Global climate action from cities, regions, and businesses

Impact of individual actors and cooperative initiatives on global and national emissions. 2019 edition.

Technical annex I: Methodology for quantifying the potential impact of individual actors' commitments

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1 Datasets used in the analysis

The analysis covers commitments from individual actors that have set quantitative greenhouse gas (GHG) emissions reduction targets, and for which historical emissions data is available. The emissions trajectories for non-state and subnational actors with commitments are developed based on the data provided by CDP for companies and by Data-Driven Lab, with data from the Alliance of Peak Pioneering Cities, Global Covenant of Mayors for Climate & Energy, Global Covenant of Mayors for Climate & Energy (EU Secretariat), Compact of States and Regions, CDP Cities, ICLEI carbon*n*® Climate Registry, C40 Cities Climate Leadership Group, Under2 Coalition, We Are Still In, United States Climate Mayors, and United States Climate Alliance, for sub-national actors. Our analysis covers quantifiable emissions reduction commitments from over 6,000 cities, more than 70 regions, and approximately 1,500 companies operating in the 10 high-emitting economies.

Direct emissions (Scope 1) and indirect emissions from electricity generation (Scope 2) are included in the analysis for individual actors. Commitments' impact on supply chain emissions (Scope 3) are excluded from the analysis if they make up the entirety of the commitment. While Scope 3 emissions are significant for most companies, it was not possible to quantify the overlaps between Scope 1 and 2 emissions and Scope 3 emissions across actors, nor to localize these emissions to specific geographies given current data availability. We include commitments with a combination of Scope 1 and 2 emissions and Scope 3 emissions, although the impact of this assumption on the obtained results are likely limited since there are only 118 companies with this type of commitment in our dataset. For cities, very few report Scope 3 emissions in their inventories, which prevented us from assessing them in this study.

1.1 Overview of data

Our analysis considered approximately quantifiable emissions reduction commitments from 6,001 cities, 73 regions, and approximately 1,500 companies. The emissions inventory totals used for the calculations were mostly self-reported by entities through one of the above-mentioned reporting platforms. Data for quantifiable climate commitments came from the sources presented in Table 1.

Table 1: Data sources for individual subnational and non-state actor commitments

Climate Action Platform	Data source
Alliance of Peaking Pioneer Cities of China	Alliance of Peaking Pioneer Cities of China (2016). Accessed from: http://www.huanjing100.com/p-1307.html. Peak emissions years were used in the calculation of the cities' projected carbon emissions.
C40 Cities for Climate Leadership Group	C40 Cities for Climate Leadership. Accessed June 2019 from: https://www.c40.org/cities.
ICLEI Local Governments for Sustainability carbon*n*® Climate Registry	ICLEI Local Governments for Sustainability carbon*n*® Climate Registry (www.carbonn.org). (Data provided directly by ICLEI in June 2019). Individual targets and action plans for carbonn participants based on 2018 GPC Inventory responses. In cases where baseline information for participating actors was absent, it was supplemented with baseline information from data collected from carbon*n*'s reporting members (individual targets, action plans, and progress data) in March 2018.
CDP Cities	CDP. (2019). 2018 Cities Emissions Reduction Targets; 2018_Cities Community-wide Emissions Map; 2018 Cities Renewable Energy Targets Map.csv; 2018 City-wide Electricity_Mix. Accessed May 2019 from: www.data.cdp.net.
CDP 2018 Disclosure Survey	CDP. (Provided directly from CDP in July 2019). *GHG emissions and action data for companies based on the 2018 responses*.
Compact of States and Regions	Compact of States and Regions. (Data provided directly by the Compact of States and Regions in February 2019). 2018 States and Regions Open Portal Dataset collected via CDP States and Regions 2018 Information Request.
EU Covenant of Mayors for Climate & Energy	EU Covenant of Mayors for Climate & Energy. Individual targets and emissions data for reporting members. Accessed April 2019 from: www.globalcovenantofmayors.org.
Under2 Coalition	Under2 Coalition (Secretariat: The Climate Group). Membership and action data collected from signatories' appendices. Accessed June 2019 from: https://www.under2coalition.org/members.
Global Covenant of Mayors for Climate & Energy	Global Covenant of Mayors for Climate & Energy. (Data provided directly by Global Covenant of Mayors in June 2019). Individual targets and emissions data for reporting members.
US Climate Alliance	U.S. Climate Alliance. Accessed July 2019 from: https://www.usclimatealliance.org/state-climate-energy-policies. Information from this source was supplemented through desk research of participants' climate action targets or plans.
US Climate Mayors	US Climate Mayors. Accessed July 2019 from: www.climatemayors.org and http://climatemayors.org/actions/climate-action-compendium/. Information from this source was supplemented through desk research of participants' climate action targets or plans.

The emission pathway in the "Current national policies plus individual actors' commitments" (CP+NSA) scenario for each actor is derived from emission levels in target year. We assume a linear interpolation of emission levels between the modelling starting year (2016) and the short- to mid-term target year (between 2020 and 2030), as well as between the short- to mid-term target year and the long-term target year. After the last target year, we have assumed that the emission levels follow CP scenario emission projections until 2030 (see Section 1.4).

