Cross-city comparison of evaluations of BAU and mitigation policy scenarios in three Indian megacities:

Emissions and climate effects

Paper draft

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CLIMATRANS

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Introduction

The Indian transport system is one of the largest in the world and serves a land area of 3.3 million square km and a population of over 1.21 billion (Census 2011). The demands for mobility and related energy used for transport within the country have increased with the rapid growth of economic activity. For ensuring continued economic development of the nation through trade and market participation, the transport sector has become pivotal. Indian cities can also be seen as an illustrative case for the enormous urban growth evident worldwide. Climate sensitivity augmented by a large population makes India a vulnerable country in terms of climate change impacts. It is thus evident that India is an important country to study in terms of both the transport sector's contributions to global climate change and the projected future climate impacts for India. These are also global issues affecting other parts of the world, both in a short and long time horizon.

This paper summarizes the main findings of the evaluation of alternate mitigation strategies for the three case cities Delhi, Bangalore and Mumbai in the Indo-Norwegian research project CLIMATRANS. The main objectives of the project are:
1) Assess climate change and environmental impacts in urban areas in India related to the transport sector.
2) Develop mitigation and adaption strategies related to the transport sector in urban areas in India.
The project is supported by the Norwegian Research Council over a period of four years. The research work in India has been conducted by research team at School of Architecture and Planning in New Delhi, Indian Institute of Technology Bombay, and Indian Institute of Science in Bombay, and The Energy & Resource Institute, New Delhi.

The main focus in this paper is on comparisons of estimations of transport related emissions under different scenarios[1]. Mitigation policy packages, comprising of sub policies, have been formulated for each of the three case cities. For each case city there has been performed a Rapid Assessment, and as well as evaluations of the Business as usual (BAU), and different mitigation policy strategies (policy packages) for the case cities. This paper provides an overview of the main results from the policy evaluation, and highlights the mitigation strategies (policy packages) that appear to be the most effective to bring down the emissions from passenger transport compared to the BAU in the three cities.

[1] In this paper the focus on mitigation policy scenarios, since adaptation policy scenarios are still under development and evaluation at this stage for some of the case cities in the project. In the final report from the project, also impact of the policy bundles on other sustainability dimensions, such as economic (i.e., consumer/government surplus) and social (i.e. health effects), will be added as they are finalized.

Research approach

The project teams for the case cities have chosen a somewhat different approach with respect to the selection of policy instruments and the combination of them into policy packages that have been chosen for evaluation, which in turn yields different results across the case cities. We consider that to be a strength rather than a weakness, since it assures that the chosen policies and policy packages are adapted to the local urban context, travel pattern and transport network and demand, local transport plans and stakeholders involved etc., and are therefore more likely to be realistic for the horizon years as seen form a case city perspective.

Moreover, the project teams in the case cities have also used slightly different methodical approaches for the calculations of the estimations of impact on future travel demand and related emissions resulting from the various policy scenarios. However, what is common is the use of city transport demand models, which have been applied in all case cites, to arrive at future transport mode shares, VKT and trip generation, and trip assignment etc. applied to in the estimated future transport network, and accounting for projected economic growth, population growth, employment etc. Emission factors applied to the estimated future travel demand of the various transport modes have been used to arrive at total emissions for each BAU and policy packages in the case cities. We refer to the referenced individual case city policy bundle evaluation reports for more details on the methodical approach, data and assumptions used for the calculations. The reports also contain valuable information on intermediate calculation results, such as total VKT and mode shares used to calculate the total emissions connected to BAU and each of the scenarios/policy packages.

Results for case city policy scenario evaluations

This section presents the overall results for the policy evaluations for the three case cities. The policy packages evaluated and the evaluation main results for the case cities are presented below.

Delhi

For Delhi, three broad level policy packages were considered for evaluation in terms of emissions. Under these broad levels, policy packages, there are sub level polices. The list of adopted broad policy packages and sub policies are presented below:

Policy Bundle 1: Planning

- Increase in Transit Network
- Promoting Transit Oriented Development (TOD)
- Combination of Increase in Transit Network + Transit Oriented Development

Policy Bundle 2: Travel Demand Management

- Increase in Fuel Cost
- Congestion Pricing
- Shared Mobility (Car Pooling + Increase % share of App based Cabs)
- Combination of Fuel cost + Congestion Pricing + Shared mobility

Policy Bundle 3: Technology

- Electric Mobility

Table 1 below summarizes the evaluation calculations for Delhi for Rapid assessment, Business As Usual and Policy Packages for horizon years 2030 and 2050, by total emissions. This is assuming electric energy supply of the IEA 2015 scenario (no. 4)

Table 1: Delhi RA, BAU and policy bundle evaluation for horizon years 2030 and 2050. Total emissions, tonnes per year.

