17 The Modern City: Electric, Smart, and Green

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Abstract

This chapter considers three broad themes that link urbanisation and electricity consumption. First, it looks at urban forms, both in terms of the sprawl or densification of the city and the nature of building envelopes. Second, it focuses on the behaviour of households, especially the adoption of air-conditioning and electric vehicles and the effect they may have on the grid. Third, it examines the initiatives related to grid management itself, discussing the effect of increased but intermittent renewable power and the progress of smart metering and the use of artificial intelligence in grid management. It concludes that in all these, multiple institutions at different levels of government, varying by country, play a significant role. Coordination across these institutions is critical in achieving the desired outcomes. As technology changes, the focus of interventions, whether technical/technological or socio-economic or institutional, would evolve. The critical question is whether there are institutions that can potentially engage with these changes and respond in a manner that is appropriate such that environmental sustainability is improved and climate risks are reduced. As of now, such institutions, even if present, are not active. The challenge of urban climate governance is not just technical, it is also to animate these institutions.

Introduction

Urban areas are locations of energy transition that are driven by the concentration of economic activities, and greenhouse gas (GHG) emissions. Increasingly, the population is concentrating in urban areas, a tendency that has been exacerbated by climate change. The per capita emissions in urban areas are lower at comparable levels of economic prosperity/consumption. An average city dweller emits more than an average villager, because on average a city dweller is richer. Globally, it is estimated that cities account for about three-fourths of global energy consumption, and with increasing urbanisation, this share is also likely to rise.

On the other hand, the concentration of population in urban areas makes the system more vulnerable to risks, both in terms of economic loss and population impact, e.g., disruption from heat, flood damage, pandemics, etc. Since cities generate resources, spending money on cities to deal with climate change aligns with elite interests, but institutions that raise and allocate resources differ widely by jurisdiction. Over time, multiple institutions have evolved to support the different types of urban activities. For example, much of the needed public investment occurs at the sub-national levels, a key component of which is transport, which highlights the role of urban in green infrastructure. Cities have the potential to be front runners, but it is not guaranteed that they will realise their potential, unless a number of coordinating issues are resolved. This chapter considers three broad themes that link urbanisation to electricity:

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1. Urban forms
2. Behaviour of households
3. The nature of energy demand and the grid.

In concluding, questions of multiplicity of institutions that influence these three linkages and offers some recommendations have been considered.

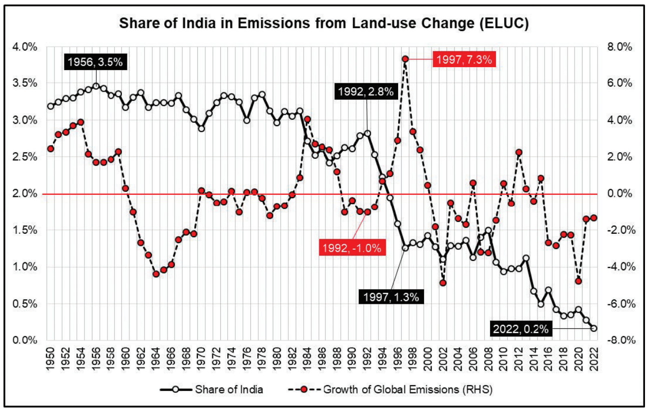
The Urban Form

The core challenge with urban forms is the lock-ins from yesterday and today's decisions. Not all these lock-ins are negative, but it means that the effects of today's policies will play out over a period of time while today's urban forms are the result of policies and investments in the past. For example, the suburban rail system in Mumbai and Kolkata have driven a certain settlement pattern; similarly, the nature of land development in Delhi and Bengaluru have led to a particular city form, which impacts the carbon-intensity of these cities into the future.

However, a substantial portion of India's urban form is yet to be built and it is being rapidly shaped in the larger cities (1 to 3 million) and smaller (300,000 to 1 million) mid-sized towns. While some of these have land use master plans[2], many have no significant planning interventions. Recently, there have been some efforts under the AMRUT and now under the Special Assistance Scheme for States, wherein there is a mandate for permanent positions for city level urban planners, a number of whom have been recruited.

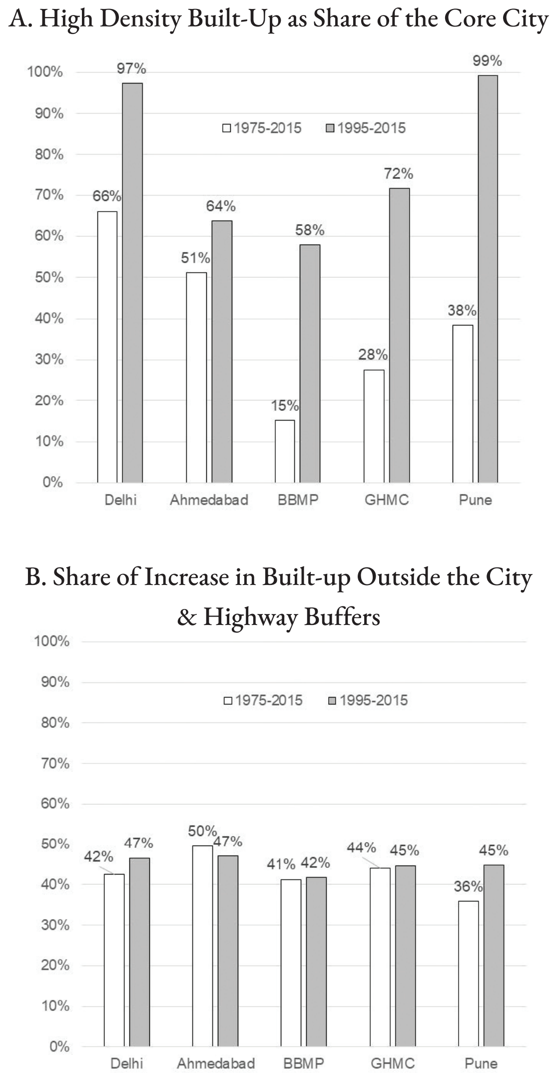
As shown in Figure 17.1, by one measure, the process of urbanisation, which involves change of land use, has not been as environmentally damaging in India, as it has been in some other countries. This, in part, reflects the high value that is attached to agricultural land by a large share of the population, who continue to be farmers and the relative sparseness and expense of transport options. Figure 17.2, Panel A shows that in five major cities, Delhi, Ahmedabad, Bengaluru, Hyderabad and Pune, the core city continues to intensify, i.e., it is not sprawling recklessly. However, concomitantly, as Figure 17.2, Panel B shows there is built-up growth outside the core city boundaries and buffers along the highways, with only half the built-up growth happening inside these lines. This is driven by high cost of land in the core city and near the highways.

Figure 17.1: Share of India in Emissions from Land Use Change (ELUC)



Source: Source: Gasser et al., 2020

Figure 17.2: Urban Growth Patterns across Five Major Cities



Source: Authors' Construct based on Communication with Dr. Shamindra Roy using data from GHSL[3]

[2] Not all of these are master plans with a statutory character with legal implications.

