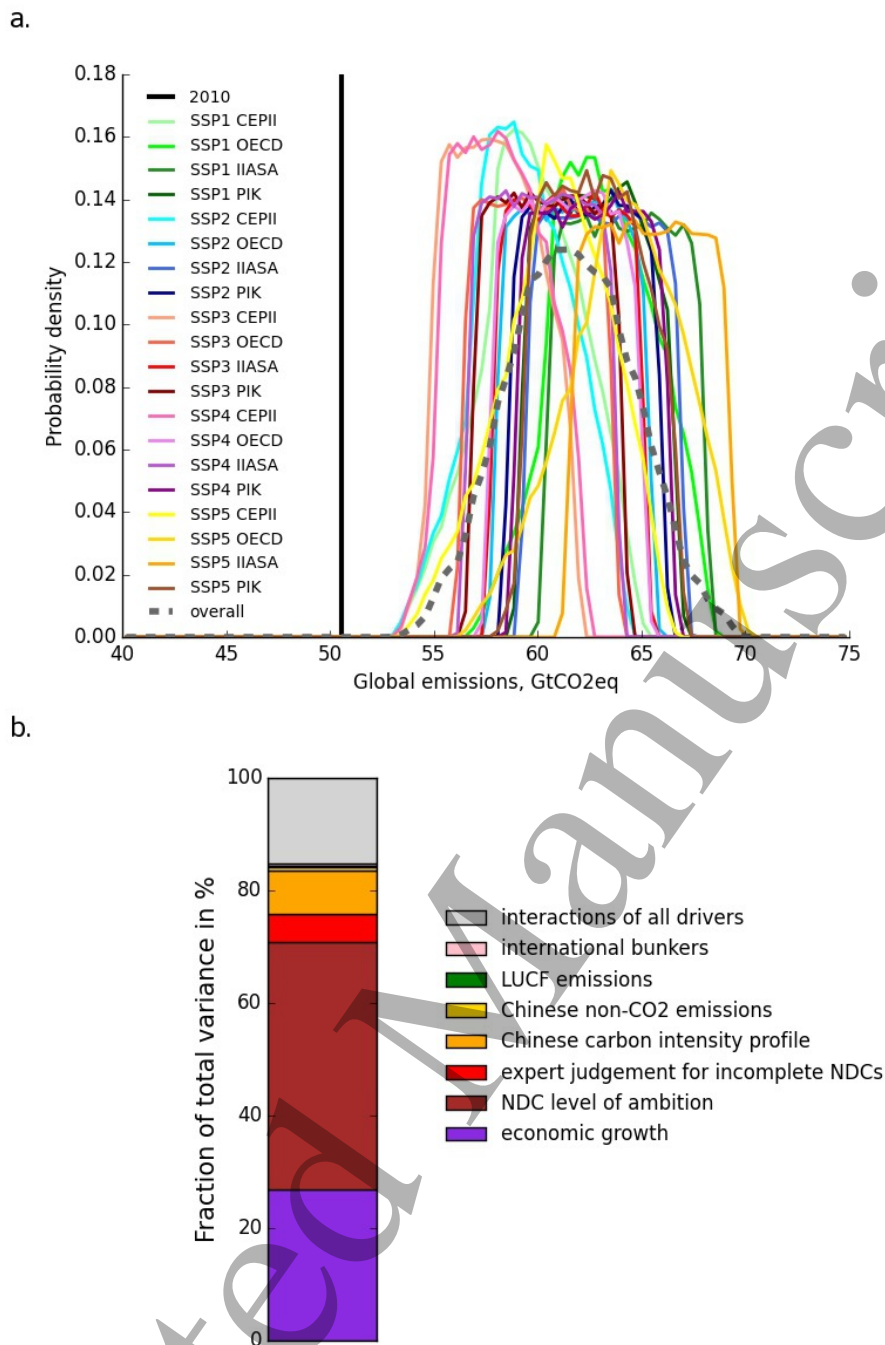


Figure 1 – Global greenhouse gas emissions distributions and uncertainty analysis in 2030 based on sole and full achievement of the NDCs. **a**, Probability distribution function (PDF) of global greenhouse gas emissions (Gt CO₂eq yr⁻¹) in 2030 for the 20 GDP scenarios based on the five Shared Socioeconomic Pathways (SSP) and four different data sources (CEII, OECD, IIASA, PIK) (colored lines), overall distribution for all scenarios (dashed line) and 2010 emissions (black vertical line). See Fig. S5 for a decomposed version of Fig. 1a, per SSP narrative and per GDP data source and Fig. S6 for a version without correction of the EDGAR Chinese historical emissions. **b**, Fraction (%) of the total

variance in 2030 global emissions explained by the various identified drivers. See Fig. S7 for a detailed version.

a.

