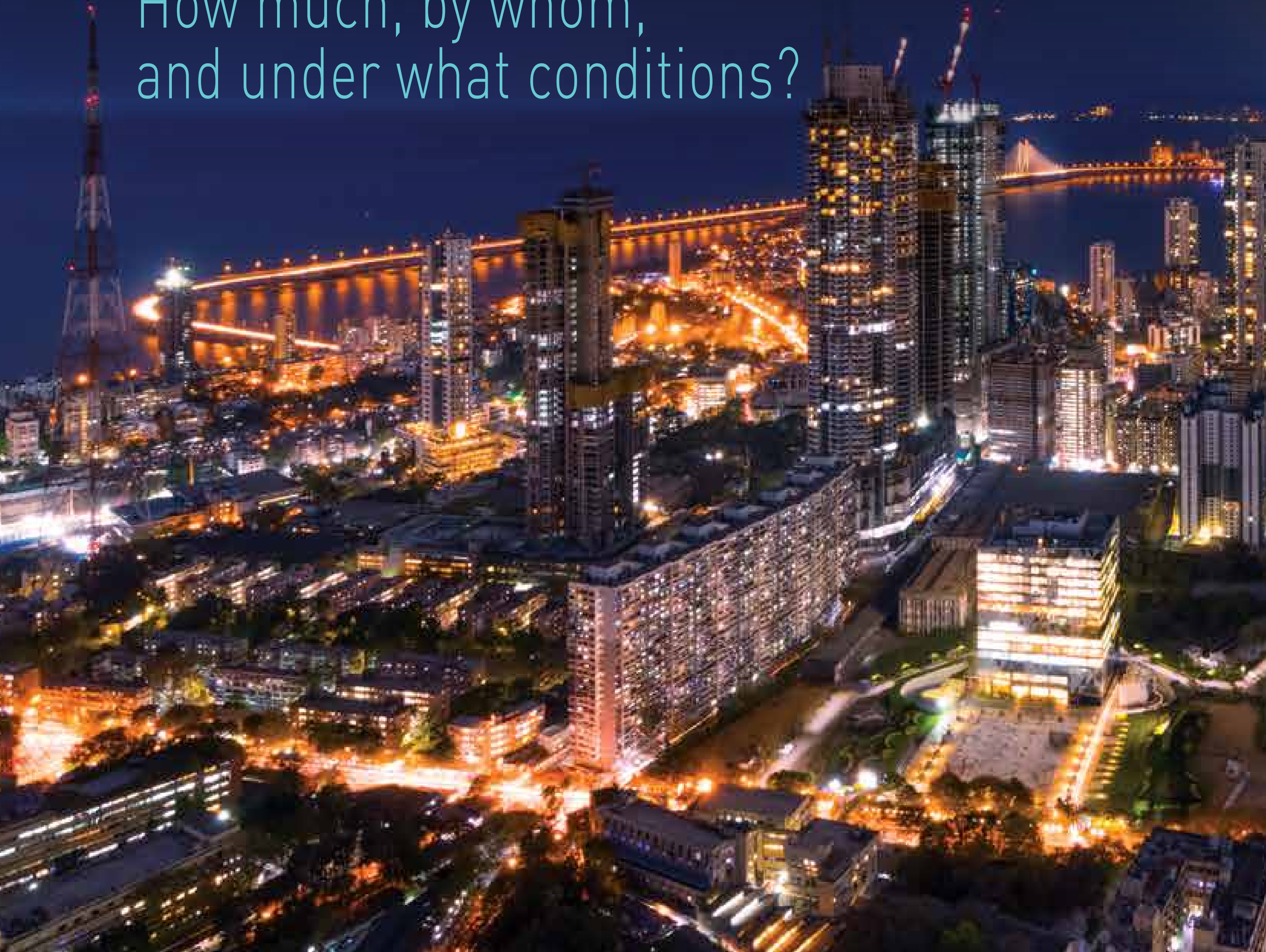
BROOKINGS INDIA

THE FUTURE OF INDIAN ELECTRICITY DEMAND

How much, by whom, and under what conditions?



BY | **SAHIL ALI**

OCTOBER 2018

THE FUTURE OF INDIAN ELECTRICITY DEMAND

How much, by whom, and under what conditions?

OCTOBER 2018

Acknowledgements

I would like to express gratitude to Rahul Tongia for his critical inputs throughout the study and helping bring nuance to the analysis. I relied on the resourcefulness and ready support of Abhishek Mishra and Puneet Kamboj to augment my database and refine my methodology.

The communications team starting with Nitika Mehta initially, and then Zehra Kazmi, Rohan Laik and Karan Seera, greatly helped improve presentation and delivery. Pranav Singhania also helped with multiple reviews and cross-checking references.

I am indebted to all the participants of the multiple review workshops for their trenchant insights into ground realities across different end-use sectors. Special thanks is due to Aayushi Awasthy (University of East Anglia, formerly at TERI), Aditya Chunekar (Prayas) and Narsimha Rao (IIASA) for in-depth reviews of the full draft and constructive feedback that helped enrich the study.

I express sincere thanks to Shamika Ravi for her support and useful feedback.

Executive Summary

- This study projects application-wise end-use electricity demand from consuming sectors as categorised by the Central Electricity Authority. It includes both grid-based as well as industrial captive demand in the future which enhances visibility from the perspective of supply planning.

    - The analysis is based on the range of possibilities of growth in service demand (eg. lighting, cooling, industrial production, pumped water for irrigation, etc.), and sector-wise and cross-cutting technology and policy options.
    - The base and terminal years for the analysis are 2015 and 2030. This is keeping in mind at 2015 is the most recent year for available data on disaggregated official baseline, and 2030 fits with a number of strategic objectives, including India's climate change commitments. Base year results are calibrated and synced with CEA data.
    - 'New loads' expected to gain prominence in the future, such as inorganic household demand from new households constructed under the affordable housing programme, electric cooking, and electric vehicles are included. Apart from these, the impact of air-conditioning and high manufacturing growth by 2030 are specifically emphasised.
    - Overall, nine 'cases' of electricity demand are generated for three scenarios of GDP growth (6.5, 7 and 7.5 percent) and three levels of energy efficiency and conservation interventions applied across applications.

- Aggregate electricity demand could grow from 949 TWh in 2015 to between 2074 TWh (low GDP, high efficiency) and 2785 TWh (high GDP, low efficiency) by 2030.

    - This corresponds to a CAGR of 5.4-7.4 percent, compared with 6.9 percent CAGR in electricity demand between 2000 to 2015. A plausible mid-scenario CAGR between 2015 and 2030 is derived at 6.2 percent.
    - The big changes in sectoral shares (and therefore growth rates) occur in the commercial and agriculture sectors—commercial likely surpassing agricultural (irrigation pumping) demand in 2030 when it was less than half of the former in 2015.
    - Industrial and domestic remain the largest consumers, with greater uncertainty (range of possible outcomes) around the latter.
    - New loads as discussed above constitute less than 10 percent of aggregate demand by 2030.

- GDP growth or sectoral value-added has historically not been a good indicator of electricity demand growth from irrigation pumping, which is based on both exogenous factors (for example, the monsoon quality) and policy choices. Accordingly, its future electricity demand may grow between 3.9 and 4.2 percent CAGR, compared to 5.2 percent in the past. The constraining factor will not be so much as pump-set ownership but service demands—usage requirement and intensity of use, amongst others.

- In residential buildings, the new demand from affordable housing units will not exceed 50 TWh (less than 5 percent of aggregate consumption in 2015), if the targets are met by 2030. Separately, the 'organic' growth in ownership and usage of residential appliances may result in additional 438 -623 TWh in 2030, leading to overall CAGR of 5-7.8 percent. The share in consumption of heating, ventilation and air-conditioning (primarily fans and ACs in the Indian context) and refrigeration increases while lighting and television reduces. Miscellaneous loads (motors, geysers, inverters, washing machines, etc.) grow faster than the overall average. New demand from electric cooking could further add 48-72 TWh. Regulations and policies on energy efficiency (super-efficient appliances, mandatory star labeling etc.) and conservation (building codes, thermal comfort standards, ToD tariffs) will be key drivers to reduce demands and synchronising with the grid.

- Growth in commercial floor-space area and air-conditioning coverage and use will be the key influencing factors for commercial electricity demand growth. Whereas commercial heating, ventilation and air-conditioning (HVAC) already consume over 50 percent of its total demand, this could likely grow up to 75 percent as total commercial demand grows to 247-348 TWh (7.6-10.1 percent CAGR) by 2030. This points to the big role of new technologies in centralised and inverter based air-conditioning, as well as building shell optimisation including insulation, roofing, window glazing, window design, and daylight control.

- Analysis of physical production growth and process-wise specific consumption across seven Perform Achieve and Trade (PAT) sectors, and value-added and electricity demand outside these, under different scenarios of manufacturing sector growth and energy efficiency, yields an industrial demand of 881- 1098 TWh by 2030. This indicates CAGRs of 5.1-6.6 percent over 481 TWh consumed in 2015. Industry remains the dominant electricity consumer, accounting for ~40 percent of total demand. High manufacturing growth driven by Make in India could increase demand by 15 percent (133 TWh) at identical levels of energy efficiency. Steel, cement and aluminium remain the dominant consumers with maximum potential for absolute energy saving.