[3] https://human-settlement.emergency.copernicus.eu/data.php

There are many possible urban form interventions, most of which essentially try to achieve four goals:

a. Increased density[4] i.e., city area grows at a lower rate than population, which is occurring to some extent as seen above

b. Energy efficient transportation, preferably public transport, with implications for both frequency and fuel

c. In-building energy and appliance use, which is affected by building designs and behavior norms at work and at home

d. Infrastructure design that minimises the overall resource use, e.g. water re-use.

These involve specific actions, e.g., coordinating land use and transit corridors as well as intercity connections. It involves planning around single or multiple CBDs and choosing between smaller mixed use[5] blocks or superblocks (even in this, there is a choice - Corbusier vs. Cerdà) and most importantly, the processes involved in building these master plans – the degree of consultation and flexibility (Amati, M., Stevens, Q., & Rueda, S, 2024).

Similarly, building codes need to be responsive to local climatic conditions and passive heating or cooling, which involves appreciating and using traditional architectural insights. Hwang et al (2009) presents evidence from a field survey in Taiwan by documenting much more use of air-conditioning at work as compared to home. While the cost incurred plays a role in this finding, the researchers also noted that only a quarter of workplaces they visited had fans or enough operable windows to facilitate the use of natural ventilation instead of air-conditioning which indicated a strong role for building design.

Another site of interaction between urban forms and energy is the nature of infrastructure; whether grid-based or decentralised. Networks have to be redesigned for water supply that allow for different types of supply, e.g., using primary treated water for local horticulture, secondary treated for flushing toilets (highest water use), and drinking standard water for other uses. Many cities now insist on apartment complexes installing STPs while houses use private contractors for fecal sludge treatment.

The energy implications of this has not been fully studied, but since sewerage has to be forced along the network and STPs are also high energy infrastructure, localised treatment may reduce energy demand. On the other hand, introducing such rules post facto, e.g. in an already sewered area may affect the minimal flow requirements in a regular sewerage network.[6]

Household Behaviour

Households have limited leeway in altering energy consumption. Urban forms and services determine the extent and mode of travel. For example, building designs determine the kind of space cooling requirements. Similarly, the modal choice for transport depends on whether there is frequent, comfortable, and predictable public transport that is available at a comparable cost to private transport (not just cars but often two-wheelers). If a two-wheeler culture sets in, then persuading people to shift to public transport may be harder than electrifying the two-wheeler stock.

This section will focus on two issues, viz. Air-conditioning and vehicle choice, which will focus on the penetration of two-wheelers and their growing importance, which is distinct from the 4-wheeler battery EV. These are chosen because of their likely impact on the grid and because of their pattern of transition i.e., how ownership is likely to change as India goes through its urban transition.

Figure 17.3 shows how the share of households owning air-conditioners and two-wheelers vary across

[4] Raising fuel prices to 1.6 USD per litre (that's about ₹130 per litre) and assuming that density grows at half the rate of population growth, will cut the increase in energy use by 25% (Creutzig, Baiocchi, Bierkandt, Pichler, & Seto, 2015).

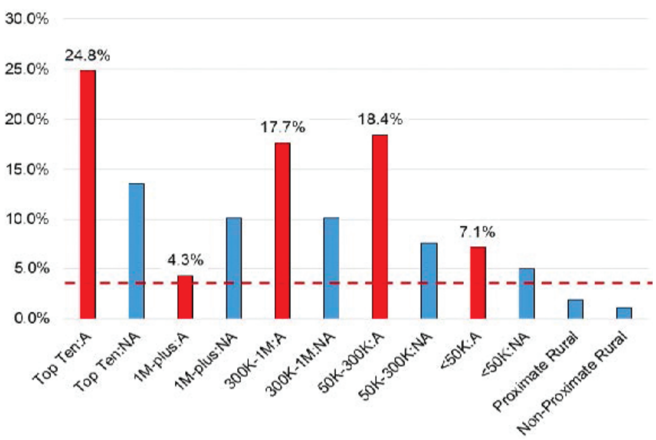
[5] One way of characterising mixed-use planning is that at least 40% floor space is for economic use in any neighbourhood, and single function blocks should cover less than 10% of any neighbourhood (Swilling et al., 2018).

[6] For an early discussion of these see Mukhopadhyay and Revi (2009).

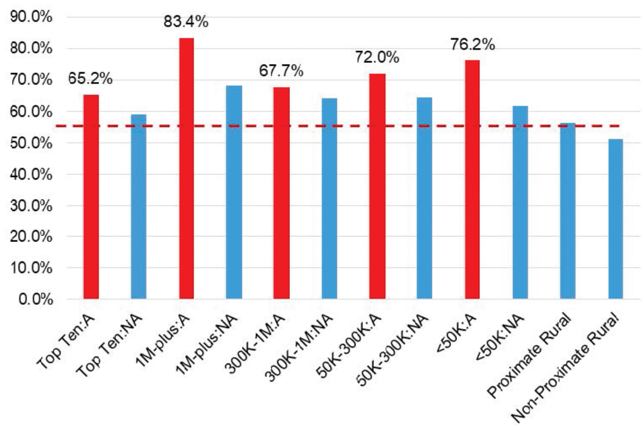
different types of settlements, starting from two types of rural areas, one not proximate to urban areas and the other close to the cities. Also, there are different scales of urban areas – small towns with a population below 50,000 to those towns with the population between 50,000 to 300,000, or between 3 lakh to a million. The large million plus cities are further separated into two categories, the top ten and others. Within each of the urban areas, there are two groups – the affluent (A) and the non-affluent (NA)[7]. Panel A shows variation across types of settlements for ownership of air-conditioners, while Panel B shows the same for two-wheelers.

Figure 17.3 Air Conditioner and Two- Wheeler Ownership by Settlement Type

A: Air-conditioners



B: Two-wheelers



Source: Authors' Construct based on Communication with Dr. Shamindra Roy, using data from NSS Household Consumption Survey 2022-23

As seen in Figure 17.3, two-wheelers have almost become ubiquitous across the country as compared to air-conditioners. It should be noted that though their proportionate share is less than that of affluent households, 98.1% air-conditioners in urban areas are in non-affluent households. This is also true of two-wheelers. This is largely because the affluent comprise a tiny proportion of households. This implies that interventions need to be targeted not to affluent households but to the broader population demographic.

Further, any intervention on two-wheelers would be limited if it did not cover rural areas. However, since electrification of two-wheelers happens in a decentralised home-based architecture, and not a network of charging stations, the implications are more for quality of power supply in rural areas than the economic challenges of sustaining a charging infrastructure in less dense areas. Another solution could be battery swapping, which is well suited to two-wheelers and the infrastructure is also easier to establish.

In addition to these two, many major areas of intervention remain. If households segregate waste sufficiently, then its handling can not only improve but also reduce methane emissions from landfills. Households can exercise a choice between fans and air-conditioning (and its temperature settings), driven by the cost of electricity, and "culture", e.g., apocryphally, Europeans wear sweaters indoor in winters while Americans do the same in summers. A degree of agency also remains for transport choices to school and for work, and most importantly to invest or not to invest in decentralised options.

