Journal of Energy Research and Environmental Technology (JERET)
p-ISSN: 2394-1561; e-ISSN: 2394-157X; Volume 3, Issue 1; January-March, 2016; pp. 12-18

http://www.krishisanskriti.org/Publication.html

Civil, Architecture and Environmental Engineering Scenario Based Analysis of CO_2 Emissions from Transport Sector: A Case of Ahmedabad, India

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Abstract—*Rapid motorization in many cities in India has become one of the major sources of green-house gas emissions. One of the major worldwide concerns today is Global warming and climate change. The huge amounts of greenhouse gas emissions from various sectors have sped up the process of climate change. Transport sector being one of major source of CO_2 emissions, has a major role to play in the process of climate change. Various initiatives and technological advancements have become a necessity to address the issue. This study is a quantitative analysis on how, advancement in technology and different sustainable initiatives impact the reduction of CO_2 emissions in the future years. The scope of the study is though limited to only city level, the purpose behind it is to understand how CO_2 emissions can be impacted in a micro level, so that it can be multiplied in a macro (country) scale.*

1. INTRODUCTION

Climate change has emerged as one of the major matter of worldwide concern today. This phenomenon has been triggered by the increasing emissions of greenhouse gas throughout the world. It is observed that the transport sector contributes to 23% of the global GHG emissions in the world. (Schipper, Fabian, & Leather, 2009) Also studies have shown that the global GHG emissions are increasing at a very alarming rate. It is expected to increase by 1.7% every year from 2004 to 2030, along with the multiplying of global fleet by three to four folds in the next few decades, majorly in the developing countries.(Dalkmann & Sakamoto, 2011) At the end of 2050, it is projected that nearly two-thirds of the world vehicular fleet will be in the non-OECD countries. (Dalkmann & Sakamoto, 2011) This will make India one of the prime sources of GHG emission through transport sector in the near future, if followed the same trend of increasing fleet using oil based fuels. Considering the importance of the emerging issue, it is needed to take actions at state policy as well as individual levels. This study focuses on the potential that a state and a country level actions and policies have, in order to impact the increasing trend of greenhouse gas emissions in a city level.

For this purpose, the city of Ahmedabad, State of Gujarat, India has been strategically chosen as the study area in regards to its shared typicality with major Indian cities, having a population more than a million and a tremendous growth of vehicular fleet. The vehicular fleet has increased massively from only 43,000 in the year 1961 to more than 70 lakhs in the year 2004, leading to a growth of 160 times in just four decades.(Ahmedabad Municipal Corporation; Ahmedabad Urban Development Authority; CEPT, 2012) A study of Ahmedabad would give a picture for the other metropolitan cities in India which also shares a major transportation demand and hosts a major bulk of the CO_2 emissions in India.

2. METHODOLOGY

The overall objective of the study is to compare the CO_2 emissions associated with the future transport demand in Business-as-usual scenario with other low-carbon scenarios. For this purpose four different scenarios have been established. One being the Business-as-Usual or BAU Scenario and the other three scenarios are: 1. Technological Advancement Scenario or TA Scenario; 2. Sustainable Transport Scenario or ST Scenario; & 3. Combined Low Carbon Scenario or CLC Scenario.

1. **Business-as-Usual Scenario:** In this scenario, the transport demand is forecasted based on the current trend of vehicular demand and motorization. It is expected that the use of Public transport and Non-motorized transport is decreasing with a tremendous increase in the use of private vehicles and mostly powered by oil and gas.
2. **Technological Advancement Scenario:** Newer and unconventional low carbon technological advancements are taken into account in this scenario. Precisely this scenario would include the rapid decarbonization of electricity due to a shift from conventional fossil fuels to

non-CO_2 emitting renewable resources and a shift of conventional vehicles to electric modes of travel.

3. **Sustainable Transport Scenario:** State and country level policy and programmes have a major potential of CO_2 emission reduction. So this scenario would be about how different sustainable transport measures impact the reduction of CO_2 emissions in a city level.
4. **Combined Low-Carbon Scenario:** This scenario would be a combination of the above two scenarios, where policy and programme level interventions would be added on to technological advancements in the energy sector.

For this study, the year 2011 is considered as the base year and emission projections have been done for the years 2021 and 2031. The whole study demands a lot of calculations. The calculations are carried out in four different steps. These are as follows:

1. **Calculating Transport Demand:** For calculating the transport demand, the following equation has been used.

