PUNE INTERNATIONAL CENTRE

Maximising the Urban Carbon Sequestration Potential of Pune Metropolitan Region

March 2023

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1. Introduction

To meet the dual challenges of a growing global population and mitigating climate change, it is necessary to consider how urban areas can sustainably grow while minimising impacts on the environment.

Urban areas are the hubs of social, cultural, and economic interactions. They are densely populated regions characterised by high human settlement, infrastructure development, and various economic activities. More than 50% of the world population (~3.5 billion) lives in urban areas, and the relative magnitude will increase to 60% by 2030. It is estimated that by 2050 every seven in ten persons will be living in urban areas.[1]

A United Nations Human Settlements Programme (UN-Habitat) report shows urban areas, including small towns and major cities, contribute over 70% emissions in India. The Brundtland World Commission on Environment and Development (1987) identified a number of serious environmental problems caused by rapid urban growth. Hence, cities globally must take initiatives to achieve Carbon Neutrality – like Copenhagen is planning to do by 2025.

Maharashtra is the 3rd most urbanised state in India, having the highest level of urbanisation in India at 45.23 per cent compared to 29.5 per cent as the all India average.[2] As per our last census of 2011, over 45% of the total population of Maharashtra lives in urban areas, and this figure is going to rise steeply over the years to come, due to the increased migration of people from rural and semi-urban areas, to urban areas. In the last ten years, there has been a 45.22 percent rise in the urban population. Although the overall population residing in urban regions is lower than in remote regions, the population density in urban areas is extremely high.

[1]https://www.iipsindia.ac.in/sites/default/files/Urban_Vulnerability_Analysis_Report_121021.pdf)

[2](https://www.researchgate.net/publication/319553254_LEVEL_OF_URBANISATION_AND_THEIR_DISPARITIES_IN_MAHARASHTRA_STATE#:~:text=Maharashtra%20has%20the%20highest%20level,as%20the%20all%20India%20average.)

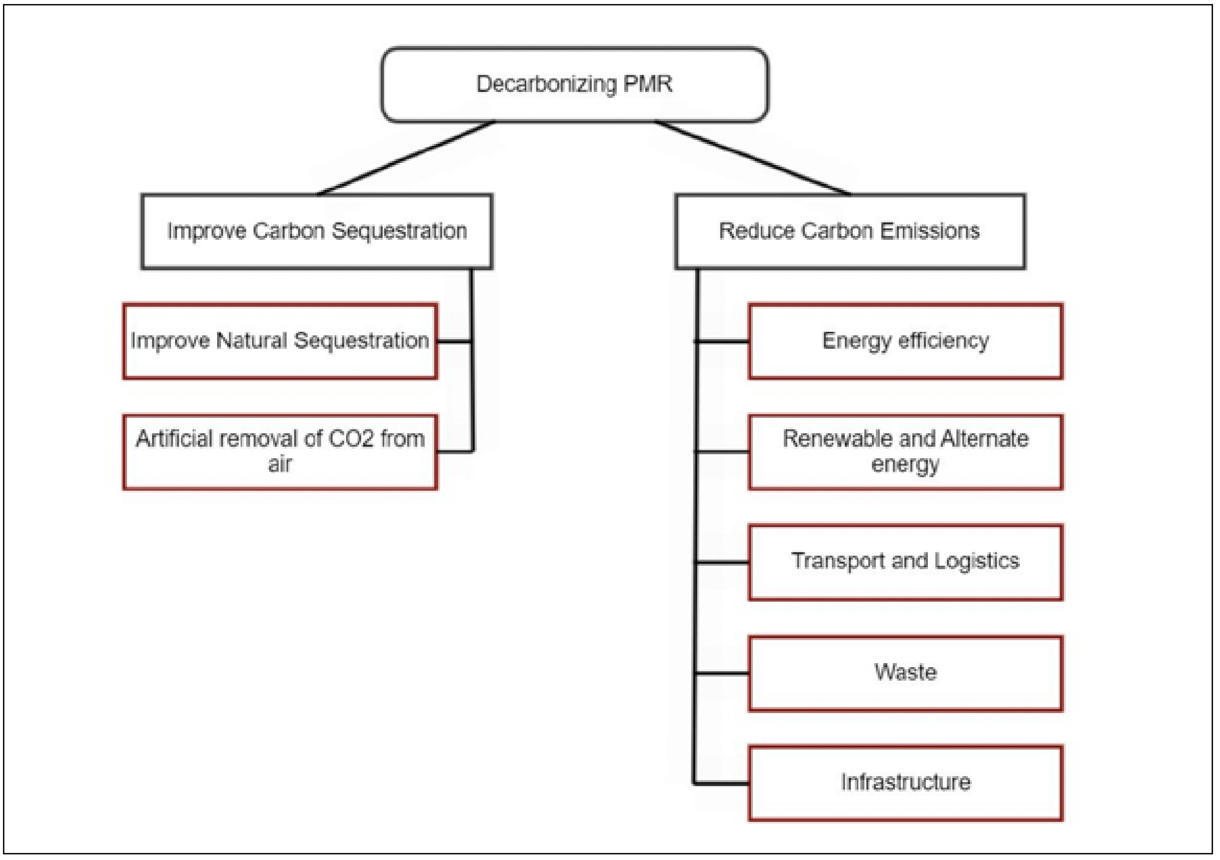
2. PMR's Carbon Neutrality Agenda

PMR (Pune Metropolitan Region) is a one of the fastest-growing urban conglomerates in the Asia-Pacific region with a large area of 7,256 sq.km. Currently, it is the 8th most populous city in India with over 7 million population, which is expected to grow to over 12 million by 2030. PMR comprises two Municipal Corporations of Pune and Pimpri Chinchwad, three Cantonment Boards, seven Municipal Councils, 13 census towns and 842 villages and most of it falls under 'Greenfield Development'.

Affluent urban areas and tier 1 cities like PMR have a higher responsibility to reduce national total emissions. This is why PMR must recognise this responsibility and take a leadership role in achieving net carbon neutrality at the earliest. It should be noted that 'Carbon Neutrality' does not refer to zero emissions but rather aims at achieving a balance between greenhouse gas (GHG) emissions being released to the atmosphere, and those being avoided or removed from the atmosphere.

PMR faces the dual challenge of accommodating rapid urbanisation and addressing the escalating climate crisis. Its transition to a carbon-neutral status would make a significant contribution to mitigating climate change. The carbon neutrality efforts would also lead to improved air quality, benefiting public health. In 2021-22, the total CO eq emissions of PMR were 25,048 KT (Kilo-Ton) and total capacity for sequestration was about 779 KT. These should be reduced considerably by 2030 if we are to have any hope of fulfilling our climate-commitments.

The journey of decarbonising PMR consists of two main agendas:



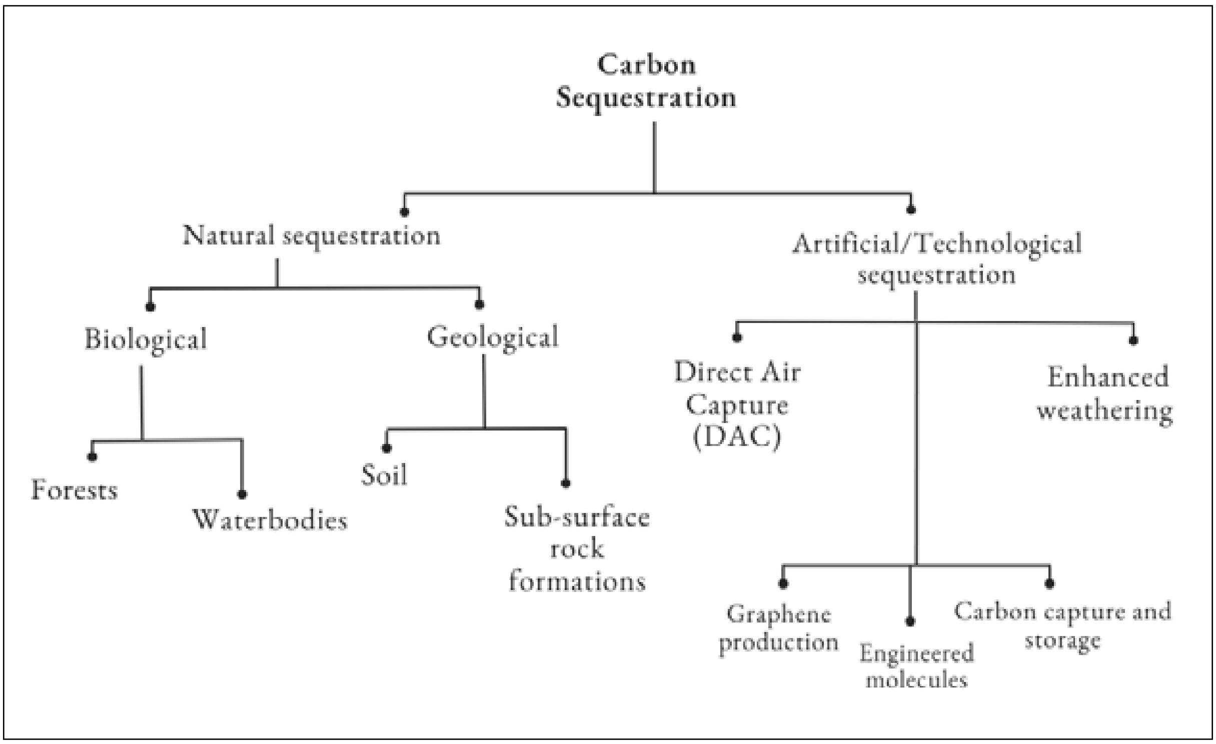
1. Rapidly Reducing the Carbon Emissions Across All Sectors

To limit global warming to under 2^{0}C, global cumulative emissions till 2050 must be less than 1000 Giga-Tons (GT) and the net global emissions must reduce to net-zero by 2050. Present trend of addition of over 50 GT per-year of COeq emission must be effectively reduced to 33 GT per year.