Decentralisation is important because it allows bypassing the challenges of "greening the grid" by "greening the cell", if one moves locally to electric modes, e.g., transportation, street lighting, etc. It also allows more experimentation and innovative products and practices, as in Indore's bio-CNG from waste being used for powering public transport, which is a double win-win, capturing methane and reducing energy consumption (Economic Times, 2022).

[7] Proximate rural areas comprise villages that are within a distance of 5-kilometres from the district headquarter or from a city/town with more than 5 lakh population. Ownership of a car is one distinguishing characteristic between these two sub-categories of affluent and non-affluent.

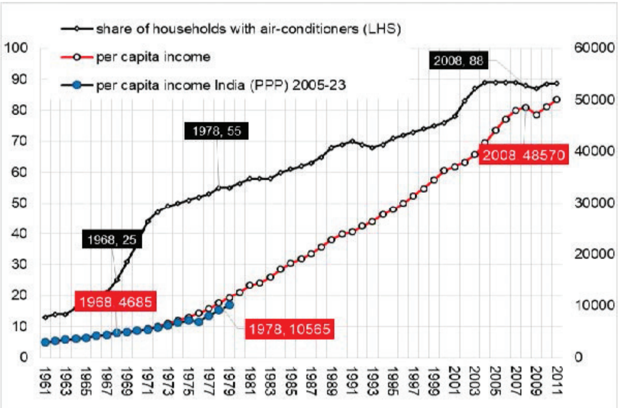
Air Conditioning

From 850 GW today, the installed capacity of space cooling equipment is expected to increase four times by 2050. This also drives peak demand, which affects grid stability. By some estimates, cooling contributes nearly a third (up from 10% today) of peak electricity demand in ASEAN (Association of Southeast Asian Nations) countries, and this is naturally more concentrated in urban areas (IEA, 2024).

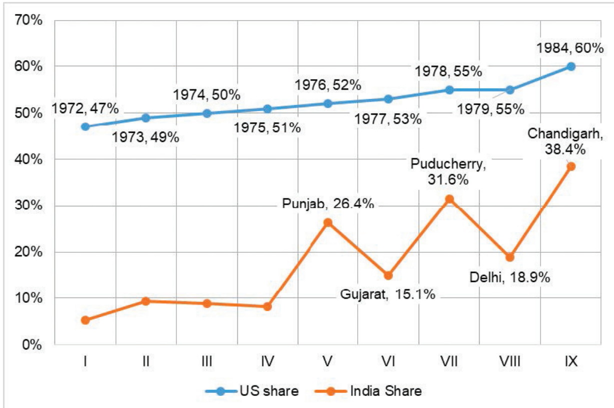
As seen in Figure 17.4, Panel A, the evolution of air conditioner ownership in the US was quite rapid. Over a decade, starting in 1961, when only 13% of households owned air-conditioners to 1971, where ownership more than tripled, to 44% in 1971, and to over 55% at the end of the 70s. The income growth during this period from 1961 to 1979 was similar in both levels (measured in PPP terms) and growth of India in the last 18 years, from 2005 to 2023. Fortunately, the air-conditioner ownership did not follow that path in India, but the break can come anytime and very quickly. As the US has shown, the penetration went from 21% in 1967 to 47% in 1972, i.e., more than doubling in just five years, and income in the US over this time was similar to India over 2011 to 2016.

Figure 17.4: Evolution and Distribution of Air-Conditioner Ownership: Comparative Analysis of US and India

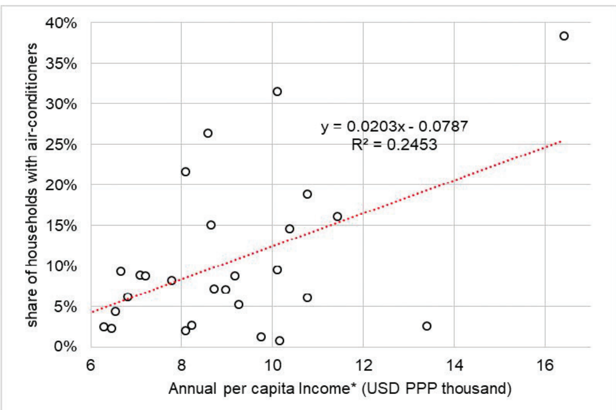
A. Growth of Air-Conditioner Ownership in the United States of America (US)



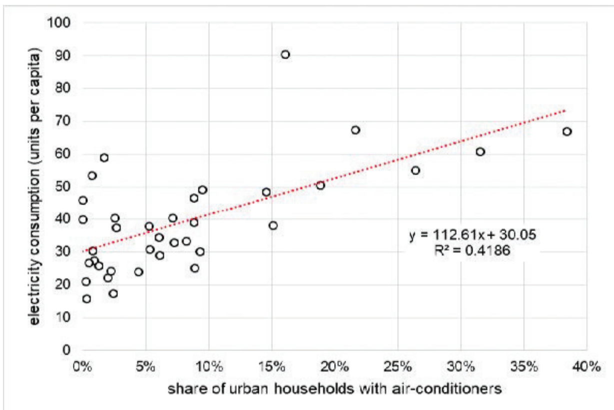
B. Comparing Urban Air-Conditioner Ownership in Indian States and the US



C. State-Wise Share of Urban Households with Air-Conditioners in India[8] (2022-23)



D. Share of Urban Households with Air-Conditioners & Electricity Consumption



Source: Horace Dediu; Comin and Hobijn (2004); NSS Household Consumption survey 2022-23

[8] The state-wise urban MPCE was rescaled in the following manner. First, it was multiplied by 12, then it was divided by a scaling factor derived from the ratio of aggregate national NSS consumption to national per capita GDP in 2022 to estimate income approximately. Finally, it was multiplied by 0.49, a conversion factor from local currency unit (LCU) to current PPP dollars in the WDI data, based on the average of annual values from 2019-23.

In Figure 17.4, Panel B, historical air-conditioner ownership in the US is compared to air-conditioner ownership in urban areas of different states and union territories (UTs) when the US was at a similar level of income. As one can see, in certain, albeit smaller states/ UTs, the levels are about half to two thirds of US levels at the time they were at the comparable income levels. So, it would be unwise not to plan for that eventuality.

In Figure 17.4, Panel C shows that the pattern of air-conditioner ownership, even in urban areas, is influenced by many other factors than only income or consumption. However, as expected, there is still a positive association, albeit with some variations, between ownership and income. Furthermore, as seen in Panel D, once there is ownership, the electricity consumption is visibly more since more households adopt air-conditioning, the average state consumption also rises.

All this indicates that India can be at the cusp of the kind of surge in adoption of air-conditioning that was seen in the United States in the 1970s. While technology has definitely improved, this will still have a substantial effect on not just demand but also on the pattern of demand, as residential units tend to be turned on and off in unison.