Policy Bundle (mitigation)	Scenario	CO (t/y)	HC (t/y)	NOx (t/y)	CO2 (1000t/y)	PM (t/y)
Base Year (2011)	Base Year	22414	8112	3495	730	803
Rapid assessment	RA - 2030	19689	5047	4515	3078	317
	RA - 2050	28232	5136	4400	6692	287
BAU	BAU - 2030	22403	8112	3449	726	774
	BAU - 2050	28137	6420	3576	2977	332
Policy Bundle 1: Planning	Increase in Transit - 2030	21670	4875	2997	2383	261
	Increase in Transit - 2050	26658	3600	2223	2938	159
	TOD - 2030	17431	3977	2498	1974	216
	TOD - 2050	20341	2824	1774	2368	127
	Transit + TOD - 2030	15068	3580	2210	1832	210
	Transit + TOD - 2050	16964	2430	1613	2120	115
Policy Bundle 2: Travel Demand Management	Increase in Fuel - 2030	21736	4868	2902	2250	264
	Increase in Fuel - 2050	30727	4019	2456	3088	173
	Congestion - 2030	20861	4610	2729	2100	252
	Congestion - 2050	29779	3787	2372	2900	164
	Congestion + Fuel - 2030	18758	4162	2668	2015	231
	Congestion + Fuel - 2050	25276	3284	2186	2661	148
	Congestion + Fuel + Car Share - 2030	14529	3251	2857	2411	164
	Congestion + Fuel + Car Share - 2050	19115	3038	1701	3096	127
Policy Bundle 3: Technology adaptation	BAU with Electric Mobility - 2030	22207	4971	3581	2805	322
	BAU with Electric Mobility - 2050	29785	3838	3598	4216	282
	Planning Policy with Electric Mobility 2030	11999	2755	2179	1699	195
	Planning Policy with Electric Mobility 2050	9388	1219	1792	1878	138
	TDM w/ Electric Mobility 2030	11339	2512	2980	2342	190

	TDM w/Electric Mobility 2050	**5265**	**1113**	**3753**	**2156542**	**1165**

Source: Gupta, S. & Saini, P. (2018) "A Report on
BAU and Policy Scenario Demand Forecast – Delhi" – CLIMATRANS project, cf. table 3.2.

Bangalore

A total of four mitigation policy packages have been formulated for Bombay, which is listed below*:*

Policies under bundle 1

- Increasing network coverage of Public Transit
- Cycling and walking infrastructure
- Additional tax on purchasing vehicles

Policies under bundle 2

- Additional tax on purchasing vehicles
- Strict Vehicles inspection/Improvement in standards for vehicle emission
- Increase in fuel cost

Policies under bundle 3

- Increasing network coverage of Public Transit
- Defining car restricted roads
- Congestion Pricing
- Park and Ride
- Cycling and Walking infrastructure
- Encouraging car-pooling and High Occupancy Lanes
- High density mix building use along main transport corridors

Policies under bundle 4

- All policies in bundle 3 + All buses and cars running on electricity

Table 2 below summarizes the evaluation calculations for Bangalore.

Table 2: Bangalore RA, BAU and policy bundle evaluation for horizon years 2030 and 2050. Total emissions, tonnes per year.

Policy Packages (Mitigation strategies)	Scenario	CO (t/y)	HC (t/y)	NOx (t/y)	CO2 (t/y)	PM (t/y)
Base Year (2008)	Base Year	14091	6428	6723	647059	921
Rapid Assessment	RA – 2030	11568	2929	2565	1895543	142
	RA – 2050	23767	5307	5270	4500561	161
	RA - 2030 kilo t. pp. yr.	2.43	0.7770	0.373	289.52	0.036
	RA - 2050 kilo t. pp. yr.	1.98	0.421	0.174	232.62	0.016
BAU	BAU - 2030	11568	2929	2565	1895543	142
	BAU - 2050	17089	3840	3842	3271670	117
	BAU - 2030 kilo t. pp. yr.	1.87	0.5717	0.274	212.76	0.029
	BAU - 2050 kilo t. pp. yr.	1.51	0.316	0.131	173.14	0.012
Policy Bundle 1: *Increasing network coverage of Public Transit + Cycling and walking infrastructure + Additional tax on purchasing vehicles*	PB1 - 2030	10234	2617	2489	1823076	125
	PB1 - 2050	15200	3528	3745	3053094	103
	PB1 – 2030 kilo t. pp. yr.	1.84	0.5634	0.270	209.68	0.029
	PB1 – 2050 kilo t. pp. yr.	1.47	0.305	0.127	168.74	0.012
Policy Bundle 2 : *Additional tax on purchasing vehicles + Strict Vehicles inspection/ Improvement in standards for vehicle emission + Increase in fuel cost*	PB2 - 2030	9845	2514	2480	1813638	120
	PB2 - 2050	14727	3421	3705	3005767	100
	PB2 – 2030 kilo t. pp. yr.	1.830	0.557	0.267	206.000	0.027
	PB2 – 2050 kilo t. pp. yr.	1.400	0.303	0.126	165.130	0.012
Policy Bundle 3: *Increasing network coverage of Public Transit + Defining car restricted zones +Congestion Pricing + Cycling and Walking infrastructure + Encouraging car-pooling and High Occupancy Lanes + High density mix building use along main transport corridors*	PB3 - 2030	9487	2416	2511	1833383	114
	PB3 - 2050	13936	3346	3724	3001135	95
	PB3 – 2030 kilo t. pp. yr.	1.74	0.5362	0.266	200.60	0.026
	PB3 – 2050 kilo t. pp. yr.	1.37	0.282	0.123	159.11	0.012
	PB 4 – w/EV 2030	4933	1240	483	296799	72
	PB 4 – w/EV 2050	5500	775	472	325208	37

