Implications of Climate Targets at a Local Level: The Study of Mumbai Metropolitan Region, India

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Paris agreement's 2°C target has set a goal for the entire World to reduce emissions. Simultaneously, the countries which are a party to United Nations Framework Convention on Climate Change are also required to set voluntary national climate targets to reduce emissions. For achieving these targets, mitigations efforts have to be made at every possible level, especially from the metropolitan cities as they are the prominent source of emissions. This raises the requirement of elucidating the meaning of climate targets at local levels. In this context, the present study tries to interpret the global and national targets at the level of a metropolitan region and quantify the amount of emission reduction required. Mumbai Metropolitan Region in India was studied for this purpose. Paris Agreement's 2°C target as a global target and India's climate target defined in its Intended Nationally Determined Contributions as the national target were studied. These climate targets were translated into emission budgets for Mumbai Metropolitan Region. Comparing these with Mumbai Metropolitan Region's emission forecast showed that it requires a 16.8% reduction to meet the national target while a 40% to 47% reduction to meet the global target. The results are significant for policy makers and planners to design focused mitigation policies and support national efforts to govern climate change.

Keywords: Paris agreement; intended nationally determined contributions; emission budgets; climate targets; emission sharing principles; mitigation rate.

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1. INTRODUCTION

In the year 2013, the Intergovernmental Panel on Climate Change (IPCC) discovered the transient climate response to cumulative carbon emissions (TCRE)' [1]. TCRE states that the global temperature increases with an increase in global emissions; implying that there has to be a limit on emissions to stay under a safe temperature limit. This has given way to several questions:

(i) What is the safe limit?
(ii) How much emissions can be allowed to be in the safe limit?
(iii) What will be the basis of the distribution of emission allowance?

While Paris Agreement defines 1.5 and 2 °C as the safe limit [2], many more studies are going on with a target of limiting the increase in temperature from 1.5 °C to 6 °C as the 1.5 °C target is being considered unrealistic [3-6]. In 2018, IPCC published a special report in which this 'safe limit' was translated into emission quota (Table 1) [7]. This emission quota is the remaining emission budget that the World can emit in order to stay under the safe temperature limit. In the past, several emission sharing principles and ideas have been proposed for dividing the remaining emission budget among countries. The most common of them are inertia and equity principles. Inertia sharing is based on the theory that the countries should be allocated future emissions based on their historical emissions trajectories [8-10]. Equity sharing is based on the theory that each person on Earth has an equal right over emissions and hence, future emissions should be allocated based on the population share of the countries [11]. Since these two principles were seen as the two ends of justice spectrum [12, 13, 14], many more modifications were proposed to them. But, until the 24th meeting of Conference of Parties, held in December 2018, none of the sharing principles were globally accepted. Research is still going on to find a justified sharing principle that may suit the interest of all the countries to the best.

Meanwhile, countries which are a party to UNFCCC are contributing to reducing emissions in their own capacity. Paris Agreement's 2°C target defines the common global climate target for all the countries. Also, all the parties that ratified Paris Agreement are required to create national-level climate targets depending on the country's potential. These are called Intended Nationally Determined Contributions (INDC).

These are the country's voluntary targets based on their capacities and ambitions.

India signed UNFCCC on 10 June 1992 and henceforth is a party to UNFCCC [15]. India has also maintained a national level climate target defined in India's INDC [16] decided by the Ministry of Environment, Forest and Climate Change (MOEFCC) (MOEFCC n.d.). This emission reduction target is disseminated from the Central Government to the state government and further to local Governments. Efforts are required at every possible level to achieve the national target.

In India, metropolitan cities are the biggest contributors to national emissions as economic development is mainly concentrated in metropolitan cities [15]. Moreover, the increasing population in these cities requires rapid urbanization which has a significant impact on carbon emissions [17,18]. Hence, to achieve climate targets at national and global level, there is a need for accelerated and focused research that improves the knowledge of cities in interpreting the meaning of climate targets at the local levels. To account for this, the present study focuses on determining the role of a metropolitan region in India in achieving climate targets. The questions that this study seeks answers to are: what do the targets mean at the local level; and how much efforts are required by the cities at the local level?

Table 1. Remaining carbon budget (from 1 January, 2018) with 1.5 °C and 2 °C warming limit above the pre-industrial level (in GtCO2)

Warming limit	1.5 °C		2 °C	
Probability	67%	50 %	67%	50 %
	420	580	1170	1500

Source: Rogelj et al. [7]

Mumbai Metropolitan Region (MMR) in India was studied in the paper. Statistical analysis was done to find out that by what extent MMR is lagging to meet the global the national climate targets. Paris Agreement's climate target as a global target and India's INDC target as the national target were studied for this purpose. MMR's emissions were forecasted based on past emission trajectory and compared with the climate targets. It was estimated how much emission reduction at the local level is required and what is the timeline to be targeted.

