The Co-Benefits of Energy Efficiency Policy to Manage the Electric Load in Delhi

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Abstract

Delhi's power demand has been increasing continuously and the dependence on the power from outside has been increasing simultaneously. Satisfying this rapidly rising demand requires huge investments, and these investments usually have significant social, and environmental consequences. The supply-side measures of meeting the growing demand for electricity will require not only increasing generating capacity, but also improving the transmission and distribution systems. The solution to this problem is to use the conventional resources more efficiently, while simultaneously developing new sources of energy. This paper has been written to address a policy designed to reduce the growth rate of electricity demand through adopting more efficient technologies in residential and commercial sectors in the city of Delhi as well as introducing the use of renewable energies and clean technologies in the city's power supply sector. The results show the saving at the end-user level would be 0.75 TWh/yr per annum, which could be achieved through improving lighting efficiency and air conditioning performance and replacing conventional water heater with efficient solar water heater in certain categories of building. On the power supply sector, the introduction of about 5MW of medium- and large-sized PV systems beside the installation of about 100 MW new capacity for hydroelectricity and generating approximately 46 MW electric power from municipal solid waste could enable a sufficient surplus for the power supply sector to meet the city's electricity demand. Finally, the Co-benefit arising from the implementation of the policy in the city of Delhi is estimated about 328 kt/yr

Keywords: Electric load, Co-benefit, supply, demand, Delhi

Introduction

Managing the electric load is all about matching supply and demand. In some case, cities may be faced with the increasing deficit in power supply, both in meeting its normal electricity requirements as well as its peak load demand. It means that the total installed power capacity is not sufficient to meet the city's electricity demand over the certain time period.

In spite of a total installed power generation capacity of about 7249 MW (as of April 2013), Delhi is still struggling to meet increasing power demand [1] . Delhi is being a city state with diminishing rural areas and agricultural activities, the thrust on the energy front in Delhi is mainly to have uninterrupted power supply and to take care of the increasing power demand. The demand and supply gap in the present phase is estimated about 6.5% due to growing demand. Delhi's demand can go up to 23 TWh/yr or even more and the gap between demand and supply is expected to grow further in the coming years.

The gap between supply and demand can be bridged only with structural reforms in the energy sector. These reforms will however take time to be implemented considering the numerous challenges involved. Consumers can mitigate these rises by taking pro-active measures. Energy efficiency, re-scheduling of operations to benefit from low off-peak tariffs and investment in renewable energy are immediate opportunities for mitigating increase in energy costs.

The aim of this paper is to analyze the power crisis in the city of Delhi as a function of both supply and demand. Given the history of underachievement in meeting the supply-demand gap, we explore some short and medium-term solutions both on supply and demand side. Adding generation capacity alone will not solve the power crisis in this big city. Efforts need to be made on the demand side as well, even though demand-side solutions can not replace supply augmentation in satisfying Delhi's power hunger. So, what short and medium-term options are available on the supply and demand sides? What are the upcoming climate co-benefits of these options? In this paper, we explore these questions looking at the Delhi power system and evaluating possible policy choice.

Delhi Power System

The power requirement in Delhi is met by generating capacity within Delhi, allocations from Central Generating Stations (CGS). The city's power plants, due to problems of low age, generate way below their capacity, at the plant load factor of 45%. The total installed capacity in Delhi is represented in table 1 [2]. The existing network of DTL consists of a 400KV ring around the periphery of Delhi interlinked by the 220KV network spread all over the city [3].

Table 1. Installed capacity to meet electricity demand in Delhi []

	Installed capacity (MW)
Coal fired	4259
Oil fired	297
Natural gas	1886

Nuclear	122
Hydro Power	666
Solar PV	3
Waste-to-electricity	16
Total	7249

The share of coal and other fossil fuels is expected to be about 88.8 per cent in total commercial energy produced by 2013. Other renewables such as wind, geothermal, solar, and hydro electricity represent a 9.2 percent share of the Delhi state electricity mix. Nuclear holds a two percent share.

Delhi has the highest per capita power consumption of electricity among the States and Union Territories of India The per capita consumption of electricity in Delhi has increased from 1259 GWh per annum in 2000-01 to 1448 GWh in 20010-11 [4].

In Delhi, domestic (Residential & Commercial) customers dominate the electricity consumption profile not only in terms of numbers but also in terms of load and consumption. Figure 1 shows the electricity consumption of different sectors.