Source: Verma, A., Vajjarapu, H. & Rodeja, N. (2017) "Comparison of Rapid Assessment, BAU and Policy Evaluation for Bangalore" – CLIMATRANS -project.

Mumbai

The mitigation policy scenarios and packages evaluated For Mumbai are as follows:

1. Population Redistribution Scenario
2. Draft Mumbai Metropolitan Regional Plan 2016-36 scenario
3. Transport Infrastructure Development
4. Travel Demand Management
5. Improvement in Technology

Two Policy Packages are modeled to analyze the combined mitigation effect of the policy scenarios recognizing the impact of promoting the public transport and discouraging the use of private vehicles simultaneously. The packages are run for the horizon years 2031 and 2050.

1) Policy Bundle 1- BAU + Policy 3+ Policy 4
2) Policy Bundle 2- Policy 2 + Policy 3+ Policy 4

Table 3 below summarizes the evaluation calculations for Mumbai.

Table 3: Mumbai RA, BAU and policy bundle evaluation for horizon years 2031 and 2050. Total emissions, tonnes per year.

Policy Packages (Mitigation strategies)	Scenario	CO (t/y)	HC (t/y)	NOx (t/y)	CO2 (t/y)	PM (t/y)
Base year (2005)	**Base Year**	**27191**	**7092**	**31920**	**2270519**	**3744**
Rapid assessment	**RA - 2031**	**28470**	**N/A**	**13870**	**N/A**	**646**
	RA – 2050	**40551**	**N/A**	**6570**	**N/A**	**372**
BAU	**BAU - 2031**	**31203**	**7621**	**7044**	**5620296**	**341**
	BAU - 2050	**52576**	**12415**	**12011**	**13337597**	**338**
	BAU – 2031 w/EV	**16638**	**5538**	**7029**	**4691627**	**172**
	BAU – 2050 w/EV	**25352**	**7703**	**9680**	**9515932**	**176**
Policy Bundle 1: ***BAU + Policy 3+ Policy 4*** **3. Transport Infrastructure Development 4. Travel Demand Management**	**PB1 - 2031**	**29028**	**7292**	**6894**	**5444227**	**326**
	PB1 - 2050	**49025**	**12004**	**11936**	**13016235**	**324**
	PB1 – 2031 w/EV	**15531**	**4120**	**5419**	**4222157**	**165**
	PB1 – 2050 w/EV	**25546**	**7762**	**9753**	**9588599**	**178**
Policy Bundle 2: ***Policy 2 + Policy 3+ Policy 4*** **2. Draft Mumbai Metropolitan Regional Plan 2016-36 scenario 3. Transport Infrastructure Development 4. Travel Demand Management**	**PB2 - 2031**	**25635**	**7292**	**6489**	**5104358**	**276**
	PB2 - 2050	**44559**	**12004**	**11645**	**12460345**	**288**
	PB2 – 2031 w/EV	**14478**	**3747**	**5262**	**4083087**	**147**
	PB2 – 2050 w/EV	**25679**	**7802**	**9804**	**9638474**	**179**

Source: Chandel, M. K., Sharma, I., Padmanabhi, R., Soni, A. & Dikshit, A.K. (2017) "Evaluation of Mitigation Policy Packages – Mumbai Metropolitan Region" – CLIMATRANS -project.

Comparison across policy packages and case cities

In table 4 the results of the BAU and policy bundle impact evaluations for the case cities are compiled and summarized. Only the "best" performing policy packages in terms of CO2 emissions for each city are shown. The compilation table for the three cities shows that there are, in general, considerable gains in terms of emissions reductions by implementing the evaluated policies. However, in some instances the reductions in emissions achieved through the policy packages are small to marginal compared to the BAU.

Table 4: Comparison of BAU and policy bundle evaluation for horizon years 2030 (2031) and 2050 for the case cities. Tonnes per year.

