Chapter 9
Securing Cities for Energy Needs

Rangan Banerjee

Abstract Cities are critical for the development of any country. For cities to grow, securing energy supply is important. This chapter reviews the energy needs of Indian cities based on end uses (cooking, lighting, motive power, transport) and source (LPG, electricity, diesel, kerosene, biomass). Electricity accounts for more than 50 % of the supply mix in terms of primary energy for most cities. Daily and seasonal variations in the demand for electricity for Indian cities show morning and evening peaks (6 pm to 10 pm). The growth rates for electricity demand range between 5.1 and 10.6 % for a sample of 12 Indian cities. Most Indian cities face electricity shortages often dealt with by load shedding (curtailment of supply). The threats to energy security for cities include supply–demand mismatch, supply disruptions, market volatility, climate variations, etc. Possible responses to ensure energy security involve enhancement of renewable supply, energy efficiency and demand side management (DSM), smart grids, mass transit, zero energy buildings and sustainable urban design. Tracking the energy and carbon performance of cities in a transparent fashion is a prerequisite for planning future sustainable energy services for the city. Securing energy needs for cities would need changes in our approach to planning cities and implementing projects.

9.1 Introduction

Cities are critical for the development of any country. There is a global trend of increasing urbanisation (UN Habitat 2013; UNEP 2011). Figure 9.1 shows the Human Development Index (HDI) for different cities in the world and the corresponding HDI for the country in which it is located. It is clear from the figure that HDI for the cities is higher than the average HDI of the country in which it is located. This difference is more pronounced in the developing countries. Cities also have a higher energy intensity per capita and emissions per capita than the rest of

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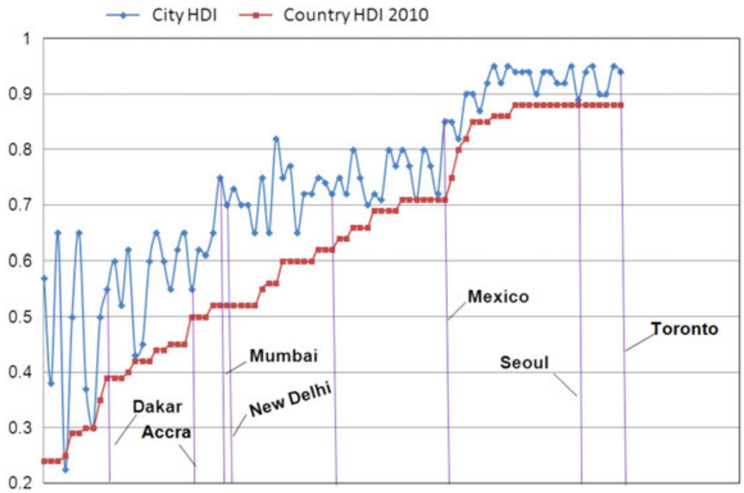

Fig. 9.1 Human Development Index (HDI) for different cities in the world (Source: UN Habitat 2013)

the country. Cities account for a larger proportion of the income of the country resulting in a higher gross domestic product (GDP)/capita than the rest of the country. In 2008, 30 % of India's population lived in cities but accounted for about 58 % of the country's GDP.

India's urban population grew from 290 million in 2001 to 340 million in 2008 (a compound annual growth rate of 2.3 %). A Mckinsey study (McKinsey 2010) projects growth of urban population to 580 million in 2030 and a total share of 40 % of the country's population. India has 42 cities with population greater than one million. The number of cities with more than a million population is expected to grow rapidly in the future.

Cities are clearly important for India's development and growth. They are a source of prosperity and GDP growth and provide employment opportunities for the population. The challenge of securing energy needs for growing cities is important for their growth.

9.2 Energy Security

What is energy security? Cherp and Jewell (2011) provide a definition and a perspective of energy security. This is depicted in Fig. 9.2. Energy security is normally a priority at a national level. The objective is to provide uninterrupted energy services. The three elements of energy security identified are sovereignty, resilience and robustness. Sovereignty indicates the protection from external threats. Robustness implies adequacy of resources, affordable energy prices and reliable energy infrastructure. Resilience of the energy system is defined as the ability of the