Electric Vehicles

To meet both transportation needs net zero goals, the global electric vehicle (EV) fleet needs to expand by multiples; by some estimates ten times, which is to 300 million by 2030 from the 30 million today. There has been a lot of attention on the impact of EV cars on the grid, for peak load, as well as for grid management (Barman et al., 2023). Some have suggested reducing the cost of ownership of EVs by pushing battery power back into the grid when renewable supply is limited, e.g., at night, by using bi-directional batteries as solar reservoirs[9].

One of the impacts of electric vehicles is the effect on the grid when the vehicles are being charged. Assume a scenario where all vehicles need to be charged when the driver goes back home and connects the EV to a charger which means that there would be an impact on the grid at roughly the same time. This is because a large proportion of people will return home at the same time and they all would connect their EVs to a charger. Recent work suggests that this kind of impact could be mitigated in multiple ways:

i. Firstly, by ensuring that charging facilities are available at work. Thus, much of the charging can happen when the vehicles are idle at work sites during the day, coinciding with a high supply of renewable power from solar energy.

ii. Another option is delayed charging. This is not necessarily based on real-time interaction with the grid but to stagger the charging time such that not all vehicles come online at the same time. For example, if people leave at different times for work and if charging takes four hours, then a charging mechanism that is four hours before the time of departure would generate a staggered demand across various owners of electric vehicles.

iii. A third key measure is time-of-day tariffs for electricity. This standard solution may not work very efficiently because users will tend to shift their charging outside the window of high tariff. Such coordinated shift in charging across a large number of vehicles could shift the peak itself. This endogeneity makes it difficult to use time-of-day tariffs as a major instrument for shifting demand that emanates from electric vehicles. However, Kacperski et. al.'s (2022) report on an experiment that tried to incentivise charging when the renewable share share was high. Customers of a charging service provider were notified of cost-free and "green" charging by being invited to charge between 11am and 3pm on days with high predicted shares of renewable energy. Despite only marginal savings of €5 on an average, there was a significant rise in the number of charging processes and in the amount of energy consumed during the critical time and on weekends. If these charging processes replaced the regular overnight home charging, it could cut CO_2 emissions by half.

iv. Finally, renewable energy may be stored for non-coincident use. Chen, et. al. (2023) examined

[9] See the section on AI and grid management later in this chapter.

a second life for EV batteries for such stationary storage, thereby adding another degree of synergy.

Indian Scenario

In India, currently the peak loads are usually during the day (Figure 17.8), which is already coincident with a high renewable share. However, vehicle charging is often at night, when it is not used, but the grid's renewable share is also low at that time. As more solar generation comes online, policy may have to shift charging to daytime, to take advantage of high solar output (IEA, 2023). The other aspect in which India differs is the composition of the EV fleet, which is skewed towards electric two- and three-wheelers. There has been comparatively little work done on their impact.

Figure 17.5, Panel A shows the distribution of car and two-wheeler ownerships across states, thus showing that in India, two-wheeler penetration is now quite high, especially as compared to cars. It is also high both in rural and urban areas, unlike cars, which have an urban bias. Over time, the share of cars will grow, as noted in Figure 17.5, Panel B, which shows the extent of car ownership (subject to the caveats about the consumption survey) that has grown in the last decade, but as seen in Panel A, it remains low, barring states like Goa and cities like Chandigarh.

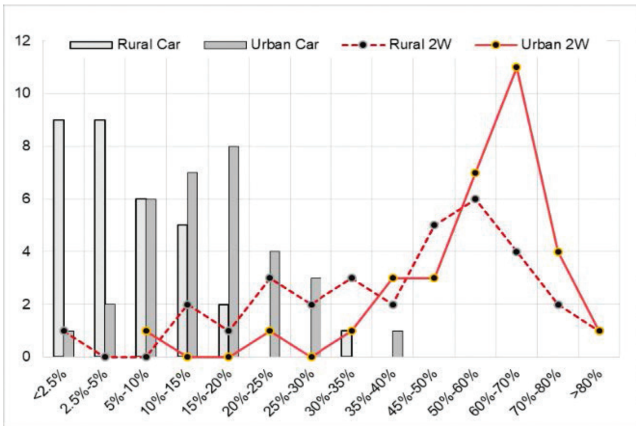
When we turn to EVs, the picture is even more skewed. In India, electric cars constitute less than 6% of all electric vehicle sales in the country. Of the nearly 1.6 million units of electric vehicles sold in 2023-24, only 90,033 were electric cars and SUVs. India is projected to be the largest two-wheeler market in the world and the share of electric two-wheelers is growing rapidly (Counterpoint, 2024). From a negligible share five years ago, Table 17.1 shows that it is now 7.9% of the market, comprising 45.6% of three-wheelers and 5.4% of the two-wheeler market.[10]

While they still have a relatively small share, electric two-wheelers are growing rapidly. While all two-wheelers grew at 9.3% per annum, electric two-wheelers grew at 29.7%. This growth is driven by the lower cost of ownership and a per km cost of operation that is a fifth of the cost of the most fuel-efficient petrol motorbikes and scooters. Within a decade, electric two-wheelers are expected to dominate, and most likely they will be charged at home, at night. Given the small size of their batteries, they are also less suited to act as energy reservoirs (Check Box 17.1 for a discussion on batteries as energy reservoirs).

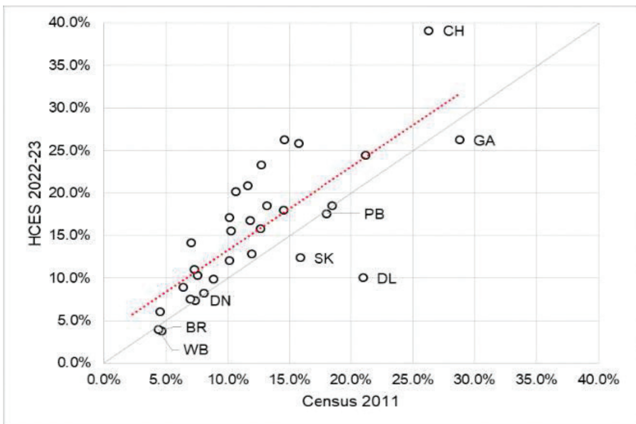
It may still be possible to shift the charging load to daytime, if there are facilities for charging at work, or if battery swapping becomes popular (allowing reserve batteries to be charged during the day), etc., but this would require policy action at multiple levels.

Figure 17.5: Vehicle Ownership Trends in India[11]

A. Distribution of State-Wise Ownership of Cars and Two-Wheelers



B. Change in Urban Car Ownership 2011 to 2022-23



Source: NSS Household Consumption Survey 2022-23; Census of India, 2011

[10] Given that most electric two-wheelers at the moment are scooters, which comprise more than a third of total two-wheeler sales, their share of scooter sales is higher. Electric motorbikes are now being introduced, which may further increase the share of electric two wheelers.

[11] Estimates of car ownership are to be taken with caution because survey sampling was stratified in part on car ownership as an attribute. It is presented here for illustration to compare with changes in two-wheeler ownership.