$TD_i = \Sigma Tr_i \times Tl_i \times Pop_i \times 365$ (Dhar & Shukla, 2014)

TD_i : Travel demand for the year i (PKT)

Tr_i : Average trip rate for the year i

Tl_i : Average trip length for the year i

Pop_i : Projected population for year i

This formula gives the total passenger kilometers travelled in the particular year.

2. **Estimating mode shares:** Data availability has been a major constraint for estimating the mode shares. The vehicular data has been collected from the Regional Transport Office, Ahmedabad for the years 1989-90 to 2012-13. Based on it, a trend has been developed for mode shares in BAU Scenario. Other data for generating the mode shares have been taken from MEGA DPR (Metro Link Express for Gandhinagar and Ahmedabad, 2011) and BRTS Ahmedabad Report (CEPT University, 2003). Based on their model and assumptions, the mode share for 2021 and 2031 has been estimated for all the four scenarios.
3. **Estimating CO_2 emission factors:** The present day vehicular emission factors have been taken from a report on Dynamics of Urban Mobility (Reddy & Balachandra, 2010). The projections in vehicular emissions have been done based on the CMP Toolkit (Ministry of Urban Development, 2014). Emissions associated with electricity generation have been estimated based on the report on CEA Emission factors (Government of India Ministry of Power, 2011) and emissions associated with electric vehicles have been estimated based on the study by UNEP (Dhar, Subash; Pathak, Minal; Shukla, 2013).

The following table shows the mode wise and scenario based CO_2 emitted in Grams/Passenger kilometers travelled, which the result of the evaluation that is done based on the above mentioned secondary data.

Table 1: Scenario based CO_2 emission factor in grams/PKT for different modes

Vehicle Type	Base Year	BAU Scenario		TA/CLC Scenario		ST Scenario	
	2011	-21	-31	-21	-31	-21	-31
2W	36.78	30.51	30.40	23.71	18.14	30.51	30.40
e2W	--	15.62	13.18	12.13	5.09	15.62	13.18
4W	152.23	140.28	139.11	102.77	79.08	140.28	139.11
e4W	--	83.93	78.57	65.18	30.36	83.93	78.57
IPT	39.49	31.86	30.79	25.78	19.07	31.86	30.79
Bus	31.34	28.62	28.00	23.42	17.25	28.62	28.00
Metro Rail	--	20.87	9.96	16.21	3.85	8.76	5.73

From the above table it is observed that four wheelers (private cars) have the highest CO_2 emissions per passenger kilometers travelled. This is due to the low occupancy of the private cars. On the other hand, Bus and Metro rail have least CO_2 emissions per passenger kilometers due to the very high occupancy of public transport. The higher the occupancy, the lower is the CO_2 emissions associated per passenger. Thus a shift from private motorized transport to public transport leads to reduction in overall CO_2 emissions. Another mode of travel, i.e. non-motorized transport, has not been mentioned in the above table, since it is associated with zero emissions. Non-motorized transport (NMT) includes walking and cycling, which is absolutely emission free. There are policies and programmes which emphasizes on the promotion of non-motorized transport.

It is also observed that Electric vehicles are associated with CO_2 emissions as well, though not at the site, but at the source. In India, the electricity generation is mostly powered by fossil fuels, thus emitting huge amount of CO_2 at the source of generation. It is expected that in future the share of fossil fuels in the main grid will decrease substantially and in turn taken up by renewable, non-CO_2 emitting sources like solar, wind, geothermal etc.

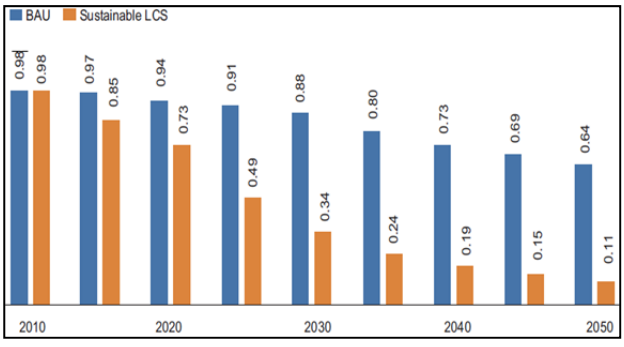

Fig. 1: CO_2 Intensity of Electricity from grid connected power 2010 – 2050 (Dhar, Subash; Pathak, Minal; Shukla, 2013)

These would in turn reduce the emission coefficients of the electric two-wheelers, electric-four wheelers and metro rail. No emission coefficient from the electric vehicles and metro rail has been shown in the table since there is nearly negligible electric vehicles and no metro rail in the base year 2011.