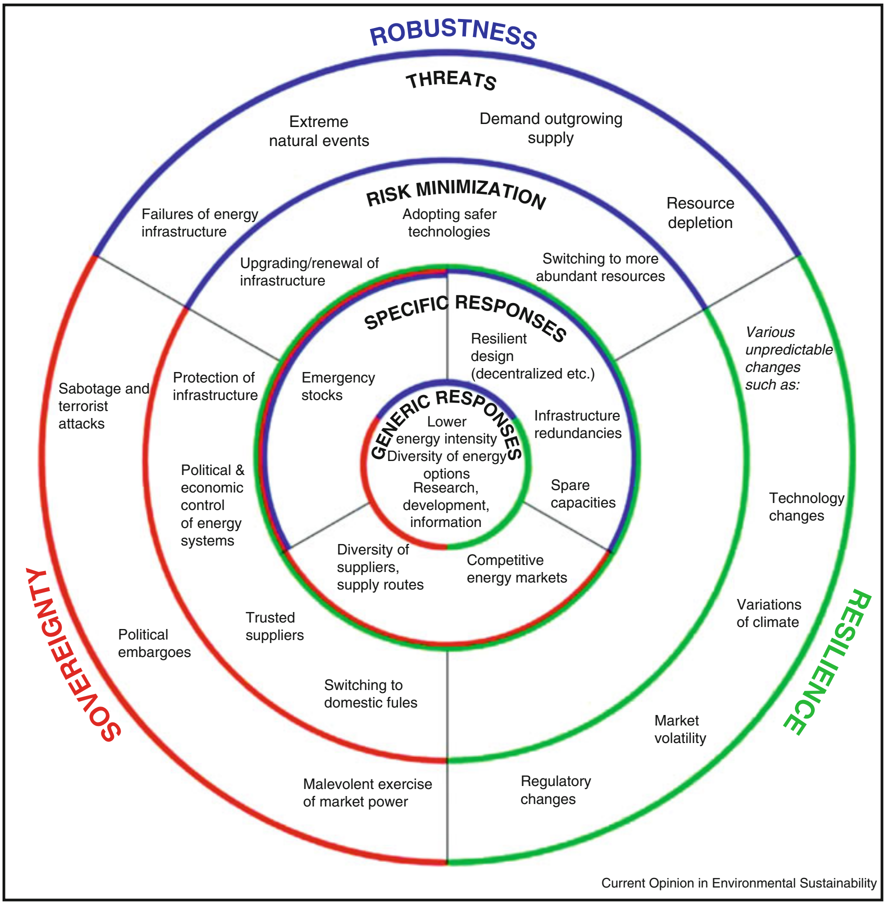

Fig. 9.2 Perspectives on energy security (Source: Cherp and Jewell 2011)

system to withstand disruptions. The threats and responses possible for each of these measures are shown in the figure.

This framework can be used to understand the basis for securing cities for future energy needs. In order to understand this, it is essential to analyse the energy needs of cities. This is done in the context of Indian cities.

9.2.1 Energy Needs of the City

What are the energy needs of cities? Figure 9.3 shows the energy flow diagram showing the chain from primary energy that is available in nature (coal, oil, natural gas, solar energy) to secondary energy to the final energy or the delivered energy that is bought by the consumers. Each of the conversion steps or processes has

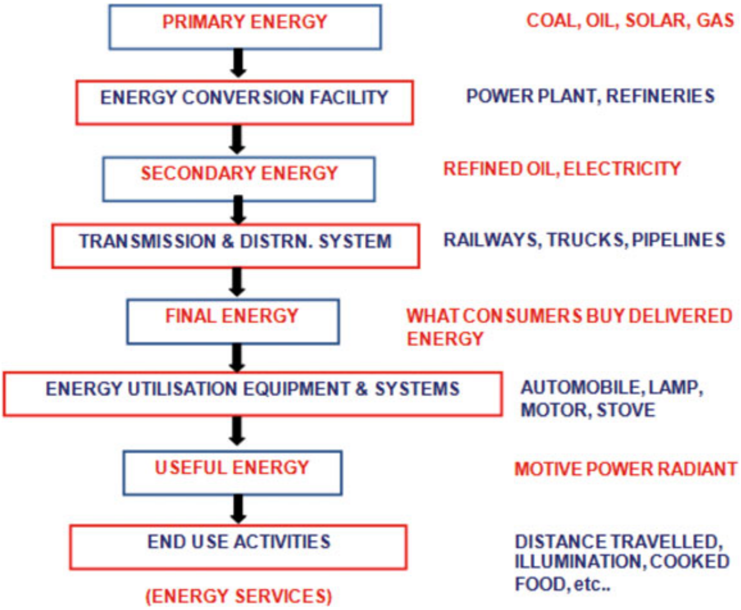

Fig. 9.3 Energy flow diagram (Source: Developed by the author)

associated with it some losses. The final energy bought by consumers is utilised in end-use equipment to provide energy services.