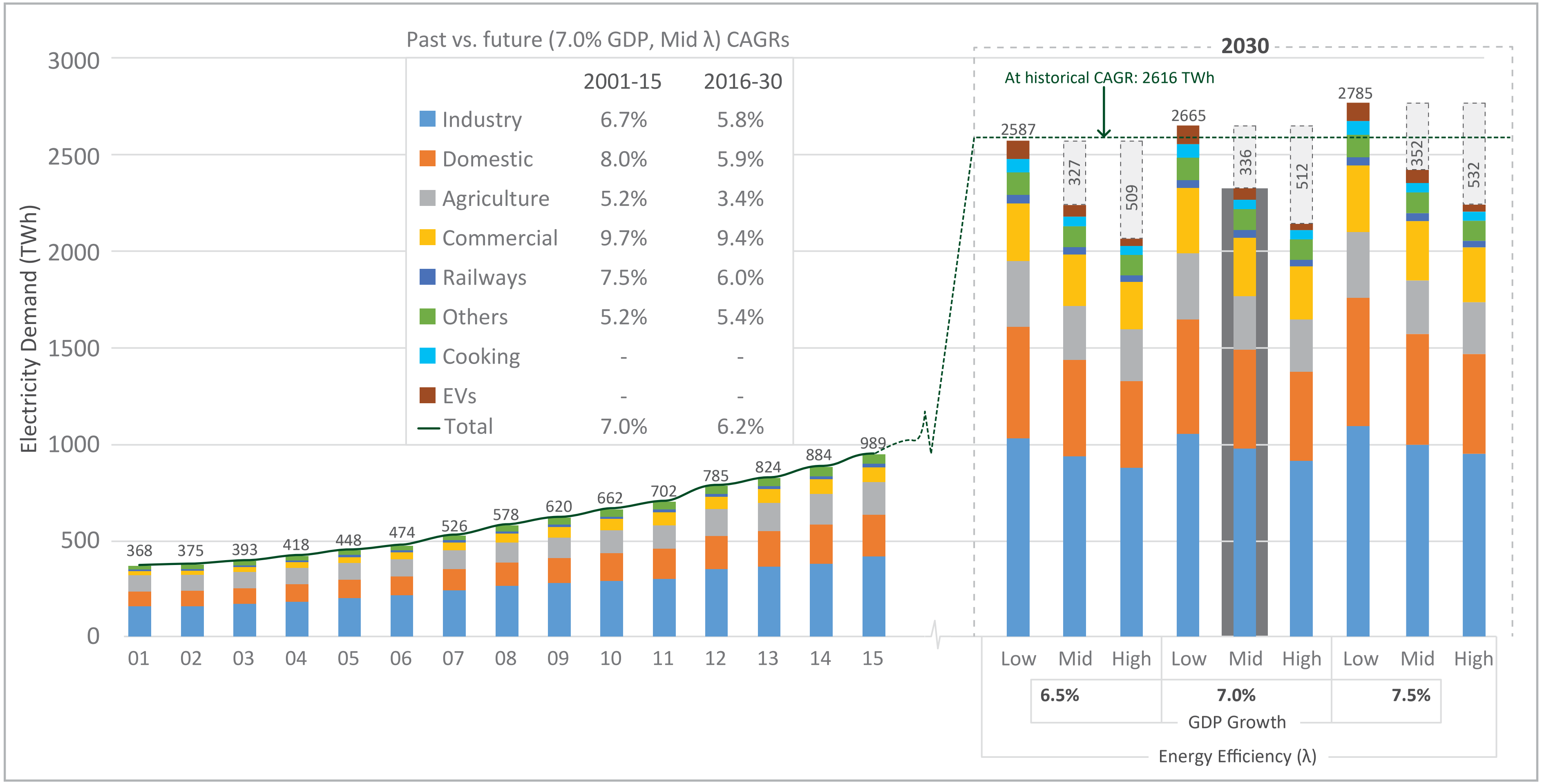
- As the Indian government plans to increase electrification of rail-route kilometers from 40 percent presently to 77 percent by 2022, the level of electricity consumption achieved by 2030 could be 35-43 TWh, growing at 5.0-6.3 percent CAGR from 17 TWh in 2015. Whereas the impact of electrification is minor on electricity demand, significant savings on account of efficiency gains and oil substitution accrue.

- The potential electricity demand from transition to electric vehicles (EV) across private and fleet categories, even with 100 percent EV sales by 2030 turns out to be less than 100 TWh, which is only 10 percent of aggregate consumption in 2015. However, the aggregate load potential of such a transition can lead to significant volatility in instantaneous demand, with EVs potentially contributing 50 percent to peak load by 2030 in case of unmanaged charging.

- Increasing urbanisation facilitated by shrinking household sizes and concentration of economic opportunities in urban areas will increase pressure on municipal services such as public lighting and water-pumping. These plus the ‘miscellaneous’ demand as reported by CEA are likely to more than double from 2015 levels of 49 TWh to 104-115 TWh (5.1-5.8 percent CAGR) in 2030. Here again, while the quantum of electricity demanded is manageable (representing about 5 percent of total demand) enhancing the supporting infrastructure to keep pace with urban demand will be crucial. Land availability for these as well as EV charging infrastructure will be the major challenge.

- Overall, the analysis points towards a high likelihood of electricity consumption elasticity to GDP falling to four-fifths from the base year level of 0.95, indicating an ongoing process of decoupling of energy and GDP growth. This is owing not only to enhanced consumption efficiency but the continued dominance of the services sector in GDP growth. Per capita electricity consumption is likely to double or more, but still remain much lower compared to current global average. Policies must focus on stimulating ‘good’ and curbing ‘bad’ demands. The addition of new and more complex loads, especially in cities, indicates that the key bottlenecks to meeting demand will lie in the realm of distribution infrastructure and regulatory frameworks to manage increasing volatility in daily and seasonal loads, rather than expansion of total electricity supply.

Snapshot of key results: Past vs Future of Electricity Demand



Contents

List of Figures

List of Tables

Introduction-Why model electricity demand ?

As of 2017, 73 percent of electricity generation in India was based on coal (Central Electricity Authority, 2017). The electricity sector (grid and captive generation) consumes over 80 percent of the domestic coal off-take in India (Ministry of Coal, 2017). Due to its capital intensive and public good nature, electricity supply in India is highly regulated, where policies and plans are focused around creating adequate supply capacity and reserves, to generate, sell and purchase power. Coal demand for electricity depends on the overall level of electricity demand, its nature (who is demanding, at what location and what time in the day) and the availability and preference ordering of other sources of supply. Aside from the more immediate issues of supply planning, electricity demand modelling directly feeds into concerns around access, energy security and environmental sustainability.

Electricity demand, as is elaborated later, depends on a number of variables, some with deep uncertainty into the future. For example, India's GDP growth projections till 2030 vary from around 7-8 percent projected by governmental sources and IMF, to 5.5-6.5 percent as projected by certain banks, development organisations, and research institutions (Uehara, Masashi; Tahara, Kengo; et al, 2017; Ministry of Environment, Forests and Climate Change, GoI, 2015). These have profoundly different implications in terms of levels and composition of economic activity and associated energy intensities (Uehara, Masashi; Tahara, Kengo; et al, 2017; Ministry of Environment, Forests and Climate Change, GoI, 2015). It then becomes necessary to understand plausible and marginal yet possible scenarios of electricity demand to plan for the future electricity grid accordingly.

Electricity demand projections in India

Electricity demand forecasts form the basis for supply (generation capacity and transmission and distribution (T&D) infrastructure) planning at the central and state level. In India, this exercise is carried out once in every few years as the Central Electricity Authority's (CEA) Electricity Power Survey (EPS). The recently released 19th EPS projects an electricity demand of 1743 TWh (6.59 percent CAGR from 2017) and peak load of 299 GW (6.32 percent CAGR) by 2027 (Central Electricity Authority, 2017).

NITI Aayog, private think tanks, and other multilateral organisations also undertake electricity projection exercises, at times using proprietary models. In system planning exercises, these projections are used as means to determine optimal system configuration under various scenarios, rather than as an end in itself. However, based on how models are set-up, significant insights can be obtained regarding the nature of relationships between macroeconomic drivers, technology options, policy levers and the responsiveness of electricity demand.

In the recent past, significant changes have taken place in the demand-supply dynamics as well as policy formulation in the electricity and related sectors. Energy and peak deficits have seen a secular decline, reducing to as low as 0.3 percent in the last quarter of 2016-17 (Central Electricity Authority, 2012- 2018). Thermal power plants have been operating at low plant load factors (PLFs) owing to suppressed demand growth and utility-offtake, in addition to coal linkage issues. On the other hand, renewable energy (RE) capacity additions have picked up pace as new solar tariffs keep falling under reverse-bidding. In addition, the central and state governments' policies on 24/7 Power for All, electricity market reforms, domestic manufacturing via Make in India, electric mobility, and energy efficiency will be instrumental in influencing the level and pattern of future demand.

Scope and methodology

Why model on bottom-up and end-use basis?