The following Fig. gives a comparison of the reduction in emissions in Business-as-Usual Scenario and a Low-Carbon Scenario.

The graph above shows that in BAU Scenario there is only a minor decrease in the CO_2 emissions from the main grid. That implies that, though presently little, there would be an increase in the share of non-CO_2 emitting energy sources in the main grid. On the other hand it is seen, that due to higher intervention of policy and programme interventions, there is a substantial decrease of CO_2 emissions in the main grid.

4. **Calculating total and per-capita CO_2 emissions:** Based on the above estimates, year wise, overall and per-capita CO_2 emissions have been calculated for all the four scenarios.

Base Year (2011) Inventory

For analyzing the future scenarios, the first thing is to generate a baseline. For this study, 2011 has been considered as the base year. Firstly the total travel demand is calculated based on the data available.

Table 2: 2011 Data for Travel Demand Calculation

Data for 2011		Data Source
Population	5,570,585	(Census Organization of India, 2011)
Average trip rate	1.44	(Metro Link Express for Gandhinagar and Ahmedabad, 2011)
Average trip length	7.7 Kms	(Wilbur Smith Associates Ltd., 2008)

Based on it, the total travel demand is calculated. The total passenger kilometers traveled in the year 2011 comes to be 22.54 Billion Kilometers. Now based on the mode share of 2011, the passenger kilometers travelled per mode is estimated.

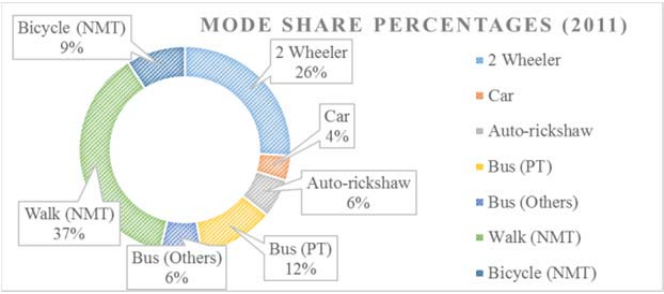

Fig. 2: Mode share for base year 2011 (Metro Link Express for Gandhinagar and Ahmedabad, 2011)

Now the mode share and the share of CO_2 emitted from each mode if compared, the result comes to be very different. The image below shows the comparison between the travel demand mode shares and CO_2 emitted from each mode.

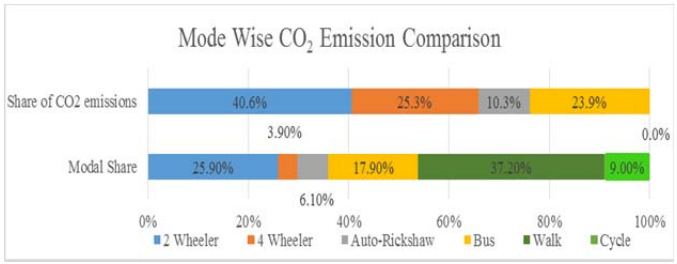

Fig. 3: Mode wise CO_2 emission comparison

It is observed that, though private vehicles (2 wheelers and 4 wheelers) occupy less than one third of the modal share, it occupies more than two third of the share of CO_2 emitted from different modes. Particularly 4 wheelers which have a mode share of only 3.9%, emit 25.3% of the total CO_2 emissions. This is due to the low occupancy of four wheelers and high emission per travel kilometers. Buses have higher emission levels per kilometer compared to four-wheelers, but also have a very high occupancy, which in turn reduces the emissions per passenger kilometer travelled. The assumed vehicular occupancy is given in the table below.