In cities the different sectors where energy is used are the residential, transport, industry commercial and municipality sectors. The major end uses are cooking, cooling, heating, appliances, motors and water pumping. Most cities are driven by fossil fuels. This includes diesel, petrol and compressed natural gas (CNG) for transport; LPG, kerosene and fuelwood for cooking; and electricity for lighting, appliances and motive power. Normally aggregate energy balances are not available for cities and have to be compiled from different sources and are subject to uncertainties. Figure 9.4 shows the share of final energy used in Mumbai in 2010 as estimated by Reddy (2013). The direct final energy use was 14.7 GJ/capita for Mumbai. In terms of primary energy, the share of electricity would be higher (as the electricity delivered would be divided by the conversion efficiency of about 30 %). For Mumbai in 2010 in terms of primary energy, the electricity share would be more than 60 %. Agra's energy balance has been estimated by ICLEI (2011).

Among the energy supply option, electricity is particularly important since it is a convenient energy source and tends to substitute other sources with increasing income. Electricity supply needs investment in generation, transmission and distribution infrastructure. Table 9.1 shows a comparison of the four large metros in terms of area, income, energy use and carbon dioxide footprint. Some of the differences in the indices can be accounted for – e.g. Bengaluru has a lower carbon dioxide footprint since the electricity generation has a larger share of hydro. However, Kolkata's larger carbon footprint seems to be caused by data inconsistency and

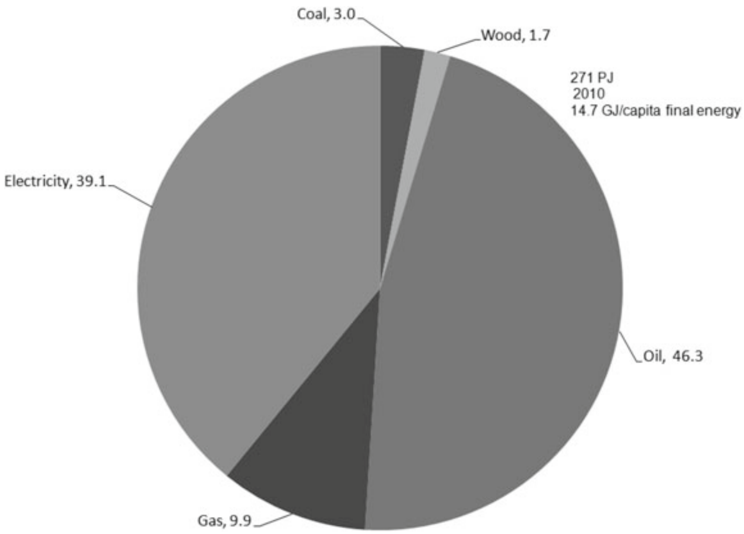

Fig. 9.4 Mumbai – final energy mix (Source: Reddy 2013)

Table 9.1 Comparison of large metros in India

	Population million	Area (km^2)	GDP/capita US$	Energy/capita	CO_2 emissions/ capita
Mumbai	12.7 (24)	468	2,184	14.2	1.0
Delhi	17.4	1,483	2,004	15.4	1.1
Kolkata	15.6	1,851	1,414	5.65	1.5
Bengaluru	7.1	710	2,066	9.5	0.5

Source: Asia Green City Index (2011)

uncertainty. It is important to be able to accurately quantify and benchmark the energy use by sector and end use for different Indian cities.

The energy use for the transport sector of a city would depend on the share of mass transport, share of the mode of transport, layout and design of the city and income of the city. Using data from Reddy and Balachandra (2010) for the transport use and income for Indian cities in 2005, a scatter plot is shown in Fig. 9.5. It is seen that the transport energy use varies from 0.5 to 2 GJ/capita/year and does not show any clear correlation with income.