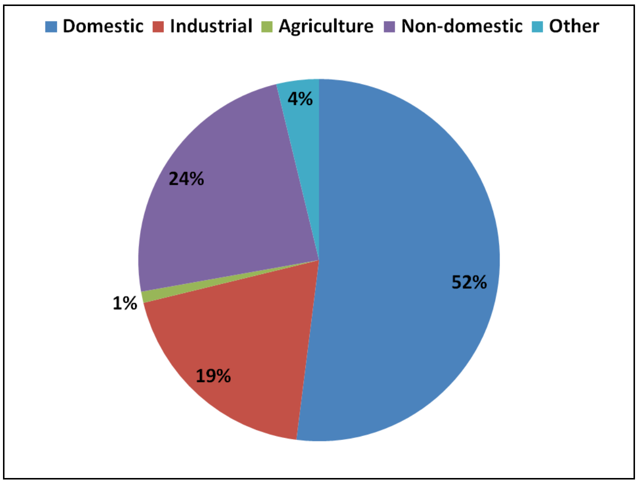

Fig. 1. Delhi sector-wise electricity consumption [3]

Total consumption of electricity in the domestic sector as a percentage of total demand has been increased to 52% in 2010. Total consumption of electricity in Delhi during 2011-12 is 21700 GWh out of which 10396 GWh used for domestic purpose, 6253 GWh used for non-domestic purpose, 2989 GWh used for industrial purpose and rest in others.

There has been a consistent gap between electricity requirement and availability and between peak demand and peak met. The peak seasons in Delhi coincide with that of the other nearby states, thereby creating a peak deficit in the grid. The peak demand is increasing every year, while the load shedding has reduced tremendously. Figure 2 highlights with peak demand in Delhi likely to increase to 5942 MW by 2013, the gap between demand and supply is expected to grow up to 6.5% [5].

Owning to their dominance in the overall consumer profile, domestic consumers also contribute to a high residence of peak load and it would be worthwhile to examine the introduction of managing demand and improving the efficiency of various end-use appliances to reduce power demand in residential and commercial customers and its impact on the overall load profile of the city.

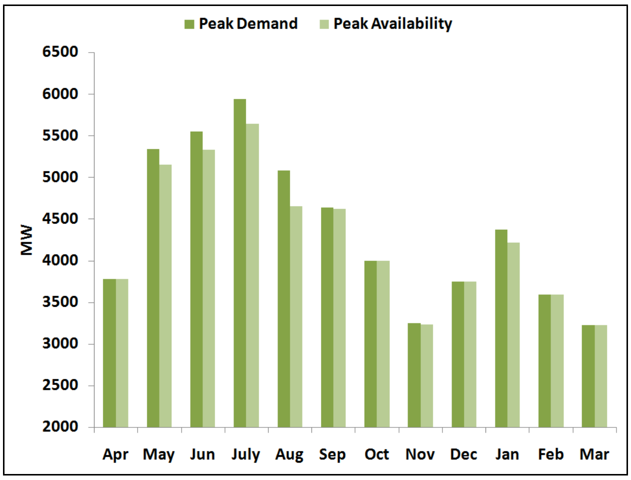

Fig. 2. Month wise power supply/demand position of the city of Delhi during the year 2012-13 (in terms of peak demand) [4]

Methodology

A large number of urban climate-energy evaluation models now exist with different assumptions about the important features of city's profile that need to be incorporated. These models have been developed to incorporate urban features for different applications climate-energy modeling.

SynCity is a model for the integrated assessment and optimization of urban energy systems, developed at Imperial College London and supported by funding from BP. The model has been developed on the basis of a mixed-integer linear programming approach that seeks to satisfy urban demands for housing and activity provision, while minimizing energy demand from buildings and transport [6]. "MEU" is the acronym for 'Innovative tools for planning and management of energy systems in urban areas'. The main goal of this model is to evaluate the impact of the regulatory framework (Laws, subsidies…) on decision processes and on energy supply systems design [7]. An audit tool that evaluates a city's urban mobility policies is developed as QUEST by the European Commission. The aim of the QUEST audit is to support cities in their efforts of developing more sustainable urban mobility systems [8]. ICES Municipal Policy Toolkit takes advantage of cross-sectoral opportunities in the areas of land use, infrastructure, building, water and sanitation, transportation, and waste which is developed by the Canadian Urban Institute [9]. Across these schemes a wide range of urban features is incorporated. The models have varying levels of complexity, and different approaches.