But even after reducing carbon footprint drastically, some emissions due to urban activities will still persist. This is because especially for a developing country like India, the rate of emissions can't be practically reduced to zero. Hence, the solution for a planned transition to low-carbon economy is incomplete without using carbon sequestration (natural and artificial) to complement the emission-reduction strategies.

2. Sequestering of Carbon Which has Already Been Emitted and is Being Emitted

Carbon sequestration refers to the process by which carbon dioxide is removed from the atmosphere and stored in different reservoirs. This removal of emissions is originally a natural occurrence, but it may also be brought on by human activity, artificially, which prevents carbon from becoming carbon dioxide gas. It plays a critical role in balancing the carbon cycle, regulating the Earth's climate, and mitigating the impacts of anthropogenic greenhouse gas emissions. Before human-caused CO2 emissions began, the natural processes that make up the global "carbon cycle" maintained a near balance between the uptake of CO2 and its release back to the atmosphere. Different modes of sequestering carbon are given in the following chart:



Natural sequestration of carbon is the capture and long-term storage of carbon which is a natural process taking place in oceans, vegetation, soils and geologic formations. In the 'Urban context' of a metropolitan region like Pune, natural carbon sequestration is done by: urban soil, forests, urban green spaces, waterbodies, residential greenery, and hills (tekdis).

Carbon sequestration provides a complementary and necessary approach to mitigating climate change alongside reducing emissions. This is because the historical emissions from coal-fired power plants in the 19th and 20th centuries still persist and continue to contribute to the current levels of atmospheric CO_2. This excess CO_2 remains in the atmosphere for decades to centuries, contributing to global warming and climate change. Simply reducing future emissions won't remove the CO_2 that has already accumulated. Secondly, the sectors such as aviation, heavy industry, and certain agricultural practices, are challenging to decarbonise fully, especially for a developing country like India. Carbon sequestration offers an opportunity to offset emissions from these hard-to-abate sectors, providing a more comprehensive and inclusive strategy to combat climate change.

Hence, to reach the goals specified in Paris Conference Climate Targets and the commitments made by India to go net-neutral by 2070, we need to seriously prioritise the efforts to study and increase the carbon sequestration capacity of tier-1 cities like Pune and effectively extrapolate and implement it pan-India.

2.1 PMR's Urban Landscape and Carbon Emissions Profile

To study and analyse the current carbon sequestration potential of PMR and the future potential to increase the sequestration, we need to study the geographical, biological, and urban characteristics of this metropolitan region.

1. **Geographical Location and Climate:** PMR has an average elevation of 560 meters above sea level. The city experiences a tropical monsoon climate, characterised by hot summers, moderate rainfall during the monsoon season, and cool winters. The climatic conditions play a vital role in determining the growth and distribution of vegetation, which directly influences carbon sequestration potential.

2. **Urban Landscape:** The city's urban fabric comprises a mix of high-rise buildings, suburban developments, and informal settlements. Understanding the land use patterns and distribution of green spaces within the urban landscape is crucial for identifying potential carbon sinks and designing targeted carbon sequestration strategies.

3. **Vegetation and Ecological Features:** The city is surrounded by the the Western Ghats mountain range, which harbours diverse and ecologically significant ecosystems. It has 11 major hills, occupying approximately 5% of the total area of PMR. The presence of natural vegetation, including urban forests, parks, and gardens, contributes to carbon sequestration potential and enhances the city's resilience to climate change.

4. **Water Bodies:** The region is blessed with several rivers, lakes, and reservoirs, such as the Mula and Mutha rivers, Pashan Lake, and Khadakwasla Dam. These water bodies contribute to carbon sequestration through aquatic plant growth and wetland ecosystems. Assessing the carbon sequestration potential of these water bodies is essential for understanding the overall carbon dynamics in the study area.

5. **Socio-economic Factors:** The city's socio-economic factors, including population density, income levels, and urban lifestyles, influence carbon emissions and the potential for implementing carbon sequestration measures. Analysing these factors can help identify opportunities and challenges for promoting urban carbon sequestration within the local context.

For setting up a plan to achieve net-neutrality, it is important to annually track the GHG emissions and prepare an inventory of the current emissions scenario for PMR. This will help analyse trends and identify potential areas to drastically reduce the region's carbon footprint.

As per the PMC Environment Status Report 2018-19 (ESR), the city's average per-capita emissions have increased by 12% from 1.46-tonne carbon dioxide equivalent (tCO eq) in 2012 to 1.64 tonne in 2017, a rise within 5 years.[3] This rising trend will contribute significantly to India's national emissions, if not curbed urgently.

An estimate of PMR's emissions from Scope 1,2 and 3, for the year 2030 has been presented in the table below. (This data was calculated in the year 2022).

[3](Environment Status Report, 2018-19, PMC)

	CO_2 eq. T/Year	CO_2 eq. T/Year in 2030 (Current trend)	Percent of Total
Scope 1	7,580,709	10,049,434	25.62%
Scope 2	10,873,200	20,729,780	52.85%
Scope 3	6,594,139	8,440,498	21.50%
Total	**25,048,048**	**39,219,712**	**100.00%**
Natural sequestration capacity of PMR	779,830	1,569,840	
Emissions Gap to be offset	**24,268,218**	**37,649,872**	

Table 1: This table summarizes the current emissions in PMR from Scope 1,2 and 3, and estimated for the year 2030.

(Source: http://eecc.puneinternationalcentre.org/wp-content/uploads/2023/01/GFinal-PMR-Report-with-Cover.pdf)

The total carbon emissions of PMR per year (calculated in carbon dioxide equivalent tonnes) are approximately 25 million tonnes. These emissions are projected to be approximately 39.2 million tonnes by the year 2030.

The current capacity of PMR to sequester carbon through natural processes (Natural Carbon sequestration) is just approximately 7.8 lakh tonnes per year. This capacity is projected to increase to 15.7 lakh tonnes per year, by 2030. This estimate is prepared assuming that the current urban forests and pieces of natural vegetation and water bodies in PMR will still be present in 2030.

Hence, we can see that the main challenge is to reduce and offset the 24.3 million tons of CO2 eq. emissions today and 37.6 million tons CO2 eq. by 2030 or later, within the PMR.

3. Current Natural Carbon Sequestration Capacity and Identification of Potential Carbon Sinks and Sequestration Strategies for PMR

To strategise the plan for making PMR net carbon neutral, we first need to assess the current natural carbon sequestration potential of PMR, and the status quo of its carbon sinks. Only then can we effectively map the need for increasing the sequestration (natural and artificial) and make policies to aid the same.

3.1 Methods of Assessing Carbon Sequestration Potential

Assessing carbon sequestration potential involves various methods and techniques to quantify the amount of carbon that can be captured and stored in different ecosystems. Here are some common methods used to assess carbon sequestration potential:

1. **Forest Inventory and Monitoring:** India has diverse forest ecosystems, and conducting regular forest inventories is essential to assess the carbon sequestration potential. Periodic forest inventories involve a systematic collection of data on tree species, age, size, and health to estimate the carbon sequestration capacity of forests. The Forest Survey of India (FSI) conducts periodic forest inventories across the country. As of the last inventory in 2019, India's total forest cover was approximately 21.67% of the country's geographical area, and the total carbon stock in forests was estimated to be around 7,124 million tons.

2. **Biomass and Soil Sampling:** One of the fundamental approaches is to measure the biomass (aboveground and belowground) and soil organic carbon content in the ecosystem. This involves taking representative samples from different vegetation types and soil layers to estimate the total carbon stocks. Soil carbon sampling in agricultural fields in Punjab, known as India's "breadbasket," revealed that adopting conservation agriculture practices like zero-tillage and cover cropping could increase soil carbon sequestration by up to 0.5 tons per hectare annually.

3. **Remote Sensing and GIS:** Given India's vast geographical area, remote sensing technologies like satellite imagery and aerial surveys play a crucial role in monitoring land use changes, forest cover, and vegetation density. Geographical Information Systems (GIS) are employed to analyse and interpret the spatial data, allowing for a comprehensive assessment of carbon sequestration potential at a landscape level. In the state of Karnataka, remote sensing and GIS technologies were used to monitor the Western Ghats region's forest cover. The study revealed that the region had significant carbon sequestration potential, and conservation efforts could help capture and store approximately 500,000 tons of carbon annually.

4. **Allometric Equations:** Allometric equations relate easily measurable parameters like tree height, diameter, and species to biomass, allowing for quick estimates of carbon content in forests. Researchers in the Western Himalayan region developed species-specific allometric equations to estimate carbon stocks in different types of forests. Using these equations, they found that the oak forests in the region sequestered an average of 150 tons of carbon per hectare.

5. Eddy Covariance: This method measures the exchange of carbon dioxide between the

atmosphere and ecosystems directly. Eddy covariance towers equipped with gas analysers and meteorological instruments collect continuous data on carbon fluxes. In India, Eddy covariance towers have been set up in regions like the Western Himalayas, Sundarbans and the Indo-Gangetic Plains to measure CO2 fluxes from these ecosystems. These studies help assess the carbon sequestration potential of grasslands under different land management practices, such as rotational grazing or no-till farming. Eddy covariance measurements have also been conducted in urban green spaces, such as parks and urban forests, in cities like Delhi and Bengaluru.