Table 3: Vehicular Occupancy (Munshi, 2013)

Vehicle Type	Occupancy
2 Wheeler	1.02
4 Wheeler	1.12
Auto-Rickshaw	2.25
Bus	28.4

The total CO_2 emission comes to be 0.53 million tons of CO_2 in 2011, and the per capita CO_2 emission is 0.1 ton per capita for the same year. According to European commission, the Indian per capita CO_2e emissions in the year 2010 was 1.5 tons, which included, emissions from all sector, not just transport. (Europian Commission, 2015) Transport sector accounts for 13.1% of the total CO_2e emissions in India. (Dhar, Subash; Pathak, Minal; Shukla, 2013) "CO_2e" i.e. CO_2 equivalents, also incorporates other greenhouse gas emissions and not just CO_2. Thus it can be said that, Ahmedabad city has an overall per capita greenhouse gas emissions of more than 0.76 tons in the year 2011. Though the value seems to be lower than the national average of 1.5 tons per capita, it would be nearly equivalent to it if all the greenhouse gas emissions are taken into account instead of just CO_2 emissions.

3. BUSINESS-AS-USUAL (BAU) SCENARIO

This scenario is focused in projecting the future based on the present trends assuming that there is no major change in peoples' attitude and priorities, or no significant changes in technology, programmes and policies. The future mode share

analysis is the first and foremost projection that had to be done in order to analyze the future CO_2 emissions. In order to estimate the mode shares, the new vehicular registration data is analyzed to understand the trend of purchase of vehicles in different modes. The second thing that has been taken into account is the different projections made by MEGA DPR (Metro Link Express for Gandhinagar and Ahmedabad, 2011) and Ahmedabad BRTS report (CEPT University, 2003). Following representation shows the mode shares in this scenario for the years 2021 and 2031.

Table 4: Mode shares in BAU Scenario

BAU Scenario	2011	2021	2031
2 Wheeler	25.9%	26.4%	22.8%
E2W	0.0%	0.5%	1.5%
Car	3.9%	4.8%	4.9%
E4W	0.0%	0.1%	0.4%
Auto-rickshaw	6.1%	5.0%	3.6%
Bus (PT)	11.6%	17.1%	27.6%
Bus (Others)	6.3%	2.8%	1.8%
Metro Rail (PT)	0.0%	1.9%	4.7%
Walk (NMT)	37.2%	36.2%	30.4%
Bicycle (NMT)	9.0%	5.1%	2.4%

It is observed that the share of private vehicles as increasing, on the other hand the share of public transport and non-motorized transport is decreasing drastically. This is due to the improvement in economic condition of people, more private vehicles would be purchased and thus people would use lesser public transport and non-motorized transport; which would be the major reason for increasing emissions. There would be the penetration of electric vehicles and metro rail in 2021 and 2031, leading to a modal shift. Still the expected penetration would be negligible to impact the increasing CO_2 emissions.

Based on the above mode share, the overall and per capita CO_2 emissions are calculated for this scenario.

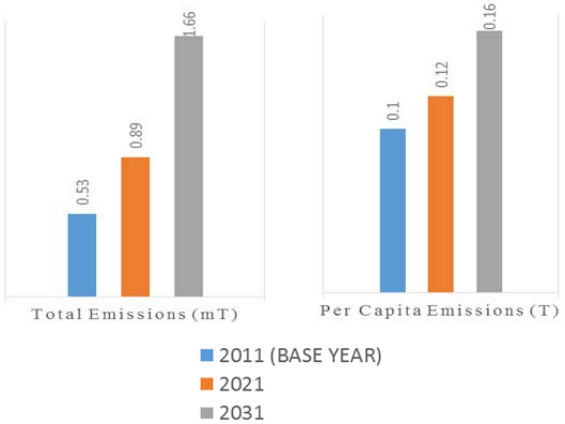

Fig. 4: Total and Per capita CO_2 emissions in BAU Scenario

The total emission would be increasing by 0.53 million tonnes in 2011 to 0.89 million tonnes in 2021 and 1.66 million tonnes in 2031, which is a tremendous growth of 63% from year 2011 to 2021 and 86.2% from years 2021 to 2031. The total emissions would be increasing by three folds in just two decades. One of the major reasons of this increase would be the growth of population. As the population increases, so the number of vehicles and thus resulting in higher emissions. On the other hand it is also observed that, the per capita emissions are also increasing from 0.1 ton per year in 2011 to 0.12 tonnes in 2021 and 0.16 tonnes in 2031. An increase of 60% per capita emissions in two decade added to the increasing population amplifies the total threat of climate change if continued in the same path. Necessary actions have to be taken in this regard.