The CAUES (Co-benefits Assessment tool in the Urban Energy System) is a simulation model designed for evaluating the climate co-benefits of an urban energy system in the short term which is developed by UNU-IAS. The tool evaluates climate co-benefits of the urban energy system based on different scenarios of socioeconomic, technological and demographic developments and relates systematically the climate change based on the specific energy demand in different sectors in cities to the corresponding social, economic and technological factors that affect this demand. The nature and level of the demand for energy are a function of several determining factors, including population growth, number of inhabitants per dwelling, number of electrical appliances used in households, local priorities for the development of certain economic sectors, the evolution of the efficiency of certain types of equipment, penetration of new technologies or energy forms, etc.

The objectives of the methodology which is used through developing the tool can be categorized as follows:

- ✓The structural changes in the energy system of a city in the short term. This is done by means of a detailed analysis of the social, economic and technological characteristics of the given city's energy system. This approach takes especially into account the evolution of the social needs of the population, such as the demand for space heating, lighting, air conditioning, and this as a function of the distribution of population into different dwelling ranges; the city's policies concerning, housing etc., as well as the technological development;
- ✓The evolution of the co-benefits resulting from the structural changes in the energy system.

In this survey, CAUES has been used to simulate the gap between electricity supply-demand of the city of Delhi and to estimate the potential reduction of GHG emission and air pollution by offsetting the existing gap through the following steps:

Estimation of the electricity supply-demand

The tool calculates the total electricity demand for each end-use category, aggregating the Delhi energy system into three main "energy consumer" sectors: Residential, Commercial and Service. According to this procedure, the demand for each end-use category of electricity is driven by one or several socioeconomic and technological parameters, whose values are given as part of the scenario. The calculations for the domestic sector are performed taking into account the living conditions of the population, i.e. the place of residence (city local climate conditions), and type of residence (dwelling mode and size). This permits a better representation of the proper needs of the individuals, of their living style, as well as a more appropriate definition of the potential markets for the alternative forms of final energy and using new technologies. The final electricity demand is then calculated from the penetration into the potential market and the efficiency of each energy form (network loss, heat loss, COP) as specified in the assumptions.

The tool estimates the total electricity required to meet the energy demand for each end-use category in Delhi, segregating whole urban power supply system into different electricity generation technologies through considering two connection modes: On-grid (from the network) and Off-grid (District Generation) by using the set of following equations:

$$\mathrm{ELEC_k(GWa)} = \left[\mathrm{Cap_k(GW)} \times \mathrm{OF_k}\left(\frac{\mathrm{h}}{\mathrm{yr}}\right) \times \mathrm{LF_k(\%)}\right]/8760 \quad (1)$$

$$\mathrm{ELEC_T(GWa)} = \sum_{\mathrm{k}} \mathrm{ELEC_k} \quad (2)$$

Where : $\mathrm{ELEC_k}$, $\mathrm{Cap_k}$, $\mathrm{OF_k}$, $\mathrm{LF_k}$ and $\mathrm{ELEC_T}$ are defined respectively as: annual electricity generation form technology k, installed capacity of technology k, annual operation, the load factor of technology k and total annual electricity generation.

Managing the electricity load

To ensure supply can meet expected demand at a given moment in time *t*, the city's power supply system must plan and procure generation in staggered amounts over the course of time leading up to time *t*. The level of demand for electricity in a city varies hourly, daily and seasonally as well as regionally. In this case, local generations can be able to concurrently match or exceed that portion of demand for electricity at each moment in time. The CAUES provides a simple approach to formulate matching electricity supply with demand in the context of the capacity constrained electricity system by introducing the build-up new capacity variable as follows :

$$F_{T_{\mathrm{elec}}} = \mathrm{ELEC_T} + \Delta\mathrm{ELEC_T} \quad (3)$$

$$\begin{cases} \Delta\mathrm{ELEC_T} > 0 & if \quad F_{T_{\mathrm{elec}}} > \mathrm{ELEC_T} \\ \Delta\mathrm{ELEC_T} = 0 & if \quad F_{T_{\mathrm{elec}}} = \mathrm{ELEC_T} \end{cases} \quad (4)$$

$$\Delta\mathrm{ELEC_T} = \sum_{\mathrm{k}} \mathrm{NewAdd_k} \quad (5)$$

$\mathrm{NewAddCap}$ represents the amount of new-built capacity and k, refers to alternative energy types such as: photovoltaic, small hydro, wind turbine, geothermal, waste-to-electricity and biomass. The amount of $\Delta\mathrm{ELEC_T}$ can be estimated through calculating the electricity gap at time *t* by the implementation of new intervention policy to facilitate the city's local generation by different available alternative energy sources.
F_T is a function of the activity level and the energy intensity in each end-user and its amount can be reduced through introducing different policy intervention scenarios as "energy efficiency programs in the domestic sector".