1.2 Subnational actions

Subnational climate action data was collected from a variety of climate action registries and platforms, including the Global Covenant of Mayors for Climate and Energy, Global Covenant of Mayors for Climate and Energy (EU Secretariat), Compact of States and Regions, CDP Cities, ICLEI carbon*n*® Climate Registry, C40 Cities Climate Leadership Network, Under2 Coalition, United States Climate Mayors, United States Climate Alliance and We Are Still In.[1]

Different platforms report participants' climate actions in different formats and to different levels of detail: CDP Cities report the breakdown of Scope 1 and Scope 2 emissions of subnational actors, whereas others do not include information on emissions scopes if inventory information is reported by an actor. Climate action platforms also capture different types of targets that span absolute greenhouse gas (GHG) emissions reduction, energy efficiency, renewable energy, and intensity-based targets, among others.

To overcome the inconsistencies in each platform's method of categorizing targets and to include as many subnational actors' targets as possible, we chose the most common targets across platforms. We included city- or region-wide absolute GHG emission reduction targets and quantified each target's emissions reduction using the following variables: actor's base year Scope 1 and Scope 2 emissions, the target percent reduction, the target base year, the target year, and the actor's most recent GHG inventory data.

In the preliminary analysis presented in this paper, sector-level and government-operations targets for cities and regions were excluded if city- or region-wide emissions reduction targets existed.

In sum, the hierarchy was applied as follows:

1) City- or region-wide absolute GHG emissions reduction targets, in terms of:
    - Absolute emissions reduction
    - Reduction relative to base year emissions
2) Government (e.g., direct and indirect GHG emissions from buildings and other government-owned sources) GHG emission reduction targets, in terms of:
    - Absolute emissions reduction
    - Reduction relative to base year emissions

We supplemented data on subnational actors from a range of external sources for key countries in our analysis. Chinese subnational commitments were derived from the C40 Cities for Climate Leadership Group, the iGDP China Policy Mapping Tool (IGDP, 2019), and the Chinese cities and provinces participating in the Alliance of Pioneer Peaking Cities (2016). China's 2012 emissions inventory data (including both Scopes 1 and 2) of these cities in 2012 were taken from Liu & Cai (2018). Population data and projections from the World Urbanization Prospects 2014 were also used in the calculation of these Chinese cities' emissions (UN DESA, 2014b). GDP data were derived from the China Economic Database (CEIC, 2019). For US subnational actors, we gap-filled some missing information on baseline emissions and climate action commitments through internet desk research of city climate action plans and progress reports.

[1] Several of these networks are included as data sources for both the analysis of individual commitments by cities, states, and regions and the analysis of ICIs. In this analysis, we assess the specific commitments already made by each city, state, and region, while the ICIs analysis assess the aspirational goals of included initiatives.

In other cases, when city-level GHG emissions data was missing cities' emission values were calculated by multiplying per-capita provincial-level emissions by the cities' population. An example of such a case is Semarang in Indonesia. The city's emissions inventory value was calculated by multiplying per capita emissions of Central Java Province (where Semarang is located), as reported in the World Resources Institute (WRI)'s CAIT Indonesia Climate Data Explorer (PINDAI) (WRI, 2016), by Semarang's population.

While the 2018 report included renewable energy targets for subnational actors without GHG emission reduction targets, this analysis does not incorporate renewable energy commitments. The 2018 report revealed that there were only a few subnational actors with no GHG emissions reduction targets but with renewable energy targets, which were considered but resulted in very small total reductions.

We also made several corrections to the reported data based on additional desk research and expert judgment. When we could not verify questionable data, we removed these commitments from our analysis. In total we quantified commitments from 6074 subnational actors from 37 countries in our key 10 high-emitting economies.

The emissions data for the subnational commitments was carefully examined; we corrected or excluded erroneous data points whenever identified. Most commonly observed errors were emissions reported in wrong orders of magnitude in the original source from which we collected data. At the same time, it was not possible to verify the orders of magnitude for all commitments, which add up to more than 6,000. Therefore, we applied filters to exclude commitments with per capita GHG emissions lower than 0.2 tCO_2e/capita and higher than 40 tCO_2e/capita, with a few exceptions for which were able to verify the correctness of the data (e.g., many GHG commitments for local government operations, which often had very low per capita GHG emissions values, were still included in the analysis).

For the analysis described section 2.1, we combined company revenue data from the 2019 Fortune Global 500, Forbes Global 2000, and Hoovers datasets, supplemented, when possible, with desk research. Population data for cities and regions came from the data sources listed above, supplemented, when possible, with desk research.

1.3 Companies' actions

The dataset of companies' actions was provided by CDP. It is based on the 2018 responses to CDP's investor climate and supply chain program (CDP, 2019). The CDP dataset on company-level action provides information necessary for the analysis, such as the amount of GHG emissions generated in each country's jurisdiction, by a company operating worldwide. While CDP is not necessarily comprehensive of all corporate global climate action, they report that over 6,900 companies responded to their climate change questionnaire (CDP, 2019). Of these companies, about half reported that they had an absolute or intensity GHG emissions reduction target in place (CDP, 2019). We quantified the mitigation impact of approximately 1,500 companies that reported quantifiable GHG emissions reduction targets and operated within the 10 high-emitting economies this report focuses on.

The CDP questionnaire for companies encourages the use of GWPs from the IPCC's Fifth Assessment Report (AR5) (IPCC, 2014) for reporting emissions. We consider these data to be comparable with that reported in terms of AR4 GWPs as most companies are categorised to be emitting predominantly CO_2, with only a minimal amount of tracked emissions (<1%) coming from non-CO_2 emissions from the waste sector.