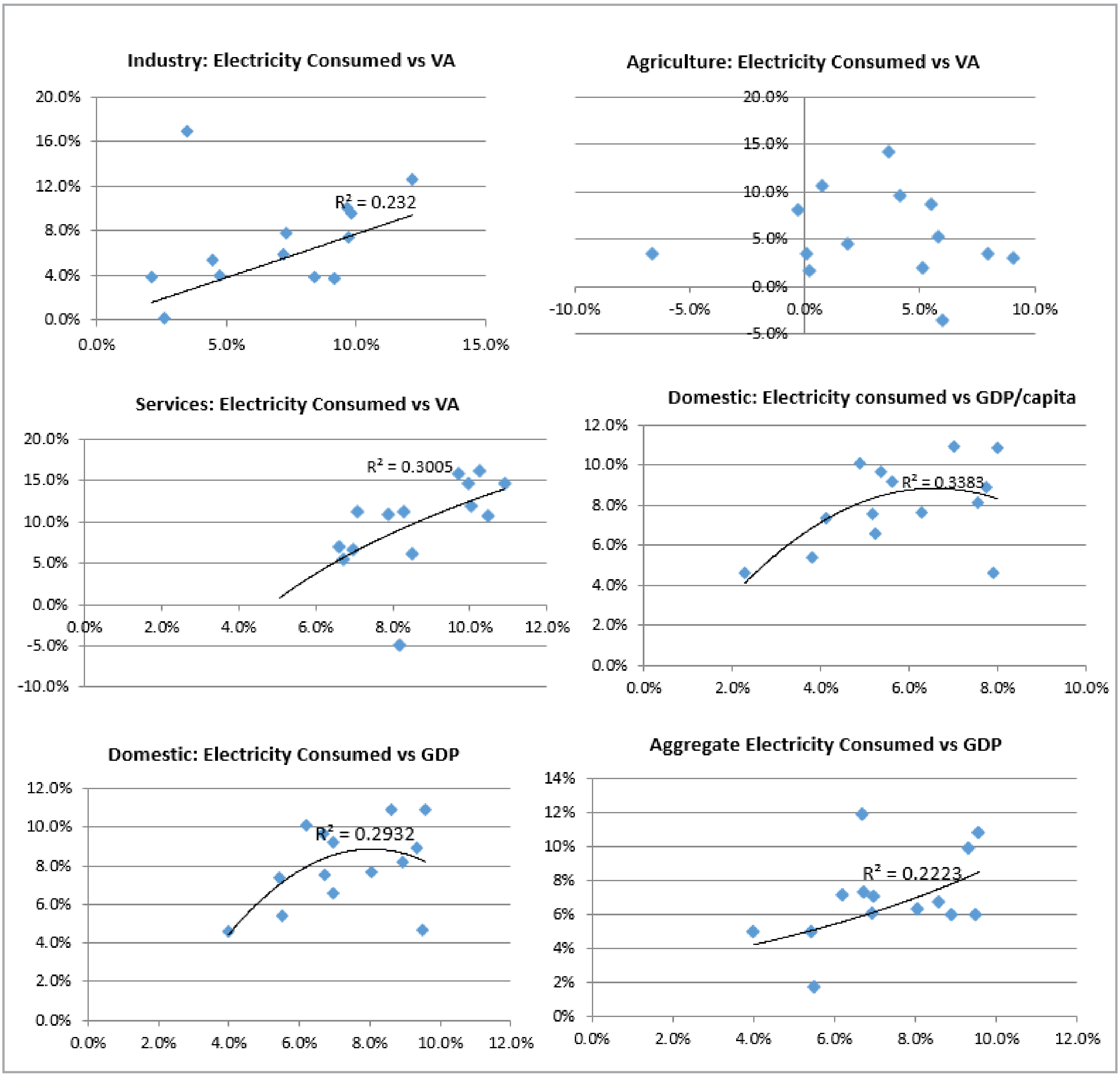
This study was designed to understand the growth in electricity demand from the individual end-use sectors. It forms a building block for a multi-year study on the future of coal ecosystem being undertaken at Brookings India. Electricity demand for 2020 as assessed in an interim report under this study was estimated at 1,634 TWh at bus-bars (8 percent CAGR from 2015) (Sehgal & Tongia, 2016). While the 2020 demand analysis considers planned growth in capacity addition of thermal and RE, and a notional lifeline consumption for unelectrified households, an estimate for 2030 necessarily needs to consider growth in the electricity demand for end-use sectors. This is because capacity additions are typically planned for a horizon of three to five years, for which electricity demand growth is reasonably well estimated. For a 2030 horizon, an estimation of the service (end-use) demand growth that leads to electricity consumption as well as the technology-policy interplay becomes necessary for planning supply. Accordingly, this study projects the electricity demand in 2030 from the end-use (agriculture, commercial, residential, industrial, transport, municipal lighting and water pumping and miscellaneous) sectors.

Some studies use a top-down methodology for estimating electricity demand based on its relationship (regression equations or elasticity factors) with macroeconomic variables (Saxena, Gopal, Ramanathan, & al, 2017). However, this approach is limited with regards to addressing the transformational aspects of such relationships over a longer horizon, since electricity requirement is in effect obtained as either a second or third order effect from changes in macroeconomic factors.[1] It follows that all-encompassing variables like GDP or sectoral value additions will fail to account for dynamism in new economic activities, service demands, technologies, policies, and institutional frameworks, that in turn play a more direct role in determining level, composition and growth of demand. Hence, the role of choice and innovation in the technology-policy space needs to be factored in order to translate changes in macroeconomic variables into service demands and finally into electricity demand.

This is demonstrated in Figure 1, which plots the CAGRs of sector-wise electricity consumption against the growth of value-added in these sectors between 2001-02 and 2015-16. If the absolute values for consumption and value-added are examined, they yield high R-squared relationships. But this accounts for absolute changes year-on-year and not the rates of change, the latter being the relationship of interest in projecting future values of electricity demand based on GDP growth (or the growth sectoral value-added or any derived variables such as per capita GDP).

[1] Globally, CO¬2-GDP 'decoupling' (Saha & Muro, 2016) has been empirically established to demonstrate how the rate of greenhouse gas (GHG) emissions growth relative to GDP growth slows to the extent that the traditionally understood linkage between development and emissions is no longer meaningful for a futuristic analysis. On the other hand, intermediate factors such as technological innovation, choice and underlying policy framework better explain emissions growth.

Figure 1: Top-down assessments of economy-energy growth nexus



Note: Y-axis and X-axis in each plot indicate annual growth rates in electricity consumption and value added respectively.
Source: CEA General Reviews, RBI Database for Indian Economy and author's calculations.

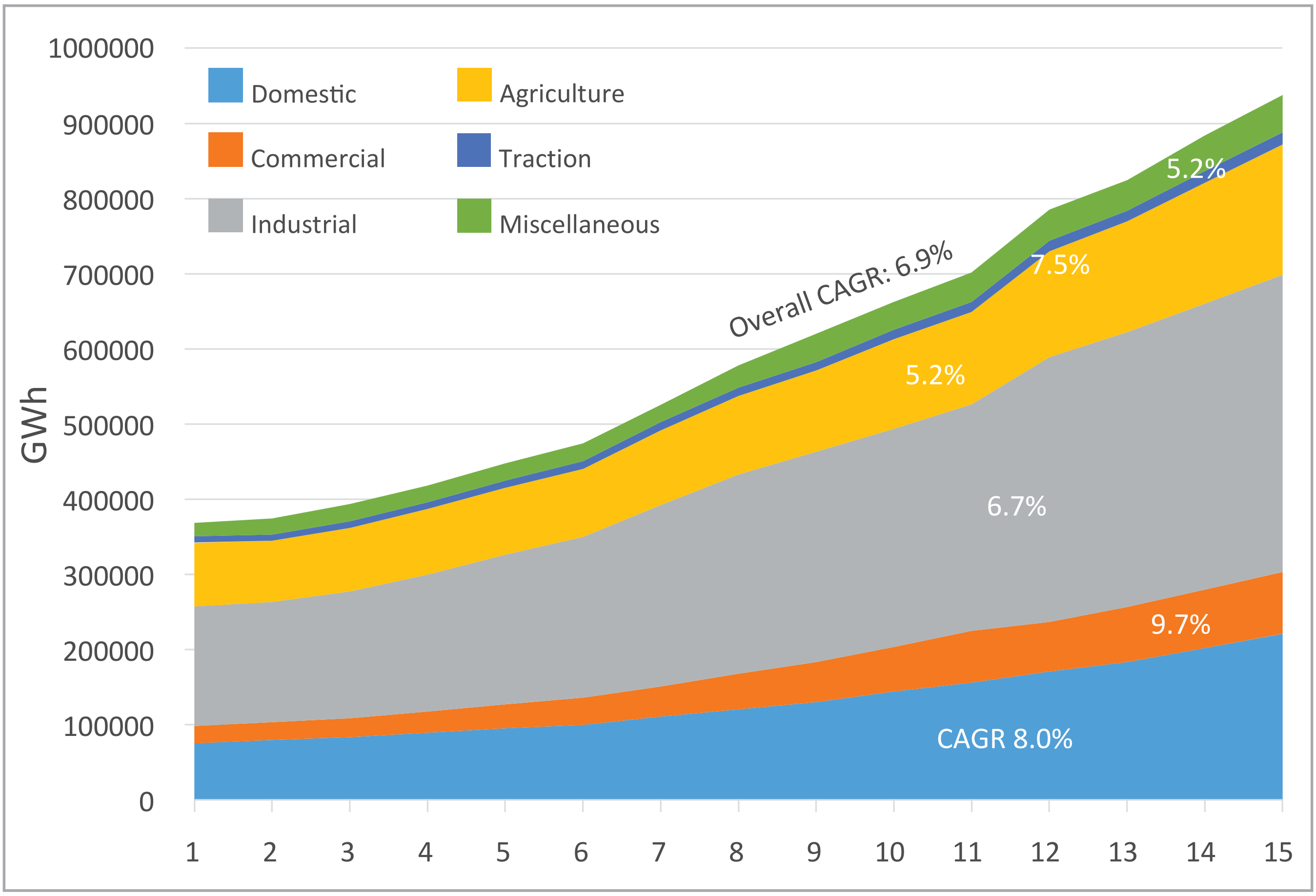
When we scatter-plot the respective y-o-y growth rates of electricity versus GDP, they yield low R-squared, which implies that GDP value-added growth alone is not useful for projecting electricity demand of the future. This makes sense intuitively, because the technology-policy interplay, frameworks and choices in the energy and related sectors will affect electricity demand more directly, and the output with a greater lag, if at all.