Evaulation of the co-benefits

The tool estimates the potential reduction of GHG emission and air pollutions which is accessible through offsetting the electricity gap at a given moment in time *t* based on the life-cycle analysis method considering the operation, transportation, and processing levels for each contributor technology.

Results and Discussion

Reference Energy Diagram

The diagrammatic representation of the main energy flows in the Delhi energy system which is used by the CAUES tool is given in Figure 3. End-use methodology is used for energy demand forecasting and related emissions.

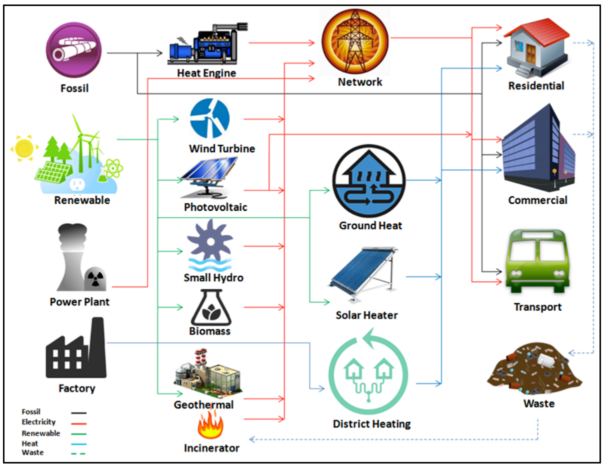

Fig. 3. Delhi Reference Energy Diagram in CAUES

Application of the tool is subject to the identification and estimation of the performance function of the urban energy system which is possible by segregating the whole energy system of the city of Delhi into incremental elements such as end-user, final energy, energy conversion and energy resources.

Scenario Generation

The scenarios are used for a number of ‘‘what if’’ questions, such as—what if more efficient appliances are introduced or what if the percentage share of a particular fuel use is changed in the urban energy system of the city of Delhi. The set of conditions is detailed in the respective scenarios. The scenarios in CAUES are generated to encompass any factor that is anticipated to change over time. For the Baseline scenario, data have been generated using end-use methodology. In the present study, extensive micro-level data have been collected from various sources. The Baseline scenario computes energy consumption and emissions for the base year (2011). The demographic details of this scenario are taken from the Economic Survey of Delhi [10-12]. The number of dwellings is a refined determinant of energy use than population, as a dwelling acts an energy consumption center. The number of dwellings is a function of population and household size.

Two different policy intervention scenarios are developed in the tool under different sets of alternative energy usage scenario and end-user efficiency improvement scenario to show that how the gap between electricity supply and demand can be set in this city.

The efficiency improvement scenario takes into account different energy conservation technologies coupled with policy options for energy emission reduction. This scenario takes into account the replacement of energy-intensive appliances by efficient and less energy-intensive technologies.

The policy options and assumptions are given in table 2.

Table 2. Policy options and assumptions for scenario generation

Scenario	*Policy option*	*Assumptions*
Baseline		• Basic demographic data availability: Population,Average household size, Fraction of dwelling by type, Average floor area, Degree of urban electrification, Commercial sector floor area and fraction of commercial sub-scetors in total area • Installed electrical capacities (table 1) • Monthly temperature and solar irradiation[13] • Electric load distribution

Alternative Energy usage	1) Introducing 5MW solar PV	• NDPC Photovoltaic Plant, Delhi [14]
	2) Increasing the installed capacity of hydro up to 100 MW	• 300 MWh Hydropower Lakhwad project [15]
	3) Increasing the installed capacity of waste-electricity to 46 MW	• Generating power from waste, with three plants at Okhla and Timarpur (16 MW), Gazipur (10 MW) and Narela-Bawana Road (36 MW)[16]
End-user efficiency improvement	1) Replacing conventional water heating system with solar collector	• Global Solar Thermal Energy Council. The cabinet's decision no.1309 [17]
	2) Replacing regular lighting system with Compact Fluorescent Lighting in residential sector	• For 3 million Delhi households to save nearly 1200 MW of power[18]
	3) Improving COP of air conditioning to 2.7	• At present, for air conditioners, co-efficient performance (COP) has to be minimum 2.5 to qualify for 1-Star rating, which will be raised to 2.7 by January 2014 [19].