For the quantification of absolute emission levels under the commitments, we used values provided by CDP. CDP either received GHG emissions reduction levels directly, or calculated levels based on another indirect measure of climate mitigation (i.e., a commitment to increase renewable energy generation). Starting year (inventory) emission values were calculated as the sum of total Scope 1 and 2 emissions in the country of operation, while target year emission values were calculated using the company's target percentage in emissions reduction for absolute targets, anticipated emissions reduction for emission intensity targets. Targets aiming at exclusively reducing Scope 3 emissions were removed from the dataset since we were unable to quantify probable overlaps, while targets that also include Scope 3 emissions alongside Scope 1 and/or Scope 2 emissions were included due to their low group size (~1% of the number of total company commitments).

From all companies in the dataset, for each country branch one GHG target was selected, based on the following priority order

- Target years after 2017 were preferred to those before 2017
- Absolute emission reduction targets were preferred to intensity targets
- Scopes preferred in order of "Scope 1+2", "Scope1+2+3", "Scope 1", "Scope 1+3", "Scope 2", "Scope 2+3"
- Targets closest just before and closest to 2030 are preferred

The starting point of the scenario analysis is 2016, and therefore the emission pathway of each company branch consists of interpolated emissions between base year, start year and the selected target year. If the target year is before 2030, emission growth in line with the current policies scenario is assumed.

1.4 Emission projections for cities and companies from the IMAGE model

Our assessment makes use of business-as-usual and current policy projections for non-state actors derived from the Targets IMage Energy Regional (TIMER) model developed by PBL. These projections were done for the following cases (see Section 2).

- Emission projections for regions, cities and companies without commitments (partial effect method);
- Current policies scenarios representing emission pathways as the results of national climate- and energy policies.

The TIMER model forms part of the integrated assessment model IMAGE 3.0 (Stehfest *et al.*, 2014). It describes future energy demand and supply for 26 global regions, of which some are large countries (e.g., US, China), and enables us to assess the implications of energy system trends for all major greenhouse gases and air pollutants. This model simulates long-term energy baseline and mitigation scenarios (Van Vuuren et al., 2014) on the global and regional levels. The investments into different energy technologies are calculated by a multinomial logit function that accounts for relative differences in costs and preferences (e.g., technologies with lower costs gain larger market shares). The model is built up from different modules, including energy demand modules for transport, industry, buildings and modules for energy supply, industrial processes and emissions.

The TIMER model does not represent specific actors, but instead a carefully chosen subset of CO_2 emission projections was used from the TIMER Shared Socio-Economic Pathway 2 (SSP2) scenario from van Vuuren et al. (2017). Based on the emission projections from the SSP2 and current policies scenario calculated using the TIMER model, projections have been made for the aggregated regions, cities and companies of a country. This has been done for Brazil, Canada, China, EU (based on Western and Central Europe), India, Indonesia, Japan, and the US. The emission projections for regions were assumed to be the same as the country projections. For cities and companies, the selection of sub-sectors and weights is shown in Table 2 and Table 3. The current policies scenario from Kuramochi et al. (2018) was derived to represent aggregated region, city and company emission growth.

Table 2: Weight applied to total sub-sector CO_2 emissions from TIMER Model to construct (per country) aggregated CO_2 emission projections for companies (for scope 1 and scope 2)

Sector	Sub-sector	Weight scope 1	Weight scope 2
Industry	Cement	100%	100%
	Steel	100%	100%
	Other	100%	100%
	Total industry		
Transport	Bus	0%	
	Train	0%	
	Car	5%	25%
	High speed train	0%	
	Air	0%	
	Trucks	0%	
	Other freight	0%	
	Total transport	0%	
Residential	Urban	0%	0%
Services		100%	100%
Other		100%	100%
Losses/leakages		100%	100%
Bunkers		0%	0%

Table 3: Weight (as percentage of total emissions coming from urban areas) applied to total sub-sector CO_2 emissions from TIMER Model to construct (per country) aggregated CO_2 emission projections for cities (for scope 1 and scope 2)

