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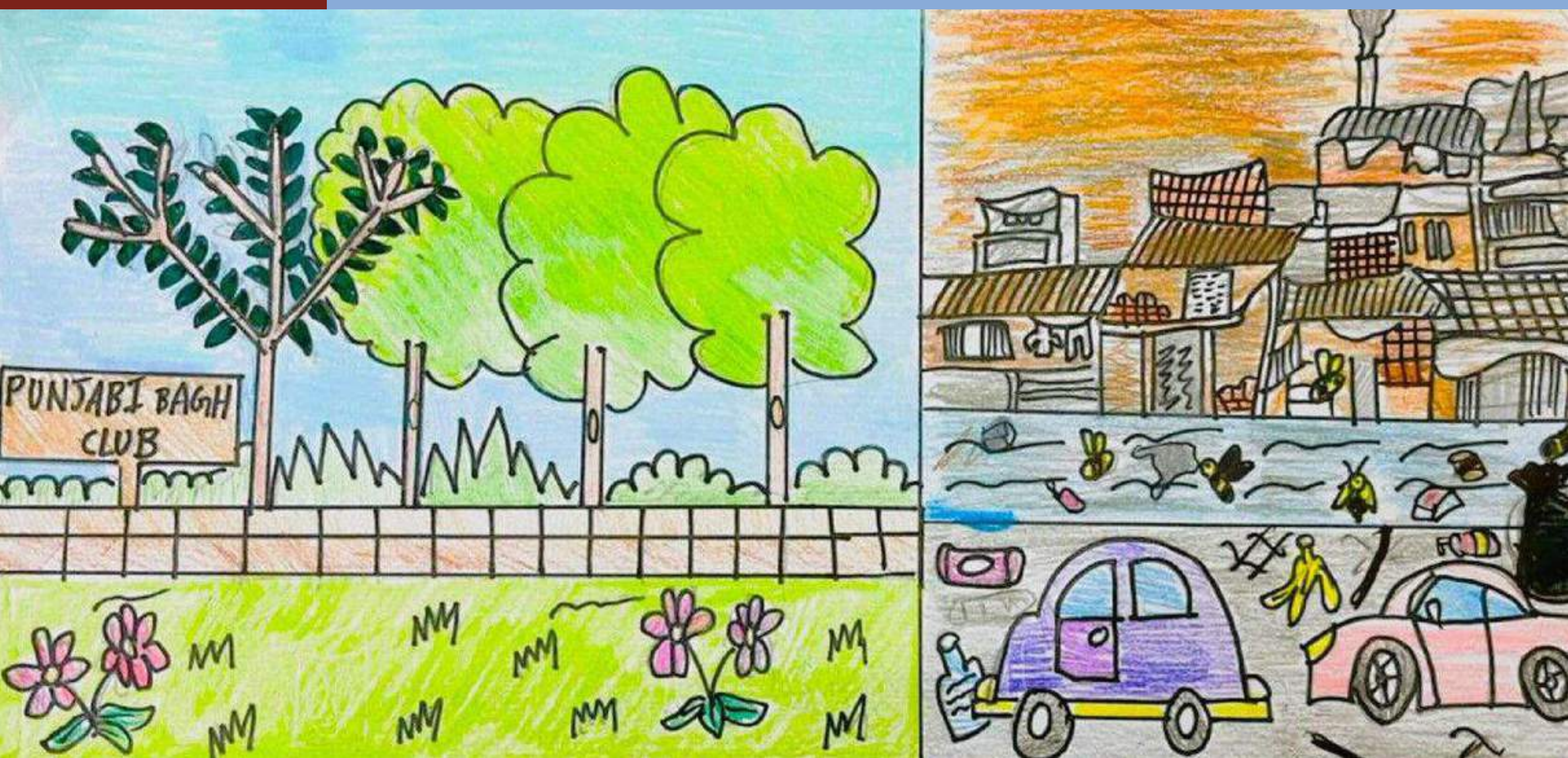
Policy Briefs

Ashwin Mahalingam and Pokhraj Nayak



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How Green will Chennai be? Understanding and Reducing the Carbon Footprint due to Residential and Commercial Construction over the next two decades

Ashwin Mahalingam and Pokhraj Nayak

Introduction

As India urbanises rapidly, more and more building stock will be added to cities. Buildings consume up to 40% of the total energy consumption in a city and produce 33% of worldwide greenhouse gas emissions. In India, the building industry is estimated to account for around a quarter of total CO2 emissions. This is due to emissions that arise out of the production of raw materials such as cement and steel, their transportation to construction sites, the energy used during construction, and most importantly, the energy used during the operations of a facility. Energy sources in most of these processes continue to be fossil-fuel based.