City	BAU & "Best"* Policy Packages	CO (t/y)	HC (t/y)	NOx (t/y)	CO2 (t/y)	PM (t/y)
Delhi						
BAU 2030	BAU - 2030	28163	6421	3793	2977792	447
BAU 2050	BAU - 2050	50613	6978	3623	5085667	380
"Best" policy bundle 2030	Transit + TOD - 2030	15141	3580	2844	1834125	544
"Best" policy bundle 2050	Transit + TOD - 2050	17006	2430	2099	2113958	338
"Best" policy bundle 2030 w/EV	Planning Policy with Electric Mobility 2030	12139	2756	3364	1724625	797
"Best" policy bundle 2050 /EV	Planning Policy with Electric Mobility 2050	9633	1220	4426	1891917	1314
Bangalore						
BAU 2030	BAU - 2030	11568	2929	2565	1895543	142
BAU 2050	BAU - 2050	17089	3840	3842	3271670	117
"Best" policy bundle 2030	PB2 - 2030	9845	2514	2480	1813638	120
"Best" policy bundle 2050	PB3- 2050	13936	3346	3724	3001135	95
"Best" policy bundle 2030 w/ EV	PB 4 – w/EV 2030	4933	1240	483	296799	72
"Best" policy bundle 2050 w/EV	PB 4 – w/EV 2050	5500	775	472	325208	37
Mumbai						
BAU 2031	BAU - 2031	31203	7621	7044	5620296	341
BAU 2050	BAU - 2050	52576	12415	12011	13337597	338
"Best" policy bundle 2031	PB2 - 2031	25635	7292	6489	5104358	276
"Best" policy bundle 2050	PB2 - 2050	44559	12004	11645	12460345	288
"Best" policy packages w/EV 2031	PB2 – 2031 w/EV	14478	3747	5262	4083087	147
"Best" policy packages w/EV 2050	PB2 – 2050 w/EV	25679	7802	9804	9638474	179

* "Best" policy packages are here named after estimated impacts on CO_2 emissions.

For Delhi, the greatest reduction in CO2 emissions can be achieved by implementing Policy bundle 3, a combination of policy bundle 1 with electric mobility: Planning Policy with Electric Mobility, reducing CO2 emissions from 3.0 million tonnes of CO2 emissions per year in 2030 under the BAU, to 1.7 million tonnes with this combination of policy packages. For 2050 the reduction is even greater, from 5.1 million tonnes to 1.9 million tonnes. In terms of CO, the "best" combination of policy packages is estimated to reduce emissions of CO units from 28.1 kilo tonnes in 2030 under BAU to 12.1 kilo tonnes, and from 50.6 kilo tonnes to 9.6 kilo tonnes in 2050. Similar reductions can also be seen for HC emissions.
PM2.5 emissions, however, will not be reduced compared to the BAU, with 797 tonnes of PM in 2030 as compared to the BAU with 447 tonnes. For 2050 PM2.5 emissions will be 380 tonnes under the BAU, compared with to 1314 tonnes with the Planning policy and EM combination. NOX emissions can be slightly reduced under Policy bundle 3, whereas higher in 2050 compared to the BAU.

For Bangalore, the impacts of the policy packages on total emissions are less pronounced. The better among the policy packages (Policy bundle 2, PB2) slightly outperforms the BAU for 2030 in terms of CO emissions, with 18.1 million tonnes of CO2 emissions for Policy bundle 2 compared to 19.0 million tonnes in the 2030 BAU. Similarly, the PB3 yields slightly lower CO2 emissions for 2050 than BAU in Bangalore. The emission numbers for CO are also lower for PB2 than for the BAU for 2030, with 9.8 kilo tonnes of CO emissions vs. 11.7 kilo tonnes (BAU). In 2050 the CO emissions are estimated to be 13.9 kilo tonnes for PB3 vs. 17.1 kilo tonnes under the BAU. Regarding PM, the emissions under PB2 are considerably lower than under the BAU for both 2030 and 2050; whereas for NOx and HC emissions the numbers are only slightly lower with PB2 and PB3 than for the BAU.
However, introducing policy bundle 4 with Electric Mobility /EV implementation added as part of the policy packages does have a significant effect. CO2 emissions can be reduced to 0.30 million tonnes per year in 2030 and to 0.33 million tonnes in 2050.

The BAU and policy bundle evaluations for Mumbai identify policy bundle 2 (PB2) as the "best" compared to the BAU considering CO2 emissions. With implementation of PB2 for Mumbai CO2 emissions are estimated at 5.1 million tonnes of CO2 vs. 5.6 million tonnes in 2031 (BAU). In 2050, emissions of CO2 are estimated to have risen to 13.3 million tonnes of CO2 under the BAU, compared to 12.4 million tonnes for PB2 for Mumbai. A similar pattern, with somewhat lower emissions for PB2 than for BAU can be seen for the other emission types in 2031 and 2050.

However, when combining PB2 with a substantial introduction of electric vehicles, the differences between the PB2 with EV and the BAU becomes more pronounced. In terms of CO2 emissions, they are reduced to 4.1 million tonnes of CO2 in 2031 and to 9.6 million tonnes in 2050 compared to the emissions under BAU named above. PM emission values are down from 341 tonnes of PM under the BAU to 147 tonnes with PB2 w/EV in 2031, and down from 338 tonnes to 179 tonnes in 2050.

Likewise, CO emissions are reduced to less than half the amount in 2031 with 14.5 kilo tonnes of CO for PB2 w/EV compared to 31.2 kilo tonnes under the BAU. Amounts of CO emissions are also less than half the corresponding values for 2050. Similar reductions are calculated when applying the PB2 w/EV to evaluate impacts on the other emission types for 2031 and 2050 in Mumbai.