The aim of the study is to strengthen the research base of a developing country in the field

of climate change governance. The research is built upon the idea that actions at the local level will eventually aid in achieving the targets at national and global level.

1.1 India's INDC Target

India is in the list of non-Annex I countries which are not legally bound to reduce emissions. According to India's INDC, a 33 to 35% reduction in GHG intensity of Gross Domestic Product (GDP) of 2005 levels by 2030 is aimed (MOEFCCC 2015]. This is a development-oriented target by India. With the responsibility of a reasonable Human Development Index and economic progress of its vast population, MOEFCC has defined this voluntary aim as a part of communication to UNFCCC.

1.2 Paris Agreement's Climate Target

Paris Agreement's climate target is more complicated to translate. In the 1990s, a limit of 2°C was proposed by IPCC which now serves as the aim of Paris Agreement. In October 2018, IPCC published the most recent figures for the remaining carbon budget consistent with 1.5°C and 2°C warming limits, shown in Table 1 [7]. This budget is to be distributed among countries in the response to which, countries need to reduce their emissions.

1.3 Study Area

MMR is a metropolitan region in India with an area 4,311.75 sq.km built around Mumbai city at the core. It is the sixth largest urban agglomeration in the world. It is located on the western coast of India in the state of Maharashtra (Fig. 1a). It comprises of five districts of the state (Fig. 1 b, c, d). Mumbai city contributes 5% to the national GDP [19] and MMR contributes 11% to the national GDP [20]. MMR has an extensive local train network, country's major seaport, and airport which are the prime source of emissions [21,22].
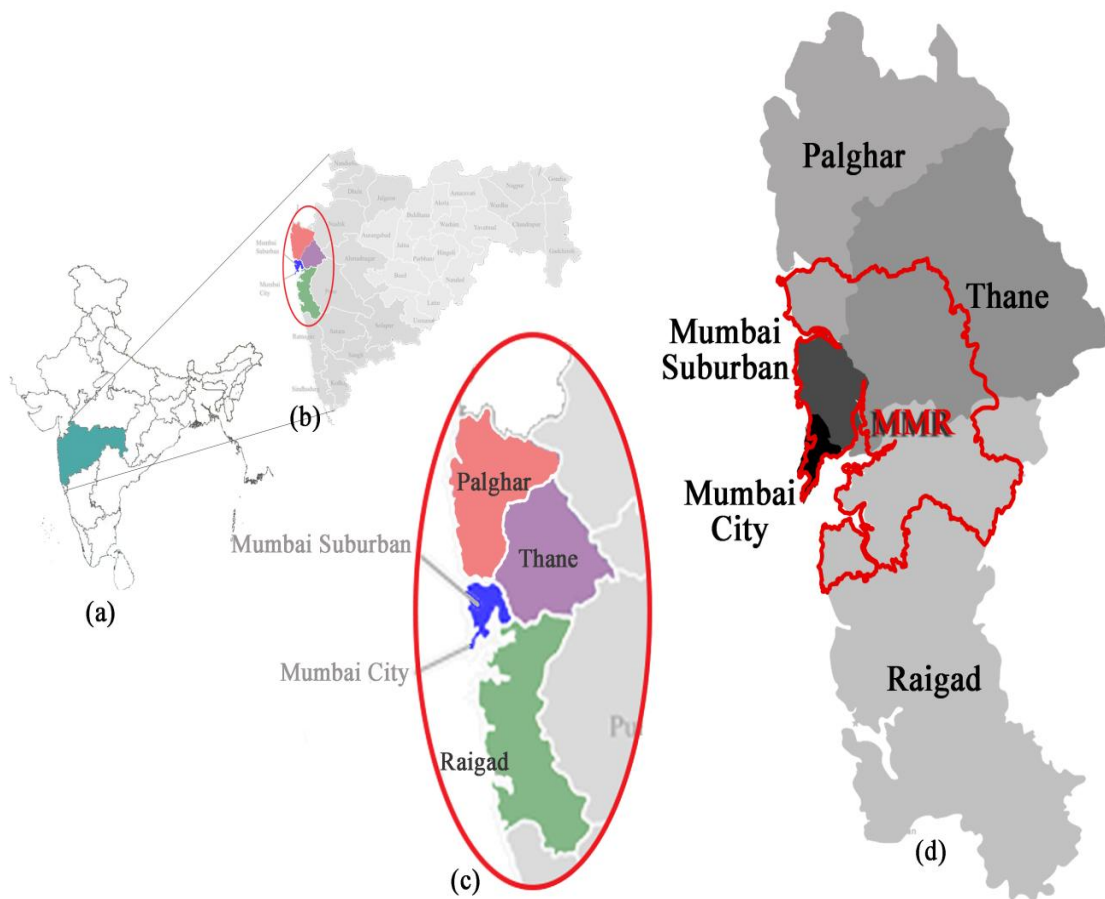

Fig. 1. Location of MMR in the state of Maharashtra in India

2. METHODOLOGY

The study uses the following simple procedure for determining MMR's position in meeting climate targets.