As cities grow and as more buildings, commercial and industrial complexes are built, it is likely that this situation will worsen. Massive amounts of concrete, steel, glass, aggregates, sand and other building materials will be required to cater to this growth rate. Procurement and transportation of these materials will create a huge burden on the city's environment in terms of carbon emissions. These structures also last for several decades and consume considerable amounts of energy during their day-to-day operations. If business-as-usual technologies that are fossil fuel based are used, the energy requirements of the city and its corresponding emissions are going to soar.

Of course, these risks can be addressed, and this trend can be halted. Recycling and reuse of materials through a cradle-to-cradle system can reduce emissions since new materials are not being produced from natural resources. The choice of materials, too can determine the extent to which greenhouse gases are emitted into the atmosphere. Some materials may be more energy-efficient to produce and/or may lead to lower energy requirements in built facilities.

What is the quantum of emissions that a city is likely to be responsible for as it urbanises? To what extent can these emissions be mitigated? Quantitative analysis that answers these questions is absent. It is, therefore, to answer these questions that we now turn. Using the case of Chennai, this policy brief demonstrates the extent of carbon emissions over the next two decades and the extent to which this can be reduced through technologies that are readily and commercially available. We next briefly describe our analytical methods before discussing our findings.

Methodology

Our approach to answering these questions consisted of three phases. First, we leveraged geo-spatial modelling techniques to simulate how Chennai's urban landscape would look like two decades hence. Second, we used Life Cycle Analysis (LCA) techniques to understand the extent of carbon emissions that Chennai would accrue due to urbanization. To do this we assumed that conventional building materials and energy sources would be used. We also only considered impacts due to the growth of building stock and did not consider impacts due to the development of infrastructure – roads, urban transit systems, desalination plants and so on. Our estimates of emissions due to urbanization are therefore on the conservative side. Finally, we developed several scenarios where alternative building materials and energy sources are used in Chennai's development. We then systematically evaluated the carbon emissions in each of these scenarios to understand the extant to which environmental impact could be reduced, and which combination of technologies would lead to the largest reduction in emissions.

For the first phase of our study, we used geo-spatial land use models developed by The Nature Conservancy – a global environmental non-profit. Satellite images of Chennai from 1998 and 2019 were taken and classified into 9 land use types – Vegetation, Urban Low Rises, Urban Medium Rises, Urban High Rises, Water, Crops, Scrub, Wetlands and Open Spaces. We then used a recently developed technique known as Patch-generating Land Use Simulation (PLUS) to determine the nature of change from 1998 to 2019, as well as to predict how land use in Chennai is likely to change in the future, to arrive at a land use map for 2040. While a detailed description of this simulation is beyond the scope of this paper, our model used a technique known as a Land Expansion Analysis Strategy (LEAS) in conjunction with another technique called Cellular Automata-based multiple Random Seeds (CARS). These techniques use land-use constraints (ensuring development does not happen on water bodies for instance) and drivers (development is likely to take place closer to infrastructure such as roads for instance) to assess the development potential of Chennai in future years. Using mathematical techniques such as Markov chains, a future map of Chennai in 2040