Results

Figure 4 shows the estimated load profile for the domestic sector of the city of Delhi. It seems that the ACs are the major contributor to the peak load in summer and lighting can be considered the second main contributor. In winters, space heating and water heaters have significant contribution to the peak load.

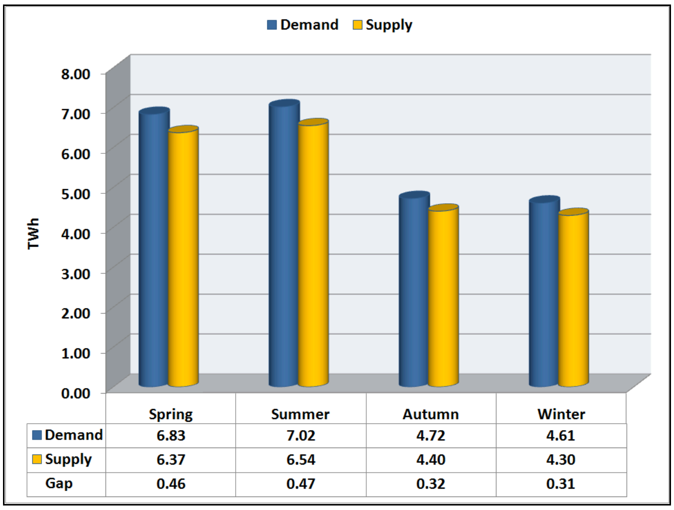

Fig. 4. Estimated electrical load profile for the baseline scenario in the domestic sector

In the above figure, the load curve analysis is based on the estimation of CDD (Cooling-Degree-Day) and HDD (Heating-Degree-Day) in different seasons and simulation of energy consumption in domestic end-users. The electricity supply is estimated on the basis of the maximum power made available from existing capacity (table 1) and the technical restrictions on power supply (Figure 2). The seasonal load profile is a typical bell-shaped curve showing peak variations in summer months. The average gap between electricity demand and availability is estimated about 6.5 percent.

Figure 5 shows that how the annual electricity supply and demand can be matched through implementing the policy interventions which have been indicated in table 2.

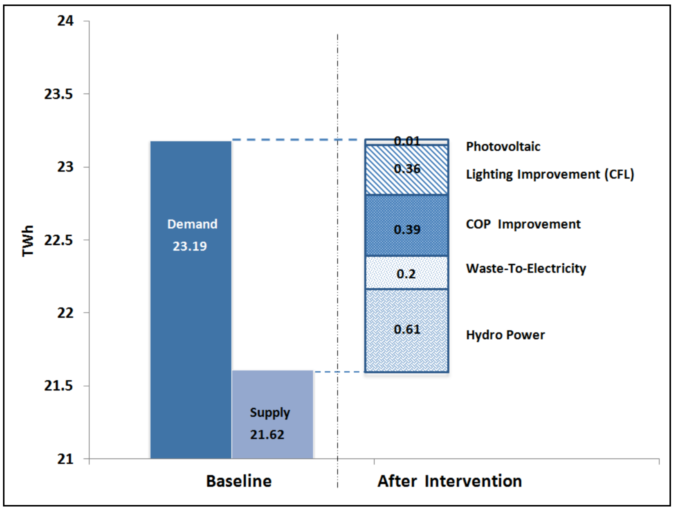

Fig. 5. Matching electricity supply/demand load by the implementation of policy interventions over the year 2012

The end-user efficiency improvement has a lead role to play through the improvement of the lighting and the coefficient of performance of space conditioning in the residential and commercial sectors. Lighting improvement can be possible when the customers shift from using incandescent lamps to CFL's, savings accrue to them by way of reduced consumption due to the lower wattage rating of CFL. Commonly used appliances for space conditioning during summer in the residential sector are air-coolers and AC. There are more air-coolers with low COP (< 2) in lower income groups of the city of Delhi, which can be replaced with high COP air conditioners (> 2.5).