Step 1: Firstly, India and MMR's past emissions were estimated. This data was used to forecast MMR's future emissions to match the timeline of climate targets for the business as usual scenario.
Step 2: Paris Agreement's target and India's INDC target were translated into absolute emission targets for MMR
Step 3: The forecasted emissions were compared with MMR's emission targets to determine the emission reduction required by MMR to meet targets.

2.1 Emission Calculation

In India, the availability of emission data at the local level is poor. For emission inventory, the data for different emission sources are collected at the national level for each sector. Hence, national emission data is available but, at a smaller scale, emissions calculation is a tedious task. Ramaswami et al. [23] discussed the issues faced in emission accounting due to relatively small spatial sizes. In order to ensure uniformity, both MMR and India's emissions were calculated using the same method. The top-down approach was applied to calculate the past emissions from MMR and India. Annual grid maps, starting from the year 1970 to 2012 from EDGAR (version 4.3.2), were used [24]. EDGAR was used as the data source in this study because it provides a broad time series for comparison, the data format is easy to use and handle which makes it a convenient source of global emission information. It is believed that the start of the United Nations Environmental Program should be identified as the start of the budgeting period' which was the start of the 1970s [25]. Hence, 1970 was chosen as the start year. 2012 was the last year for the analysis in this study because it is the last year for which emission data is available from EDGAR. The uncertainty estimates of EDGAR have been published for EDGAR version 2 [26] and are under review for the current version - EDGARv4.3.2 [27]. For this study, the uncertainty percentage for India and MMR (for CO_2) was 10% [9]. The data from Edgar is available in Network Common Data Form (NetCDF) format which was processed in R studio 3.5.0 to extract data on required boundary limits and convert it into Comma-separated value (CSV) files for further processing. ArcMap 10.4.1 was used to extract CO_2 emission data from these CSV files for India and MMR. Table 2 presents the results.

2.2 Emission Forecast

MMR's emissions were forecasted for the duration 2013 to 2048. The duration for forecast was chosen based on the requirements of climate targets. Statistical Analysis System (SAS) University Edition 3.71 (Basic Edition) software developed by SAS Institute at North Carolina State University (SAS Institute 2018) was used for forecasting. Forecasting was done using Linear (Holt) exponential smoothing forecasting model with 95% confidence level. Table 3 shows the results and Fig. 2 show the emission forecast band produced by SAS software.

Table 2. CO_2 emissions from MMR and India from the year 1970 to 2012 (Gg CO_2)

Year	MMR	India	Year	MMR	India	Year	MMR	India
1970	23253.62	636653.31	1985	50617.34	1285668.18	1999	99643.17	2873620.61
1971	23365.36	639714.60	1986	55333.63	1396401.45	2000	106276.83	2917399.84
1972	26275.47	665164.98	1987	57696.14	1491533.49	2001	104301.38	2973998.12
1973	27205.50	663879.37	1988	57686.16	1584535.77	2002	107503.07	3066241.99
1974	28173.11	712536.21	1989	62786.79	1702640.08	2003	104401.40	3160510.87
1975	29474.60	760095.53	1990	64282.53	1804250.59	2004	101204.40	3314878.84
1975	30161.93	810238.92	1991	64370.17	1922746.67	2005	102328.27	3469419.43
1977	32324.81	828428.60	1992	65902.61	2018539.16	2006	109059.06	3730186.97
1978	33183.09	790532.71	1993	64265.70	2104509.08	2007	89087.83	3968303.70
1979	35654.23	851430.51	1994	68840.90	2231699.17	2008	105545.07	4216322.17
1980	34429.72	886864.44	1995	69939.69	2393720.60	2009	111731.40	4774164.77
1981	36101.82	985897.59	1996	87465.55	2515538.52	2010	122591.26	5052993.98
1982	41664.15	1056536.05	1997	91832.22	2639003.38	2011	123992.18	5372827.89
1983	43766.54	1122391.61	1998	93590.46	2680488.11	2012	137166.44	5672045.08
1984	49750.62	1222555.16						

Table 3. Emission forecast (Gg) for MMR calculated using SAS software

Year	Emissions	Year	Emissions	Year	Emissions	Year	Emissions
2013	1,37,596.00	2022	1,61,041.60	2031	1,84,487.20	2040	2,07,932.80
2014	1,40,201.10	2023	1,63,646.70	2032	1,87,092.30	2041	2,10,537.90
2015	1,42,806.20	2024	1,66,251.80	2033	1,89,697.40	2042	2,13,143.00
2016	1,45,411.20	2025	1,68,856.80	2034	1,92,302.40	2043	2,15,748.00
2017	1,48,016.30	2026	1,71,461.90	2035	1,94,907.50	2044	2,18,353.10
2018	1,50,621.40	2027	1,74,067.00	2036	1,97,512.60	2045	2,20,958.20
2019	1,53,226.40	2028	1,76,672.00	2037	2,00,117.60	2046	2,23,563.20
2020	1,55,831.50	2029	1,79,277.10	2038	2,02,722.70	2047	2,26,168.30
2021	1,58,436.60	2030	1,81,882.20	2039	2,05,327.80	2048	2,28,773.30