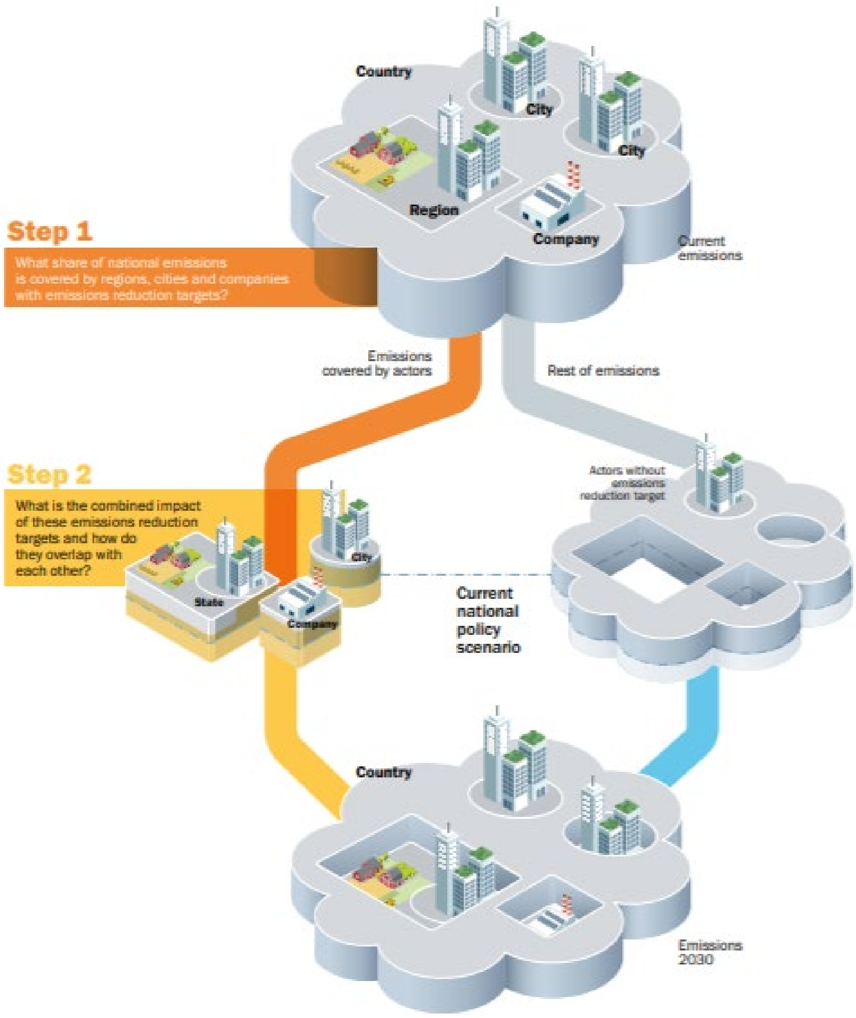
Sector	Sub-sector	Weight scope 1	Weight scope 2
Industry	Cement	0%	0%
	Steel	0%	0%
	Other	75%	75%
	Total industry		
Transport	Bus	75%	
	Train	50%	
	Car	Share of urban population	75%
	High speed train	50%	
	Air	0%	
	Trucks	50%	
	Other freight	0%	
	Total transport	0%	
Residential	Urban	100%	100%
Services		100%	100%
Other		75%	75%
Losses/leakages		0%	0%
Bunkers		0%	0%

2 Quantification of GHG emissions reductions at national level

The quantification of national-level aggregate mitigation impact includes three steps (Figure 1):

- First, additional reductions to national policies per actor group (state/region, city, company) are calculated by comparing GHG emission levels assuming commitments are fully achieved with GHG emissions that would result from only implementing national current policies for that actor group.
- Second, the share of current national emissions that is covered by regions, cities and companies with targets is determined. The share of current emissions that is not covered by regions,' cities' and companies' targets follows the right-hand trajectory of the "current national policies scenario" (see top arrows in Figure 1).
- Third, for the share of emissions covered by targets, first the geographical overlap in GHG emissions between actor groups is determined. Then for overlapping targets, additional reductions to other actor groups is calculated. Finally, the combined effect of all actor groups is determined. See Table 6 and sections below for more details.
- Note that we do not consider the interaction between national policy instruments (included in the current policies scenario) and subnational or non-state actor policy instruments that were implemented to realize the committed emission reductions. We assume that reductions by subnational- and non-state actors do not decrease efforts elsewhere.

Figure 1: Process employed to account for overlaps and quantify the overall impact of all targets.



The emission pathway for the "Current national policies plus individual actors' commitments" (CP+NSA) scenario is defined as the total GHG emissions in a country in year *t* under (E_{tot}(t)) and is given by (Eq. (1)):

$$E_{\text{tot,CP+NSA}}(\text{t}) = E_{\text{tot,CP}}(\text{t}) * \frac{E_{\text{tot}}(2016) - E_{\text{NSA}}(2016)}{E_{\text{tot}}(2016)} + E_{\text{NSA}}(\text{t}) \quad (1)$$

$E_{tot,CP+NSA}$(t): total GHG emissions under "Current national policies plus individual actors' commitments" scenario in year *t*,

$E_{tot,CP}$(t): total GHG emissions under the current national policies scenario in year *t*,

E_{NSA}(t): total GHG emissions from subnational and non-state actors in year *t* as a result of achieving pledged commitments, accounting for overlap between non-state and subnational actors. Derivation of E_{NSA}(t) is elaborated in Section 2.2.3.

We assume in Eq. (1) that the GHG emissions not covered by existing subnational and non-state actor commitments will grow proportionally to the current policies scenario projections.

In the following sections the details of the four calculation steps are described: (1) quantify the target emission levels for individual commitments and then aggregate for each actor group (e.g. regions, cities, and companies) (Section 2.1), (2) quantify the geographical and supply chain overlaps between commitments (Section 2.2.1), (3) compare ambition for emission sources for which targets are overlapping (Section 2.2.2), and (4) determine the combined effect of all targets in cases of overlap (Section 2.2.3).

2.1 Quantification of target emission levels under individual commitments and their aggregation by actor group

Regions, cities and companies are assumed to fully implement their committed reductions in the target year, following a linear emissions reduction pathway from the starting year of the projections. The time period analysed in this study (2016—2030) extends past the target years of many regions, cities and companies. For those non-state and subnational actors, whose target years end before 2030, it is assumed that they follow the average of the two current policies pathways from Kuramochi et al. (2018) after the target year. For regions, cities and companies with multiple GHG emission reduction targets in the same operating country, absolute targets were prioritized above intensity targets, and in addition, the target before and closest to the year 2030 was chosen.

2.1.1 Subnational actors

To calculate the individual subnational emissions reductions, we used three tiers of interpolation between the starting year of our projections (2016) and the quantifiable emissions reduction targets, depending on data reported by individual actors.