Therefore, in order to undertake a meaningful analysis of electricity demand, its underlying drivers and policies need to be analysed. This helps build a systems-level view of how policy tweaks in one or more particular sector/application, can impact the levels and technology allocation in both the demand and supply sectors.

Historical context and future drivers of electricity consumption

The end-use sectors considered in the base-year of this analysis are based on CEA's categorisation–Residential, Commercial Agriculture, Industrial, Traction and Others/ Miscellaneous[2]. Figure 2 shows the historical consumption and compounded annual growth rates (CAGRs) in these sectors between 2000 and 2015[3]. This includes the captive component of electricity consumption in case of industrial users, which stood at just over 134 Terawatt hours [TWh or billion units (BU)] in 2015, and overall electricity demand has grown by nearly 7 percent CAGR in this period (Central Electricity Authority, 2007-2016).

Figure 2: Historical category-wise consumption in India (2001-2015)



Source: CEA General Reviews.

[2] Miscellaneous primarily includes municipal lighting, sewage and water pumping. In certain cases, (like CEA General Reviews) the three consumption buckets are reported separately and miscellaneous shown as a distinct category under 'Others'.

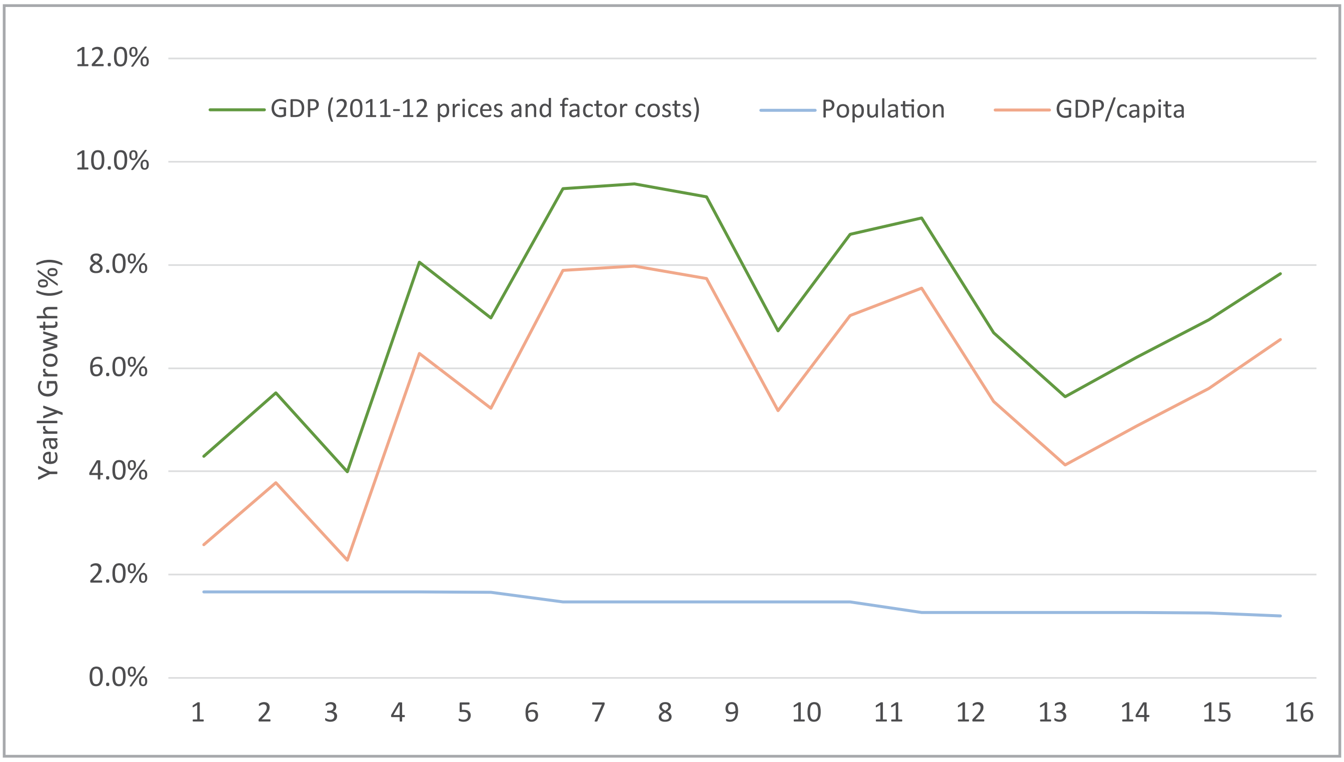
[3] Revised estimates of sector-wise electricity consumption are usually available with a two-year lag. In the period the research was conducted, the latest estimates available were for 2015, which is used as the base-year for future projections.

From Figure 2, while the industrial sector consumes the bulk of total electricity consumption (~42 percent), it is the residential and commercial buildings that have been driving consumption growth, presently at about a third of total consumption and growing at over 8 percent CAGR. Surprisingly, while the commercial/services sector contributes 60 percent to GDP growth, it only accounts for less than 9 percent in electricity consumption. The services sector driven GDP growth and consequent rise in per capita incomes, especially in urban and formal sector households, seems to have provided the impetus for electricity demand growth, even though electricity consumption intensity is lower in services sector compared to agriculture and industry[4].

Economic growth and demographics

The preceding discussions highlight the role and importance of economic growth, its structures and patterns in influencing the electricity demand, notwithstanding the limited role it plays in explaining the full picture (as demonstrated in Figure 1). The year-wise economic, population and per-capita income growth is shown in Figure 3. The GDP and population CAGRs in this period are 7.1 percent and 1.5 percent respectively, yielding a per capita income CAGR of 5.6 percent.

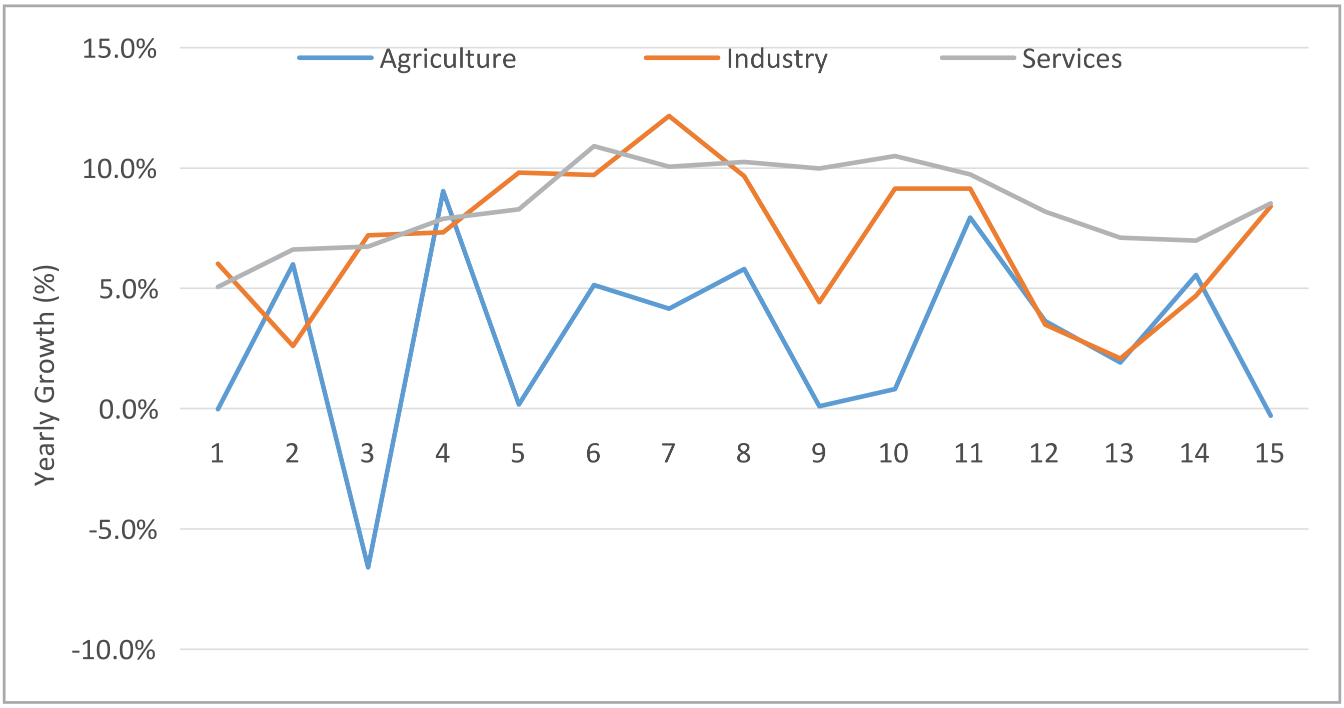
Figure 3: Historical GDP and population growth (2001-16)



Sources: RBI Database on Indian Economy, UN Population Monitor and author's calculations.