2.3 Translating Climate Targets

2.3.1 India's INDC target

For translating this target for MMR, it is required to apportion the country's emission target for the scale of MMR. The INDC target is relative to the economy of the country. A reduction in emission intensity of GDP is aimed; a direct reduction in absolute emissions is not the aim of this target. According to the World Resource Institute, the GHG intensity of GDP is the level of GHG emissions per unit of economic activity measured in GDP of a country [28]. A study derived this target in terms of absolute emissions for India [29]. According to this study, India's economy is expected to grow at 7% between 2005 and 2030 and it will reach 18 trillion USD based on 2005 prices. With this growth, India's emissions in 2030 will be 5.6×10^6 Gg (7% increase 2005 emissions).

In the year 2005, MMR's emissions were 2.94% of India's emissions (Table 2). Assuming that MMR's share in India's national emissions in 2030 is the same as in 2005, MMR's targeted emissions in 2030 were calculated to be 164640 Gg. This target was to be compared with MMR's emission forecast based on its current emission trajectory assuming that no climate change related policy is implemented in the due course.

3. RESULTS

According to the forecast (Table 3), MMR's emissions in 2030 will be 181882.20 Gg. Comparing this prediction with MMR's targeted emissions, it can be observed that MMR needs to reduce its emissions by 17242.20 Gg in the year 2030. This is approximately 16.8% of the 2005 emission level of MMR. Hence, for meeting India's INDC target, a 16.8% reduction in emissions from the 2005 levels is required from MMR in the year 2030.

3.1 Paris Agreement's Target

For translating the Paris Agreement's target for the scale of MMR, it is required to estimate that out of the remaining budget for the World, how much emissions will be allocated to MMR. Unlike INDC, Paris Agreement's targets are to be implemented uniformly at a global level. Hence, for this part of the study, MMR was considered an exclusive region, and independent calculations were done for MMR. India's emissions or population were not taken into account and emission sharing principles were applied directly to MMR. Other than inertia and equity sharing (discussed above), two other sharing principles were used in this study. One was the 'blended sharing' proposed by Raupach [30], which introduces a sharing index (w) to maintain a balance between equity and inertia extremes. The other was 'inclusive sharing' proposed by Neumayer [31]; including the factor of historical accountability with equity sharing. The principles are briefly described below:

i. Inertia sharing–based on the past emissions of the country.

ii. Equity sharing–based on the population of the country.

iii. Blended sharing–incorporates the sharing index concept and may lie anywhere between inertia and equity sharing. However, for the purpose of analysis, blended sharing combines equal parts of inertia and equity sharing, with sharing index = 0.5 (as developed by Raupach et al. [30] and used by Sahu & Saizen [32].

iv. Inclusion sharing–adds the factor of historical responsibility (in the form of compensation) to the population-based emissions sharing criteria. Compensation is the debt/credit a country owes to the world (or other countries) depending on its past emission trajectory (developed by Neumayer [31] and used by Gignac & Matthews [33] and Sahu & Saizen [32].

Additionally, Messner et al. [34] raised the importance of four fundamentals in calculating the emission budgets:

- period of total budgeting defined by the start year and end year;
- the year when the emission distribution is to start;
- Probability of the estimations;
- demographic reference year - the year on which the future calculations are to be based

Considering the importance of these factors, special attention was given to them in this study. As mentioned above, the budgeting period starts in 1970 and ends in the year 2012. 2018 was chosen as the start year depending on the budgets published by IPCC [7]. 2°C warming limits with 67% and 50% probabilities were considered (Table 1). As explained by Messner [34], the more recent is the demographic reference year is, the higher are the chances that countries with larger populations benefit through equity sharing, while countries with higher emissions benefit with inertia sharing. To neutralize this effect in the current study, the demographic reference year was superseded by the reference period, i.e. instead of choosing data from one year as the reference year, the

average of budgeting years was used. It implies that the reference emission was the mean of emissions from 1970 to 2012 and reference population was the mean of the population from 1970 to 2012. This method is meant to counterbalance the advantages for highly populated countries and high emitting countries.