- Tier 1: if inventory year and inventory emissions are both available, we interpolate between the latest inventory emissions reported and the target year emissions, assuming a constant rate of decrease.
- Tier 2: if inventory emissions are known but not inventory year, we assume that inventory year is 2010, and apply the same interpolation as Tier 1 (the average year of last inventories was 2013; we assumed an earlier year of 2010 in order to not overestimate the emissions reductions for 2016 and consequently the emissions reductions between 2016 and 2030).
- Tier 3: for cases with no inventory emissions or inventory year, we base our interpolations on base year emissions and base year.

For cities that only report one target year, we assume a constant rate of reduction until the target year, after which we assume emissions have the same trend as the current policies scenario. For cities that have multiple targets, we interpolate from either the inventory or baseline emissions, whichever is available, up to the first target year (i.e., 2030). If a longer-term target (i.e., 2050) is available, we interpolate from the first target year (i.e., 2030) to the second target year (i.e., 2050) by assuming different rates of reduction between the target years.

Because of the nature of China's Alliance of Pioneer Peaking Cities' peak emissions year targets, we had to calculate the emissions reductions differently. We extrapolated emissions from 2012 until 2030, assuming the rate of change in emissions is identical to the rate of change in population. The population projection time series data is obtained from UN Populations Division, World Urbanization Prospects: The 2014 Revision (UN DESA, 2014a). For two Chinese cities (Nanping and Jinchang) and two provinces (Sichuan and Hainan) that did not have population projections available, we used national level emissions growth rates based on the TIMER BAU model to extrapolate future emissions pathway.

For subnational actors that report inventory-year emissions that are lower than the estimated target-year emissions, we assume that these actors have achieved their target emissions reductions in the inventory year and then assume a constant emissions level after the inventory year (i.e., no additional reductions are assumed).

2.1.2 Companies

The analysis divided the companies' actions into two groups based on the target type and the data availability in the CDP dataset:

1) Energy end-use companies with GHG targets;
2) Electricity-generating companies with commitments;
   2a) Utilities with absolute or intensity-based GHG targets
   2b) Utilities and energy end-use companies with renewable electricity generation targets

For each company country branch, absolute emissions reduction targets were prioritized over emission intensity targets if multiple targets from the same company report identical baseline emissions within the same operating country, as this suggests overlapping targets from the same branch. When companies report multiple near-identical targets in the same operating country branch, we consider the target that is before and closest to 2030. We also applied the split between direct emissions (Scope 1) and emissions from electricity generation (Scope 2) of the last available data year to the target year emissions since our data does not report this for both base and target year.

Those records from the CDP dataset that were reported as "poor quality" or reported higher company GHG emissions from the operating branch than the total company were removed from the dataset.

2.2 Quantification of GHG impact overlaps between commitments

2.2.1 Quantification of geographic overlaps between actor commitments

Multiple actors have commitments that target the same geographic area or the same subset of emissions. To avoid the double counting of emission reductions, we first determined to what extent the commitments target the same set of emissions (overlap, described in this chapter) and then, in the cases of overlap, compared the stringency of the various actions (described in the next chapter).

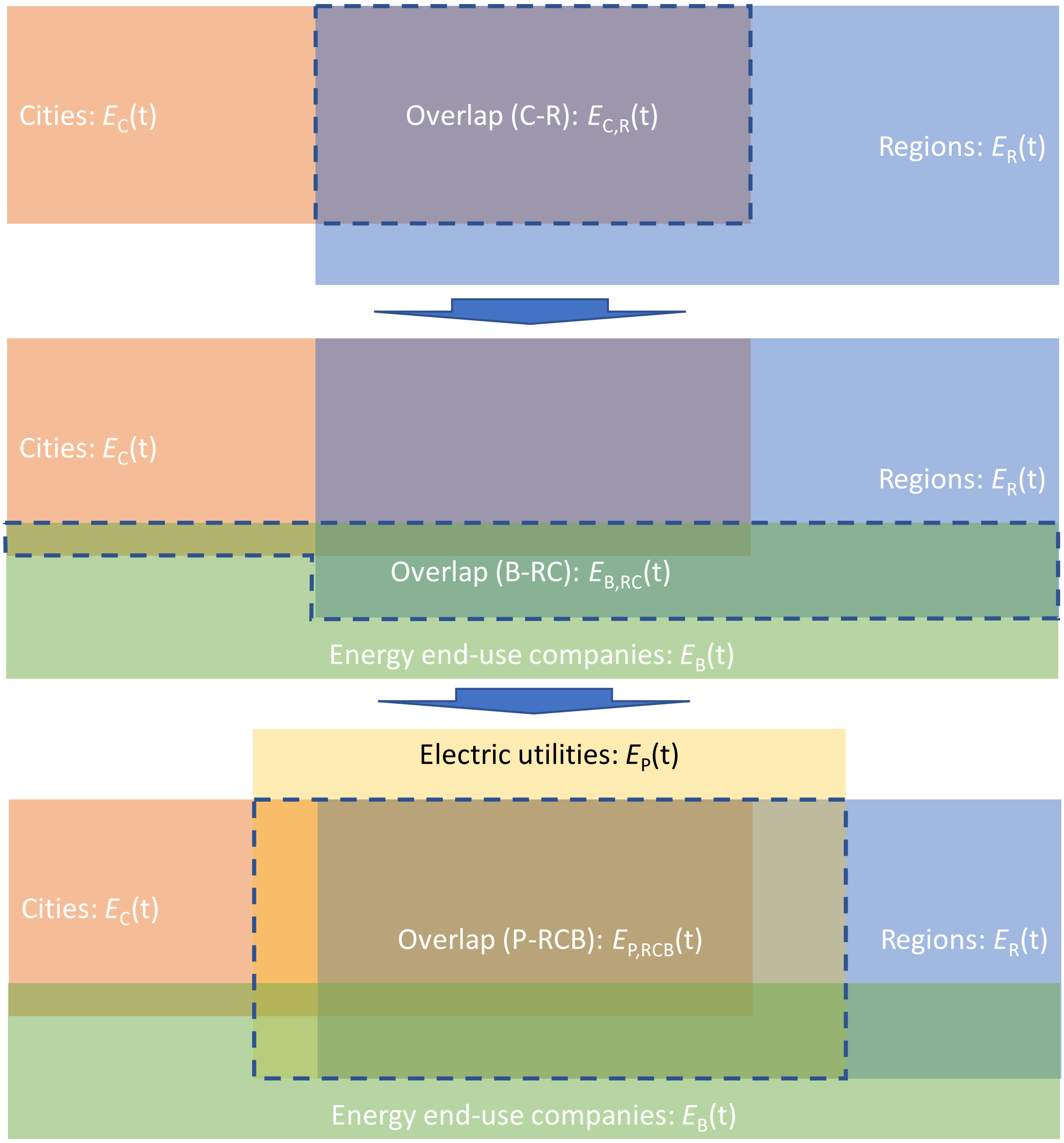
The determination of the overlap was conducted in three steps (see Figure 2).