6. **Modelling and Simulation:** Ecosystem models, such as the Eddy Covariance model, Biome-BGC, or CENTURY, use data inputs like climate, soil, vegetation, and land use to simulate carbon sequestration rates over time.

Using a combination of these methods, we can get a comprehensive understanding of the carbon sequestration potential of the following ecosystems, which is crucial for designing effective climate change mitigation and carbon offset strategies.

a. Urban Green Spaces

Urban green spaces, including parks, gardens, urban forests, and street trees, have the potential to sequester carbon and contribute to mitigating the carbon footprint of cities. These artificially curated spaces play a huge role in sequestering carbon, especially in tier 1 metropolitans like PMR. Urban green infrastructure includes all the natural, semi-natural and artificial networks of ecological systems in urban and peri-urban areas, such as forests, parks, community gardens, private yards and street trees.[4]

The carbon sink potential of green spaces is highly dependent on critical factors, particularly weather conditions and land management.[5] Although one cannot control weather, the sequestration capacity can be increased by maintenance practices such as fertilisation regime and management strategies.[6]

The parks/reserves maintained by PMC spread over 65 gardens covering an area of 317.25 acres. Only the gardens having a size of one acre and above have been considered.

[4]Tzoulas et al., 2007; Gómez-Baggethun and Barton, 2013; Lähde and Di Marino, 2019

[5](Luyssaert et al., 2007; Mudge et al., 2011; Smith, 2014)

[6]Guo and Gong, 2017

A few examples of the urban green spaces and parks managed by the Pune Municipal Corporation are:

1. Pu La Deshpande Garden (Okayama Friendship Garden)
2. Saras Baug
3. Empress Garden
4. Kamala Nehru Park
5. Rajiv Gandhi Zoological Park (Katraj Zoo)

The total amount of carbon sequestered by 2022 (historically) is about 7,27,291.785 Tonnes (~727 Kilo-Tonnes) while the total amount of carbon sequestered (annually) is 73,824 Tonnes /year.[7] The findings are based on the carbon pool above ground, belowground, litter biomass and dead wood, and soil organic carbon.

Recommendations:

- There is a dire need to document urban green spaces in the PMR and update the data periodically. The storage potential in India is poorly defined with only a few broad assessments completed.
- The litter and dead wood biomass can be managed carefully from a viewpoint to increase the soil carbon content. It should not be burnt away; instead, it must be used as a source of increasing carbon content in soil. Further study is required to determine what would be good management and design strategies to build more efficient Urban spaces in Pune.
- Green Campuses and organisations should create or preserve native vegetation.
- Strategies must be implemented for smart and efficient management of the already existing urban green spaces.
- Efforts should be made to plan and develop urban green spaces in the city. This can be done in collaboration with the Garden department and the Urban planning department. The mapping of potential spaces to be converted into Urban green spaces should be tailor-made for PMR, keeping in mind the natural water network of the city, its climate, soil properties and composition, natural vegetation, and the prevalent urban infrastructure.
- Preservation of urban green spaces should be included in the smart city agenda.
- Carbon accounting should be done for every Green space in PMR, and it should be periodically updated. A detailed method of carrying out a Life Cycle Assessment (LCA) of a green space has been given later in this report.

[7]Vijayalaxmi, R. &, Mahajan, D. (2021). Assessment of Carbon Sequestration Potential of Urban Green Spaces (PMC Gardens) in Pune City, India. 10.9734/bpi/magees/v7/2691E. (Available at https://www.researchgate.net/publication/356775537_Assessment_of_Carbon_Sequestration_Potential_of_Urban_Green_Spaces_PMC_Gardens_in_Pune_City_India)

International case studies:

- A study by the Toronto Environmental Office revealed that Toronto's urban forest, which includes parks and street trees, sequesters approximately 1.1 million metric tons of carbon dioxide equivalent per year.
- In Bogotá, a study conducted by the Humane Society International found that the city's urban trees sequestered around 99,000 metric tons of carbon dioxide annually.

b. Hills

Carbon sequestration capacity of hills in Pune:

The natural vegetation and soil mass on the hills play a huge role in carbon sequestration. In the Pune Municipal Region (PMR), currently, we have 10 major hills:

1. ARAI
2. Baner
3. Bhopdev Ghat
4. Chaturshringi
5. Fergusson College
6. Kothrud hill
7. Sutarwadi
8. University
9. Vetal-Parvati.

These hills occupy over 1245 hectares of area (5.10% of the total area of PMR). The carbon pools for which the stocks are to be estimated were: above-ground biomass, below-ground biomass, litter and dead wood biomass and soil organic carbon.

The total amount of carbon sequestered by hills (historically) is 212,89,05,681 Tonnes. (~2129 million Tonnes) while the total amount of carbon sequestered (annually) is 10,132,013.5 t/year. (~10 million Tonnes/year).[8]

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[8] Vijayalaxmi, Shinde &, Mahajan, D. (2021). Carbon Sequestration Potential of Hills (Studied) Around Pune City, Pune. Applied Ecology and Environmental Sciences. 9. 450-457. 10.12691/aees-9-4-4. (Available at https://www.researchgate.net/publication/350786412_Carbon_Sequestration_Potential_of_Hills_Studied_Around_Pune_City_Pune)

The type of vegetation and its density in the hills directly impact carbon sequestration. Older and larger trees generally store more carbon than younger ones, so the age and size distribution of trees in the hills are crucial factors. Along with this, altitude, topography, climate conditions, as well as elevation gradient affect the capacity.

Recommendations:

- Policies should be made to protect the existing hills within PMR.
- Hill slopes owned by the Government within Growth Centres should be reserved as Wilderness Areas and Biodiversity Parks. Wild plantations can be undertaken here. Keeping the area under 'benign neglect' will allow forests to regenerate at their own pace.
- The western part of PMR, having mountains and hill slopes, has high species diversity and high endemism. There is a movement of many fauna from here to areas of water and food. Passages for the movement of wildlife are recommended to be reserved. The streams and nalas marked have good vegetation cover. These longitudinal paths are relatively far from settlements, connecting the ridges to the water areas.

In a recent case making headlines in Pune, the Vetal tekdi, a very prominent hill situated in the western region of PMR, faced the threat of being destroyed. This destruction was to be caused by the PMC's traffic plan that includes the Balbharati Paud Phata Road-surface road on Law College tekdi slope, HCMTR-elevated road on Law College tekdi slope and two tunnels with exits at Sutardhara, Panchavati and Gokhalenagar. If successful, this project would have destroyed the green cover on the hill, leading to a massive reduction in the carbon sequestration capacity of this space. Being one of the major hills in PMR, the destruction of Vetal hill would have been a severe blow to the natural sequestration capacity of PMR. Instances like this are a warning signal for preserving the last remaining hills and biodiversity hotspots in PMR.

c. Water Bodies

The freshwater bodies of PMR also play a significant role in sequestering carbon. But research has not yet been done on the carbon sequestration capacity of the freshwater bodies in the PMR region, which remains a lacuna. It's important to note that the carbon sequestration capacity of freshwater bodies can vary based on several factors, including the size of the water body, the surrounding land use, nutrient inputs, water flow, and seasonal variations. Detailed studies and measurements are necessary to determine the specific carbon sequestration capacity of freshwater bodies in Pune.

To calculate the sequestration done by water bodies, we first need to identify the water-atmosphere interfaces that exist within the PMR region, and calculate their total surface area.

These interfaces include the areas of freshwater lakes, rivers and reservoirs, artificial tanks, nalas and various other permanent or seasonal water bodies. It is important to distinguish between different types of surface water bodies in a region on the finest scale possible, as different types of water bodies can have vastly different emission or sequestration potential.

Recommendations:

- The current capacity of the water bodies in PMR to sequester carbon has not been studied. We need thorough research and documentation on this.
- PMR has 10 major rivers originating in the Sahyadri. This is part of the upper Bhima basin and the Krishna Basin. There is a great potential for creating carbon sinks along river banks and reducing bank erosion in extreme rainfall events (high intensity, high frequency, short duration).
- It is imperative to preserve the first and second-order streams and the stream vegetation along their banks. Those that are barren can be used for plantation. Plant growth along the streams is relatively faster since soil moisture can be higher.
- Efforts need to be taken to rejuvenate the water bodies appearing in the revenue records and Land Use Map.
- No construction should be allowed within 100 m from high flood lines of natural wetlands and rivers. (As prescribed in the Unified Development Control and Promotion Regulations for Maharashtra enacted in 2022)
- Efforts should be taken to clean and restore the nalas forming a dense network within the city.

d. Forest Cover

The Global Forest Watch data reveals that 29% of the carbon stored in trees across the world is concentrated within Intact Forest Landscapes. Those in the tropics like peninsular India account for 23% of the world's tree-stored carbon, despite making up just 13% of the world's total forest area. Secondly, 11% of all GHG emissions (comparable to the emissions from all of the cars and trucks on the planet) are caused by deforestation. To reach the Paris Agreement goal of reducing economy-wide emissions, countries around the world must manage forests better, and especially Intact Forest Landscapes, to both reduce emissions and increase global sinks.

On an average, carbon sequestration potential for forest per hectare is 8.44 TCO eq.[9] It is estimated that total carbon stored by the urban trees is 23.8 million tonnes from an estimated 7.79 million ha urban area, i.e. 3.01 tonnes of carbon/ha. Urban forests contribute only 2.21% of the carbon stock against 17.11 tons carbon/ha from overall forest and tree cover.

In a study conducted by Bernal et al[10], the researchers found that planted forests and woodlots have the highest CO2 removal rates, ranging from 4.5 to 40.7 T CO2 per hectare per year, during the first 20 years of growth. Importance of forested areas in carbon sequestration is already accepted, and well documented; however, not many attempts have been made to address the potential of trees in carbon sequestration in urban scenarios.