3.2 Data

The current study used the remaining carbon budgets from IPCC's report published in 2018 [7]. The budget consistent with the 2 °C target, applicable from 1st January, 2018 was used for the estimation (Table 1). As mentioned above, historical emissions of MMR were calculated using EDGARv4.3.2. The corresponding world's historical emission data was compiled from the Carbon Dioxide Analysis and Information Centre [35]. It includes emissions from fossil fuel combustion, oxidation, and cement production and bunker fuels. The data on global population was obtained from The World Bank [36]. MMR's population data was taken from Census of India [37]. In India, demographic data is collected on a 10-year basis, hence, exact population data was only available for the years 1961, 1971, 1981, 1991, 2001, and 2011. The population data of the non-census years was extrapolated using available data.
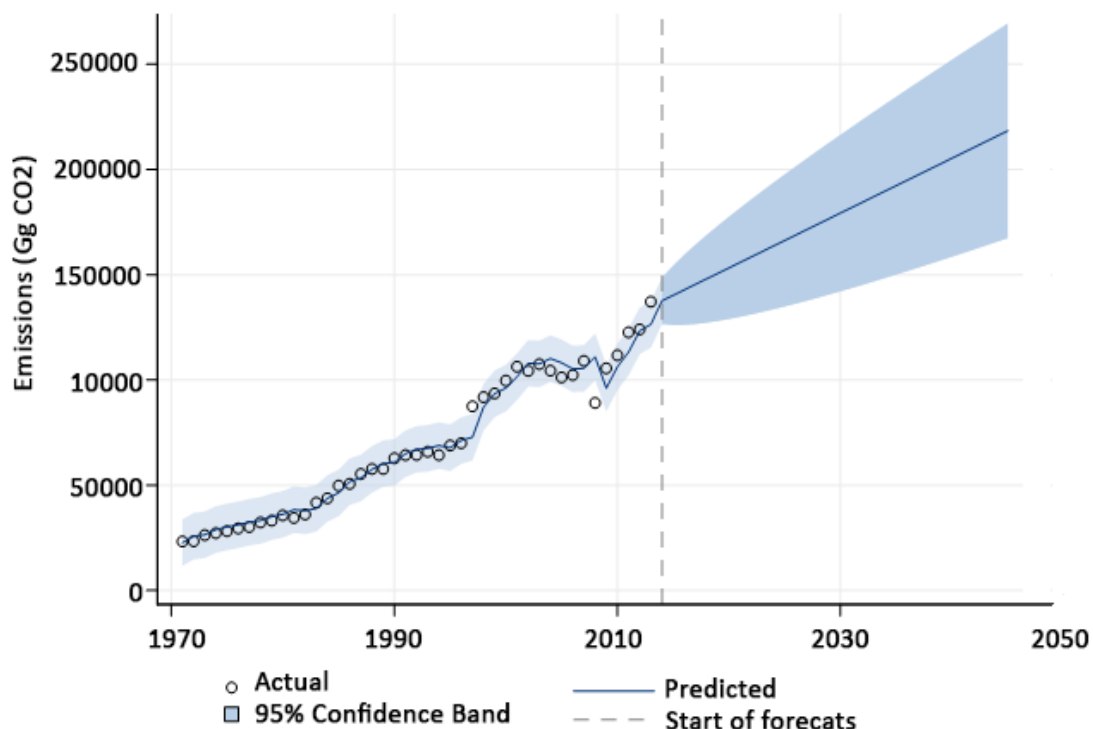

Fig. 2. MMR's emission forecast band (Source: SAS software [29]

3.3 Methods-Budget Calculation

The following equations were employed for allocation of future cumulative carbon budgets:

(i) Inertia sharing

$$E^t_c = (E^b_c / E^b_w) \times E^t_w \qquad \text{(Equation 1)}$$

(ii) Equity Sharing

$$E^t_c = (P^b_c / P^b_w) \times E^t_w \qquad \text{(Equation 2)}$$

where,

Etc (E^b_c) = Emission of region C in target year t (base year b)
E^t_w (E^b_w) = Emission of the world in target year t (base year b)
P^b_c = Population of the region C in base year b
P^b_w = Population of the world in base year b

(iii) Blended sharing

$$E^t_c = [(1-w) \times (E^b_c / E^b_w) + w \times (P^b_c / P^b_w)] \, E^t_w \qquad \text{(Equation 3)}$$

(iv) Inclusion sharing - Calculations based on the principle of inclusion are more elaborate. This principle takes into account the historical emission debt (or credit) of the region and compensation that the region deserves (or owes) to the world. Following are the equations:

$$HED_c = \Sigma [E_c - (P^b_c / P^b_w) \times E_w] \qquad \text{(Equation 4)}$$

$$C^n_c = (1/N) \times HED^n_c \qquad \text{(Equation 5)}$$

$$E^t_c = [(P^b_c / P^b_w) \times E^t_w] - C^n_c \qquad \text{(Equation 6)}$$

where,

HED_c = Historical emission debt (or credit) of the region C
C^n_c = Compensation that the region C agreed in N years (where n = 1,…..N)

Here, the calculations were done for future cumulative emissions, hence we assume that the region is to be compensated for all the years. It numerically means that, for this study, we assume that 100% of HED is to be compensated to the region. Therefore, we dissolve the factor N from our equation in order to make the compensation factor (C^n_c) = Historical emission debt (HED^n_c). Fig. 3 presents the change in HED of MMR from 1970 to 2012.