First, **the geographic overlap between regions with GHG targets and cities with GHG targets** was quantified in terms of GHG emissions. This overlap is calculated based on whether a city with a target is located within a region with a target. After identifying such cities, the net coverage of GHG emissions of sub-national actors (i.e. regions and cities) with commitments (overlap (C-R) in the top panel of Figure 2) was calculated. We have assumed that all electricity consumed by cities is generated in regions in which the cities are located.

Second, **the geographic overlaps between energy end-use companies with GHG targets and sub-national actors with GHG targets** were quantified (overlap (B-RC) in the middle panel of Figure 2). Energy end-use companies are companies that are not electric utilities. We assumed the same percentage of GHG emissions for the overlap between energy end-use companies with GHG targets and sub-nationals with targets as that between sub-nationals and the national target. Therefore, if the net coverage of national total GHG emissions by sub-national actors with commitments in a country is *xx*% of national total GHG emissions, we assumed that the same *xx*% of emissions under end-use companies' commitments are overlapping with subnational actors' commitments. This simplified approach was taken because there was no data available on which subnational jurisdictions the companies' emissions were generated (the CDP dataset provides country-specific emissions data per company).

Third, **the overlaps between electricity-generating companies with commitments and all other sub-national and non-state actors with commitments** (overlap (P-RCB) in the bottom panel of Figure 2) was quantified. This overlap is calculated to avoid double counting of emissions from electricity production by electric and gas utilities (Scope 1), and the use of electricity by other sectors (Scope 2).

Figure 2: Step-by-step quantification of overlaps between actor groups.



We assumed that the overlap rate for electricity-generating companies is equal to the net coverage rate of electricity-related GHG emissions by subnational actors and energy end-use companies. For the calculations, the share of electricity-related GHG emissions in total emissions of a region is assumed to equal the national average; the shares of Scope 2 emissions in energy end-use companies' total Scope 1 plus Scope 2 emissions were often not available, so we mainly used the median values for companies with the data available (Table 4). Country-level total GHG emissions from electricity generation in 2015 were estimated based on IEA (2018a, 2018b).

Table 4: Share of Scope 2 emissions in total Scope 1 plus Scope 2 emissions from cities by region.

Country	Value	Source
Brazil	17%	average of 14 cities data from CDP (2019)
Canada	20%	average of 15 cities data from CDP (2019)

China	45%	Authors' estimate from Liu (2016) on four major cities (Beijing, Shanghai, Tiangjin, Chongqing) in 2009
EU28	34%	average of 53 cities data from CDP (2019)
India	20%	Authors' estimate from Ramachandra et al. (2015) on seven cities (Delhi, Mumbai, Hyderabad, Chennai, Kolkata, Bangalore, Ahmedabad) in 2009-2010
Indonesia	57%	average of 2 cities data from CDP (2019)
Japan	54%	average of 2 cities data from CDP (2019)
Mexico	25%	average of 5 cities data from CDP (2019)
South Africa	60%	average of 5 cities data from CDP (2019)
US	38%	average of 81 cities data from CDP (2019)

The quantification of overlaps was done in the following order: regions, cities, and companies. This order implies starting from the largest emissions scope to the smallest, but it is important to note that this order was taken only to maximize the transparency of the calculation methods and does not imply in any possible way the relative importance of different actor groups.

2.2.2 Comparison of ambition when targets are overlapping

In the previous section we identified emissions that overlap for multiple actor groups, i.e. overlap areas (C-R), (B-RC) and (P-RCB) from Figure 2. For these emissions, we assessed which of the actor group's targets is more ambitious compared to the others.

Two extreme approaches could be taken: 1) emission reductions by actors with commitments are fully counterbalanced by actors that do not act on climate change, and 2) action by actors with commitments is fully additional to other actor's commitments. In the first case, the additional emissions reduction impact of city A's commitment compared to the commitment of region B, in which the city is located, could possibly be zero even if city A's emissions are reducing at a faster rate than region B's. In the second case, city A's action would lead to significant emission reductions, as the reduction effort is not reversed by inaction elsewhere within region B.