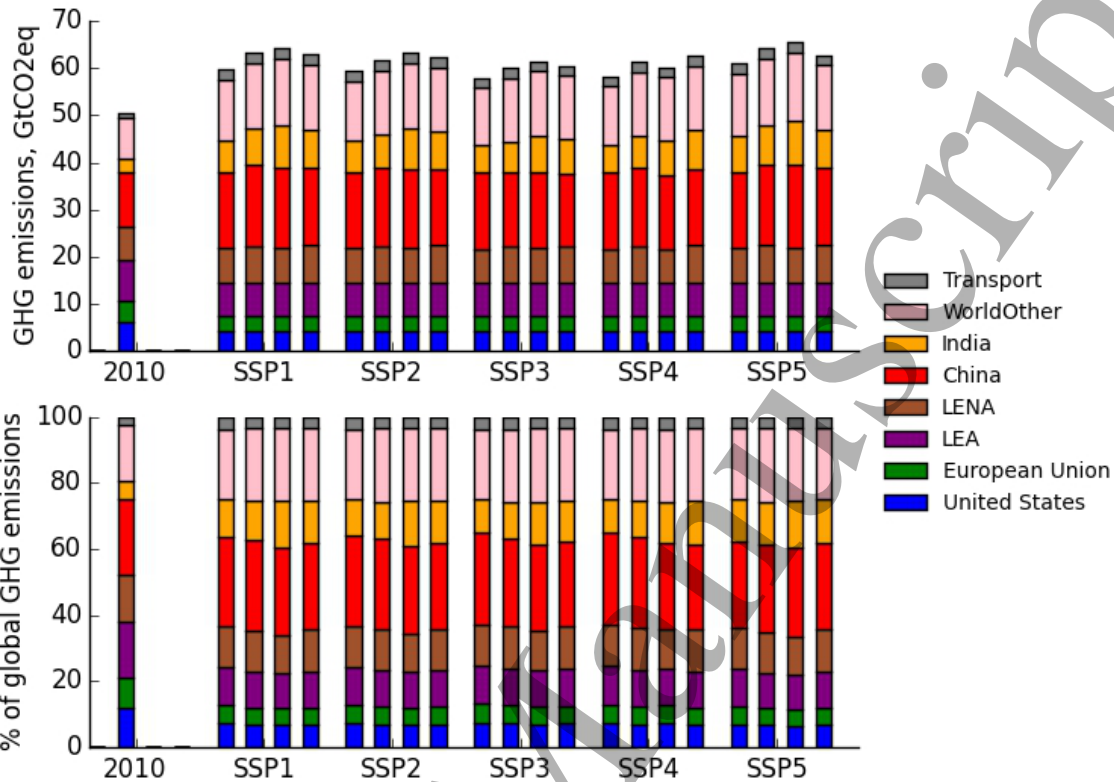


Figure 2 – Contributions of main countries and groups of countries to 2010 and 2030 global emissions based on full and sole achievement of the NDCs. Absolute (a) and relative (b)

contributions of countries and groups of countries to the global emissions in 2010 and 2030, for the five different Shared Socioeconomic Pathways (SSP) and the four different data sources (from left to right: CEPII, OECD, IIASA, PIK). LEA stands for Large Emitters with NDCs containing an Absolute reduction with respect to a base year target (gathering Australia, Brazil, Canada, Japan, Kazakhstan, Russia and Ukraine). LENA stands for Large Emitters with NDCs Not containing an Absolute reduction with respect to a base year target (including Egypt, Indonesia, Iran, South Korea, Malaysia, Mexico, Saudi Arabia, South Africa, Taiwan, Thailand, Turkey and the United Arab Emirates).