Attempts have been made to study the potential of trees in carbon sequestration from urban areas in Pune, India[11]. At present, the forest cover in the PMR (Pune Metropolitan Region) area is merely 13.4%.[12] Therefore, it is of utmost importance to avoid further degradation to safeguard the environment's well-being. Preserving these existing forest patches is vital as they can serve as seed banks for restoring nearby areas and contribute to maintaining biodiversity.

[9] Mallik A, et.al. (2020). Making PMR Carbon Neutral by 2030 – A Policy Roadmap. PIC.

[10] (https://cbmjournal.biomedcentral.com/articles/10.1186/s13021-018-0110-8)

[11] (Warran, A., Patwardhan, A. (2005); and Aurangabad, Maharashtra, India, by Chavan, B.S, and Rasal, 2010).

[12] (Page 222, PMRDA Draft DP Vol. 1.)

The following table shows the land use in Pune district.

#	Taluka	Taluka area Sq.km	Land falling in PMR	Taluka area in PMR	Forest land in PMR	Barren land in PMR	Built-up land in PMR	Trees and groves in PMR	Farmland in PMR
1	Pune city	120.44	100%	120.44	2.36	6.73	96.49	-	0.05
2	Haveli	1,337.39	100%	1,337.39	78.77	148.18	40.92	-	926.14
3	Mulshi	1,040.19	100%	1,040.19	167.37	110.88	66.05	-	443.85
4	Maval	1,132.48	100%	1,132.48	327.74	11.55	67.84	9.40	689.91
5	Shirur	1,559.51	73%	1,138.44	44.06	66.03	48.95	11.50	959.48
6	Khed	1,374.93	70%	962.45	140.71	52.74	13.96	6.45	736.85
7	Bhor	893.16	43%	384.06	52.77	67.33	7.45	0.15	207.12
8	Daund	1,292.03	41%	529.73	20.13	49.53	29.88	7.20	474.22
9	Velha	500.54	40%	200.22	43.27	11.79	7.71	-	95.72
10	Purandhar	1,104.33	37%	408.60	8.21	20.63	9.77	3.88	330.03
11	Junnar	1,385.88	0%	-	-	-	-	-	-
12	Ambegaon	1,044.89	0%	-	-	-	-	-	-
13	Baramati	1,384.32	0%	-	-	-	-	-	-
14	Indapur	1,470.35	0%	-	-	-	-	-	-
	Total	**15,640.44**		**7,254.01**	**885.39**	**545.41**	**389.01**	**38.59**	**4,863.37**

From this data, it is clear that there is a forest cover of 885.39 sq. km and a possibility to undertake afforestation programmes in at least 545.41 sq.km. This possibility needs to be evaluated by competent authorities and assessed for a cost-benefit analysis.

The carbon sequestration potential of tree cover (forest area) in PMR is given in the following table.

Table 3: Carbon Sequestration Potential of Tree Cover in PMR

Description	Units	Value
PMR Total Area	sq. km	7,256.46
PMR Forest Area	sq. km	885.39
PMR Trees and grooves	sq. km	38.59
Total	sq. km	923.97
Carbon Sequestration Potential	TCO_2 / sq. km / year	844
PMR C. sequestration Potential	TCO_2 / year	779,833.56

(MoEFCC- https://pib.gov.in/Pressreleaseshare.aspx?PRID=1629587)

The total area occupied by tree cover is around 924 sq km in PMR, and the total carbon sequestration potential of this tree cover is estimated to be around 7.8 lakh tonnes CO2/yr.

Mr. Javadekar at a press update highlighted the importance of developing and managing urban forests in Pune. Development of Urban Forests will contribute to India's decision to sequester 2.5 to 3 billion tonnes of carbon dioxide equivalent in the country's forest.

Case Study: Warje City Forest

Warje City Forest in Pune is the best example of Private-Public Partnership for developing urban forests and can act as a model for building urban forests under MoEFCC's Nagar Van scheme in 200 cities across the country. This forest has been developed over about 22 hectares of forest land amounting to about 9000 acres. It bears 6,500 trees as on date and about a thousand people visit the place every day. The project also helps in absorbing approximately 129,000 Kg carbon-dioxide and producing about 5,62,000 Kg oxygen per year.

Assistance under CAMPA Fund is pledged to be provided for this initiative. Warje Urban Forest in Pune can become a role model for the country in implementation of the Nagar Van scheme.

The project ‘Urban Forest’ was started by the Ministry of Environment, Forests and Climate Control (MoEFCC) with assistance from the Forest Department, Government of Maharashtra. This is the beginning of creating 200 forests under the Nagar Van scheme, within the next couple of years.[13] Thus, there is ample scope to increase the contribution of urban forests to overall carbon stocks.[14]

International Case Studies

According to research conducted in the USA, urban trees sequester approximately 700 million tonnes of carbon, with a gross carbon sequestration rate of 22.8 million tC/yr.[15]

Recommendations

Throughout the ages, forests have amassed substantial carbon stocks, and it is imperative that our climate mitigation endeavors adopt a similarly long-term perspective when safeguarding them.

- There is a need for Municipal corporations to map forest and degraded land in cities and to reserve them for development of urban forests, making it a people’s movement. Areas like Warje around Pune should be identified where similar projects can be conducted.
- The government should ensure 100% preservation of forest lands and where degraded forests are observed, an optimal restoration programme is recommended.
- Diversion of forest land for non-forest purposes from critical and ecologically fragile wildlife habitat, should be prohibited.
- Efforts to increase the forest cover and conserve existing forests, including ‘sacred groves/ Devrai’ forests as per National Conservation Strategy and Policy Statement on Environment and Development, National Forest Policy, Indian Forests Act and National Environmental Policy by Ministry of Environment and Forest, GOI, should be promoted.
- We recommend keeping forests within Growth Centres open for passive recreation. These act as ‘Green Lungs’.
- Ecological restoration projects should be undertaken in barren/degraded areas. Trees have a symbiotic relationship with other organisms in an ecosystem, and this bestows the net primary productivity to the landscape. Therefore, ecological restoration is important for enhancing the carbon sequestration capacity.

[13] https://www.pib.gov.in/PressReleseDetailm.aspx?PRID=1629568 Press release. 5 June 2020.

[14] (National Mission for a Green India - document, 2009)

[15] (Nowak & Crane, 2002: Nowak, D. J., & Crane, D. E. (2002). Carbon storage and sequestration by urban trees in the USA. Environmental Pollution, 116(3), 381-389).

- If additional land is reserved across the migration corridors, watersheds and hilltops and hillslopes in PMR jurisdiction, the sequestration also will be triple of the current potential. Pune will hence be the first Indian city to lead by example in biodiversity Planning.
- To reduce Emission Gap, PMR may also take stewardship to protect Western Ghats and watersheds outside its jurisdiction after reaching the ideal percentage of 33% or more forest cover within PMR.
- Plantation and afforestation programmes can bolster the natural sequestration capacity of a landscape.

e. Residential Greenery

Residential yards are an important part of urban green, and an increasing amount of studies highlight the importance of private residential greenery in the carbon sequestration potential of an urban region.

Limited tools are available to effectively guide the planning process for private infrastructure and ensure the quality of green infrastructure in courtyards. Although some widely recognised sustainability standards like LEED, BREEAM, and DGNB systems include criteria for green infrastructure and landscape, their adoption is only partially obligatory, and they tend to focus on specific aspects.[16]

However, one tool specifically designed to address green infrastructure elements in courtyards is the green factor. Green factor serves as both a planning tool and a sustainability metric, and aims to enhance the quantity and quality of green elements on private properties. This tool has been successfully implemented in various cities, including Finland, Sweden, Norway, Germany, and the USA, with many other cities planning to adopt it in the near future.

But these tools are not available in PMR.

A recent study gave guidelines on how CS by residential yards can be increased. The findings highlight that the potential can be significantly enhanced by three measures:[17]
(1) increasing the number of trees
(2) selecting tree species with a high ability to sequester carbon and to grow large on the spots
(3) maximising the vegetated areas in the yards
(4) adding biochar in the planting beds

[16] (Pedro et al., 2019)

[17] (https://www.sciencedirect.com/science/article/pii/S1618866720307561)

(5) focusing on the quality and quantity of the topsoil that functions as a productive growing medium for the plants.

The carbon sequestration capacity of urban green spaces is affected by the vegetation type and density, vegetation age, organic matter and the composition of the soil, land-use and management, urbanisation and development, and the water availability in the region. It can also be impacted by the urban heat island effect, and the infrastructure surrounding it.