4. TECHNOLOGICAL ADVANCEMENT (TA) SCENARIO

Technology is an ever evolving process. Advancements in the automotive sector has led to better vehicles with higher efficiency and lower emission levels. In a country like India, there is a good mix of old and new vehicles, still it is observed that the purchase of new vehicles is increasing each year. For this scenario, it is expected that the upcoming vehicles will be much more efficient than the present day. Also, for this scenario it is assumed that there will be a higher penetration of electric vehicles due to higher awareness and lower price of EVs. Since electricity is also associated with a very high amount of emissions in India, so, for this scenario it has been assumed that there will be a higher penetration of non-CO_2 emitting sources of energy.

In this case, the modal share will have minor alterations from the followed trend of BAU Scenario. Only in this scenario, there will be higher share of electric two-wheelers and four-wheelers. The following representation shows the mode share for TA scenario.

Table 5: Mode shares in TA Scenario

TA Scenario	2011	2021	2031
2 Wheeler	25.9%	18.9%	5.3%
E2W	0.0%	8.1%	18.9%
Car	3.9%	4.7%	3.2%
E4W	0.0%	0.1%	2.1%
Auto-rickshaw	6.1%	5.0%	3.6%
Bus (PT)	11.6%	17.1%	27.6%
Bus (Others)	6.3%	2.8%	1.8%
Metro Rail (PT)	0.0%	1.9%	4.7%
Walk (NMT)	37.2%	36.2%	30.4%
Bicycle (NMT)	9.0%	5.1%	2.4%

The share of conventional two-wheelers and four-wheelers would be decreasing drastically due to the higher popularity of electric vehicles. But the share of non-motorized transport would still decrease. Due to the upcoming metro rail line and a successful bus rapid transit system, the share of public

transport would be increasing, but not drastically due to lack of policies and programmes to force a modal shift. The following representation shows the total and per-capita CO_2 emissions for 2021 and 2031 for this scenario.

Fig. 5: Total and Per capita CO_2 emissions in TA Scenario

The increase in the total emissions has substantially decreased compared to BAU scenario, but still it is showing an increasing trend. The total emissions would increase by 43% in the next two decade, which is comparatively lower than 63% in BAU scenario. Also the per capita emission seems to decrease from 0.01 Ton in 2011 to 0.09 ton in 2021 and 0.08 ton in 2031. The substantial decarbonization of electricity would drastically reduce the emissions associated with electric vehicles. The major reduction in per capita emissions is mainly due to the higher penetration of electric vehicles. But technological advancements cannot be the solution alone. Though these advancements seem to reduce the per capita emissions, but the total CO_2 emissions would still be increasing severely.

5. SUSTAINABLE TRANSPORT (ST) SCENARIO

A number of policies and programmes are being implemented countrywide to promote sustainability in transport sector. This includes encouraging public transport (PT), non-motorized transport (NMT), and discouraging the use of private motorized vehicles. This scenario would be talking about the impact these policies and programmes would have in the reduction of CO_2 emissions in future. The first major assumption that has been made in order to draw the scenario is that, there would be a very well developed public transport network. There is an upcoming metro rail and an already implemented bus rapid transit system in Ahmedabad. It is expected that these services would operate to its full capacity. Also since it is expected that the public transport network is very well developed, there would be policies to discourage private vehicles, like congestion charges, even-odd rule for private vehicles, high parking charges, and other policies to discourage private vehicles. Another factor i.e. a higher penetration of non-motorized transport is assumed in this scenario. A better and walkable transport network ensures a good share of NMT. Also in a place like Ahmedabad, the major reason of people not walking or cycling is the hot and dry climate of the city, unsafe roads for cycling, and lack of walkways and cycle tracks. Special infrastructure like shaded walkways, dedicated cycle track, walkability from the public transport stations would help in increasing or at least maintaining the present share of non-motorized transport. The following representation describes the forecasted modal share for years 2021 and 2031 in this scenario.

Table 6: Mode shares in ST Scenario

ST Scenario	2011	2021	2031
2 Wheeler	25.9%	17.3%	10.1%
E2W	0.0%	0.4%	0.6%
Car	3.9%	2.6%	1.5%
E4W	0.0%	0.1%	0.1%
Auto-rickshaw	6.1%	4.1%	2.5%
Bus (PT)	11.6%	21.9%	30.5%
Bus (Others)	6.3%	4.3%	2.6%
Metro Rail (PT)	0.0%	3.1%	6.5%
Walk (NMT)	37.2%	36.2%	34.4%
Bicycle (NMT)	9.0%	10.1%	11.0%

In the above mode share, it is observed that the share of conventional two-wheeler and four-wheeler is decreasing substantially. Though the penetration of electric vehicles is too low compared to the previous scenario that is compensated by the increased share of public transport. The share of non-motorized transport is still decreasing but compared to BAU scenario, the decrease in the share of people walking is very gradual. In fact, the share of people cycling would actually increase in this scenario. So if evaluated, the following would be the trend of CO_2 emissions.