9.2.2 Variation in Energy Demand and Growth Rates

Aggregate load profiles of different cities are available from the load dispatch centres for each state. Figure 9.6 (MSLDC 2013) shows the sample load curve for Mumbai in the summer of 2013. Most Indian cities have their maximum period of

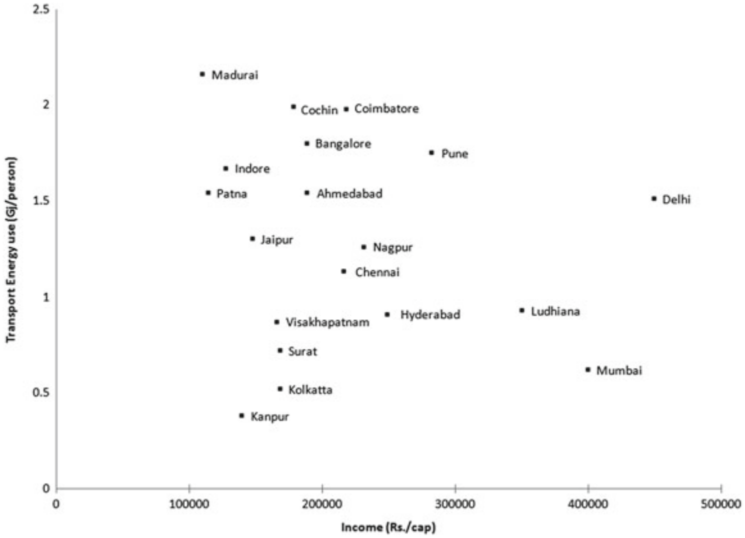

Fig. 9.5 Transport energy use per capita and income in Indian cities in 2005 (Source: Reddy and Balachandra 2010)

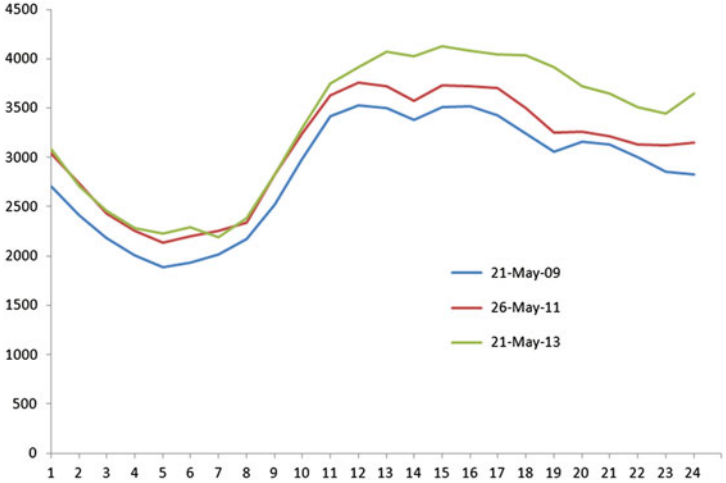

Fig. 9.6 Mumbai electricity load profile (Source: MSLDC 2013)

electricity consumption (peak) during the evening and night (7–10 p.m.) when the residential and commercial lighting and appliances loads come onto the system. The morning peak is caused by the office loads and air-conditioning coming onto the system. Between the morning and the evening peaks is a period of high consumption (partial peak) or shoulder region. During the night, there is a period of low consumption (11 p.m. to 6 a.m.). In some cities, there is a significant seasonal

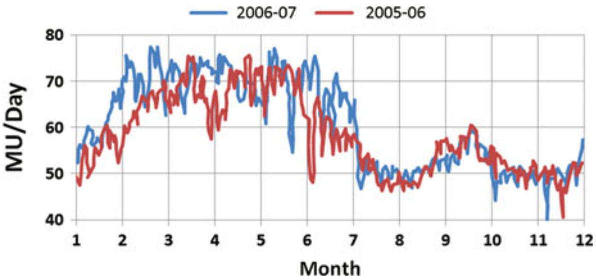

Fig. 9.7 Seasonal variations – Delhi (Source: NRLDC 2006)

Table 9.2 Electricity supply – Indian cities

	Average MW	Peak MW	Average/peak	Annual growth rate
Lucknow	553	750	0.73	6.5
Kanpur	348	580	0.6	5.4
Jaipur	446	771	0.58	10.6
Ahmedabad	897	1,320	0.68	7.4
Surat	917	1,309	0.7	6.6
Nagpur	264	315	0.83	7.6
Indore	229	391	0.59	10.2
Pune	886	1,173	0.76	10.5
Mumbai	2,524	3,605	0.7	6.9
Hyderabad	1,544	2,134	0.72	8.2
Chennai	1,743	2,291	0.76	5.6
Bengaluru	1,404	2,090	0.67	5.6
Kolkata	1,773	2,577	0.69	5.1

Source: CEA (2013)

variation in the cities' electricity use pattern. Figure 9.7 shows the seasonal variation in the electricity use for Delhi (NRLDC 2006). It is clear that electricity demand in summer is significantly higher than the winter demand mainly due to the increased demand for air-conditioning.