[4] Nevertheless, commercial sector electricity demand is the fastest growing consumption category in the past decade and a half, although it is starting out from a lower base of demand in 2000.

Figure 4: Structure of Growth (2001-15)



Source: RBI Database on Indian Economy and author's calculations.

Figure 4 shows the historical growth pattern across industry, agriculture and services sectors, highlighting how services (growing at 8.5 percent CAGR) has been consistent in driving growth. Industrial sector has grown at the overall GDP growth rate at 7.1 percent, but experienced much more volatility in growth. The agriculture value-added growth is highly volatile since it is predicated on a number of exogenous factors, such as the quality and duration of monsoon.

Comparing across Figure 3 and Figure 4, we find that since 2008 the 'snake in a tunnel' pattern followed by the industrial value-added is reflected in GDP growth pattern. However, the diameter of the tunnel is also higher in the case of industry, since overall GDP growth is also buttressed by the relatively smoother growing services sector, making the GDP growth less volatile. This co-variation is also observed in absolute electricity consumption (Figure 2) owing to the high share of industry.

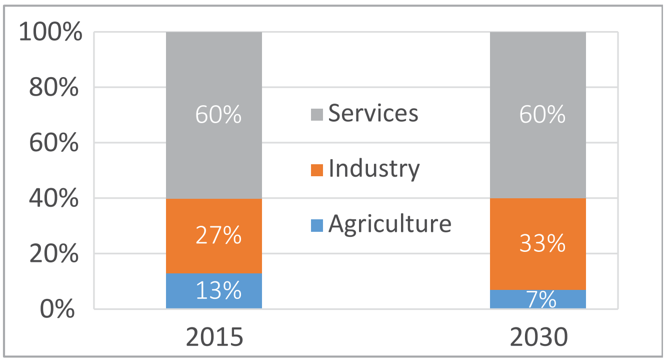
Future scenarios of sectoral value-added and overall and per capita GDP, are used to determine service demands in certain sectors, that in turn determine the employment of various appliances and equipment to convert electricity into end-use services (such as water pumped, steel produced, lighting and air conditioning, etc.). The government over successive years has prioritised the manufacturing sector to draw surplus labour from primary activities and enhance growth, productivity and meaningful employment. This has reflected in the National Manufacturing Policy (NMP) as well as the more recently launched Make in India (MII) campaign. Among key priorities has been increasing the share of manufacturing from 16-17 percent at present to 25 percent of GDP (Bhattacharjee, 2015). If this is achieved by 2030, then industry will need to grow at 1.5 percentage points higher than overall GDP, assuming services retains its current 60 percent share (Figure 2). This is illustrated in Table 1 at GDP growth rates of 6.5, 7 and 7.5 percent respectively, which have been chosen as the low, mid and high GDP scenarios for this study.

Table 1: Scenarios of GDP Growth (2016-30)

GDP Growth Scenarios (2016-2030)				
CAGR	GDP	6.5%	7.0%	7.5%
	Agriculture	2.2%	2.7%	3.2%
	Industry	8.0%	8.5%	9.0%
	Services	6.5%	7.0%	7.5%

Source: Author's calculations.

Figure 5: Sectoral shares under high manufacturing scenario



Source: RBI Database on Indian Economy and author's calculations.

Table 2 shows the population and household characteristics (size and distribution) based on the urbanisation levels in 2015 and 2030. Over 100 million new households are expected to be added between 2016 and 2030, with three-fourths of these expected in urban areas owing to rising urbanisation and shrinking household sizes. This impacts the overall electricity and energy use from urban India based on demand for housing, urban infrastructure and related services.

Table 2: Present and future demographics

Demographics	2012	2015	2030	CAGR (16-30)
Population (million #)	1262	1311	1528	1.0%
Urbanisation (%)	31.4%	32.3%	40.0%	1.4%
HH Size Urban	4.52	4.36	3.54	-1.4%
HH Size Rural	5.06	4.96	4.45	-0.7%
HH Urban (million #)	88	97	173	3.9%
HH Rural (million #)	171	179	206	0.9%
HH Total (million #)	259	276	379	2.1%

Source: Census 2001, Census 2011, UN World Population Prospects, India's INDC to the UNFCCC and author's calculations.

Besides the cross-sectoral impact of macroeconomics, and demographics on service and (in turn) electricity demand, a number of sector-specific policies and technology decisions directly determine the range of possible electricity demand from the individual end-use sectors.

Sector-specific factors and policies

From a bottom-up perspective, drivers of economic activity from each end-use sector are outlined based on the nature of evolution of the sector, current status, and technologies and policies for the future. These may have direct or indirect implications for electricity demand.[5] Table 3 summarises such factors considered for the analysis, along with the cross-sectoral drivers discussed in the previous section.

Table 3: Summary drivers of electricity demand

Sectors	Drivers
Agriculture	Net sown area, cropping intensity, surface and micro-irrigation coverage/ schemes, cropping pattern and water requirements, pump-set characteristics (size, head, discharge), solar, micro and canal irrigation policies, Ag-DSM
Buildings	Floor space area, urbanisation and household sizes (rural and urban), affordable housing gap, service demand in low income households, appliance types, technologies and ownership, building shell design efficiency and electrical controls, ECBC, standards and labelling
Industry	National Manufacturing Policy, Make in India, Perform Achieve and Trade scheme (PAT), historical production and consumption patterns, infrastructure/development related demand, sub-sectoral policies and targets (eg. Steel target, NG switching in fertilizer production), alternate fuels and raw material, waste/scrap recycling, thermal substitution).
Transport	Railway track growth, targets for rail route electrification, EV urban passenger demand (PKM demand, vehicle ownership and usage, EV sales targets, EV technologies, duty cycles and charging provisions)
Others	Historical rates of growth and urbanisation, smart cities (smart metering)
Cross Sectoral	GDP growth → sectoral value added → service demands (industrial production, residential and commercial floor-space area, appliance stock and ownership)
	Demographics → housing stock, rural-urban share, household sizes → service demand per capita → inorganic demand from new households

The impact of these drivers on electricity demand and the range of outcomes so obtained are discussed in the following section. This is followed by sector-wise appraisal of current status and future cases considered in the study.

[5] For example, while the Perform, Achieve and Trade (PAT) scheme for industries and Energy Conservation Building Code (ECBC) for buildings directly impact energy efficiency, policies for accelerating manufacturing production or infrastructure development (eg. housing) raise the demand for energy in general. Both are drivers for the analysis.

Boundary conditions and other salient features

The approach towards case building in this study is based on deriving the upper and lower bounds for electricity demand based on demand drivers, ambition and influence of policies, and technological choices. The bounds obtained also reflect the underlying 'plausible extremes' in the levels of the determining variables described in Table 3. So a combination of lowest service demand (under a low growth pathway) combined with high energy efficiency will give the lower bound for electricity demand in a particular sector. Further, a 'mid' scenario is also computed that is based on a plausible or likely configuration of economic growth, infrastructure, policy decisions and technology deployment that is achieved within the lower and upper bounds.

Table 4 provides the boundary conditions for deriving the sector-wise plausible ranges of electricity demand. These are derived based on our quantitative and qualitative assessments of starting situation, ambition (or lack thereof) and plausibility of outcomes, described in greater detail in sectoral descriptions that follow. The bounds should be understood in line with the earlier description.

Table 4: Boundary Conditions for Demand Cases

	Upper Bound	**Lower Bound**
Agriculture	2/3rd irrigated area by UG pumping	Half irrigated area by Micro and Surface Irrigation
	20% Improvement in Pump-set Efficiency	40% Improvement in Pump-set Efficiency
Buildings	100% housing access by 2030	35% housing access by 2030
	Medium Penetration of Efficient Appliances and ECBC	High Penetration of Efficient and Super- Efficient Appliances and ECBC
Cooking	20% rural and 10% urban HH use electric cooking	5% HH use electric cooking
Industry	Medium penetration of efficient technologies, processes and alternate fuels and raw materials	High penetration of energy efficiency measures
	High Non-PAT sector growth due to NMP/MII	Medium Non-PAT sector Growth
Transport	90% rail-route kms electrified	75% rail-route kms electrified
	55-60% penetration of EVs in new sales since 2016[6]	30-35% penetration
Others	5% energy efficiency improvement	10% energy efficiency improvement

[6] Only intra-city transport demand for passenger EVs is considered, owing to range and charging issues for EVs in long distance travel.

As is evident from Table 4, analysing demand this way throws open opportunities to understand and test how sector and application-wise composition of demand varies, which has significant implications for supply planning and thrust areas for energy efficiency. This segues into the question of instantaneous demand facing utilities in order for them to reserve energy capacity, and manage day to day loads within their consumer mix.

There are existing and potential future loads that do not show up prominently in the current context but will likely be significant from the supply perspective[7] going forward, including electric cooking, electric vehicles, surging heating, ventilation and air-conditioning (HVAC) demand, and inorganic (latent) demand from individuals/households that do not occupy any dwellings. These form individual components in the analysis.