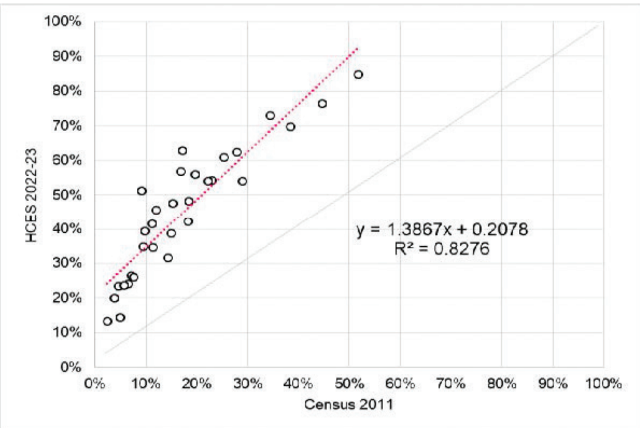
Table 17.1: Two- and Three-Wheeler Sales (in numbers)

	FY2024	FY2023
Total 2-Wheeler and 3-Wheeler sales	18,682,872	16,810,668
Total 2-Wheeler sales	17,517,173	16,027,411
Total 3-Wheeler sales	1,165,699	783,257
Total Electric 2-Wheeler and 3-Wheeler sales	1,475,650	1,102,022
Total Electric 2-Wheeler sales	944,126	728,054
Total Electric 3-Wheeler sales	531,524	373,968
Share of electric in total sales	7.9%	6.6%

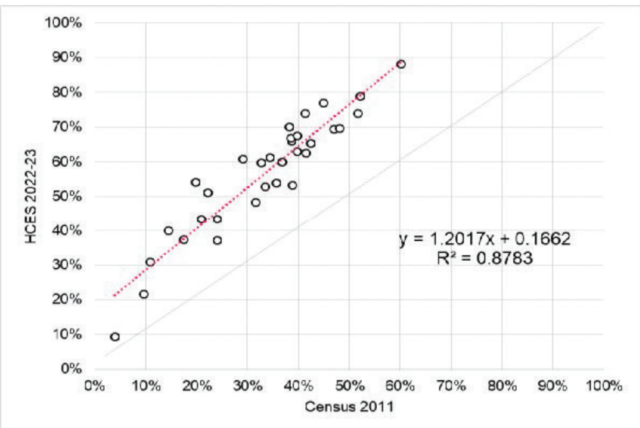
Source: SMEV Database (2024); FADA Research (2024)

Figure 17.6 : Change in Ownership of Two-Wheelers

A. Change in Rural Two-Wheeler Ownership



B. Change in Urban Two-Wheeler Ownership



Source: NSS Household Consumption Survey 2022-23; Census of India, 2011

Furthermore, while distribution of rural two-wheeler ownership across states is still less than urban areas but, as shown in Figure 17.6, Panels A and B, two-wheeler, two-wheeler ownership is growing quite rapidly in rural areas, perhaps more rapidly than in urban areas. This signifies that the penetration of electric two-wheelers into the rural market will lead to a growing demand for charging in a much more distributed manner, which would have a different (perhaps more manageable) impact on the grid, as compared to in an urban area and/or urban periphery. This points to the need to understand the vehicle mix in India and its possible evolution, given our needs for transportation and the interaction that it would have with the grid and the opportunities it would afford for smart management, to which we now turn.

Structure of Energy Demand and the Grid

How will the power system respond to planning interventions and vice versa? While the grid is well understood, decentralisation may need more explanation. Is it at the level of households (as currently understood) or apartment complexes (size of complexes of 1,000 apartments – not far from an urban area population threshold of 5,000 – are not uncommon), or at the level of ULBs (Urban Local Bodies) (as was the case for initial electricity distribution systems in India and elsewhere), i.e. a mini-grid? It is important because such local agglomeration of demand can also contract for dedicated renewable power at a distant site. Thus, it is useful to think of the electric power system as outlined in Table 17.2.

Table 17.2: Power Generation Systems

Type	FY2024	FY2023
Grid/Centralised	Superthermal coal	Solar Parks
Decentralised (Mini-grid/Off-grid)	Diesel generating sets	Roof top solar/wind but also others, e.g., "small"-nuclear

Source: Authors' Construct

There is interaction with other systems as well, e.g. EV charging. The practice of charging vehicles at night is about flattening the load in conventional power systems, and to increase the share of baseload power. But if renewable power production is time-varying, like solar or wind, then it is better to shift demand to match, e.g., by charging batteries during the time of power production.

Load Curves

To understand the pattern and structure of urban energy demand, it is instructive to compare Delhi and Mumbai.[12] In Figure 17.7, Panel A, the maximum monthly loads in two cities have been compared. It can be seen that while there is a clear seasonal pattern in Delhi with the highest maximum load in July which is more than 75% higher than the lowest maximum load in November, in Mumbai. This difference is only 26% between June and January. In addition, the difference between the annual maximum and the annual minimum is 3.4 times in Delhi vs. 1.8 times in Mumbai, thereby indicating that one must plan for load management differently, depending on the city. Hydropower that accumulates. Hydropower that accumulates during monsoon can be used, but that is a solution for an intra-day peak rather than for seasonal changes in electricity demand.

Similarly, within the day, not only do peak levels vary over months, they also occur at different times of the year. Figure 17.7, Panel B shows that Delhi has an afternoon peak at 3pm or 4pm between April to October (even in September, the consumption at 4pm is only 2.3% less than the peak at 11pm or 2300 hours) and a morning peak between 10am and 11am during November to March. Similarly, Mumbai has a noon peak between December and March, then a summer peak around 4pm between April and June, and then a return to noon during the monsoon between July to September and back to 4pm in October and November. This is important because, within renewables, only hydro resources can be time-shifted. Thus, energy storage is essential if renewable energy has to supply such shifting demand.

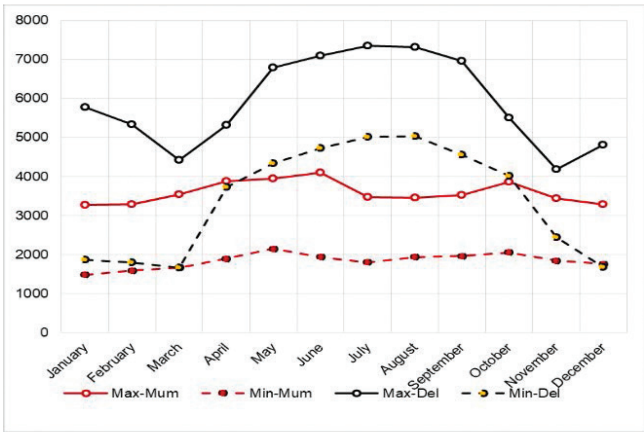
The two-regime pattern in Delhi allows the challenges to be depicted clearly, but other cities have a similar, if attenuated version. From March to April, as shown in Figure 17.8 Panel A, Delhi transitions from a 'Higher Difference but Lower Peak' regime, which runs from November to March, to a 'Lower Difference but Higher Peak' regime between April to October, where the intra-day variation is reduced but the peak is higher than in November to March.