Using the above equations, remaining carbon budget to be allocated to MMR (starting from the year 2018) was estimated. Table 4 shows the results of budget estimation for MMR and Fig. 4 is a graphical illustration of the results.

It was found that inertia sharing allocated highest emission budget to MMR, followed by blended sharing and equity sharing, while inclusion sharing allocated lowest budget to MMR.
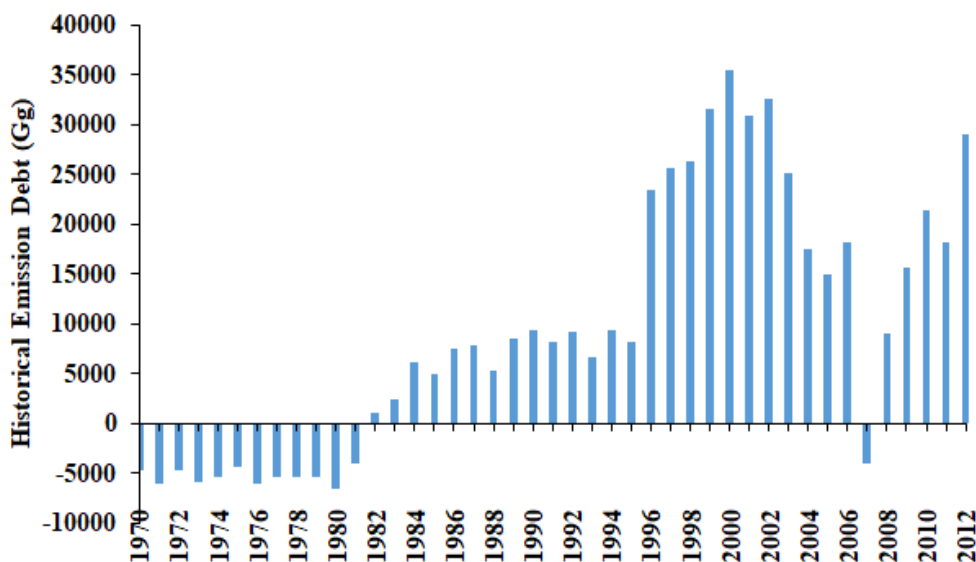

Fig. 3. Change in Historical Emission Debt of MMR from the year 1970 to 2012

Table 4. MMR's remaining carbon budget consistent with 2 °C warming limits

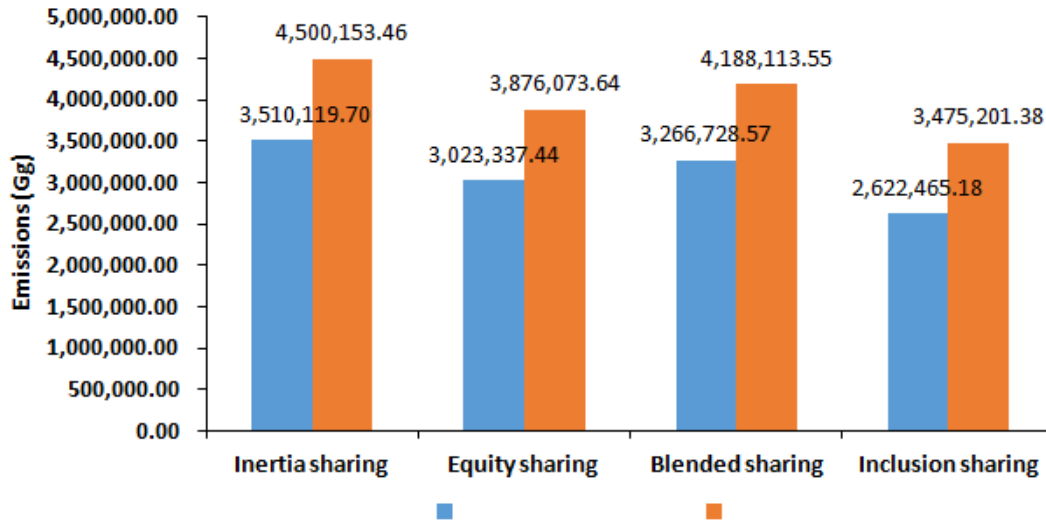| Warming limit	2 °C	
Probability	**67%**	**50 %**
Inertia sharing	35,10,119.700	45,00,153.462
Equity sharing	30,23,337.437	38,76,073.637
Blended sharing	32,66,728.569	41,88,113.550
Inclusion sharing	26,22,465.181	34,75,201.381

Fig. 4. Budget allocation to MMR for 2 °C warming limit with different sharing principles

3.4 Mitigation Rate

Mitigation rates required to meet Paris Agreement's 2 °C target with 67% probability were calculated using the methodology provided in the supplementary paper by Raupach et al. [30].