Further, the end-use approach followed in the study allows for projecting captive consumption from industries, which currently constitutes over 14 percent of total end-use consumption in India (Central Electricity Authority, 2007-2016). Once the entire industrial electricity demand is computed this way, it allows for users and decision-makers to place their preferences on how much of this demand should they target to supply through the grid—a decision that holds much significance owing to the strategic importance of the sector to the overall economy and the role it plays in cross-subsidising residential users. With rooftop solar, the possibility of migration of commercial users, who are presently paying the highest rates for grid consumption, is also looming large for distribution companies (Discoms). In this way, completeness is emphasised for this analysis which attempts to account for such structural transitions (present and envisaged) in the power sector[8].

Finally, any reasonable estimation of future demand needs to achieve maximum coincidence with base-year actuals. It is on this basis that individual components of future electricity demand (pertaining to service demands and technology penetration) are projected forward. While the underlying data gaps in conducting such analyses is well acknowledged, this effort builds upon a number of studies to calibrate and validate the underlying assumptions and intermediate outputs. The final calibration takes place at the level of sector-wise consumption obtained in the base year of the model with the official statistics provided by the CEA. In doing so, the intermediate assumptions/results are cross-checked and validated.[9]

7 As we later discuss, most of these categories turn out to be not significant in terms of the quantity of energy demand, but more so in terms of the underlying infrastructure and investments necessitated to synchronise these with the grid.

8 By including both grid-based demand from end-use sectors and captive demand from industry, the study explores the full market for electricity demand that is useful at the aggregate level to establish likelihoods of potential demand that will be met by self-generation or outside the grid (via captive, rooftop, microgrids, open access, etc.).

9 For example, estimates on built up floor-space are validated against energy consumption in commercial and residential buildings using the energy performance index (EPI) values in terms of units of energy consumed per square foot area annually, for air conditioned and non-air conditioned buildings. EPIs are obtained from independent survey studies by private institutions, government prescribed codes and manuals, and estimates provided by the Bureau of Energy Efficiency (BEE). This also validates the average energy input and share of energy consumed by air conditioning in residential and commercial buildings and lends credibility to future projections.

Key determinant of future electricity demand—policies or prices?

The extent to which prices impact the choice of technology deployment and use in any model is based on the cost-benefit assessment of the various alternatives or substitutes over their lifetimes. Ultimately the levels of technology deployment and their associated consumption profiles across sectors and end-uses, determine electricity demand. There are two factors at work here—capital and operational costs, the latter represented by electricity tariffs in these models. What is not sufficiently captured are inertia against rational choice (preferences, tastes, etc.), availability of supporting services (eg. quality electricity supply), and most importantly, differential discount rates across consumer categories (often much higher than the prevailing weighted average cost of capital).[10] Based on technology and electricity prices alone, an optimisation model may provide corner solutions disregarding bounded rationality and lack of perfect foresight, heterogeneities in consumption preferences and low capacity to pay higher front costs for operational efficiency, even when energy efficient investments have definite (discounted) payback periods over their lifetimes. Next, electricity remains a regulated market in India and therefore tariffs (and its adjustments) may not necessarily reflect the true electricity costs (and changes over time). Lastly, the cost trajectory of new technologies is predicated on disruptions or scale deployment (also, learning by doing)—the former is not easy to project and latter poses a chicken-and-egg problem, whereby mass deployment can only take place when a new technology is a proven substitute and cost-competitive, as evidenced by its acceptance and use.

In such a scenario, experience with new technologies in India shows that policies geared towards increasing uptake by means of either direct intervention (mass procurement, production subsidy, concessional financing, etc.) or signaling (standards and codes, performance guarantees and promotions) has helped transform the efficiency floor, ceiling and median of the technologies in use (Ali M. S., The Path to Light: A case for LEDs, 2015). Due to the rigidities and imperfections previously discussed, price-focused mechanisms fail to capture reasonable scenarios of technology deployment.

Thus optimisation models face a choice between fidelity to the least-cost optimisation logic or reasonable deployment scenarios over the modelling horizon. To establish policy relevance, the latter route is employed via constraining the outcomes within reasonable bounds. This forces the model to engineer outcomes, which is an exercise that can be undertaken by more transparent scenario planning tools, whereby the system of equations that translates inputs to outputs is under full knowledge and control of the analyst/decision-maker.

The key takeaways can be summarised as:

i) Policies rather than prices function as better determinants of future technology configurations to obtain realistic (usable) model outcomes.

[10] For example, a casual analysis of Refrigerator popularity (controlling for sizes and brands) on the popular e-commerce platform Flipkart reveals an overwhelming preference for 1-2 star refrigerators that have lower front costs but turn out much more expensive in life cycle costs compared to their more efficient but higher priced/ counterparts. Similarly, Bureau of Energy Efficiency certified efficient irrigation pump-sets are much more expensive and less resilient to fluctuations in electricity supply than locally manufactured ones, so that even if an average farmer with a landholding of less than 5 acres was charged for the electricity they consume, their cash flows and finances would render this upgrade unviable, given they over-value front costs (cash in hand) compared to life-cycle benefits of efficient pump-sets (Ali M. S., Energy Efficient Irrigation Pumping: 96 GWh of power can be saved, 2015). It is in recognition of this gap that Ag-DSM scheme was launched.

ii) Scenario planning tools offer more flexibility and transparency over optimisation models to specify policy transmission mechanisms directly, rather than by restricting outcomes.

Accordingly, the analysis is undertaken in a transparent environment that scenario planning tools and calculators offer, where the rationale for pricing (capital costs and electricity prices) is embedded in scenario design, informed by historical trends in technology adoption and price trajectories. More importantly, the study employs 'cases' rather than more prescriptive 'scenarios'[11], derived as combinations of different levels of growth in economic output, service demands and market penetration of end-use technologies. Together, the three GDP growth scenarios outlined earlier (6.5, 7.0 and 7.5 percent CAGR) and the three scenarios of conservation and efficiency give nine scenarios of electricity demand in this study. The thresholds obtained from the solution set, provide the range of uncertainty over which economic and policy outcomes will play out.

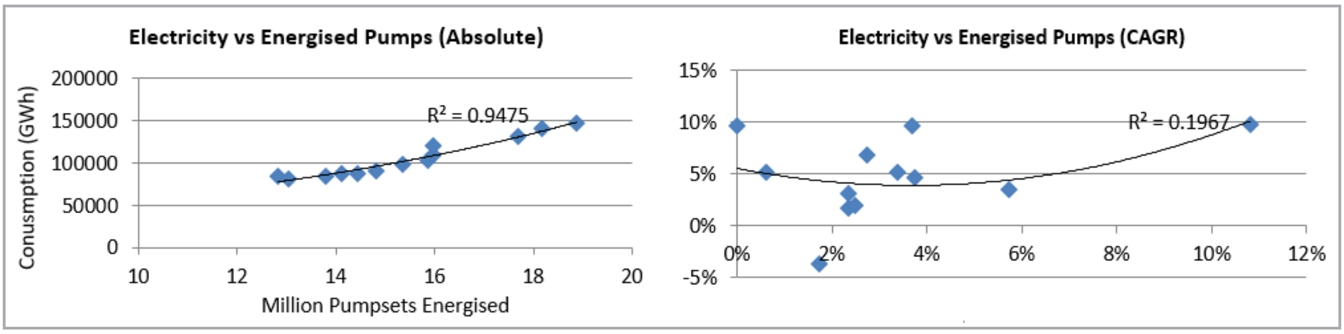
Sector-wise electricity demand: Context, drives and outcomes

Irrigation pumping

In 2015, India is estimated to have approximately 20 million energised pump-sets consuming 169 TWh of electricity, with decadal CAGRs of 3.2 and 6.9 percent respectively (NITI Aayog, 2015; Central Electricity Authority, 2007-2016). This indicates that intensity of pump-set use has increased faster than pump-sets energised over-time.

Figure 6 shows how absolutes of electricity (Y axis) and pump-sets (X axis) show a strong correlation (R sq. = 0.95), while the plot of yearly growth rates conveys a very different picture (R sq. = 0.20).

Figure 6: Electricity consumption and pump-sets energised



Source: NITI Aayog IESS Agriculture Documentation, CEA General Reviews and author's calculations.

[11] A traditional prescriptive 'scenario' approach would be based on a counterfactual policy narrative, for example,'business as usual' versus 'low carbon' in which all variables move based on that narrative. In this exercise, however, policy implications are modelled directly, and therefore embedded within outcomes so that their impact on electricity demand can be studied both in isolation and in terms of cumulative effect on the system. This allows examination of unlikely but plausible cases—progressive policy outcomes on energy efficiency with low overall economic growth and service demands that may obtain, but not necessarily fit within a scenario narrative. This is advantageous, especially given the recent context of suppressed electricity demand and revised projections by CEA indicating lower future demand than previously estimated, as evidenced from the 18th and 19th EPS.

Accordingly, projections of future scenarios for this analysis is not based on merely pump-set growth and energy input, but more fundamentally on the land under cultivation, cropping pattern, water requirement and alternate sources of irrigation. India has approximately 141 million hectares of land under cultivation (net sown area) with a cropping intensity[12] of 139 percent (Department of Agriculture, Cooperation & Farmers Welfare, 2017)[13]. Of this, more than 50 percent land is rain-fed, which partly explains the volatility in agricultural electricity demand and economic output. Of the irrigated area, more than two-thirds is via groundwater sources using tube-wells and tanks. India's net sown area and average landholding sizes have fallen since 1970s, with the latter facing a secular decline (Department of Agriculture and Cooperation, 2013). This indicates that the growing need for food, fiber, and intermediate produce has been met through enhanced productivity. However, big gaps in improving productivity through soil and water management and scientific farming practices remain. The cropping intensity has also increased steadily. Water requirement per hectare from cereals, pulses, fruits, vegetables, oilseeds, fiber, tobacco and other crops, representing over four-fifths of the gross cropped area is examined along with irrigated area for principal crops to arrive at an annual water requirement per hectare of 840 mm[14] (IIT Kanpur, 2010).