In Figure 17.8 Panel B, the contrast between the month with the highest difference (3907 MW) and the highest peak (7347 MW) shows the variations between the regime periods and within the regimes. The peak increases by 2025 MW between April to July, while the difference between peak and trough in November (1748 MW) is less than half that of January. The regime shifts from one where the intra-day peak is about 1.5 times the trough to one where it is 3 times the trough, which changes the nature of energy mix required for the city.

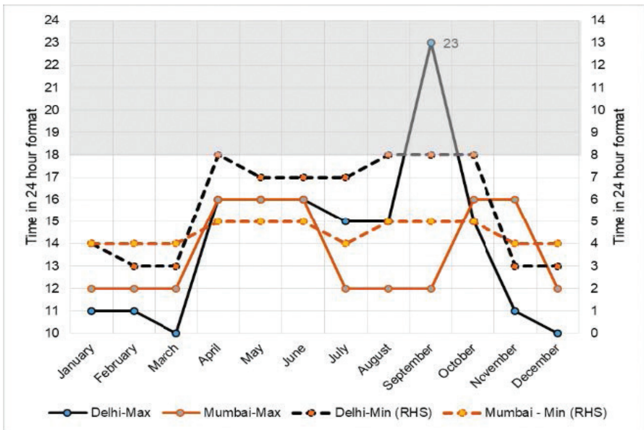
[12] The data is not strictly comparable for Delhi and Mumbai for the minimum load. In Delhi, it is the minimum load on the day the maximum load for the month was reached. In Mumbai, it is the minimum load for the month. Thus, the Delhi minimum load is likely to be biased upward compared to the Mumbai load

Figure 17.7: Seasonal and Intra-Day Load Variability in Delhi and Mumbai

A. Monthly Maximum and Minimum Loads for Delhi and Mumbai



B. Month wise Intra-day Patterns in Load for Delhi and Mumbai



Source: Monthly Reports from Delhi Transco State Load Dispatch Centre and Maharashtra State Load Dispatch Centre

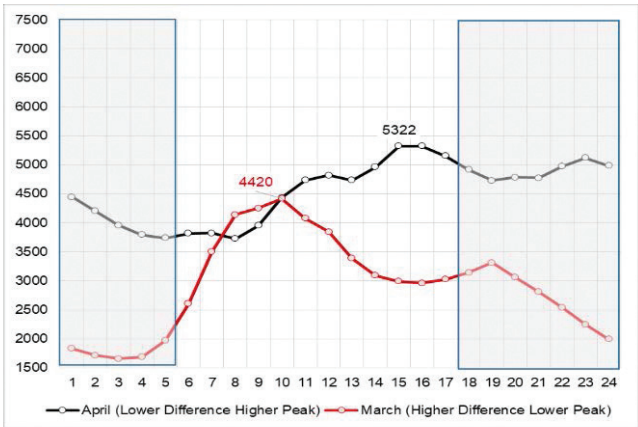
In July, the demand is never below 5000 MW while in January it exceeds 5000 MW for only four hours of a day and never exceeds 6000 MW (in July, the demand for 15 of the 24 hours is more than 6000 MW). In July, the demand is between 7000 MW and 7500 MW for only three hours, it is between 6000 MW and 7000 MW for 12 hours and between 5000 MW and 6000 MW for the remaining nine hours.

In January, it is between 5000 MW and 6000 MW for four hours but less than 2000 MW for three hours. Thus, in the Higher Difference regime, the need for flexible resources is high.

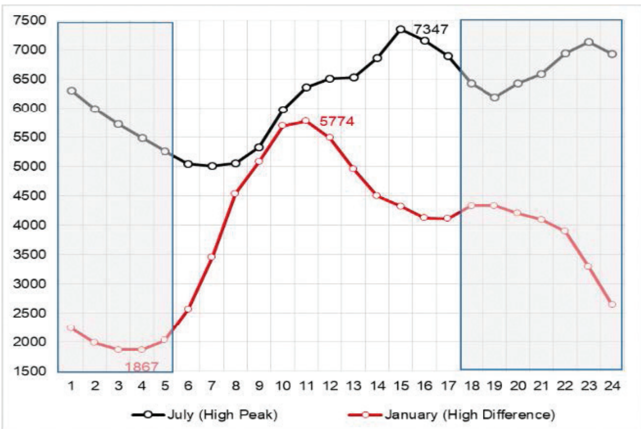
The ability of renewable resources to meet this kind of demand variation requires substantial storage capacity, such as in traditional pumped storage, battery storage, or newer molten salt storage for concentrated solar. The Higher Peak Lower Difference regime is more suited to absorb the limited renewable resources that are currently operating. The July demand peak is between 3pm and 5pm (and another late at night), and it stays between 6000 MW and 7000 MW (a 15% band) for about four hours of the day and eight hours of the night. This kind of demand, especially at night requires either changing the load factor of baseload fossil fuel plants (which is possible, given the range, e.g. ramping up a coal plant from 75% to 85% PLF (Plant Load Factor), or running gas capacity. If wind production is high during this time, it could attenuate the need for fossil fuel plants. The other increase between 5000 MW to 6000 MW happens entirely during the ramp up from night to mid-morning.

Figure 17.8: Delhi Energy Demand Patterns: Regime Transitions and Variations

A. Delhi: Regime Transition (March to April)



B. Delhi: Months of Highest Peak and Highest Difference



Source: Monthly Reports from Delhi Transco State Load Dispatch Centre and Maharashtra State Load Dispatch Centre

As the air conditioning load increases, this gap may also reduce or increase. The adoption of space cooling by households will increase the night-time load while its adoption at work will increase the day time loads, but to the extent that adoption at work has already occurred, the increment may be less. Electric charging, especially of scooters, will add to the night-time load, thus reducing the gap between the trough and the shoulders. Capacity planning for different types of renewables and their associated storage will need to consider these regime types.

Inter-regional transfers can mitigate the issue. For example, when one combines the monthly peaks for Mumbai and Delhi, the ratio between the maximum and minimum falls from 1.76 to 1.47. Given that there is an almost 30-degree difference in longitude between India's eastern and western ends, solar insolation varies from one end to another. Further, in India, wind resources also vary geographically as shown in Table 17.3. Half the potential capacity is in two states, viz. Rajasthan and Gujarat. Three other states, Maharashtra, Andhra Pradesh, and Karnataka account for almost another 40%. Increased inter-regional transfer capacities benefit in meeting peaks in one region with the supply from another region.

Smart Grids

Smart grid automatically adjusts both demand and supply to maintain grid integrity. This needs two-way communication and devices so both ends can respond to such instructions. For example, to reduce demand, the air-conditioning load can be reduced by adjusting the temperature settings, or supply can be enhanced by ramping up plants or bringing battery storage online, etc. For this the grid needs to be connected and monitorable. How far has India progressed along the road to a smart grid? It has made progress in one direction, i.e., interconnection and begun making progress in another, i.e., metering.