$$\text{Mitigation Rate} = \frac{1+\sqrt{1+rT}}{T} \qquad \text{Equation 7}$$

Where,

r = initial proportional growth rate $= 1/f_0 \times \frac{df}{dt}$ Equation 8

T = emission time (defined by quota q) $= \frac{q}{f}$ Equation 9

and,

f = capped emission trajectory (and f_0 = initial cumulative emissions)
q = emission quota (in this case, emission quota is different for different sharing principles)

MMR's past emissions for 43 years (1970 to 2012) was adopted as capped emissions for future. Past cumulative emissions were found to be 2974226.23 Gg. Hence, for this study, f_0 = 2974226.23

$$r = \frac{1}{2974226.23} \times \frac{f(2012)-f(1970)}{2012-1970} = 9.119 \times 10^{-4} \qquad \text{Equation 10}$$

q (Inertia sharing) = 3510119.70
q (Equity sharing) = 3023337.43
q (Blended sharing) = 3266728.56
q (Inclusion sharing) = 2622465.18

According to this, mitigations rates calculated for limiting the global temperature rise to 2 °C with 67% probability for different sharing principles were found to be:

- Inertia sharing – 1.70
- Equity sharing – 1.97
- Blended sharing – 1.82
- Inclusion sharing – 2.27

It means, if inertia sharing is followed, 1.70% mitigation in emissions will be required every year to meet the Paris Agreement's target.

In addition to the mitigation rates, the time duration, in which the remaining budget will be exhausted was also found by applying the mitigation rates to MMR's emissions. It was found that emission budget consistent with inertia sharing would be exhausted in the year 2048,

budget consistent with equity sharing will be exhausted by 2043, and the budget consistent with blended and inclusion principle will be exhausted by 2045 and 2040 respectively.

3.5 Results

For finding required emissions reductions, the emission forecast of MMR was compared with Paris Agreement's targets. For each sharing principle, the duration of exhausting the remaining budget was different. Following this, reduction required for different sharing principles was also different. It was found that according to Inertia sharing principle, MMR is remaining with 3510119.7 Gg carbon budget and with 1.70 % mitigation rate every year, the budget will be exhausted by the year 2048. While emission forecast shows that MMR is expected to emit 5880618.3 Gg emissions by the year 2048 (Table 3). Comparing the two results, it can be concluded that MMR needs a 40.31% reduction in its emissions to achieve Paris Agreement's 2 °C target with inertia principle. With equity sharing, MMR is remaining with 3023337 Gg carbon budget and with 1.97 % mitigation rate per year, the budget is expected to exhaust by the year 2043 and reduction required is 44.80%. With blended sharing, MMR is remaining with 3266728.56 Gg budget and with 1.82 % mitigation rate per year, the budget is expected to exhaust by the year 2045. Therefore, 44.78% reduction will be required. Lastly, with inclusion sharing, MMR is remaining with 2622465 Gg budget and with 2.27% mitigation rate per year, the budget will be exhausted by the year 2040 and a 45.79% will be required. Table 5 shows the details.

Overall, it was observed that approximately 40 to 46 % reduction in emissions was required to meet the Paris Agreement's target.

Table 5. Implication of Paris Agreement's 2 °C target for MMR

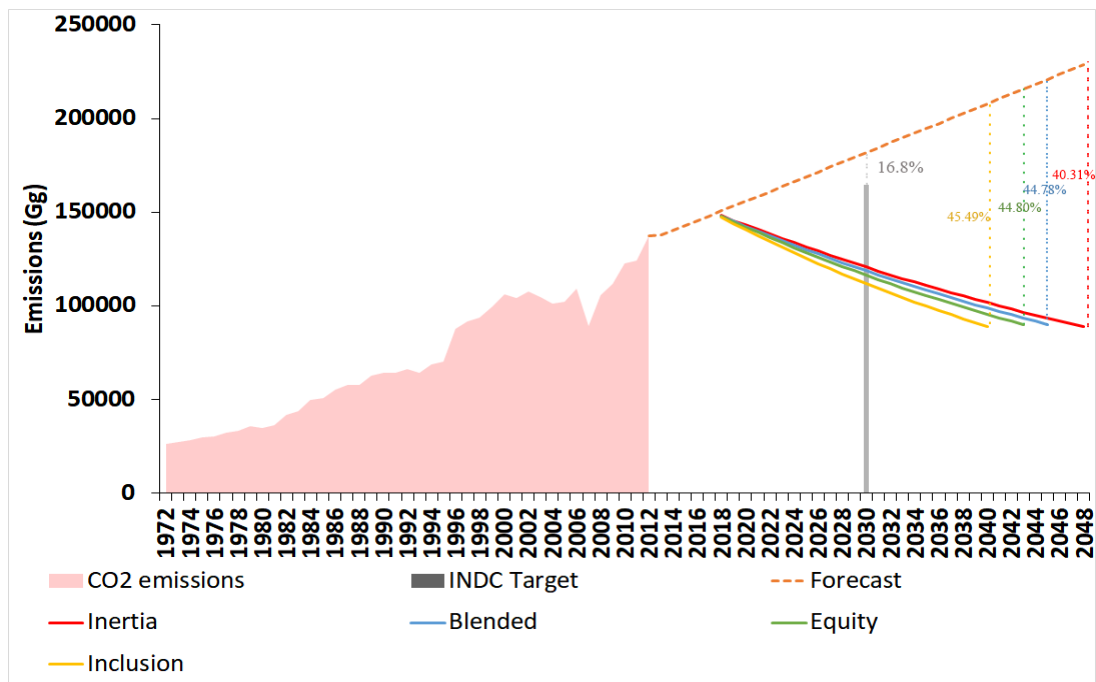| Sharing principle	Remaining Budget (Gg)	Difference in emissions (Gg)	Emission Reduction required (%)	Durations in which budget will be exhausted
Inertia sharing	3510119.700	2370498.6	40.31	2018 - 2048
Equity sharing	3023337.437	2453495.6	44.80	2018 - 2043
Blended sharing	3266728.569	2649415.7	44.78	2018 - 2045
Inclusion sharing	2622465.181	2214938.9	45.79	2018-2040