Based on these trends, it is assumed that future expansion in gross cropped area will happen via increase in cropping intensity to nearly 150 percent by 2030 and increase in irrigation coverage. In response to higher water requirements and depleting water tables, the average size of pump-sets in operation will likely increase from just over 5HP in 2013 to 7.5 HP by 2030, with discharge rates around 700-100 litres per minute (lpm), compared to 300-600 lpm for 5 HP pumps. Groundwater-use efficiency is taken to improve from less than 15 percent currently to 25 percent by 2030, in line with NITI Aayog's assessment of a 33 percent efficiency potential[15] (NITI Aayog, 2015).

Further distinctions are made for lower and upper bound cases of electricity demand in 2030:

- Irrigated area by surface, micro, and solar irrigation: An additional 12 million hectares is covered under surface water schemes and micro irrigation (MI), with 20 percent coverage under solar and solar-MI schemes in the lower bound for electricity demand (PPPAU NITI Aayog, 2017)[16]. In the upper bound, two-thirds of the irrigated land continues to be supplied by underground pumping, with limited expansion in alternate means (10 percent solar and solar-MI irrigation).

- Pump-set efficiency: The efficiency of average IP sets (under standard testing conditions) improves from 50 percent in 2015 to 60 and 70 percent respectively in the upper and lowerbound cases, the latter based on an aggressive market transformation facilitated by Agricultural Demand Side Management (Ag DSM).

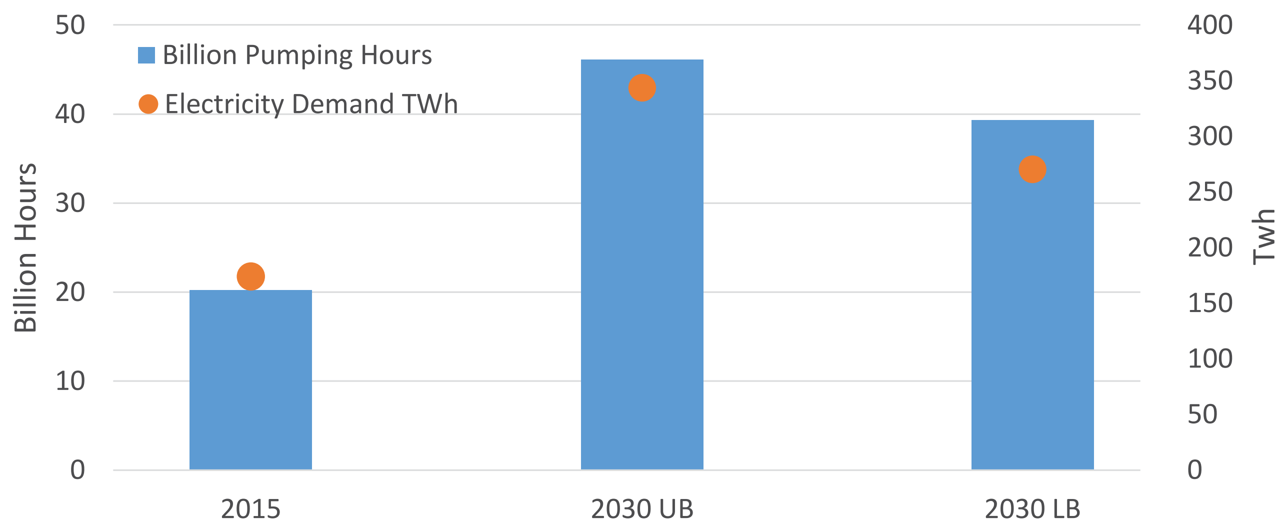
The key results obtained for the range of irrigation pumping demand by 2030 are shown in Table 5. Table 6 compares the hours of pumping and electricity demand across 2015 and 2030.

[12] Related to the number of cropping cycles in a year.
[13] Net sown area x Cropping Intensity= Gross Cropped Area
[14] A 5-10 percent diversion from food to cash crops causes negligible change in consumption requirement.
[15] This happens due to improved water transport technologies in new/retrofitted pump-set installations, enhanced application of micro-irrigation and government policies aimed at sustainable water use.
[16] Of the 70 Mha of MI potential, less than 1 Mha is currently deployed.

Table 5: Water and energy demand for irrigation

	2030 UB	2030 LB
Gross Irrigated Area groundwater (Mha)	77	63
Pumping water requirement (million m3)	622,378	530,435
Million pumping hours	46, 102	39,292
Average Input (kW)	7.46	6.39
Electricity Demand (TWh; CAGR)	358 (4.85%)	251 (3.19%)

Figure 7: Pumping Hours and Electricity Demand



While the energy demand may grow between 3.2 and 4.9 percent CAGR by 2030, the aggregate load of pump-sets is estimated to grow from 76 Giga-watt (GW) to 175-206 GW (5.8- 6.9 percent CAGR), indicating that the fundamental difference between past and future growth in electricity demand will come from the pump-set usage pattern and intensity and availability of viable alternatives, rather than electricity access or pump-set ownership.

Residential buildings

Residential sector consumes near a quarter of total electricity in India, having grown at 8 percent CAGR since 2000 (Central Electricity Authority, 2017). The principal components of consumption are lighting (point and tubular), refrigerators, televisions, fans, room air conditioners and other loads such as washing machines, geysers, residential water-pumps, battery-inverter systems, etc. Historically, lighting and fans have accounted for over half of the sector's consumption, with high peak coincidence. But the rapid fall in prices for first the CFLs and then LEDs facilitated by market aggregation schemes like Bachat Lamp Yojana (BLY) and Domestic Efficient Lighting Programme (DELP), have ensured that the share of inefficient incandescent bulbs drop to less than half of the estimated point lighting stock (Ali M. S., The Path to Light: A case for LEDs, 2015)[17]. On the other hand, the

[17] The share in new sales is much lower. The lighting equipment manufacturing association (ELCOMA) has announced a plan to phase out incandescent bulbs in the near future.

demand for space conditioning has been galloping at CAGRs of 20 percent per annum since 2010, and is likely to register significant deployment by 2030 (Byravan, Ali, & al, 2017; Phadke, Abhyankar, & Shah, 2014)[18].

For analysing various cases of service demand and efficiency, the following means are employed:

- Dataset of 28 appliance technologies across 7 applications and 15 ECBC interventions
- Varying appliance stock (based on per capita income growth) and energy efficiency (lumens/ Watt, Energy Efficiency Ratio, etc.), and stock shares (across appliance types, eg. window and split AC, etc.)

Differential application of efficiency and conservation measures across upper and lower bound of electricity demand.

Table 6 shows the appliance stock in 2012[19] and 2030 in a mid-growth scenario. The growth of room air-conditioners (RAC) stands out as a defining trend for the future. The stock of 'others' is not estimated; instead, others are modelled as a residual after deducting the base year consumption of the below appliances from total residential consumption reported by the CEA.

Table 6: Appliance Stock in base year and 2030 (7.0 percent GDP growth)

	Total stock (million)		Ownership (per HH stock)		CAGR	
	2012	2030	2012	2030	Stock CAGR	Ownership CAGR
Point Lighting	687	1137	2.66	3.47	2.8%	0.7%
Tubular Lighting	258	433	1.00	1.32	2.9%	0.8%
Refrigerators	47	211	0.18	0.64	8.7%	6.4%
RAC	4	101	0.02	0.31	19.5%	17.0%
CTV	123	343	0.48	1.05	5.9%	3.7%
Fans	305	673	1.18	2.05	4.5%	2.3%

Sources: Quality of Life for All (Byravan, Ali, et al 2015), Avoiding 100 power plants by Increasing efficiency of Room ACs (Phadke, Abhyankar et al 2015), Expert Group on Low Carbon Inclusive Growth (2014), IESS 2047 (NITI Aayog 2015), The case for LEDs (Ali 2015), EFFECT-India Model (World Bank ESCAP 2010), Realising efficiency savings from household appliances in India (Parikh and Parikh 2016), other miscellaneous datasets and author's calculations.

[18] Part of the reason for such high CAGR is the low base of stock, and while the growth rates may slow down in the future, all indications suggest the absolute stock addition will keep growing owing to massive gap in ownership, growth in per capita incomes, urbanisation and urban islanding and declining technology costs. We will later see how it becomes the most significant consuming category by 2030.

[19] This analysis is calibrated at 2012 since it is the latest year that stock estimates can be cross-verified via a number of sources/studies available. These are simply projected forward to the study base year (2015).

Across these applications, a mix of low medium and high efficiency technologies[20] is specified in the base year based on Bureau of Energy Efficiency's (BEE) Verified Energy Savings reports. Based on historical revisions in appliance-wise efficiency floor and ceilings as per updates to BEE's star rating guidelines, historical sales of star-rated appliances reported by BEE, impact of energy efficiency policies and historical cost curves, an assessment of plausible technology configurations in upper bound and lower bound of electricity demand are determined. Interventions pertaining to building design and control[21] are similarly applied differentially across the lower and upper bounds, which serve to reduce the intensity of HVAC and lighting loads–the key factors being penetration and compliance with star-ratings, and relative costs versus benefits of various alternatives for insulation, roofing, window glazing, window design, and daylight and lighting control (The Weidt Group, 2011a; The Weidt Group, 2011b; The Weidt Group, 2012)[22].