Table 9.2 shows the average system power demand (MW) and the peak power demand (MW) for select India cities and the annual growth rates. It is seen that the annual growth rates are high ranging from 5.1 to 10.6 % per year. CEA projects these growth rates as the expected growth continuing for the next decade. This implies significant increases in the electricity supply and investments in the transmission and distribution infrastructure. The average demand to the peak demand depends on the nature of the load variation and the share of industrial and commercial loads.

Most cities in India have a shortage of electricity supply. This is managed by load shedding (curtailment of supply). A study by Wartsila in 2009 surveyed the load shedding in different cities in India. In most international power systems, supply and demand match and loss of load expectation is low and rare. In many Indian cities,

Table 9.3 Load shedding seasons

S.No.	City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1	Bangalore	▓	▒	▒	▒	▓	▓	▓	▓	▓	▓	▓	▓
2	Bhopal	▓	▓	▒	▒	▒	▒	▓	▓	▓	▓	▓	▓
3	Chennai	░	░	░	░	░	░	░	░	░	░	░	░
4	Coimbatore	░	▒	▒	▒	▒	▒	░	░	░	░	░	░
5	Delhi	▓	▓	▓	▒	▒	▒	▓	▓	▓	▓	▓	▓
6	Faridabad	░	░	░	▒	▒	▒	░	░	░	░	░	░
7	Gurgaon	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
8	Hyderabad	▓	▓	▒	▒	▒	▓	▓	▓	▓	▓	▓	▓
9	Indore	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
10	Kanpur	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
11	Lucknow	░	░	░	▒	▒	▒	░	░	░	░	░	░
12	Ludhiana	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
13	Madurai	░	▒	▒	▒	▒	▒	░	░	░	░	░	░
14	Mumbai	░	░	░	░	░	░	░	░	░	░	░	░
15	Mysore	▓	▒	▒	▒	▓	▓	▓	▓	▓	▓	▓	▓
16	Navi Mumbai	░	░	▒	▒	▒	░	░	░	░	░	░	░
17	Noida	░	░	▒	▒	▒	░	░	░	░	░	░	░
18	Pune	░	░	▒	▒	▒	░	░	░	░	░	░	░
19	Rajkot	░	░	░	░	░	░	░	░	░	░	░	░
20	Vadodara	░	░	░	░	░	░	░	░	░	░	░	░
21	Vishakapatnam	▓	▓	▒	▒	▒	▓	▓	▓	▓	▓	▓	▓
Severity of daily outage		▓	No outage			░	Non peak months			▒	Peak months		

Source: Wartsila (2009)

Table 9.4 Load shedding estimates – Indian cities

Severity of power outage across the weak - peak & non -peak season															
		Peak season							Non-peak season						
No	City	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
1	Bangalore	1.5	1.5	1.5	1.5	1.5	1.5	1.5	▨	▨	▨	▨	▨	▨	▨
2	Bhopal	2.5	2.5	2.5	2.5	2.5	2.5	2.5	▨	▨	▨	▨	▨	▨	▨
3	Chennai	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5
4	Coimbatore	2	2	2	2	2	2	2	1	1	1	1	1	1	1
5	Delhi	2	2	2	2	2	2	2	▨	▨	▨	▨	▨	▨	▨
6	Faridabad	5	5	5	5	5	5	5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
7	Gurgaon	5	5	5	5	5	5	5	4	4	4	4	4	4	4
8	Hyderabad	1	1	1	1	1	1	1	▨	▨	▨	▨	▨	▨	▨
9	Indore	2	2	2	2	2	2	2	2	2	2	2	2	2	2
10	Kanpur	7	7	7	7	7	7	7	6	6	6	6	6	6	6
11	Lucknow	3.5	3.5	3.5	3.5	3.5	3.5	3.5	1	1	1	1	1	1	1
12	Ludhiana	4	4	4	4	4	4	4	4	4	4	4	4	4	4
13	Madurai	2	2	2	2	2	2	2	1	1	1	1	1	1	1
14	Mumbai	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
15	Mysore	2.5	2.5	2.5	2.5	2.5	2.5	2.5	▨	▨	▨	▨	▨	▨	▨
16	Navi Mumbai	2	2	2	2	2	2	2	1	1	1	1	1	1	1
17	Noida	5	5	5	5	5	5	5	2	2	2	2	2	2	2
18	Pune	3	3	3	7	3	3	3	Infrequent upto 1h			5	Infrequent upto 1 h		
19	Rajkot	Infrequent upto 3 h. No fixed pattern							Infrequent upto 1 h. No fixed pattern						
20	Vadodra	Infrequent upto 3 h. No fixed pattern							Infrequent upto 1 h. No fixed pattern						
21	Vishakapatnam	2	2	2	2	2	2	2	▨	▨	▨	▨	▨	▨	▨
Severity of daily outage			▨	No outage		░	>0<3 h		▓	>=3<6 h		▒	>=6 h		
Note: Numbers in the table indicate the average daily outage hours															