Scenarios incorporating electric mobility under different energy sources

Preliminary findings in the project suggested that electrification might be the most effective solution to bring down emissions in all three case cities, i.e. that all cars, buses and metro will be running on electric power in future years, which we her refer to as electric mobility.

In all the three cities policies including electrification of vehicles in private and public transport were incorporated in the evaluated policy packages. However, preliminary results indicated that electrification could in some instances increase total emissions, given that the electric power is generated by non-renewable (fossil-fueled) sources, for instance by power plants using coal. In most cases, since the power plants are located outside the cities, the electric energy production will not affect local pollution within the cities. Thereby it will not affect health effects, such as mortality caused by e.g., particulate matter ($PM_{2.5}$). Nevertheless, emissions global climate gases such as CO_2 would be affected by the generation of power used for electric vehicles, and should be taken into consideration as global emissions connected to transport in the case cities.

Therefore we found it illustrative to show the CO_2 emission impacts through different scenarios of the electricity grid mix used for power generation. The emissions connected to the use of electricity (g/kWh) by electric vehicles have been calculated based upon different energy mix scenarios. Renewable energy is here assuming electricity is purely generated from hydro-power, solar and wind energy sources.

Four different scenarios assumed based on the different projections of the electric energy mix in the horizon years are as listed:

- Scenario 1: New Policies Scenario (IEA, 2015)–Non-renewable sources and Electricity (74% - 26%)
- Scenario 2: Electricity from non-renewable sources (100 %)
- Scenario 3: Half electricity from renewable and another half from non-renewable sources (50 % - 50 %)
- Scenario 4: Electricity purely from renewable sources (100 %)

The estimated emissions in BAU and policy scenarios with Electric Mobility/ Electric Vehicles' (EV) Uptake considering all the scenarios of the electricity grid mix (S1, S2, S3 and S4) in the horizon years 2030 and 2050 are shown in figures 1-4 below. The results presented below are focused on emissions of CO2 under the four different scenarios for the case cities.

In figure 1 below the CO2 emission estimations are shown for Scenario 1 for the three cities in 2030 and 2050. The BAU, the estimates of the emissions with the assumption of the uptake of electric vehicles in the BAU scenario, and the "best" policy bundle in terms of CO2 emissions are shown for both the horizon years. Give scenario 1, New Policies Scenario (IEA, 2015)– with a 74% - 26% non-renewable – renewable energy mix, emissions in Delhi are estimated to decrease from 3.0 million tonnes per year in in 2030 in the BAU scenario, to 2.8 tonnes in BAU with electrification assumed, and further to 1.7 million tonnes with the "best" of the policy packages with electrification incorporated. In 2050 the reduction is from 5.1 million tonnes to 1.9 million tonnes with the best policy bundle implemented.

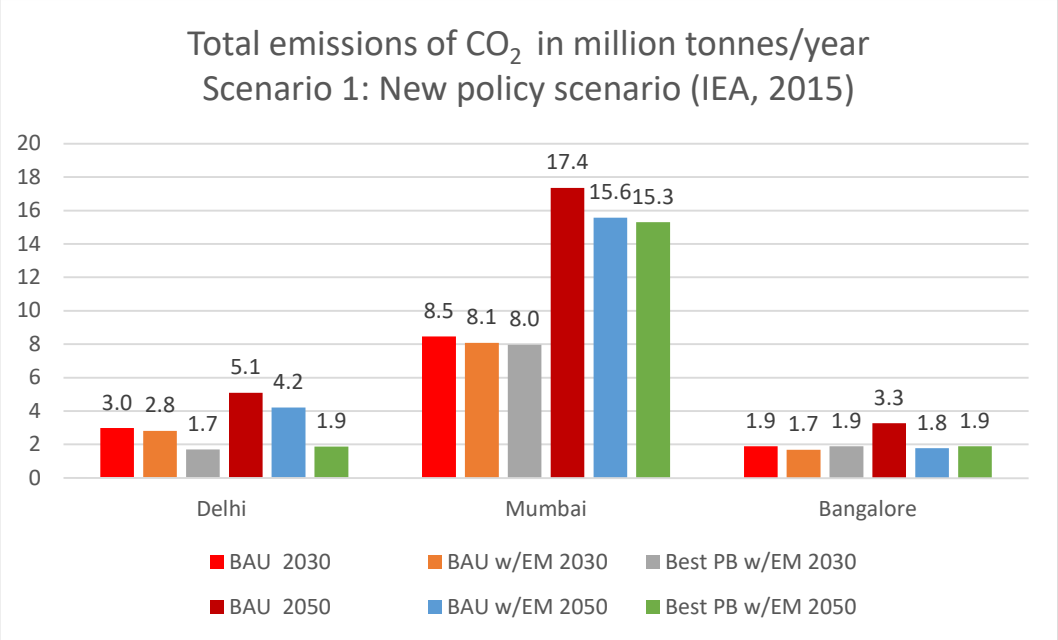

Figure 1: Scenario 1 - New Policies Scenario (IEA, 2015). Estimated emissions of CO2 for horizon years 2030(2031) and 2050 for Delhi. Mumbai and Bangalore. Total emissions, million tonnes per year.