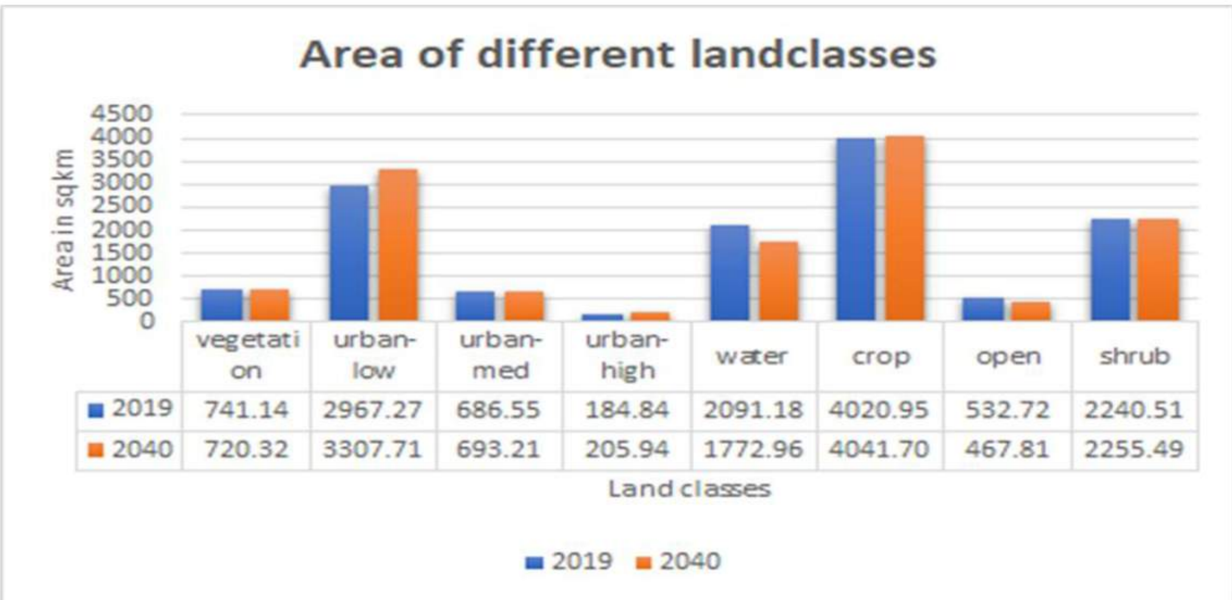

Figure 1: Changes in Landuse in Chennai from 2019-2040

that takes into account trends in the past as well as drivers and constraints for the future, was developed. This map indicates the probable total extent and distribution of urban low, middle and high-rise developments in Chennai. As expected, our model predicted an increase in urban built up areas accompanied by a decrease in water/wetlands. The figure below graphically depicts the change in land classes over a 20-year period between 2019 and 2040.

Carbon Emissions in Chennai

Our predictive simulation allowed us to estimate the total volume of new buildings that would accrue in Chennai from 2019-2040 as well as the amount of new and existing buildings that would be operated and maintained during these years. Using existing research on Life Cycle Analysis of construction activities that estimates the amount of CO2 released during demolition, CO2 released during construction (as a result of transportation of materials as well as construction activities), and CO2 released during the operations phase of a building based on energy consumed per unit area as well as the energy mix used by the Tamil Nadu electricity board, we were able to arrive at the quantum of CO2 emissions that Chennai would emit by 2040, just due to the construction of new buildings and the operations of existing ones.

Our calculations show that in the period from 2019-2040, Chennai will cumulatively emit 231.9 Million Tonnes of CO2 into the atmosphere due to energy consumed by buildings, in a Business-as-Usual scenario! Of this, the lions share will be due to the energy consumed in the operations of buildings. While a large majority of these emissions come from the operations of existing building stock, emissions due to new buildings constructed between 2019 and 2040 will account for 10.2 Million Tonnes of CO2 as shown in Figure 2 below.