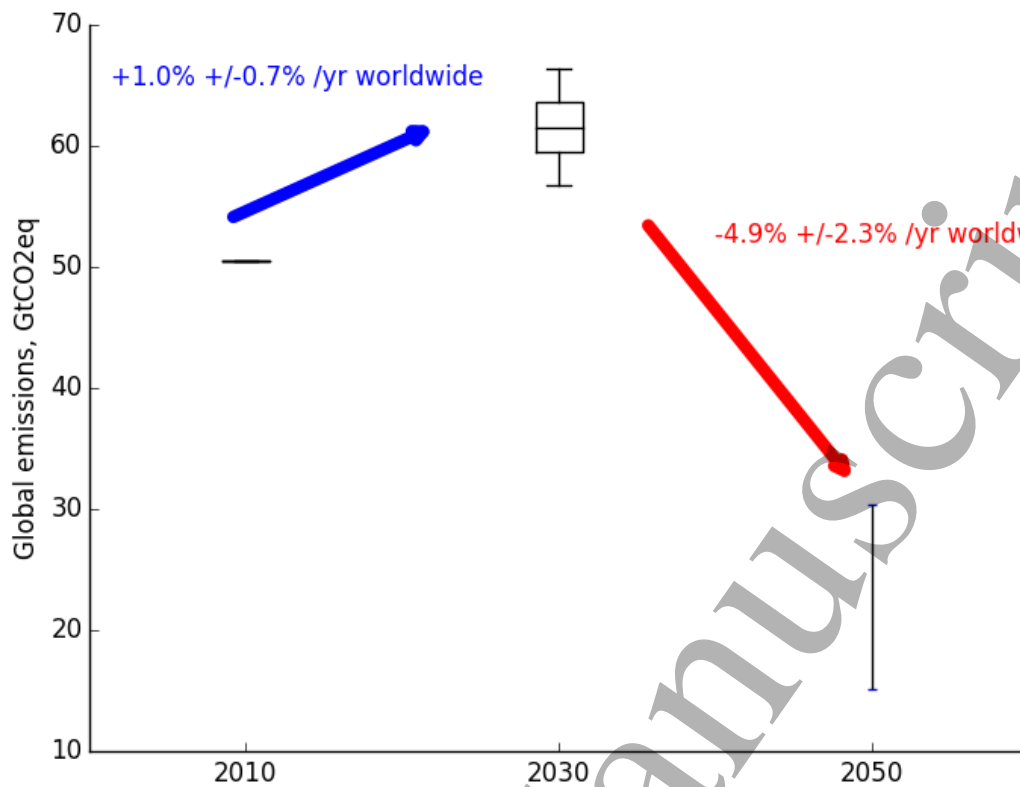


Figure 3 - Global emissions and uncertainty ranges in 2010, 2030 and 2050. The 2030 range is determined based on full and sole achievement of the NDCs, while the 2050 range corresponds to the Intergovernmental Panel on Climate Change (IPCC) milestone if global warming is to be limited to 2°C since pre-industrial times (i.e., 40 to 70% emissions reductions in 2050 compared to 2010). The uncertainty range is shown for 2030 in the form of a box-and-whisker plot representing the 5th percentile, 1st quartile, median, 3rd quartile and 95th percentile values. Arrows indicate the average rate of change in annual global emissions for the periods 2010-2030 and 2030-2050.

	UNFCCC [2]	UNEP [4]	Fawcett et al. [5]	Vandyck et al. [8]	den Elzen et al. [7]	Rogelj et al. [9]	This study (all scenarios)	This study (OECD SSP2)
Globe^a	56.2 (52.0 - 59.3)	55.2 (51.9–56.2) 52.8 (49.5–54.2)	52.8 (50.7 – 54.1)	56	54.5 (53-58) 52.0 (51-56)	52.3 (47.1 – 62.9)	61.7 (56.8 - 66.5)	61.8 (58.4 – 65.0)
United States		4.6-4.8 ^d	4.0	4.4 ^b	4.0 – 4.1		4.3 (4.2 – 4.4)	4.3 (4.2 – 4.4)
Europe (EU-28)		3.2	2.4 ^c	3.3 ^b	3.4		3.3	3.3
China		14 (13.2 – 15.3)	14.1 (13.3 – 14.2)	15.0 ^a	14.0 (12.6 – 16.8)		16.4 (14.5 – 18.2)	16.8 (15.9 – 17.6)
India		5.9 (4.8-7.9) 5.1 (4.0-6.2)	5.3 (5.1 - 5.7)	5.2 ^a	4.2		7.6 (5.8 – 9.1)	7.0 (6.9 – 7.1)

Table 1 – 2030 emission levels at the global scale and for a few large countries, as estimated by various studies cited in the present analysis. Default: emissions expressed in CO₂eq including LULUCF. a: the second line is for conditional NDCs, b: CO₂eq excl. LULUCF, c: EU-15 only, d: estimation for 2025. Uncertainty ranges in parentheses correspond to the following percentiles: UNFCCC 20%-80%; UNEP 10%-90%; den Elzen min-max; Rogelj et al. min-max; this study 5%-95%. Fawcett et al. use three groups of scenarios based on different population and GDP assumptions; we report values from the medium reference scenario, and uncertainty ranges are the low and high reference scenarios.