Source: Wartsila (2009)

the supply demand mismatch persists over years. There are often load shedding schedules. However, there are no accurate methods of quantification of load shed and the losses due to the non-availability of electricity supply. Tables 9.3 and 9.4 provide an estimation of load shedding seasons and the number of hours of load shed during these seasons for some Indian cities in 2008. It can be seen that load shedding is a widespread phenomena in most Indian cities with the summer months seeing more load shedding.

Unlike electricity, the variability in transport or cooking energy does not need to be planned for in terms of storage or capacity. The growth in personal transport vehicles in cities poses a problem in terms of congestion of roads, local emissions, lack of parking space and increased travel times.

9.3 Threats to Energy Security

(a) *Demand outgrowing supply* – The rapidly growing demand makes it difficult for investments in new supply to keep pace with the demand. This often results in peak and energy shortages.
(b) *Non-availability of fossil supply* – Non-availability coal supply to power plants on LPG supply to cities can also result in shortages. Resource depletion is a key threat for fossil fuel supplies to cities.
(c) *Disruptions/failures in supply network* – There have often been cascaded failures in the electricity grid due to overdrawal and poor grid management that have resulted in outages of the electricity supply to cities.
(d) *Variations in climate* – Changes in the climate patterns resulting in extreme temperatures may impose increases in the electricity demand that are difficult to meet. Changes in the rainfall pattern can affect the availability of water to the cities and may need a higher energy cost in transporting/pumping water from other locations.
(e) *Extreme natural events* – Floods, cyclones, and other extreme natural events can disrupt the energy infrastructure of cities and result in prolonged energy shortages.
(f) *Market volatility* – Often cities are depending on procuring energy from other suppliers. Fluctuations in market prices and demands of energy may affect the cities' ability to secure its energy supply.
(g) *Sabotage* – The energy infrastructure is susceptible to sabotage and terrorist attacks. Blockages of roads and ports and disruptions in pipelines and transmission networks can disrupt the energy supply and the functioning of cities.
(h) *Environmental impacts and health* – The adverse impacts of vehicular fuels and solid cooking fuels can result in poor indoor and outdoor air quality and have an impact on increased respiratory diseases in the city.

9.4 Responses

9.4.1 Renewable Energy Supply

Figure 9.8 shows a schematic of possible renewable energy sources for the different end uses required for the residential sector. Renewable energy technology is available and can provide reliable supply. The costs are higher than existing fossil sources but costs are rapidly coming down. The commercial sector and high-usage