We here took two different approaches that present the middle ground between those described above: the **"partial effect" method** and the **"partial conservative effect" method**. Both methods are treated equally and contribute to the uncertainty range presented with the results. The below sections describe instances of comparing the ambition of city-level targets against region-level targets.

2.2.2.1 Partial effect method

The partial effect method only counts the additional reductions of cities to regions if they are unambiguously more ambitious. Ideally, we would compare a city's commitment to the emissions reductions of that city expected under the region-level commitment, but such information does not exist. Therefore, we implement this approach by considering only reductions if a city's target is more ambitious than a long-term emission trajectory consistent with the 2 °C goal (Figure 3). Country-specific long-term trajectories are estimated from Höhne, den Elzen and Escalante (2014) by taking roughly the central estimates of all effort-sharing approaches; the values for 2030 used in the analysis are presented in Table 5.

Figure 3: Illustrative example of contribution to the overall total of a city located in a state with a target in the case of the United States (Kuramochi *et al.*, 2018).

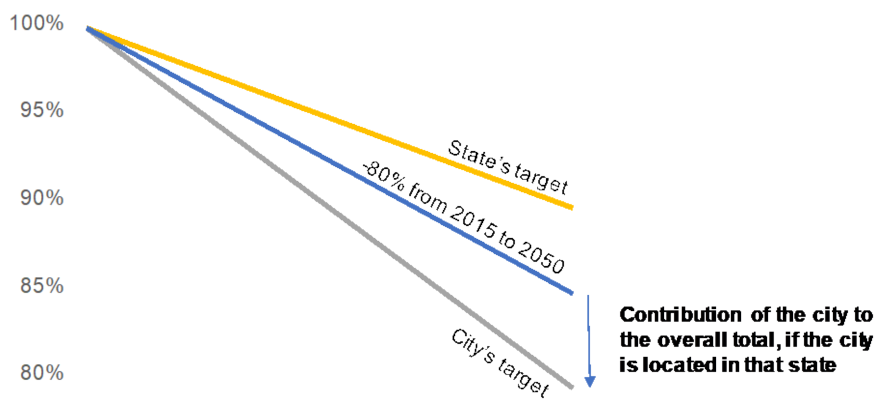


Table 5: Indicative 2030 emission levels implied by 2 °C-consistent emission trajectories under a range of effort sharing approaches used as a threshold for quantifying net additional impact. Source: authors' estimate based on Höhne et al. (2014).

Country	Emissions in 2030 relative to 2015 levels
Brazil	-40%
Canada	-50%
China	-20%
EU28	-50%
India	+50%
Indonesia	-30%
Japan	-50%
Mexico	-40%
South Africa	0%
USA	-50%

2.2.2.2 Partial conservative effect method

The partial conservative effect method assumes that there is always a group with "laggard" sub-national actors and companies that do not implement any climate action. We assume that this groups accounts for the same amount of 2016 GHG emissions as the actors with commitments ("frontrunners"). So, there is a group of frontrunners, a group of laggards, and a group of followers in between. Implicitly, the group of followers implement climate action in line with the national current policies scenario (or NDCs). The assumption on size of the groups is not based on statistical data, as such data on progress is not available. These assumptions on size can be improved when this comes available. Therefore, we have assumed that the group of laggards have the same size, in terms of emissions, as the group of frontrunners. This "laggard" group is assumed to follow a business-as-usual scenario, which is derived from the TIMER model (see Section 1.4).

For illustration purposes, we show an example of calculating aggregated additional city impact relative to the region (see top panel in Figure 2). Suppose the "forerunner" cities in area (C-R) cover 120 $MtCO_2e$/year in 2015, and this group has committed to an annual 2.8% emission reduction rate below 2015 by 2030; the "laggard" cities group which by definition also covers 120 $MtCO_2e$/year in 2015, follows a lower 0.2% business-as-usual emission reduction rate below 2015 by 2030. Further suppose the group of regions (area (C-R)) have on average committed to a 1.4% emission reduction rate below 2015 by 2030. This method assumes that the “forerunner” cities in area (C-R) would deliver emissions reductions additional to those of the regions only when the average emissions reduction rate of “forerunner” cities in area (C-R) and the “laggard” cities, i.e. 1.5% (*2.8%+0.2%*)/2), is larger the regions’ 1.4%. In this case the additional mitigation impact is 0.12 MtCO_2e/year (0.1%*120).

A summary of overlap calculations between actor groups is presented in Table 6.

Table 6 Summary of overlap calculations between actor groups.

	Regions	**Cities**	**Energy end-use companies**	**Electricity-generating companies**
Regions	---	**<u>Overlap (C-R)</u>** Overlap is calculated based on whether a city is in a region with commitments. Two methods for the consideration of additional reductions by cities: 1) “Partial effect method”: Cities’ commitments that are more ambitious than the indicative 2030 emissions (relative to 2016 levels) in line with 2°C warming; 2) “Partial conservative effect method”: The average emissions in 2030 (relative to 2016 levels) of cities’ commitments and the counterfactual “laggard cities” which follow business-as-usual pathways is lower than the 2030 national emissions relative to 2010 levels.	**<u>Overlap (B-RC)</u>** GHG emissions data is only available per country. Geographical overlap is calculated in terms of percentage of GHG emissions between regions/cities and end-use companies. Therefore, it is assumed that GHG emissions from energy end-use companies are evenly spread over the country. Thus, the overlap rate is assumed to equal the net coverage rate of national total GHG emissions by regions and cities with commitments. The same two methods used to quantify cities’ additional reductions for (C-R) overlap is also used here.	**<u>Overlap (P-RCB)</u>** It was assumed that the overlap rate for GHG emissions from electricity-generating companies is equal to the net coverage rate of electricity-related (scope 2) GHG emissions by regions, cities and energy-end use companies with commitments. The same two methods used to quantify cities’ additional reductions for (C-R) overlap is also used here.
Cities		---		
Energy end-use companies			---	