Interconnection

India has one of the largest synchronised power grids in the world. The five regional grids Northern, Eastern, North-Eastern, Western, and Southern are connected to each other through AC and asynchronous links, such as HVDC (High-Voltage Direct Current) back-to-back. The current Inter-Regional power transfer capacity of the National Grid stands at about 118,740 MW of which the public sector, Power Grid owns about 84%. In addition, it has also facilitated the evacuation of more than 110 GW of non-fossil energy capacities (Ministry of Power, 2024). This enables the transfer of power from one region to another and takes advantage of India's span of almost 3,000 km from 68°7'E to 97°25'E.

Smart Metering

There is a national programme on metering that assists the distribution utilities to install smart meters, by providing per meter subsidy to the distribution utility. As shown in Figure 17.9, Panel A, in the first glance it looks as if progress is rapid, with 34 of 95 utilities reporting that more than 90% of the sanctioned meters have been installed and 70 of 94 utilities reporting that more than 90% of the sanctioned meters have been tendered for and awarded. However, a closer look shows that much work remains to be done

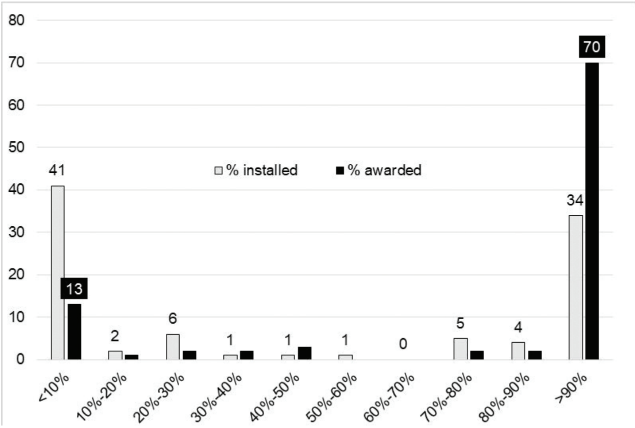
Table 17.3: Wind Power Potential in Wastelands (MW)

Rajasthan	Gujarat	Maharashtra	Andhra Pradesh	Karnataka	Tamil Nadu	Telangana	Others	Total
95821	75766	58546	39922	29659	20175	10517	9706	340112

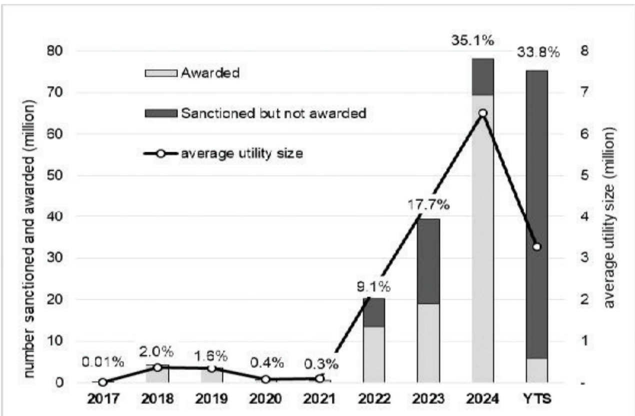
Source: NIWE, 2019

Figure 17.9: Progress of Smart Metering Deployment

A. Number of Utilities by Share of Sanctioned Consumer Meters Installed and Awarded



B. Progress by Time of Deployment Commencement in the Award and Sanction of Consumer Meters



Source: Author's Construct based on Smart Metering Database, National Smart Grid Mission

Note: YTS means yet to start.

As of September 2024, only 117.7 million meters out of a total of 222.4 million sanctioned meters, i.e., just over half, have been awarded and only 14.1 million, i.e., just over 6% have been installed. On distribution transformer metering, while 4.1 million out of 5.3 million sanctioned meters have been awarded, only around 133,000, i.e., 2.5% have been installed. The situation on feeder meters is slightly better, with 130,295 meters of 183,316 sanctioned being awarded of which 61,006, i.e., one-third have been installed (National Smart Grid Mission, 2024).

Figure 17.9, Panel B, shows progress for consumer metering over time. As seen, in the larger utilities, the award of contracts has been relatively recent. In a number of utilities where deployment had begun in 2022, many sanctioned meters have yet to be awarded. For more than 95% of sanctioned meters the deployment had begun only in 2022 and for over a third, (33.8%), it has yet to start.

Smart metering is essential in the new world of distributed generation. While withdrawal points (consumers) were numerous, distributed energy generation moved inputs from a limited number of generating stations to multiple suppliers. Thus, every consumer can also become a supplier, e.g. consumers in India who install solar power can sell back to the grid when they generate more power than what they are consuming[14].

Some initiatives go beyond selling to the grid as they establish a peer to peer (horizontal) market. In a pilot project in the Indian city of Lucknow, residents sold their surplus rooftop electricity production to other prosumers and consumers through the use of a peer-to-peer (P2P) digital trading platform (ISGF, UP Power Corporation Ltd & Power Ledger, 2023). This needs to integrate multiple withdrawals and input points that make the grid a truly complex system to manage, thus requiring a higher degree of "smartness". The ability of AI (Artificial Intelligence) models to analyse large amounts of data in real time and discern patterns that are not easily recognisable by standard data analytic tools makes it a candidate for automating energy management. Box 17.1 discusses some of these issues.

[14] Currently consumers are billed using net metering where the consumer, rather than being metered on his gross consumption is metered based on his consumption net of the energy sold back to the grid. This implies that the power cost to the utility is the same as the consumer tariff, which may need to be addressed.

Box 17.1: Artificial Intelligence and Energy Management

Recently, there was a research analysis on AI and its role in energy-related solutions (Stecuła, Wolniak, & Grebski, 2023). In principle, there is substantial integration of AI and related technologies in high energy use areas, such as heating and cooling, optimising HVAC (Heating, Ventilation, and Air Conditioning) systems, and also lighting, devices, e.g., smart refrigerators, and overall energy management. There are areas for grid integration and synchronisation for charging electric vehicles and when possible, the use of distributed energy reservoirs using electric car batteries. These real-time integrations help in ensuring that energy use is not just optimised but is also synchronised as far as possible to the time when the share of renewable energy in the grid is high, thus reducing generation from fossil fuel sources. One must also consider the fact that AI itself is also responsible for increasing energy use, thus there are negative offsets to these benefits of improved grid efficiency.

There are challenges not only in balancing comfort and efficiency, but also in the choice of timing – when to choose to invest in these technologies. The speed of development of these new technologies is so fast that very quickly the investments become outdated. This breeds a tendency to postpone investments so as to take advantage of newer and better technologies. This is true for the AI component but can also be true for the complementary investments that are needed for various use cases, e.g., using electric car batteries as energy reservoirs.