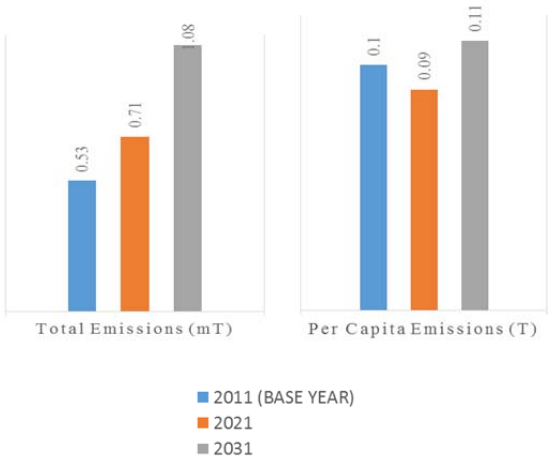

Fig. 6: Total and Per capita CO_2 emissions in ST Scenario

The total emissions would increase from 0.53 million tonnes in 2011 to 1.08 million tonnes in the year 2031 which is an increase by two folds in two decades. The increase is

relatively gradual if compared with BAU scenario, but it would not be enough to compensate the global warming and climate change. Unlike the TA scenario, in this scenario there is an initial decrease in the per-capita CO_2 emissions in the duration of 2011 to 2021, but again there is a rise in the per-capita CO_2 emissions in the duration of 2021 and 2031. This signifies that in a metropolitan city like Ahmedabad, policies and programmes alone don't have the capability to reduce CO_2 emissions to an agreeable level. Also these policies are unable to gradually reduce the per-capita emissions. The emission reduction potential reaches its saturation in 2021 itself. Therefore there is a need for joint actions i.e. technological advancements as well as sustainable transport.

6. COMBINED LOW CARBON (CLC) SCENARIO

This scenario is a combination of the Technological Advancement & the Sustainable Transport scenarios, which means, emission reduction factors from both the factors have been taken into account. The six major factors which form the spine for this scenario are, 1.Increased share of **mass transit** (public transport); 2.Discourage the use of **private vehicles**; 3.Support **non-motorized transport**; 4.**Increased efficiency** of vehicles; 5.Increased share of **electric vehicles**; 6.Increased share of **non-CO_2 emitting energy sources** in the main grid.

The first three points were considered in the Sustainable Transport scenario and next three points have been considered in the Technological Advancement scenario. So, this scenario basically deals with everything that is practically possible to reduce overall and per-per-capita CO_2 emissions. The modal share for this scenario is detailed out in the following representation.

Table 7: Mode shares in CLC Scenario

CLC Scenario	2011	2021	2031
2 Wheeler	25.9%	12.3%	2.4%
E2W	0.0%	5.3%	8.4%
Car	3.9%	2.6%	1.0%
E4W	0.0%	0.1%	0.6%
Auto-rickshaw	6.1%	4.1%	2.5%
Bus (PT)	11.6%	21.9%	30.5%
Bus (Others)	6.3%	4.3%	2.6%
Metro Rail (PT)	0.0%	3.1%	6.5%
Walk (NMT)	37.2%	36.2%	34.4%
Bicycle (NMT)	9.0%	10.1%	11.0%

In the mode share, it is observed that there is already a reduction in the private two-wheelers and four-wheelers like the Sustainable transport scenario, and this share has also been majorly taken up by the electric vehicles. The other mode shares have been considered similar to the sustainable transport scenario. The bar diagrams below shows how the overall and per-capita CO_2 emissions would vary for this scenario.

Fig. 7: Total and Per capita CO_2 emissions in CLC Scenario

In this scenario there is a very marginal rise of CO_2 emissions, 0.53 million tonnes in 2011 to 0.57 million tonnes in 2031 i.e. a rise of only 7% in the next two decades. If we compare it with the rise in population and increase in travel demand, the rise in overall CO_2 emissions for this scenario would be negligible.