Electricity generating companies				---

2.2.3 Emissions from subnational actors and companies with commitments after accounting for overlaps

Summarizing the above calculation steps, the total GHG emissions from individual actors' commitments are calculated as:

$$E_{NSA}(\mathrm{t}) = E_R(\mathrm{t}) + \left(E_C(t) - E_{C,R}(\mathrm{t}) - E^*_{C,R}(t)\right) + \left(E_B(\mathrm{t}) - E_{B,RC}(\mathrm{t}) - E^*_{B,RC}(t)\right) + \left(E_P(\mathrm{t}) - E_{P,RCB}(\mathrm{t}) - E^*_{P,RCB}(t)\right) \quad (2)$$

where

E_{NSA}(t): total GHG emissions from non-state actors with commitments in year *t*.

E_R(t): total GHG emissions from regions with commitments in year *t*;

E_C(t): total GHG emissions from cities with commitments in year *t*;

$E_{C,R}$(t): total GHG emissions from cities with commitments overlapping with E_R(t) in year *t*;

$E^*_{C,R}$(t): additional GHG emissions reductions from cities with commitments overlapping with E_R(t) in year *t*, after comparing the level of ambition;

E_B(t): total GHG emissions from energy end-use companies with commitments (excluding electricity-generating companies) in year *t*;

$E_{B,RC}$(t): total GHG emissions from energy end-use companies with commitments overlapping with E_R(t) and E_C(t) in year *t*;

$E^*_{B,RC}$(t): additional GHG emissions reductions from energy end-use companies with commitments overlapping with E_R(t) and E_C(t) in year *t*, after comparing the level of ambition;

E_P(t): total GHG emissions from electricity-generating companies with commitments in year *t*;

$E_{P,RCB}$(t): total GHG emissions from electricity-generating companies with commitments, overlapping with E_R(t), E_C(t) and E_B(t) in year *t*; and

$E^*_{P,RCB}$(t): additional GHG emissions reductions from electricity-generating companies with commitments overlapping with E_R(t), E_C(t) and E_B(t) in year *t*, after comparing the level of ambition.

2.2.4 Overlap quantification in the "NDCs plus individual actors' commitments" (NDC+NSA) scenario

For the **"NDCs plus individual actors' commitments" scenario**, cities' and companies' commitments that are not in the aforementioned overlap areas are also examined for additional reductions relative to NDCs. The areas in orange (top panel) for cities, gold (middle panel) energy end-use companies, and light green (bottom panel) electricity-generating companies in Figure 2 would be considered as overlapping with NDC targets—the additional mitigation impact from these cities is calculated similarly for the overlap areas (C-B), (B-RC) and (P-RCB) in Figure 2 as described above.

2.3 Quantification of GHG emissions at global level

We added the impact of the analysed countries to derive the global total. We did not quantify the mitigation potential outside the ten high-emitting economies, due to the relatively small scale of commitments outside of these countries. In 2018 analysis, for instance, out of the more than 6,000 quantifiable subnational actors' commitments we identified, only about 250 came from regions outside of the ten we analysed. We assume that same holds for companies.

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3 Glossary

Cities: Administrative units that pledge commitments to a climate action platform, and which include municipalities, towns, urban communities, districts, and counties defined by the actors themselves.

Climate action by subnational and non-state actors: Any kind of activity that is directly or indirectly aimed at reducing GHG emissions or driving adaptation and resilience and that is led by non-state and sub-national actors. Actions can be put forward and pursued individually (by *one* sub-national or non-state actor) or cooperatively in the form of initiatives (by a *group* of actors, including non-state and/or sub-national actors).

Commitments by subnational and non-state actors: Planned climate action as well as action currently under implementation, which has been publicly announced. Commitments can be put forward and pursued individually (by one sub-national or non-state actor) or cooperatively in the form of initiatives (by a group of actors, including non-state and/or sub-national actors).

International Cooperative Initiative (ICI): Collaborative efforts to address climate change among countries, NGOs, academia, international organizations, states, regions, cities, businesses and investors.

Non-state actor: Any actor other than a national and sub-national government. This includes private actors, such as companies and investors, civil society and international organizations, among others.

Scope 1 emissions: Direct emissions resulting from owned or controlled sources. See www.ghgprotocol.org for further details.

Scope 2 emissions: Indirect emissions resulting from purchased electricity, heat or steam. See www.ghgprotocol.org for further details.

Scope 3 emissions: Other indirect emissions not included in Scope 2 that are in the value chain of a reporting actor, including both upstream and downstream sources. See www.ghgprotocol.org for further details.

States and regions: Larger administrative units that are generally broader in population and in scope than cities. They usually have separate governing bodies from national and city governments but encompass lower administrative levels of government; often, they are the first administrative level below the national government. Regions can also include councils of subnational governments acting together.

Sub-national actor: Any form of government which is not a national government, such as cities, states, provinces and regions.