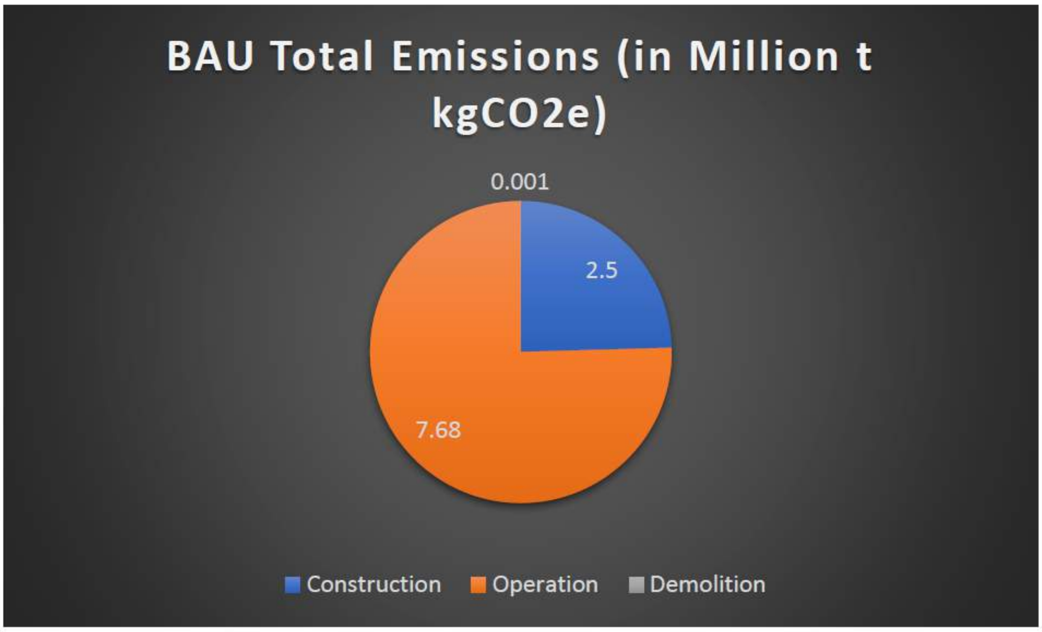

Figure 2: Emissions due to construction of new facilities

Of this, nearly 25% is due to the energy consumed during the construction of the building while 75% is due to the energy consumed during the operations of these new buildings. The emissions due to demolition of existing facilities is negligible.

To gauge the extent to which these numbers can vary, we held discussions with multiple stakeholders from government, industry, academic and civil society in the form of workshops to develop alternate scenarios for Chennai's growth. Two scenarios emerged. In the first, a high population growth rate of 3% per annum was envisaged and housing for this population growth needed to be catered to. The spatial development of Chennai in this scenario would take on an urban-sprawl type of approach with several low-rise buildings dominating the mix. In the second scenario, the population growth was reduced to 1% per annum with a more even mix of new low, medium and high-rise building. In both cases croplands and open spaces would be replaced by the new housing stock. The range of variation between these two scenarios ran from 225 Million tonnes of CO2 to 236 Million tonnes of CO2 – not very different from what our original model had predicted. Perhaps more noteworthy was the fact that emissions from the construction and operations of new buildings varied from 18 Million tonnes of CO2 in Scenario 1 to 4 Million tonnes of CO2 in Scenario 2 showing that controlling urban sprawl can be a policy lever that controls overall emissions.

How can these emissions be reduced?

230 Million tonnes of CO2 emissions is quite large, considering India's stated emissions goals. How can this be reduced? We explored three possible interventions. The first intervention was to replace traditional cements with low-carbon cements. Specifically we compared the differences in emissions when Ordinary Portland Cement (OPC) was replaced by low carbon alternatives such as Limestone Calcined Clay Cement (LC3) and Fly-Ash based blended Cement (FA30). Both LC3 and FA30 emit far fewer amounts of CO2 per tonne of cement produced. Second, we evaluated emission outcomes if demolition waste was re-used for future construction. We estimated the extent to which buildings would be demolished between 2019 and 2040, and consequently the amount of demolition waste that could be re-used as aggregates for future construction. This would then represent a reduction in emissions, since raw material would not need to be mined processed and transported, if existing materials could be re-used. Finally, we experimented with changes in energy sources. Specifically we explored the implications of drawing up to

Table 1: Emissions in Million tonnes of CO_2 across interventions for the base scenario

	No Intervention	Use of recycled Aggregates	Use of 50% renewable energy
OPC	231.9	231.9	117.2
LC3	231.7	231.7	116.9
FA30	231.5	231.5	116.8

50% of a buildings lifecycle energy from renewable sources. We analyzed the three main scenarios described earlier, as well as a number of sub-scenarios with changes in the low, mid and high rise mixes, population growth rates, energy mixes and so on.

Table 1 presents a comparison across parameters for our base case scenario. Our analysis indicated that recycling demolition wastes as aggregates had virtually no impact on the life cycle emissions associated with the development of buildings in Chennai. Replacing traditional cements with low carbon cements had a discernible but low impact on reducing emissions. However, the single largest contributor to reducing emissions was the change in energy sources. The use of renewable sources such as solar power to supply 50% of a buildings operational energy needs was also likely to result in a corresponding reduction in cumulative CO2 emissions of up to 115 Million tonnes, in the period between 2019 and 2040.

The impact of these interventions was a bit more telling when we ignored the existing building stock and only considered new buildings that would be constructed over the next two decades. Take Figure 3, below, for example, which explores how much CO2 FA30 based construction would emit under various scenarios. In scenarios featuring high rates of population growth, FA30 based new construction in Chennai could emit 23 Million tonnes of CO2 into the atmosphere over two decades. However, combining FA30 cement with recyclable materials and upto 50% of energy from renewable sources, could reduce this figure to just 0.9 Million tonnes! The corresponding figures for OPC cement would be 3.07 Million tonnes, a greater than three-fold increase.