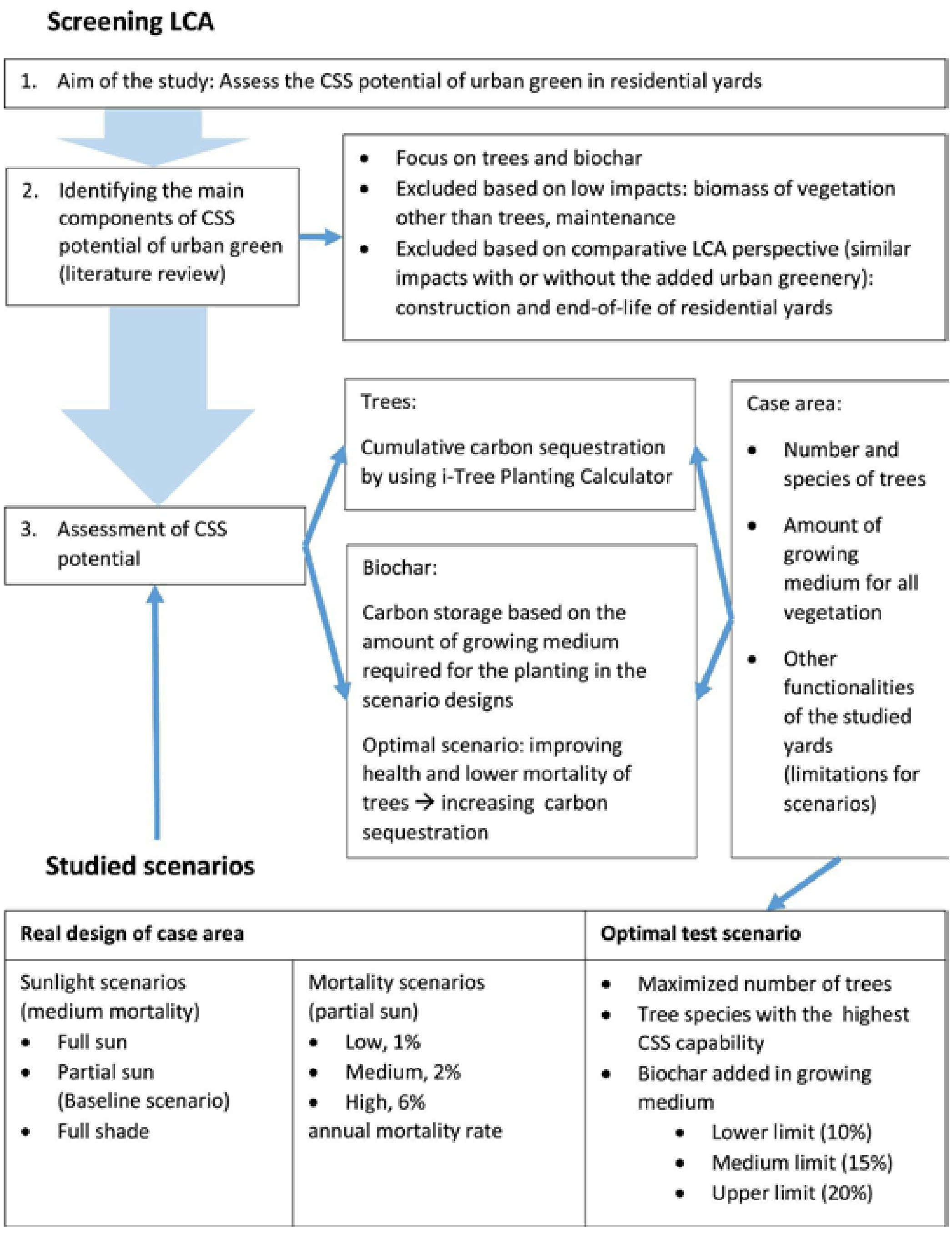
The capacity of an urban green space in the residential setting can be estimated by doing the life-cycle assessment of the area.

Conducting a Life Cycle Assessment (LCA): To assess the carbon sequestration potential of residential green spaces

A simple screening LCA (Life Cycle Assessment) can be used to assess the carbon sequestration potential of the residential yards of the case area. During the screening of LCA, the primary processes responsible for environmental impacts throughout the product or service's life cycle are identified, followed by the estimation of these environmental impacts.

Research design prototype[18]

The following chart outlines the research design prototype used for conducting this research:



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[18] (https://www.sciencedirect.com/science/article/pii/S1618866720307561)

The software which was used in this project was the freely available 'i-Tree planting tool' created by the USDA Forest Service. However, i-Tree planting is currently only adjusted to the climate conditions of the US. For the research to be relevant and accurate, we need to make a PMR-centric software, which will be used to assess the amount of carbon (kg CO2) sequestered by the trees.

Recommendations

- Guidelines on how the carbon sequestration potential of residential yards can be increased, should be issued to private gardens and community spaces.
  For this planning, planning tools and sustainability metrics like 'Green Factor' can be used. These tools and metrics help urban planners, policymakers, and stakeholders make informed decisions to maximise green infrastructure and carbon sequestration potential. Examples of these metrics include: Green Factor, LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method), SITES (Sustainable SITES Initiative), City Forest Credits (CFC), etc.
  Integrating these planning tools and sustainability metrics into urban development policies and strategies can lead to more climate-resilient and sustainable cities with enhanced carbon sequestration potential and reduced environmental impacts.
- Softwares like iTree which are specifically made for PMR should be created to be used for the LCA.

f. Urban Soil

The role of soil in urban carbon sequestration is usually overlooked and understated. Research on the carbon sequestration of urban trees usually excludes the carbon storage of urban soils. Only a few studies on urban soil carbon dynamics have been published and data on urban soil carbon is scanty.[19] However, soil has a significant impact on the carbon footprint of the city: Churkina et al. (2010) demonstrated that 64 % of the carbon storage in the human settlements is attributed to soil, 20 % to vegetation, 11 % to landfills and 5% to buildings. Moreover, soils in urban parks and lawns can store large amounts of carbon, which could highly exceed the amount stored in native grasslands, agricultural fields and boreal forests. In particular, long-term terrestrial carbon storage occurs in soils.[20] In order to efficiently mitigate climate change, carbon must remain stored for a much longer time than it can be stored in certain materials, for example, in wood material. Thus, as soil has a high capacity and potential for carbon storage, this needs to be addressed in the planning and design of urban green.[21]

[19] (Lorenz and Lal, 2015).

[20] (Lorenz and Lal, 2015)

[21] (https://www.sciencedirect.com/science/article/pii/S1618866720307561)

The soil carbon pool is an important component of home/corporate lawns, recreational/ sports grounds, forests and trees, and ornamental shrubs. The carbon sequestration capacity of soil is influenced by various factors like the organic content in the soil, the amount and composition of biochar, the composition of minerals, amount of water, the pollution and contamination, and the land-use and management.

Recommendations

The following chart gives the main strategies to enhance soil-based sinks in urban ecosystems. [22]

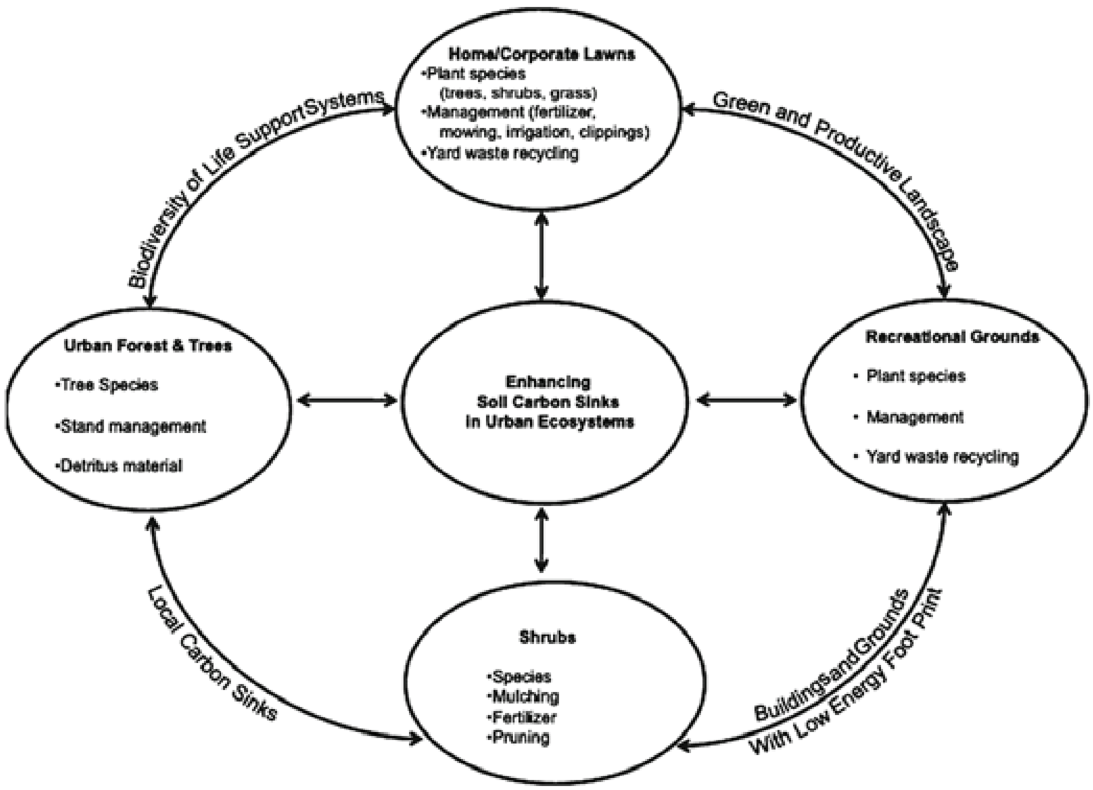


Fig. 1.5 Strategies to enhance soil-based sinks in urban ecosystems, the soil C pool is an important component of home/corporate lawns, recreational/sport grounds, forests and trees, and ornamental shrubs

[22] https://sci-hub.se/10.1007/978-94-007-2366-5 pg 13

The ecosystem carbon pool, both above-ground (biotic pool) and below-ground (pedologic pool) components, can be moderated through management. Judicious management (i.e., choice of species, fertiliser amount and rate, irrigation, mowing, pruning, mulching) is important to reducing the hidden carbon cost and increasing the net ecosystem carbon gains.

The capacity can be increased by adding biochar. At the city scale, it would be possible to collect the dead biomass generated by urban green and produce biochar from it, thus creating a circular system. The Stockholm Biochar Project provides a pioneering example of such a system in practice. For example, the city of Stockholm has started to use park and garden waste to produce biochar that is applied to urban growing media and structural soils for tree plantings.[23]

Case study: Stockholm Biochar Project

The Stockholm Biochar Project is an innovative initiative aimed at exploring the potential of biochar as a sustainable solution for carbon sequestration and soil enhancement. The project focused on producing biochar from organic waste materials.