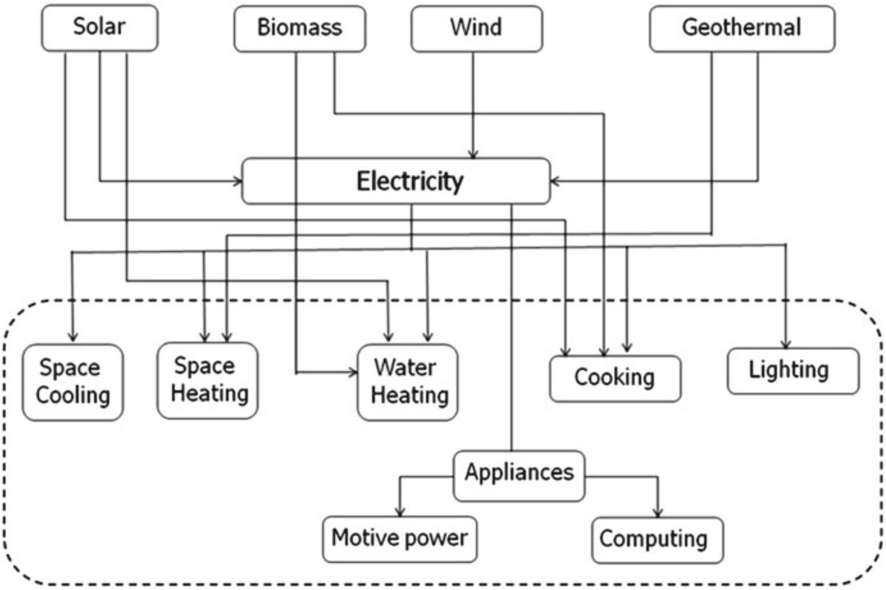

Fig. 9.8 Schematic of renewable energy options for buildings (Source: Developed by the author)

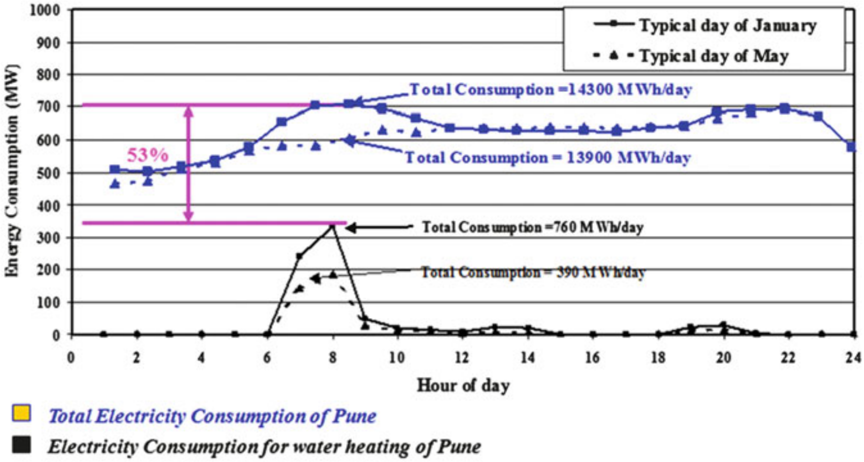

Fig. 9.9 Load profile and electric water heating share for Pune (Source: Pillai and Banerjee 2006)

residential sector pay significantly high tariffs for electricity (Rs. 8–10/kWh) in some cities in India (e.g. Mumbai). At current prices, solar water heaters are cost-effective as replacements for electric geysers with payback periods less than 3 years.

Solar water heaters have significant penetration in cities like Bangalore and Pune. Figure 9.9 shows the potential for morning peak reduction through a solar water heating programme for Pune. It is seen that electric water heaters contribute significantly to the morning peak load.

Solar photovoltaic modules on the rooftop can supply the cities' electricity requirement during the day. A study for Delhi indicated a potential of 2 GW of PV peak in the national capital region. The National Solar Mission emphasised large-scale MW-based grid-connected PV power at preferential tariffs. Similar incentives should be made available to rooftop-based PV systems for cities. Distribution companies should facilitate the connection of rooftop PV systems with net metering and buy-back schemes.

9.4.2 Energy Efficiency and Demand Side Management

Distribution and energy supply companies need to invest in demand side management – modifications of the customer load profiles to provide benefits to the utility and society. Energy-efficient lighting (incandescent to compact fluorescents (CFLs) and light-emitting diodes (LED), efficient fluorescents, lighting controls, etc.), replacement of conventional ceiling fans of rating 70 W by Brushless DC fans (BLDC fans) of rating 36 W, efficient appliances and efficient air-conditioning systems and controls are cost-effective as retrofits for many commercial and high-usage residential consumers.

A study of an office building in Mumbai (Puradbhat and Banerjee 2014) illustrates the potential of DSM in modifying the electricity load profile as shown in Fig. 9.10. DSM programmes like energy-efficient fans, efficient lighting and air-conditioning are cost-effective and can result in a reduction of electricity consumption and peak demand. Cool storage (chilled water or ice storage) can be used in large central air-conditioning systems as a technique for load shifting. This is viable under the differentials provided by time-of-use tariffs.