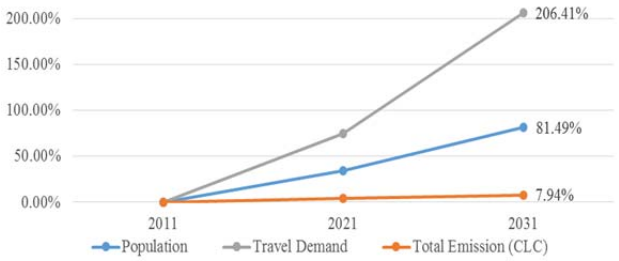

Fig. 8: Increase in population and travel demand vs. Increase in total CO_2 emissions in CLC Scenario

The above Fig. clearly shows the large variance in the increase in CO_2 emissions with reference to population and travel demand. Where population is increasing by 81.49%, travel demand by 206.41% in two decades, the overall emissions is only increasing by 7.94%; which turns to be a positive indicator in the present scenario of global warming and climate change.

The per-capita CO_2 emissions would also decrease substantially from 0.1 ton in 2011 to 0.06 tonnes in 2031, which is an overall reduction of 40%. This reduction in per-capita emissions will compensate the growing population and travel demand in future.

7. COMPARING SCENARIOS

Comparing the results of all the scenarios would give an idea of how these scenarios would impact the CO_2 emissions in future. The following representation is a comparison of total emissions between all the four scenarios.

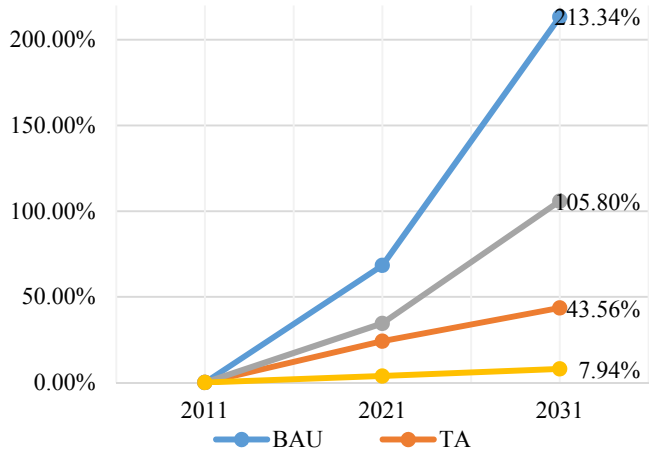

Fig. 9: Scenario based increase in total CO_2 emission comparison

The results are quite obvious. If continued in BAU scenario, the total emissions would increase by 213.34% whereas if followed the CLC scenario the rise would only be 7.94. Similarly in the following representation, per-capita CO_2 emissions have been compared.

Even the change in per capita emissions has a huge variation for all the four scenarios. Where the per-capita emissions are increasing by 72.65% in two decade for BAU scenario, the emissions are decreasing by 40.52% for the CLC Scenario in the same interval. It implies that there is hope. The process of global warming and climate change can still be controlled if necessary actions are taken without wasting time. If such are the results for a metropolitan city like Ahmedabad, it can be very well replicated all through the country and worldwide. Though this study is an analysis of different hypothetical scenarios, these scenarios are very well possible in real life. The situation is worsening, and it is needed that people start taking it seriously.

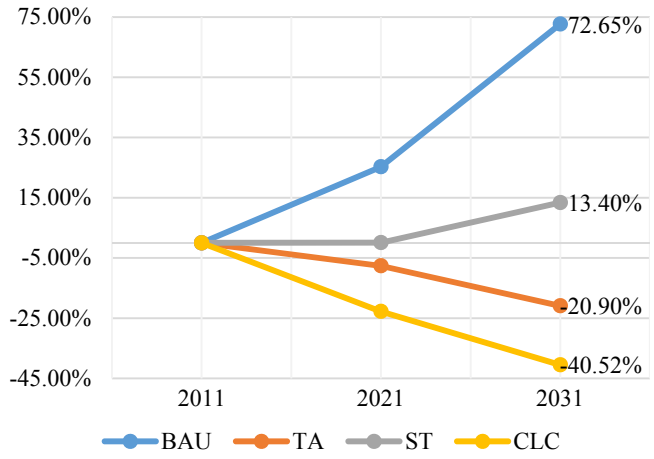

Fig. 10: Scenario based change in per-capita CO_2 emission comparison

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