In Mumbai[2], emissions can be reduced by 0,5 million tonnes in 2031 from 8.5 the BAU to 8.0 in the best policy bundle, and from 17.4 million tonnes to 15.3 in 2050. Given this electric energy mix scenario (IEA) emissions are estimated to be about the same, 1.9 million tonnes, under the BAU as with the best policy bundle with electric

[2] Emission figures for Mumbai are denoted as total emissions, including direct and indirect emissions, see the referenced Mumbai mitigation report (Chandel et al, 2018) for details.

mobility in 2030, whereas in 2050 the reductions are more pronounced, down from 3.3 million tonnes to 1.9 million tonnes.

Turning to a more emission-intense scenario in terms of electricity grid mix, scenario Scenario 2 assumes electricity purely from non-renewable Sources (100 %), with related emissions shown figure 2.

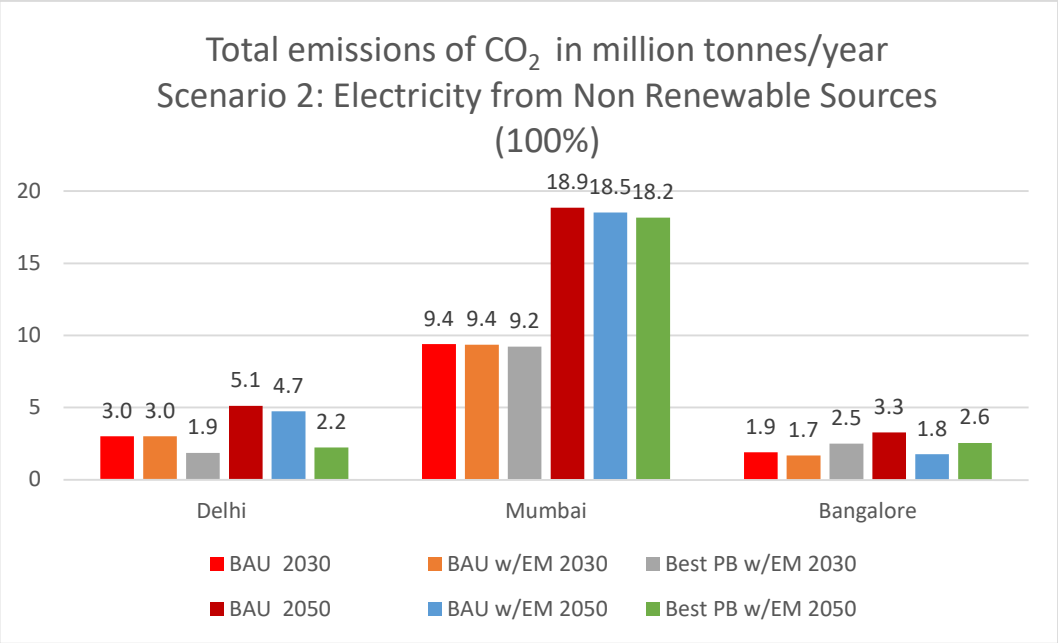

Figure 2: Scenario 2 - Electricity from non-renewable sources (100 %). Estimated emissions of CO_2 for horizon years 2030(2031) and 2050 for Delhi, Mumbai and Bangalore. Total emissions, million tonnes per year.

Even with this scenario there is a reduction in estimated CO2 emissions in Delhi from the BAU with the implementation of the best policy bundle with electric mobility assumed, both in 2030 and 2050. The same is the case for Mumbai. However for Bangalore, given electricity purely from non-renewable sources, the emissions are estimate to be higher with the best policy bundle implemented compared to the BAU in 2030. For 2050 both the BAU assuming electric mobility and the best policy bundle generates less emissions than the BAU.

The next scenario, Scenario 3, assumes an even makeup of electricity from non-renewable and renewable energy sources, with 50% for each type of source.
In this scenario emissions are estimated to be almost halved in Delhi in 2030 through implementing the best policy bundle, compared to that of the BAU. In 2050 emissions can be brought down from 5.1 with the BAU to 1.6 million tonnes of CO2 through implementing the best policy bundle and electric mobility. In Mumbai the estimated reduction that can be achieved is about 1.0 million tonnes in 2030, and 3.3 million tonnes in 2050. For Bangalore the estimated reductions are 0.6 million tonnes in 2030 and 2.0 million tonnes in 2050, when assuming a 50% / 50% renewable and non-renewable electric energy mix.