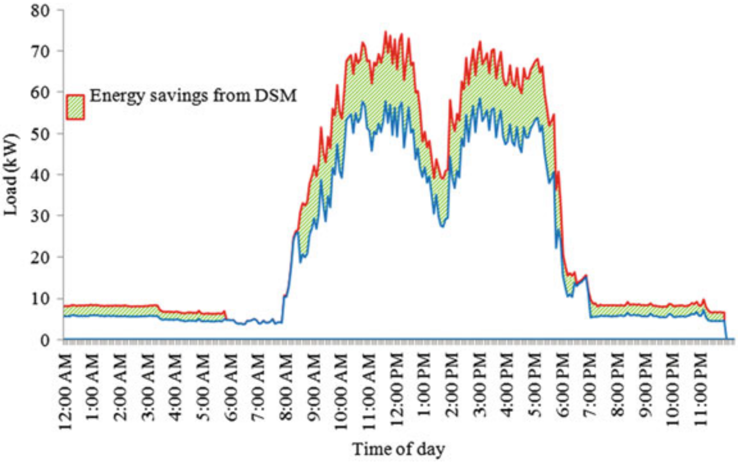

Fig. 9.10 Load profile of an office building (Source: Puradbhat and Banerjee 2014)

Some urban distribution utilities have invested in pilot DSM programmes. In order for future electricity systems to be affordable and more secure, large-scale implementation of DSM programmes should be supported.

9.4.3 Captive and Industrial Power Plants

An option to mitigate load shedding is the use of surplus captive and industrial power plant capacity. In 2006, the Confederation of Indian Industries (CII) estimated that 90 MW of load shedding was being imposed on Pune. CII identified 100 MW of captive generators in the industrial sector of Pune. A special tariff of the regulatory commission (MERC) was provided for the variable cost of generation from captive power plants ranging from Rs. 8.24 to 11/kWh. In Pune, Tata Power took on the responsibility of a distribution franchisee. This demonstrates that local solution to mitigate load shedding is possible with industry's help.

9.4.4 ICT, Smart Grids and Demand Response

Flexibility and control of loads in urban grids through improved use of ICT can be used for demand response and help electricity grids become more resilient and cost-effective. The key issue for affordability is the transaction costs of hardware and software solutions. One of the solutions that Mumbai has used has been islanding – where sensors detect conditions in the rest of the grid and isolate (or island) the Mumbai grid from the rest of the national grid in the face of impending grid failures.

9.4.5 Mass Transit

Policies of cities must encourage mass transit systems – metros, high-speed bus transits and suburban railway systems. Prioritising investments for these systems and providing accurate timetabling and information about mass transit systems can enable larger shares of passenger-kms in these systems and reduced energy intensities.

9.4.6 Benchmarking Energy and Emission Performance of Cities and Localities

Energy and emission balances for cities need to be computed and the performance of different cities compared on an equivalent basis. The direct primary energy and final energy use per person per year or per GDP can be compared. The electricity used per unit area per year or the electricity used per person per year can also be used as an indicator. The share of renewable energy in the cities' final energy or primary energy mix can also be tracked along with the carbon footprint of the city.

9.4.7 Zero Energy Buildings and Energy Plus Houses

It is possible to design houses with solar passive concepts to maximise the use of daylighting and minimise the needs for air-conditioning. The use of efficient appliances can contribute to a reduction of the electricity requirement per unit area to barely 10–20 % of the present averages. This reduced energy requirement can be provided by rooftop solar thermal and solar photovoltaics.

9.4.8 Bikable, Walkable Cities and Sustainable Urban Design

Integrated planning of cities to reduce the need for travel and provide special paths for biking and walking along with access to mass transit systems can transform the energy profile of cities. Rainwater harvesting and converting wastes to energy can help make cities more sustainable. Retrofit solutions can reduce the energy and carbon footprints of existing cities. Innovations and new design coupled with detailed computer simulations and analytical models can help evolve more sustainable urban design for future cities of India.

9.5 Conclusions

Cities are likely to provide the impetus for growth in India. The share of urban population is likely to increase in the future. Creating energy security for cities is critical to enable their growth. In order to do this, it is important to understand the existing energy use patterns in the cities. The adoption of energy efficiency and renewables can help improve the energy security and sustainability of cities. Tracking the energy and carbon performance of cities in a transparent fashion is a prerequisite for planning future sustainable energy services for the city. Several technological and design solutions exist and may be cost-effective if financed appropriately. Appropriate policies are needed to examine the city's future energy, water and waste removal needs in an integrated fashion. Securing energy needs for cities would need changes in our approach to planning cities and implementing projects.

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