Fig. 5. Past emissions, emission forecast and emission reduction required by MMR to meet INDC and Paris Agreement's target

4. DISCUSSION

In this study, climate targets were translated into emission reduction targets for the context of MMR. Comparing the results, it is evident that MMR has higher chances of meeting India's INDC goal with comparatively less ambitious efforts, while, for meeting Paris Agreement's goal, strong efforts will have to be made. In addition to that, different sharing principles have different emissions allocations for MMR. It was observed that for inertia sharing, MMR required mitigation rate is the lowest, while that for inclusion sharing is the highest. It implies that if inclusion sharing is followed, MMR will have to make very strong efforts to mitigate emissions while if inertia sharing is followed, the efforts can be comparatively weaker. And if India's INDC target is followed, the efforts will have to least ambitious as only 16.8 % reduction will be required which is an easy target for MMR comparing Paris Agreement's 2 °C target. Fig. 5 showcases the past emissions, emission forecast as well as emission reduction required for India's INDC and Paris Agreement's target.

In the figure, the differences in targets are evident. However, the emission reduction calculated for Paris Agreement's targets are different than that for INDC target. For INDC target, a 16.8% reduction in absolute emissions is required in the year 2030, while for Paris Agreement's target, reduction in every consecutive year is required, starting from the year 2018. This is the major difference between the two climate targets which distinguishes the mitigation efforts that will be required. India's INDC target aims a specific year for observing the emission reduction, while Paris Agreement's target aims at a fixed quota of emissions which is to be distributed among the different regions and countries. Interpreting the two targets for MMR shows two different end results. Success in achieving India's INDC target will be examined in the year 2030. Hence, there is not an absolute requirement of reducing emissions before 2030. However, success in achieving Paris Agreement's target will be examined by estimating the remaining emission quota in the atmosphere. Hence, for this target, continuous efforts are required throughout the target duration. This point can be seen as a flaw in INDCs and a disadvantage in contributing to the global aim of emission reduction.

5. CONCLUSION

Emission estimation is important for improving national emission inventories. Especially for local governmental bodies, it is the key step in framing emission reduction policies. This study brings out MMR's status in achieving the global and national climate targets. It highlights the efforts that MMR requires in mitigate actions. Hence, this study can be important for policy makers in decision making.

The study shows that MMR will need more convenient mitigation efforts for INDC target and very ambitious mitigation efforts for Paris Agreement's target. And among the different sharing principles, it will be most benefitted by inertia sharing and least benefitted by inclusion sharing, while equity and blended sharing will lie in the middle of the other two and will pose similar emission reduction requirements to the region.

The results of this study can be used as the base for local mitigation policy design. In order to determine the contribution of large cities in global carbon emission, similar studies should be conducted in all the high emitting cities of the world. The process described in this study (Section 3) can be used in other city cases as well. Global EDGAR data can be used for estimating historical emissions and budget calculations (Section 4.2.2) can be used to calculate emission distribution based in different sharing principles.

6. SCOPE AND LIMITATIONS

For calculating emission targets, MMR in this study was assumed to be an exclusive region to avoid complications in the study. Applications for emission forecast as well as emissions targets were directly applied to MMR, considering it an independent region. However, as a part of the country, the targets may vary depending on national targets. In the real situation, MMR as a part of India will have associated emission targets. Depending on the type of distribution accepted globally, MMR's goals will vary in large extents.

Additionally, the timeframe of emission estimation starts from 1970s in this study. This is because the first regional plan of Mumbai Metropolitan Region was implemented in 1972. Future research can benefit by expanding the timeframe of the study.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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