Biochar is a form of charcoal produced through a process called pyrolysis, which involves heating biomass, such as agricultural residues, wood waste, or organic municipal waste, in the absence of oxygen. When biochar is incorporated into the soil, it provides a long-term storage solution for carbon and improves the soil's physical, chemical, and biological properties.

While the Project showed promising results, there were challenges related to scaling up the production of biochar and implementing it on a broader scale. Cost-effectiveness, availability of feedstock, and ensuring sustainable sourcing of biomass were some of the challenges faced during the project.

Potential for urban residential areas to sequester and store carbon

Improving the capacity of residential yards to sequester carbon requires the combined effort of urban planners, builders, real estate brokers, and residents. The capacity is affected by the urban structural metrics such as housing density, land use intensity and parcel land cover outside the housing footprint. [24]

[23] (City of Stockholm, 2016)

[24] (Klobucar, Östberg, Wiström & Jansson, 2021; Robinson et al., 2012; Smith, Gaston, Warren & Thompson, 2005).

Recommendations

Apart from improving the sequestering capacity of residential greenery as discussed above, the following actionables have been identified to increase the sequestering potential of urban infrastructure.

- Utilisation of green roof and wall technologies.
- Utilisation of biogenic construction material; for e.g., Norway spruce. The more wooden products are used in a building, the greater the carbon content of the structure and subsequently the resulting carbon storage. The growth rate for typical timber construction wood has been estimated at up to 100 years; it could take substantial time for the corresponding carbon stock gain to be realised in full.[25] In contrast, many of the other biogenic materials have much shorter growth cycles and they can be utilised to increase the residential carbon stock in a more rapid fashion.[26] Hence, the fast growth rate materials should be utilised for the short-term, high-intensity accumulation of a residential carbon pool, whereas timber construction is best implemented as a long-term solution with careful policy planning.
- Utilisation of building materials with embedded carbon storage.[27] The sequestration potential can be increased by the utilisation of construction materials with embedded carbon storage.
- Accounting for entire building life cycles and essentially zero carbon escape from the materials. [28]
- Building 'Green roofs' that may exhibit vegetation sequestration rates comparable to private gardens and yards. [29]

Churkina et al. (2020) demonstrated that increasing wood-based construction globally could increase urban carbon storage levels by 170%.

Both concrete efforts from urban planners and policy-makers as well as more subtle social and preferential changes from individual consumers are needed to implement the full potential of private residential carbon-sequestration.

[25] (Gustavsson, Pingoud & Sathre, 2006; Perez-Garcia et al., 2005)

[26] (Gu, Zhou, Mei, Zhou & Xu 2019; Pittau et al., 2019; Sodagar, Rai, Jones, Wilhan & Fieldson, 2010).

[27] (Kuittinen et al., 2021; Pittau, Lumia, Heeren, Iannaccone & Habert, 2019)

[28] (Amiri et al., 2020; Kalt, 2018)

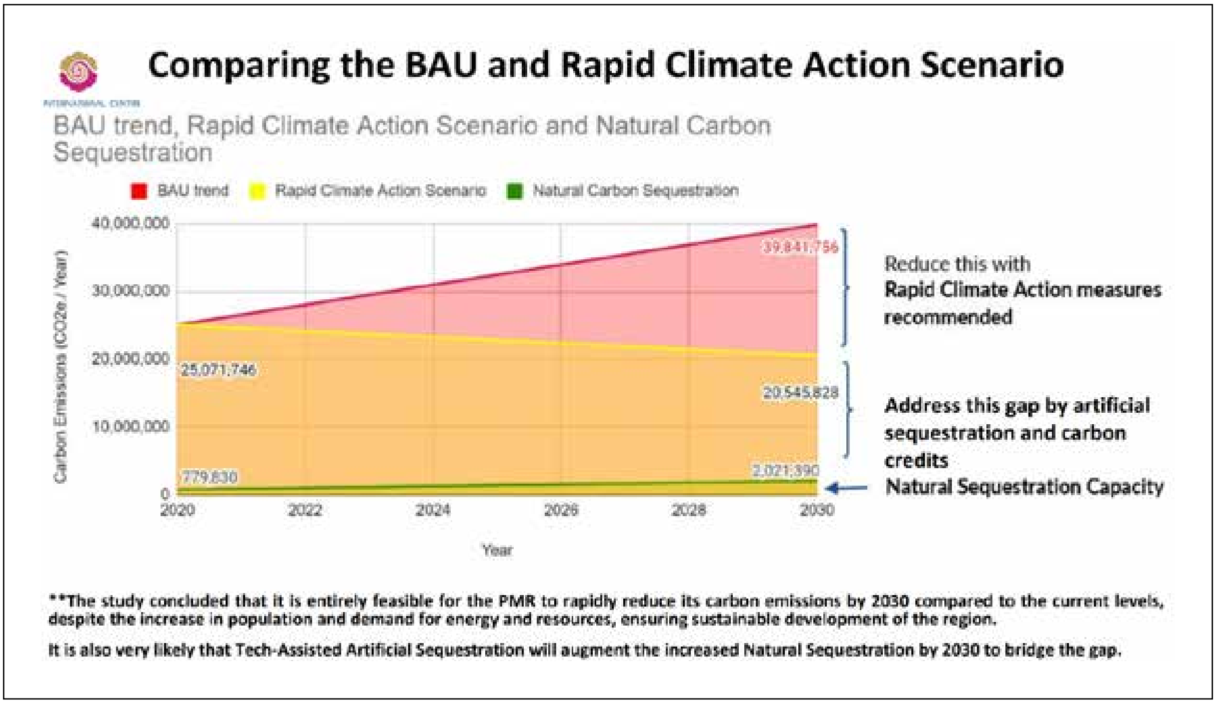
[29] (Cascone, Catania, Gagliano & Sciuto, 2018; Sultana, Ahmed, Hossain & Begum, 2021)

The current annual carbon sequestration capacity of the PMR is 779,830 TCO2/Year

To analyse the efficiency of these natural processes of sequestering carbon, we need to weigh this amount in relation to the amount of carbon emitted in the atmosphere per year.

The following graph shows the emission trend in the Business as usual (BAU) scenario. The red line shows the emissions in the bau scenario if no mitigation/adaptation efforts are taken. These emissions are projected to contribute to approximately 400 lakh CO2 eq/yr by 2030. The yellow line shows the reduced emissions if Climate Action is implemented. According to the estimates, this will reduce the emissions to 200 lakh CO2eq/yr by 2030. The natural sequestration capacity will be 205 lakh CO2 eq/yr by 2030. This is considering the fact that the current natural reserves (hills, urban green spaces, and forests) will be protected and preserved from degradation.

Still, this leaves us with an emission gap of 185 lakh CO2 eq/yr by 2030. Unless we increase our natural sequestration capacity ten-fold, which seems impossible given the current trends, this gap needs to be bridged by using tech-assisted carbon sequestration.



In 2018, the total carbon emissions in PMR were 26,063,000 Tonnes. Clearly, the amount of carbon emitted is far more than the capacity for natural sequestration. The gap is expected to increase multifold by 2030, due to a steep rise in emissions. Hence even if this newly added carbon is considered, we are not factoring in the carbon which has already been emitted and is already there in the atmosphere.

The study concluded that it is entirely feasible for the PMR to go carbon neutral in the near decades, and Carbon Sequestration plays a major role in this. The report also states that this vision of 'Carbon-neutral PMR' will be achieved only if Tech-assisted Artificial Sequestration is used to augment the increased National Sequestration by 2030 to bridge the gap.

4. Technology-Assisted Carbon Sequestration Potential of PMR

In the foreseeable future, certain industries like iron and steel, cement, and aviation fuels will continue to rely on high energy density fossil fuels, even though efforts to replace them with renewable energy sources are ongoing. The complete substitution of fossil fuels with renewables in these sectors is challenging due to factors like grid stability, meeting peak energy demands, and the limitations of current energy storage technologies. Consequently, despite efforts to reduce their usage, fossil fuels will still be employed, albeit to a lesser extent. Therefore, it is essential to acknowledge that emissions from fossil fuel usage cannot be entirely eliminated, and renewable energy options alone cannot entirely replace fossil fuels in all applications. Hence, it is crucial to develop parallel strategies for mitigating the carbon emissions resulting from the continued use of fossil fuels in the near future.

Carbon Capture Utilisation and Storage (CCUS) is the solution that can address this problem of actively reducing the carbon already present in the atmosphere, by capturing it, storing it, or utilising it for producing chemicals, fuels, etc.

To keep the global temperature rising below 2°C by 2050, capturing and storing 19% of CO2 emissions is necessary. Without CCUS, the overall cost of CO2 reduction will increase by 70% by 2050. Thus, regardless of the deployment of clean and efficient energy solutions, CCUS technologies must be adopted.[30]

[30] (Environmental, Social & Governance (ESG) risk briefing. (2022). CCUS Technologies - Can they mitigate climate change?. https://www.agcs.allianz.com/news-and-insights/expert-risk-articles/ccustechnologies.html)

Recommendations for tech-assisted carbon sequestration in PMR

We considered various CCUS technologies and approaches, and evaluated which ones to deploy in PMR. When evaluating technologies, we looked at various parameters like:

- Technology readiness level (TRL) of PMR
- Capital requirement for setting up such a facility
- Breakeven cost of capturing or utilising CO2?
- Potential impact on achieving carbon neutrality
- Potential for deploying such technologies in the PMR region
- Commercial viability
- Time-frame of deployment [is it short term (1-4 years), medium term (5-8 years), long term (9+ years)]

Recommendations for deployment of various CCUS initiatives in PMR are as follows: (The table is based on the report prepared for PIC by NCl.)