Small Hydropower is playing an important role in Delhi competitive power supply sector. It can provide sustainable energy services, based on the use of routinely available, indigenous resources and provide better solutions to longstanding energy problems being faced by the city's power supply system.

Solid waste management remains one of the most neglected sectors in Delhi. On an average, 80% of the municipal solid waste generated is collected and about 90% of the collected solid waste is disposed in landfills, and the remainder is composted. The total amount of municipal solid waste is estimated about 5500 tonnes per day contributing to about 80% of the total CH_4 emission [20]. The implementation of technology like incinerator facilitates the electricity production on the supply side and reduces the emission of GHG and other air pollutions in this city.

Table 2 shows calculated co-benefits potential of the implementation of policy intervention scenarios that had been considered in this survey. The results demonstrate that, emissions mitigation accounted for 328 kt/yr of GHG emission by promoting the city's energy performance in both electricity supply system and end-user level.

Table 2. Potential reduction of GHG and Air pollutions (kt/yr)

	Baseline	*After Intervention*	*Difference*
GHG	22819	22491	-328

CO	48.10	47.31	-0.79
NMHC	2.17	2.16	-0.01
NOx	77.80	77.18	-0.62
SO_2	205.50	202.68	-2.82
PM10	9.53	9.43	-0.1
PM 2.5	2.98	2.93	-0.05

Figure 6 shows the calculated MAC (Marginal Abatement Cost) based on the midterm payback period through considering the following definition:

$$MAC\ (\frac{\$}{tCO2}) = \frac{Total\ capital\ investment\ -\ Present\ value\ of\ the\ project}{Comulative\ GHG\ saving\ over\ life\ of\ the\ project} \tag{6}$$

The project total capital investment is estimated about 1500 million USD. It is notable that, the cost values derived in this survey are based on the theoretical ideas which provide indicative potential values that may differ from the actual field measurement value due to the number of factors which influence the capital and operational costs of different electricity generation technologies.

It can further be observed from figure(6) that improving energy efficiency at the end-user levels originates a rapid and cost-effective decrease in emissions. The cheapest option to manage the electrical load and reduce emissions in the domestic sector is the lighting improvement.

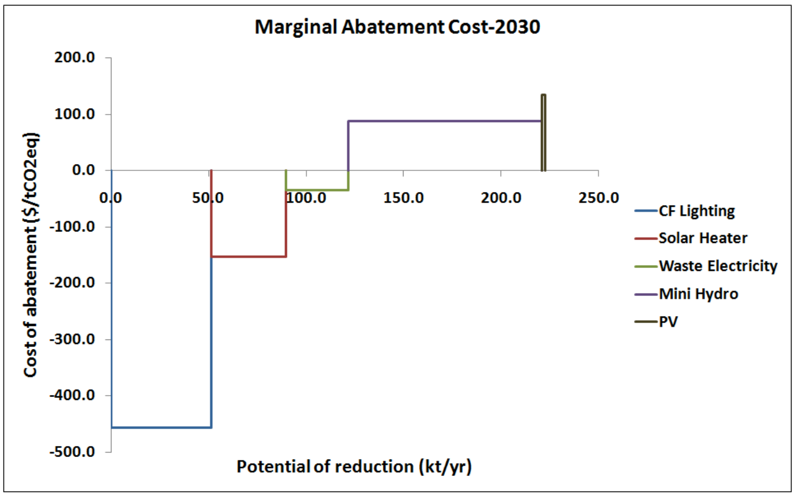

Fig. 6. Midterm Marginal Cost Abatement curve for policy intervention scenarios (based on the average electricity price about 6.5 Rs/kWh and the annual discount rate about 5.5%)

Conclusion

In this paper, a new strategy has been proposed and the associated co-benefits are simulated by the tool “GUEST” for electrical load management in the city of Delhi. It has been observed that a successful implementation of the proposed scheme can help the city of Delhi to free from load shedding. The results showed that the co-benefit policies which promote low-carbon communities have a GHG emissions reduction potential of about 328 kt/yr. The proposed intervention scenarios help in motivating both of power supply system and the connected customers to participate in system peak demand reduction. The results also reveal that about 48% of the total electricity gap (1.57 TWh/yr) can be managed by improving the lighting system, the COP of the AC's and also introducing the solar energy in the domestic sector. The city's power supply system needs to be reformed through the deployment of renewable energy sources (particularly hydropower) and also introducing the municipal waste to electricity generation system.

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