The use of electric car batteries as renewable energy reservoirs needs investment to equip vehicles for bi-directional charging. This makes it possible to provide energy from vehicle-to-grid (V2G), vehicle-to-home (V2H), and vehicle-to-load (V2L), just like there is net metering for solar power in India. In this regard, some initiatives have already begun and one of the key concerns is that while these batteries provide public benefit by enabling more renewable energy to be used, but it may incur private costs due to frequent charging and discharging of the battery in the process of providing such support. As Adegbohun, et. al. (2024) concludes: "Significant progress on understanding aging-reliability trade-offs will be integral for EVs and charging infrastructure to unlock their full potential within an increasingly complex energy ecosystem". In addition, there are issues with privacy, cybersecurity, standardisation, etc. all of which will affect the adoption of technology.

While AI has the potential to transform urban energy management, it needs more collaboration across researchers, policy makers, and practitioners to overcome challenges and create smarter and more sustainable urban environments.

Institutions

Institutions that influence the decisions referred above are of different scales and types. They can be national (e.g., Power Grid), regional (water utilities) and public (or private or some mix of the two). The institutions that regulate them at the national (CERC) or state (SERC, MWRA) levels or even local level (District Town and Country Planning offices). Even condominium associations could have a regulatory role. In addition, there are standard organisations (for energy efficiency) or regulations for emissions. Many SERCs have mandated various forms of support for renewable power. Transport authorities may be local (BMTC, district transport office), state (APSRTC), or national (Mumbai Suburban rail).

The key challenge is that the multiplicity of institutions needs to be aligned to common energy transition goals. Since they are answerable to different levels of government or even citizens, this is not easy to ensure, but it is necessary if one has to make the urban form energy efficient, green the electric power system, and incentivise climate-positive behaviour in citizens.

For example, it is instructive to consider institutions in the context of community renewable energy projects, whether they are solar installations or community battery back-ups. Such projects have the potential to both save costs for the community as well as deliver benefits at the grid scale. There are at least two possible institutional reasons why India may be better positioned to implement such projects. Both these are driven by the unreliability of supply from the existing grid – which may now become a blessing in disguise.[15]

First, in major cities, as a way of economizing land costs, multi-family housing complexes such as apartment blocks or even clusters of gated single-family homes are becoming common. These are ideal candidates for such initiatives. They have an existing governance structure for collective goods such as security and maintenance, which are usually called Residents' Welfare Association (RWA). Given the unreliability of grid supply, many RWAs provide electricity back-up services through diesel generating sets. Shifting them to solar power with battery back-up (the initial cost could be financed through a private implementation partner) allows the RWA to sell power to the grid, thus creating a source of revenue. However, significant capacity building is required for both the utilities and the RWAs or else these initiatives can devolve into desultory installations of a few roof-top solar assets without substantial benefits to either the RWA members or the grid.

Second, in smaller towns, away from major cities while the RWAs and apartment complexes are less widespread, the unreliability of the electricity grid means that there are entrepreneurs who supply back-up electricity to businesses, especially in market areas. In the same manner as the RWAs, it is possible to re-purpose these institutions to provide community-based renewable energy support. In addition, they also help in shifting the grid load, since evening commercial load contributes to peak demand. Like RWAs, businesses too will benefit from the reduced energy bills.

However, such initiatives need several institutions to work together. First, there are non-government RWAs and private entrepreneurs. Then, there are electricity utilities who enter into arrangements with them even though the utilities may be private or owned by the state (province). Such arrangements which include the relevant tariffs, are overseen by the electricity regulator, which is an independent state-level entity. The assets receive subsidy from a central government entity, e.g. from the *Pradhan Mantri Surya Ghar Muft Bijli Yojana*' (PM-SGMBY). Thus, for even such a local initiative, institutions at local, central, and provincial levels, both private and public are involved. Besides, this is just a subset of institutions, many others such as fire clearances, shops and establishment regulators, etc. can be added to the mix.

[15] The unreliability in grid supply has led individual houses to install "inverters" – devices that use power to charge batteries, which then supply power when there is no grid supply. This investment defrays significant costs where these batteries need to be charged by using local decentralised renewable energy, e.g. solar panels. If unreliability on the grid continues, this will mean that supply from the inverter would increase the renewable share of energy consumed.

Consider another initiative – fare-free public transport, especially buses. This is imperative if the shift has to be made to public transport. To wean people away from the inexpensive and ubiquitous two-wheelers, buses have to be free and frequent and the networks should cover almost all origins and destinations. People need to be assured of being able to get from point A to B as predictably and inexpensively as using a two-wheeler. This is financially feasible, example through a relatively small tax on cars.

Buses are also a more predictable way of electrifying transport, as compared to relying on the electrification of two-wheelers, and have additional benefits of having batteries that act as renewable energy reservoirs. In India, the central Pradhan Mantri E-Bus Sewa is an initiative that expands the concept of gross cost contracts and provides one part of an institutional structure for this to happen. But there are many other parts, e.g., the charging needs to shift to renewable modes, the state transport authorities and local bodies have to provide services, and a manufacturing ecosystem of electric buses has to be developed by the private sector, which is again a mix of public and private institutions at different governance levels, as with community renewables.

Similarly, while local government building codes change building envelops to reduce cooling demands, it will affect only the new structures going forward and thus the impact, even if fully enforced, will be limited. Along with such changes, it is necessary to improve the efficiency of air-conditioners and simultaneously focus on behaviour change of households, which includes pricing of electricity. Again, this brings in multiple institutions.

Why and how should such disparate institutions co-operate towards a common climate goal?

The broader understanding of the importance and existential nature of climate threats might be able to answer the "why" but the answer to the "how" continues to elude us. There are no platforms where such institutions can come together and it is hard to achieve change only through a top-down manner. A platform is needed where people are front and centre of attention, so that there is integrated planning that is based on data, a focus on cities and which empowers the local governments, so that solutions fit the purpose and place by learning from each other across the globe (IEA, 2024).

Such platforms only emerge from either civil society or political actors, who have the power to bring different technocratic and bureaucratic elements together. To make it sustainable and not episodic, even if the initial coming together is driven by civil society, its continuance and institutionalisation, e.g., through currently dormant bodies such as Metropolitan Planning Committees or by expanding the roles of bodies such as District Transport Authorities, needs political acceptance and legislative action. Without politics, there is no permanence.

Conclusion

This chapter focused on urban forms, especially the built-up expansions, household behaviours with respect to air-conditioning and transportation, the potential of smart grids, and the role of AI. In all these, as emphasised in the immediately preceding section, multiple institutions play a significant role and coordination across these institutions is critical in achieving the desired outcomes.

Ensuring high quality transportation, e.g., free buses along the infrastructure corridors and in the core city, and allowing mid-rise mixed-use densification along corridor buffers ensures that the built-up growth is more environmentally sustainable. As discussed, managing the inevitable growth in electricity and fuel demand due to rising air-conditioners and two-wheeler use needs multiple interventions in energy efficiencies and household behaviours. As technology changes, the focus of interventions, whether technical/technological or socio-economic or institutional would evolve.

The critical question is whether there are institutions in place that can engage with these changes and respond in a manner that is appropriate and which will affect household choices such that it improves environmental sustainability and reduces climate risks. As of now, such institutions, even if present, are not active. The challenge of urban climate governance, especially with respect to electricity and power, is to animate them. Let us hope that there is still enough time to do so.

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