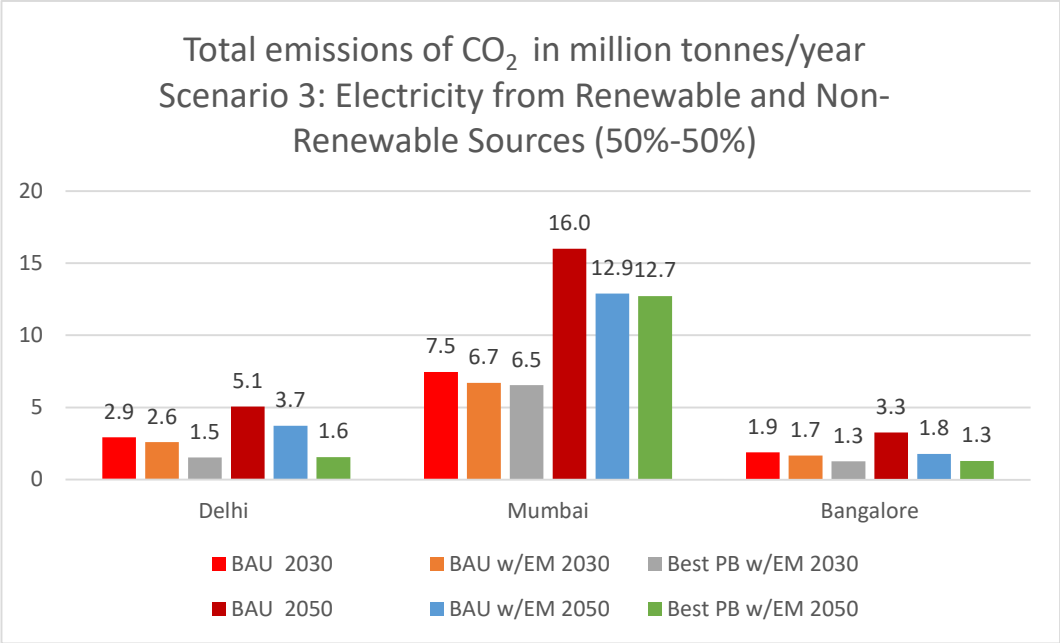

Figure 3: Scenario 3 - Half electricity from renewable and another half from non-renewable sources (50 % - 50 %). Estimated emissions of CO_2 for horizon years 2030(2031) and 2050 for Delhi, Mumbai and Bangalore. Total emissions, million tonnes per year.

The last scenario considered is one with electricity for 100% renewable sources. Although this scenario, with electricity purely from renewable sources, is as of today not very likely, it is still illustrative of the emission decreases that could be achieved with such renewable energy supply combined with the uptake of electric mobility.

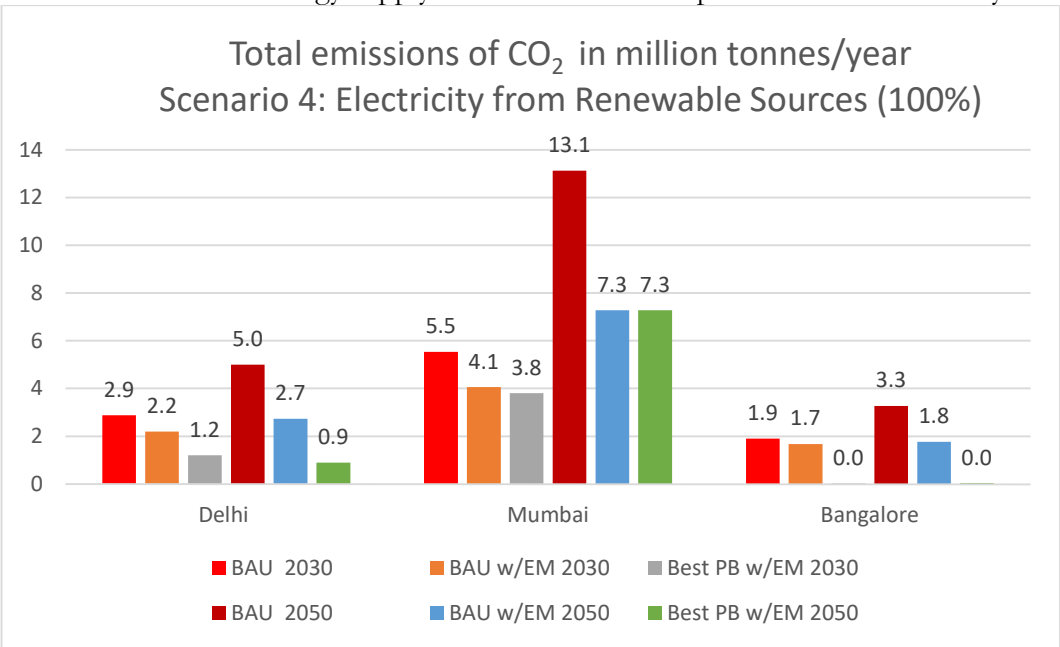

Figure 4: Scenario 4 - Electricity purely from renewable sources (100 %). Estimated emissions of CO_2 for horizon years 2030(2031) and 2050 for Delhi, Mumbai and Bangalore. Total emissions, million tonnes per year.