(short-term refers to 1-3 years; medium-term to 4-7 years, long-term to 8+years)

Capture	What is it	Pros	Cons	Expected timeline for deployment in PMR
Fermentation, bioenergy	To capture the CO2 produced during fermentation process (in various industries), and also while using biomass for energy generation	There are many industries in PMR which can deploy these technologies, and integrated, could result in additional revenue from the sale of CO2 (or from tax credits)	It is decentralized; hence solutions have to adapted at this scale; Upfront investment for these processes may not be borne by these industries (which are low margin operations)	Short-term
Waste Combustion	Capturing CO2 emitted during disposal of solid waste (both wet and dry).	Could integrate existing waste management systems to create a robust, sustainable waste management strategy; the captured CO2 could be traded when carbon tax credits are operational	It is decentralized; hence solutions have to adapted at this scale; Upfront investment is high	Short-term
Internal Combustion Engines	Capturing CO2 emitted in internal combustion engines	PMR has a large vehicular count and this method would make a large impact	Low TRL, upfront costs have to be borne by the industry, and also this method has to be evaluated against the alternate fuel-based technologies (like fuel cells) for efficiency and impact	Medium-term
Direct Air Capture (DAC)	Capturing CO2 in the atmospheric air and separating the CO2 from other gases to produce a concentrated stream of CO2	Is not location specific—these plants can be theoretically set-up anywhere, with the only constraint being the availability of abundant renewable energy source.	Is capital intensive to set-up; the process is also very energy intensive;	Long-term
Utilization				
Methanol, DME, Polymers	Utilizing CO2 to make fuels and chemicals like polymers (polyols), methanol and DME	Many of these technologies are at an advanced TRL, with local partners available. Polyols from CO2 is commercially viable today, and hence no	The overall impact this would make on the CO2 reduction is moderate to low. Also, in the case of fuels, CO2 is emitted back into the atmosphere	Short-term

		special incentives are required.	within weeks. Breakeven cost for methanol and DME from CO2 is high.	
Methane, Fischer–Tropsch fuels	To produce methane and hydrocarbon based fuels from CO2	These are high energy density fuels, that have a ready application. Also, utilizing CO2 also reduced the dependence on fossil fuels.	The process for producing such chemicals from CO2 is energy intensive, and hence also costly. If affordable renewable energy sources become available, these methods can be adopted widely.	Medium-term
Microalgae	Utilizing microalgae to produce fuels or other high value chemicals (carbohydrates, proteins)	Carbon content in microalgal biomass is much higher (45-50%) when compared to the biomass;	High water requirement, and also other effects like emissions from open ponds etc., need to be studied, risks mitigated	Medium-term
Cement Curing, Aggregates	Utilizing CO2 in curing of concrete and in mineralization of aggregates (construction and industrial waste)	This is a commercially viable solution even today, with many technologies at commercial scale. The utilized CO2 remains locked in for hundreds of years.	Most solutions look at making concrete blocks. More work needs to be done to deploy it at construction sites for non-standard formations.	Short-term
BECCS	Growing biomass (energy crops) to sequester CO2 and further transforming the biomass to yield an energy product, with the resulting CO2 emission captured and stored.	If utilized for generating electricity this results in negative emissions, and if used for producing biofuels, results in carbon neutrality.	The breakeven cost for capturing and utilizing CO2 is high, hence it not commercially viable without additional incentives. TRL has to be increased through further development.	Medium-term
Enhanced Weathering	Silicate or basalt rocks are crushed (to increase surface area) and spread over land and oceans to	Potential to sequester CO2 for long durations, while also increasing soil fertility and agricultural productivity.	High cost of deployment, low TRL level; benefits on agricultural productivity has to be proven beyond doubt.	Medium-term

	increase mineralization, and use as fertilizers or agrochemicals.			
Forestry	Managed forests, where trees are planted, maintained and harvested for wood after 30-40 years, and other such efforts.	Large potential for sequestering CO_2; commercially viable even today.		Short-term
Land Management	Adopting practices in agriculture, forestry and other lands to increase the CO_2 content in the soil, and hence aiding CO_2 utilization	Large potential for sequestering CO_2; commercially viable even today.	Various efforts have to be systematically studied for their impact on crop productivity, etc.	Short-term
Biochar	Production of carbon rich material by pyrolysis (high temperature process, in the absence of oxygen) of biomass	Potential for moderate impact in achieving carbon neutrality.	Validity of claims in aiding crop productivity needs to be verified; TRL is low	Medium-term
Sequestration				
Basalt (In-situ)	PMR has rich deposits of basalt rocks underground—after sufficient study and identification of suitable sites, CO_2 can be sequestered (through mineralization) in basalt rock formations	Potential to store large volumes of CO_2 in PMR, particularly with large deposits of basalt rocks in PMR; Once mineralized, it locks CO_2 for over 100,000 years	Very capital intensive process to set-up; Since no point source emitters of CO_2 are there in PMR, also have to account for transpiration of large volumes of CO_2 through pipelines.	Medium to long term

Basalt (ex-situ)	To mine basalt rocks in PMR, make them undergo accelerated mineralization though chemical/electro chemical interventions, and utilize the products for construction and other purposes	Potential to store large volumes of CO2 for a long duration; If the process details are mapped out, it could result in a commercially sustainable operation, without too many incentives	Very capital-intensive process to set-up; Requires lot more study to operationalize	Medium-term

5. Policy Recommendations

Seeing the rate at which the green cover is vanishing, and our water bodies are being polluted and converted into sewage dumps, it's not wrong to say that the current efforts are not going to be enough. Hence the policies and planning for carbon-neutral cities, countries and regions, including PMR, should include measures to prevent loss of green areas, and nature-based solutions to increase carbon sink resilience and capacity. Several scholars have discussed the possibility of increasing the carbon sequestration of urban vegetation through policy initiatives[31] or careful planning.[32]

The broad overarching agenda is to:
"Ensure major increase in natural CO2 sequestration capacity of PMR by 300 % by 2030 in calibrated steps"

Along with the actionables given to increase the potential in each sector, the following actionables have been identified.

[The policy agendas have been distinguished based on the time-lines into short (0-5 years), medium (5-10 years), and long term (20-50 years) goals]

[31] (Davies et al., 2011; Muñoz-Vallés et al., 2013)

[32] (Niemelä et al., 2010).

Short term (0-5yrs):

1. The current forest cover in PMR should be mapped. This can be done in collaboration with private NGOs, using softwares like GIS mapping, etc.
2. 35% area should be allotted to forests, urban forests, native plant gardens and open spaces in PMR Development Plan
3. 10% of existing Forest Cover should be restored by collaborating with 'ecological restoration' organisations. This will ensure that unregulated plantation doesn't take place which results in ultimately degrading the ecosystems.
4. Periodical monitoring of the regions which have been taken up for ecological restoration, should be done.
5. The existing tree cover and forest areas should be strictly protected.
6. Steps should be taken for inclusion of Green Lines with Riparian Zones for Rivers and Streams
7. Mechanisms should be established for plantation of 5000 trees per month for next 10 years on roads and building premises. These trees should be selected after consulting experts in the field.

Medium term (5-10yrs):

1. The area of green cover in PMR should be increased to 25% of the total area.
2. 50% of existing forest cover should be restored and all the areas should be monitored periodically.
3. Strict mapping, assessment, and monitoring of all preserved forest areas, hills, and urban green spaces should be carried out.

Long term (10-20yrs):

1. 20% of total PMR area should be protected as forests and an additional 15% as urban forests, urban wilderness, gardens and open spaces.
2. Ecological Restoration of all natural habitats should be carried out, with monitoring and least intervention.
3. Strict mapping and demarcation of all types of Forests and Water Bodies as Carbon Sinks should be done.
4. Dense network of Native Plants and Wilderness Patches should be included within the Urban Infrastructure blueprints.

Along with this,

1. A balanced approach is recommended towards environmental protection by strictly limiting environmentally damaging activities but also creating an enabling process by introducing activities such as Ecotourism and other environmentally sound developments to benefit the

locals and the economy.

2. Development of Ecotourism, Nature tourism and Adventure tourism should be promoted. The conservation, protection and restoration of forests, wildlife sanctuaries and the Western Ghats is a mandate of the following authorities: Ministry of Environment and Forests, GOI, and the State Forest Department.
3. A no-tolerance policy is recommended with respect to intervention and environmentally damaging activities such as mining and other polluting industries in environmentally sensitive and biodiversity-rich areas.
4. Technologically assisted carbon sequestration mechanisms should be deployed, referring to the report presented above. Capture technologies are currently employed widely at scale globally. Costs for employing these technologies are falling rapidly as new facilities come on stream while next generation technologies are unleashed. China is the first country in Asia to take up sequestration in saline aquifers and is carrying out research and modeling work on a large scale. More than 200 million Tonnes of CO2 has been captured and injected deep underground till November 2017![33]

Despite efforts to address climate change adaptation and mitigation through green infrastructure planning, the potential of urban carbon storage has received limited attention. As a result, further research is necessary to evaluate the carbon sequestration potential of urban green spaces, encompassing both vegetation and soil, as well as their interactions and various materials and production methods.