Conclusion: Greening Chennai

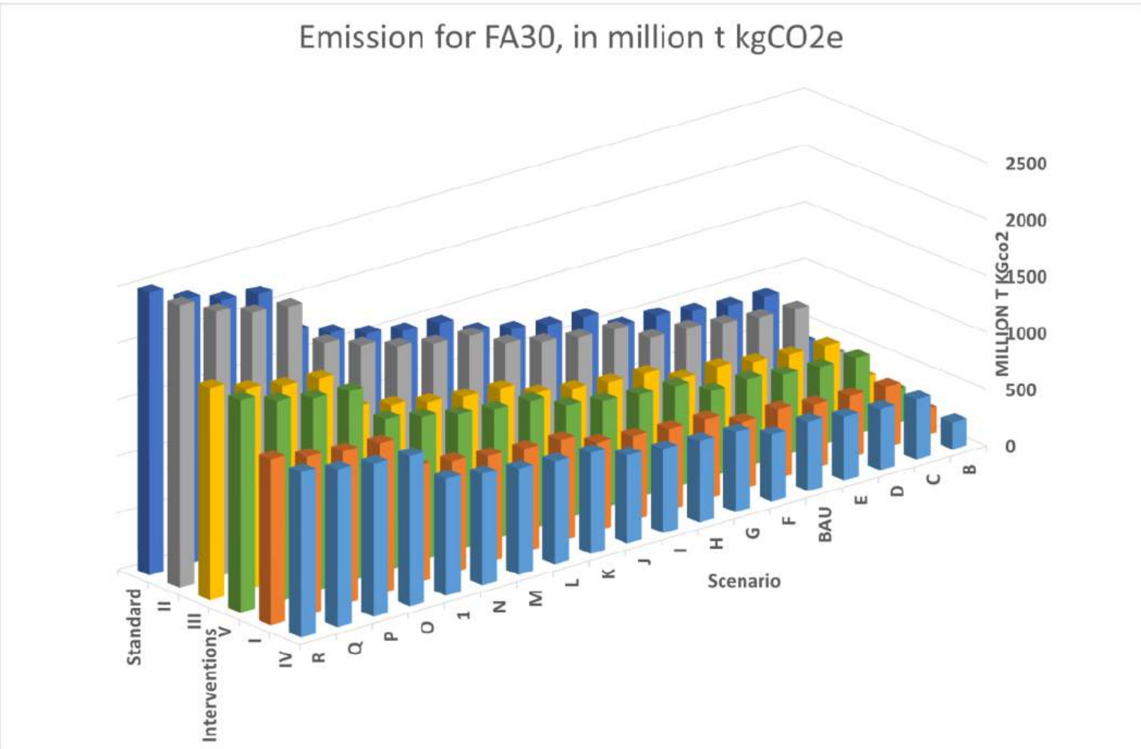

Figure 3: Emissions for FA30 cement-based construction across different scenarios

It is clear that if left unchecked, the residential and commercial building sectors in Chennai alone will contribute to considerable amounts of CO_2 emissions in the future – to the tune of more than 220 Million tonnes. On the one hand, the type of cement used for new construction can have a non-trivial impact on future emissions, and there is a case for moving from OPC to variants such as FA30 or LC3. However, most of the energy consumed by a building over its lifecycle is in its operations phase (nearly 75%). Given new stock that will be added to existing building stocks, the operational energy requirements for buildings are likely to be massive, and renewable energy sources are going to be the KEY driver in reducing emissions from buildings along with urban plans that limit the extent of the built environment. The emission numbers indicate that it is time for the building industry to get its act together, and invest in alternative materials and energy systems to try and mitigate emissions as much as possible. Challenges abound – retrofitting existing buildings, for instance, is not trivial. Only time will tell if we will be successful in minimising emissions due to the construction of new buildings and the operations of existing ones, but the fate of our planet rests on it!

References

Devi, P., & Palaniappan, S. (2014). A case study on life cycle energy use of residential building in Southern India. Energy and Buildings, 80, 247-259.

Gettu, R., Pillai, R. G., Santhanam, M., Rathnarajan, S., Basavaraj, A., Raju, S., & Dhandapani, Y. (2019). Service life and life-cycle assessment of reinforced concrete with fly ash and limestone calcined clay cement.