In Delhi the estimated reductions compared to the BAU in 2030 is 58% through implementation of the best policy bundle and uptake of electric mobility. In 2050 the reductions are estimated to be as much as 82% in Delhi.

In 2030 in Mumbai the CO2 emissions can be lowered by 31% through implementing the best policy bundle combined with electric mobility, and in 2050 the emissions can be 45% lower. Lastly, in Bangalore CO2 emissions can almost be eliminated with the best policy bundle and electric mobility, with only 0.03 million tonnes of CO2 in 2030, which is a 98% reduction compared to the BAU. In 2050 the reductions are even bigger in absolute terms, with emissions estimated to be brought down from 3.3 million tonnes to 0.03 million tonnes, also a 98% reduction.

The figure below depicts a comparison of the CO2 emissions with the best policy packages implemented for each case city given the electric grid mix of Scenarios 1 through 4. The discussion of the scenarios has shown that the emissions can be reduced substantially through implementing policy packages combined with electric mobility, but impacts are highly dependent on the electric power source. For instance, the estimations show that in Mumbai there is a 10.9 million tonnes and 60% difference in emissions under the 100% non-renewable electric energy Scenario 2 to the 100% renewable energy scenario 4.

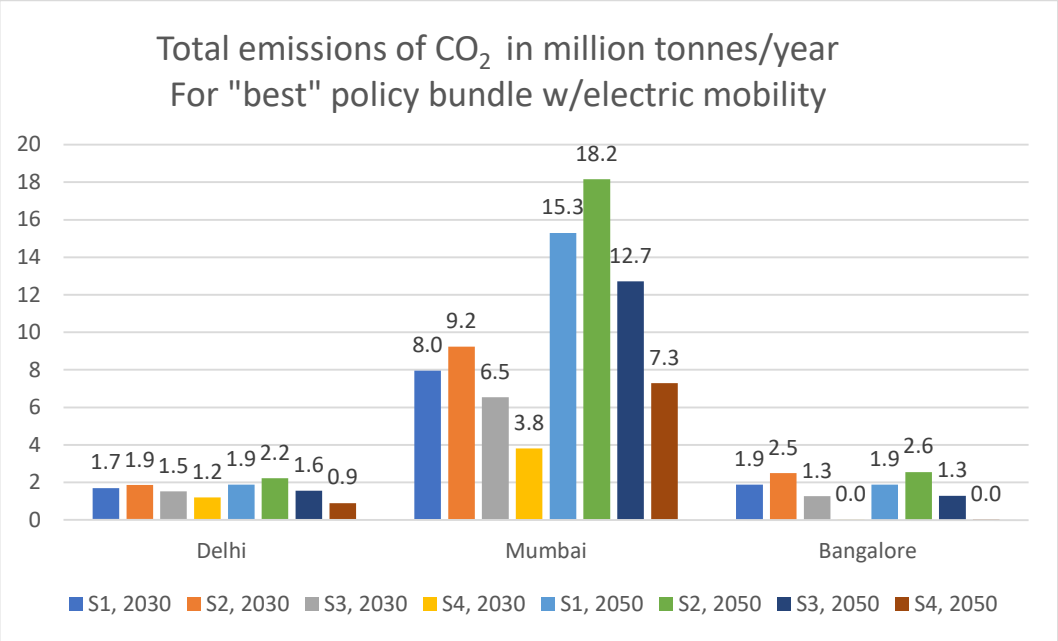

Figure 5: Comparison of Scenario 1through 4 – for Best policy bundle combined with electric mobility. Estimated emissions of CO_2 for horizon years 2030(2031) and 2050 for Delhi, Mumbai and Bangalore. Total emissions, million tonnes per year.

Conclusions

In conclusion, implementation of the different policy packages have varying impact on the different types of emissions compared to that of the BAU in all cities. For both Delhi, Mumbai, and Bangalore a larger scale conversion of the fossil-fueled vehicle stock into electric powered vehicles will by far have the greatest impact on CO2 emissions for both horizon years, compared to that of the BAU. In particular, this is the case when EVs are combined with the "best" performing policy packages in terms of CO2 emission, comprising Policy bundle 3 for Delhi, Policy bundle 2 in Mumbai, and policy bundle 3 in Bangalore for 2050.

For Bangalore in particular, the differences on emission impacts of the policy packages vs. the BAU are small to marginal in some cases. However, with reference to the Bangalore report, when considering the differences between policy packages and BAU in terms of emissions per person per km, or tonnes per person per year, the differences become clearer, and thus emphasizing the positive impacts of the policy packages from a policy perspective. Of course when incorporating electric mobility in policy bundle 4, the results are much more pronounced also for Bangalore.

However, the positive impacts of the introduction of EVs and electric mobility are highly dependent on the power source for the electric vehicles, whether it is from renewable or non-renewable sources. In some cases, utilizing electricity from non-renewable (fossil-based) power sources can have little positive impact terms of CO2 and other emissions. Notwithstanding, the electricity energy source scenarios show that just a modest introduction of renewable power sources can have profound positive effects.

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