Urban planning strategies for maximising carbon sequestration potential

Maximising carbon sequestration potential in urban areas requires comprehensive and well-thought-out urban planning strategies. Steps should be taken to integrate carbon sequestration with the urban infrastructure development of PMR. The following actionables have been identified:

- Green Infrastructure Integration: We need to incorporate green infrastructure, such as green walls and permeable pavements, in the urban infrastructure strategies and tenders.
- Sustainable Land Use Planning: We need to adopt land use planning strategies which prioritise green spaces, reduce urban sprawl, and preserve natural areas.
- Brownfield Restoration: Brownfield areas are abandoned, idle, or underutilised industrial or commercial sites that may be contaminated or perceived to be contaminated. The government needs to identify and map brownfield areas in PMR. Then steps should be taken to transform brownfield sites into green spaces or reforestation areas, which will help convert previously degraded land into valuable carbon sinks.

[33] (Gupta, A. et al. (2019). Energy Procedia 160 (2019) 848–855)

- Carbon-Positive Building Design: We should encourage carbon-positive building design, which incorporates features like green roofs and living walls.
- Composting and Organic Waste Management: We need to implement efficient composting and organic waste management programmes that can reduce landfill emissions and contribute to soil carbon sequestration when used as soil amendments.

The integration of nature-based solutions in urban planning is crucial for building more resilient and sustainable cities for the future.

7. Opportunities for Collaboration and stakeholder Engagement for Effective Implementation

Although spearheaded and led primarily by the government, effective implementation of carbon sequestration projects requires collaboration and engagement with various stakeholders like industries, urban planners, builders, real estate brokers, scientists, and residents. By involving different actors, projects can benefit from diverse perspectives, resources, and support.

The fulfilling of the actionables mentioned above will be facilitated by collaborating with the following stakeholders.

Collaboration with

1. Industries: To explore potential funding opportunities, corporate social responsibility (CSR) collaborations, or carbon offset partnerships. Businesses may have incentives to support carbon sequestration projects to demonstrate environmental stewardship.
2. Research institutes: To aid the research and studies in tech-assisted CS and the potential of carbon sinks within PMR. The government can partner with research institutions and universities to gain access to scientific expertise and data that can inform project design and monitoring. Collaborative research can also help validate the effectiveness of carbon sequestration methods.
3. Garden department and private gardens: To provide material for biochar, and effectively manage the spaces for maximising the sequestration potential.
4. Builders: To implement the green infrastructure guidelines.
5. Software engineers: To make a software similar to iTree for PMR.
6. NGOs: To provide valuable insights, mobilise community support, and assist in project management.
7. Financial Institutions: To engage with banks, impact investors, and climate funds to secure financing for carbon sequestration projects. Financial institutions may be interested in funding projects with clear environmental and social benefits.

8. Media and Communication Channels: To utilise media and communication channels to raise awareness about the project's objectives, benefits, and progress. Effective communication can garner public support and attract potential partners.

8. Financing of Carbon Sequestration Projects/Initiatives

Financing of carbon sequestration projects and initiatives in India is primarily facilitated through various channels, including government schemes, international funding mechanisms, private investments, and corporate social responsibility (CSR) initiatives. Here are some examples and data on financing sources for carbon sequestration projects in India:

1. Government Schemes: The Government of India has launched several schemes and initiatives to support carbon sequestration projects. For instance, the National Afforestation Programme (NAP) aims to increase forest cover and enhance carbon sequestration. The Compensatory Afforestation Fund Management and Planning Authority (CAMPA) has been established to manage funds collected from diverting forest land for non-forest purposes and allocate them for afforestation and reforestation projects.

2. International Funding Mechanisms: India is eligible to access international climate finance mechanisms, such as the Green Climate Fund (GCF) and the Clean Development Mechanism (CDM). These mechanisms provide financial support for projects that contribute to climate change mitigation and carbon sequestration. The GCF has financed several projects in India, including afforestation and sustainable forest management initiatives.

3. Private Investments and Corporate Initiatives: Private investors and companies are increasingly recognising the importance of carbon sequestration projects in their sustainability strategies. Companies operating in India may also allocate funds through their CSR programmes to support environmental projects, including carbon sequestration efforts.

4. Voluntary Carbon Markets: Voluntary carbon markets offer individuals and organisations the opportunity to voluntarily offset their carbon emissions by purchasing carbon credits generated from carbon sequestration projects. Several projects in India, such as agroforestry and mangrove conservation, participate in these markets to generate revenue for their activities.

5. Research Grants and Foundations: Research institutions and non-governmental organisations (NGOs) often receive grants from national and international foundations to conduct research and implement carbon sequestration projects. These grants help support studies on innovative carbon sequestration techniques and their implementation in India.

The scale of financing can be significant, as India is committed to its climate goals and is actively working to increase carbon sequestration capacity. Examples of specific project financing may range from a few thousand dollars for community-led initiatives to several million dollars for large-scale afforestation and reforestation projects backed by international funding mechanisms or private investments.

9. Role of Carbon Neutrality Facilitation Cell (CNFC)

The Carbon Neutrality Facilitation Cell (CNFC) was proposed by the Pune International Centre to be set up in the Pune Municipal Corporation (PMC).

The Carbon Neutrality Facilitation Cell's primary objective is to officially ensure rapid decarbonisation of the Pune Metropolitan Region in accordance with interim targets for 2025 and 2030 that will help us achieve Net Carbon Neutrality by 2040. Hence, this cell will play a pivotal role in proposing strategies for PMR to document and map the current carbon sinks, as well as increase its carbon sequestration potential.

CNFC will be a body that will help to ideate and plan carbon neutrality measures, including the measures to preserve the current natural sequestration potential as well as increase this potential for the future. It will also monitor the Pune Regions carbon emissions annually and create a database of the current carbon flows and sinks. The following actionables are how the CNFC would help this agenda:

1. **Carbon Accounting:**

a. Facilitating Carbon Accounting at government bodies/ institutions
b. Developing and implementing a regulatory framework for Carbon Accounting like SEBI to ensure that it is done correctly and under government supervision to build trust in the market
c. Creating, maintaining and monitoring a database for accounting of carbon/GHG emissions within PMR. This database will include the current carbon sinks, potential carbon sinks, as well as the current and projected carbon emissions which need to be sequestered. It will keep records on
    - energy, transport and infrastructure being added each year
    - green measures/ projects being taken up in Pune District.
    - urban forests, hills, and urban green spaces in PMR
    - state of waterbodies in and around PMR.

2. Awareness and Community engagement:

- Carry out awareness initiatives regarding Carbon Neutrality on a large scale that has the capacity to change mindsets from various backgrounds.
- Facilitate training and workshops for upskilling for students and young professionals to work in this sector.

3. Create a web portal to list out solution providers of green technologies/ services in PMR region. The web portal should give out the following info:

- Key outcomes of Feasibility Study/interesting numbers
- Actionables for reducing carbon content in the atmosphere
- Solution providers/Green Business directory based on sector
- Listing out of government schemes and programmes on a single platform to build transparency and awareness
- Web portal can be a link between solution providers/citizens/and interested parties that want to take up action.

4. Developing guidelines for local industries on how they can achieve carbon neutrality over a specified time period. These guidelines will include recommendations for setting up CCUS (carbon capture and storage) technologies and assessing the viability of the same.

5. **Aiding technological transfer and knowledge exchange:** Cooperating and coordinating with local and international entities in exchanging new knowledge, technologies, and expertise. These technologies will also include artificial carbon-sequestration technologies.

6. **Studying the capacity for Artificial sequestration:** Recommending and monitoring technological instruments like GHG emission sensors for GHG emissions measurement in PMR. These technologies will also include Artificial carbon-sequestration technologies. Hence the cell can conduct an analysis of the current sequestration technologies in the market, and check the viability and relevance of these technologies in PMR.

The cell can also make a carbon inventory for Pune, as proposed by TERI (Tata Energy Resource Institute). [34]

[34] T E R I. 2012 Carbon Inventory of Pune City 70 pps [Project code 2010WR02], available at https://www.pmc.gov.in/sites/default/files/miscellaneous/Carbon_Inventory_of_Pune_City_2012.pdf

10. Using PMR as a Model for the Major Metropolitans of India

The previous studies suggest that Pune's emission profile aligns with that of comparable Indian cities such as Bangalore, Kolkata, and Thane, with Pune ranking 5th among the top CO2 emitters[35]. Consequently, this study and analysis serve as a valuable model survey applicable to all tier-1 metropolitans in India. If effectively utilised, India can strategise to sequester over a significant amount of carbon annually, representing a substantial advancement towards meeting our climate commitments outlined in the Paris Agreement. This proactive approach would also inherently fulfill our Intended Nationally Determined Contributions (INDCs).

11. Way Ahead

PMR can achieve its goal of net-zero local emissions by 2050 if it succeeds in reducing urban emissions in line with current plans and ensures protection for existing carbon sinks. The findings clearly demonstrate that PMR holds substantial opportunities for implementing carbon sequestration strategies, such as urban greening, afforestation, and sustainable land use practices. To fully harness the urban carbon sequestration potential of PMR, key steps involve the development and implementation of comprehensive urban planning policies that prioritise green spaces, promote sustainable infrastructure, and encourage public participation.

As the global community faces the urgent challenges of climate change, the urban carbon sequestration potential of PMR offers a tangible and actionable pathway towards a more sustainable and resilient future. This model study can be replicated to other major tier-1 cities in India, and globally. By acting decisively on the policy recommendations presented in this paper, PMR can set a powerful example for other regions and nations to follow, ultimately contributing to the global fight against climate change and fostering greener, healthier, and more vibrant urban environments for generations to come.

[35] T E R I. 2012 Carbon Inventory of Pune City 70 pps [Project code 2010WR02], available at https://www.pmc.gov.in/sites/default/files/miscellaneous/Carbon_Inventory_of_Pune_City_2012.pdf

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