Based on the above, the application-wise upper and lower bounds of electricity demand[23] is shown in Table 7. Lighting and fans offer the highest potential since the markets are mature, the best efficient technologies are known and therefore ripe for upgrade. Overall, variations in GDP growth and energy efficiency and conservation combined, shows up a difference of 183 TWh between the UB and LB, which is almost identical to the total residential electricity demand in 2013.

Table 7: Electricity Demand from Residential Appliances

	Demand in TWh (CAGR)		Difference (LB vs UB)	
	2030 UB	2030 LB	TWh	Percentage
Point Lighting	4.6 (-10.91%)	1.5 (-16.40%)	3.2	68.2%
Tubular Lighting	18.9 (2.75%)	13.9 (0.93%)	5.2	27.4%
Refrigerators	81.6 (8.60%)	60.5 (6.82%)	21.1	25.8%
RAC	279.6 (21.04%)	209.3 (19.10%)	70.3	25.1%
CTV	46.1 (5.16%)	36.2 (3.76%)	9.9	21.5%
Fans	69.3 (2.57%)	29.2 (-2.23%)	40.1	57.8%
Others	120.9 (7.56%)	87.3 (5.63%)	33.6	27.8%
Total	620.9 (7.42%)	437.6 (5.36%)	183.3	29.5%

[20] Low and mid technologies broadly correspond to representative median BEE 3-star and 5-star rated appliances as of August 2014, shortly after which the list of accredited appliance models and their technical characteristics was no longer public on the BEE website. High efficiency appliances pertain to LEDs, inverter ACs, super energy efficient fans (for which request for expressions of interest have been floated by BEE in the past), refrigerators and televisions based on best available technologies that have significant market potential, 20-40 percent savings over 5-star appliances and have low commercial penetration due to high costs.

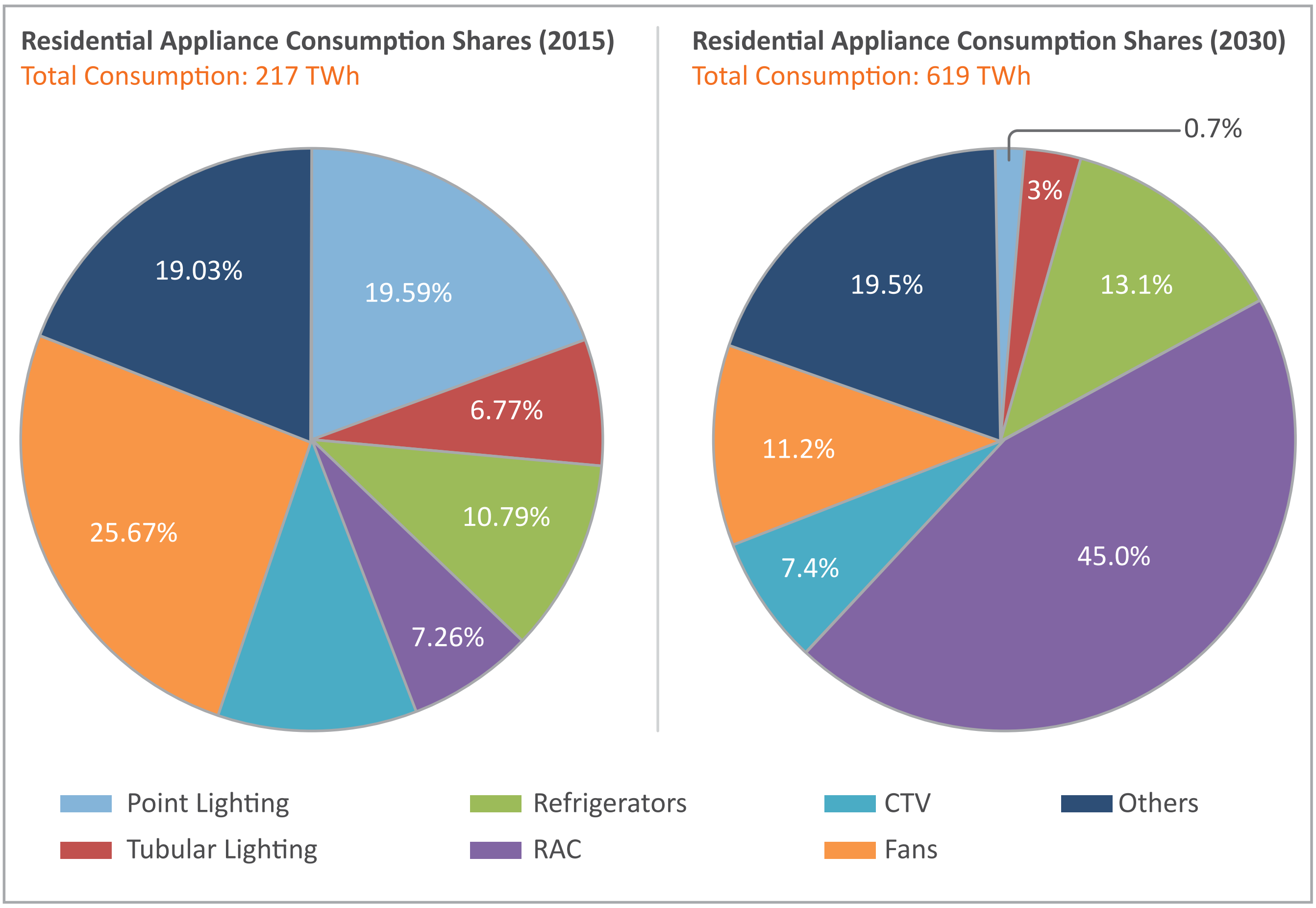
[21] Also referred to as 'ECBC interventions' in this report— named after the Energy Conservation Building Code (ECBC) that mandates energy efficient building design (apart from use of energy efficient equipment).

[22] These are applied on the residential floor-space area and work to reduce the EPI (kWh/sq. m.) of the buildings.

[23] Unlike irrigation pumping demand, the ownership of residential appliances is affected by per capita income growth in the model. Accordingly, the lower bound is the 6.5 percent GDP growth and high energy efficiency case, while the upper bound is the 7.5 percent GDP growth and low energy efficiency case. Unless explicitly specified, LB and UB for the forthcoming sectors or applications will be denoted this way.

Figure 8 shows how the shares of different end-use applications are likely to change by 2030[24].

Figure 8: Appliance-wise share of electricity consumed



From Figure 8, air-conditioning grows more than six times in share, while lighting reduces from almost 27 percent to less than 4 percent and fans by more than half. This has implications for distribution of the load, which will likely be much more urban-centric than in the past, and may cause local congestion issues for the Discoms.

Affordable housing

So far we have discussed the organic demand growth, represented in utilities' supply plans, and accounting for electrification and energisation. There is however, an unaccounted component of electricity demand from a vast number of homeless families, for which the government's Affordable Housing Programme promises dwellings by 2022. Often it is stressed that owing to a significant latent electricity demand from 300-400 million people, Indian grid may not be able to abandon coal-based expansion. This is an attempt to investigate the latent demand from the new households of the future that are currently off the map.

[24] Results are presented for the UB case. There are minor variations between LB and UB but the general trend remains the same.

National Housing Board estimates a housing gap of 18.78 million urban and 43.67 rural million houses in 2012 (Byravan, Ali, & al, 2017; National Buildings Organisation, 2015). Approximately 18 percent of urban households are estimated to be in slums that need rehabilitation and regular electricity supply. By 2022, the expected deficit in urban households may be in excess of 34 million (Mint, 2015). This raises the cumulative housing deficit to 78 million households, growing at over 8 percent per annum in urban areas. On the other hand, yearly stock addition growth as per two latest Census has been at 5 percent per annum, which is lower than the rate of deficit growth (Central Statistics Office, 2011). This implies that a massive push in building houses for the deprived population is required.

As per Affordable Housing (AH) guidelines available in various policy documents (eg. Rajiv Awaas Yojana), the built-up floor-space gap for urban and rural households combined will be nearly over 3,100 million sq. meter, of which the urban demand will be nearly 44 percent (JNNURM Mission Directorate, 2012). Considering the steep requirements, the AH target is relaxed to be met by 2030 in two phases (2017-22 and 2022-30) and resulting electricity demand from these households is obtained. Table 8 shows the rate of yearly floor-space construction under two specific cases— LB, when only 35 percent of the target is met by 2030 and UB when the AH gap is wiped out by 2030.

Table 8: Affordable Housing stock addition till 2030

Affordable Housing (AH) floor-space Construction (million m2)				
	AH target met	**Total**	**Yearly**	**Million Homes Yearly**
Phase I (15-22)	50% (UB)	1512	216	5.4
	10% (LB)	268	38	1.0
Phase II (22-30)	50% (UB)	1411	176	4.4
	25% (LB)	633	79	2.0

We find that even with the relatively modest LB target, the yearly rate of housing stock addition is steep, and much higher than the present rate of construction

Table 9 shows the assumptions on electricity consumption per household for these units. From 500 kWh per annum, households built in the first phase are assumed to reach an annual consumption of 700 kWh by 2030, while those constructed between 2022 and 2030 reach 600 kWh per annum of consumption by 2030[25].

Table 9: Phase-wise Electricity requirement for AH units

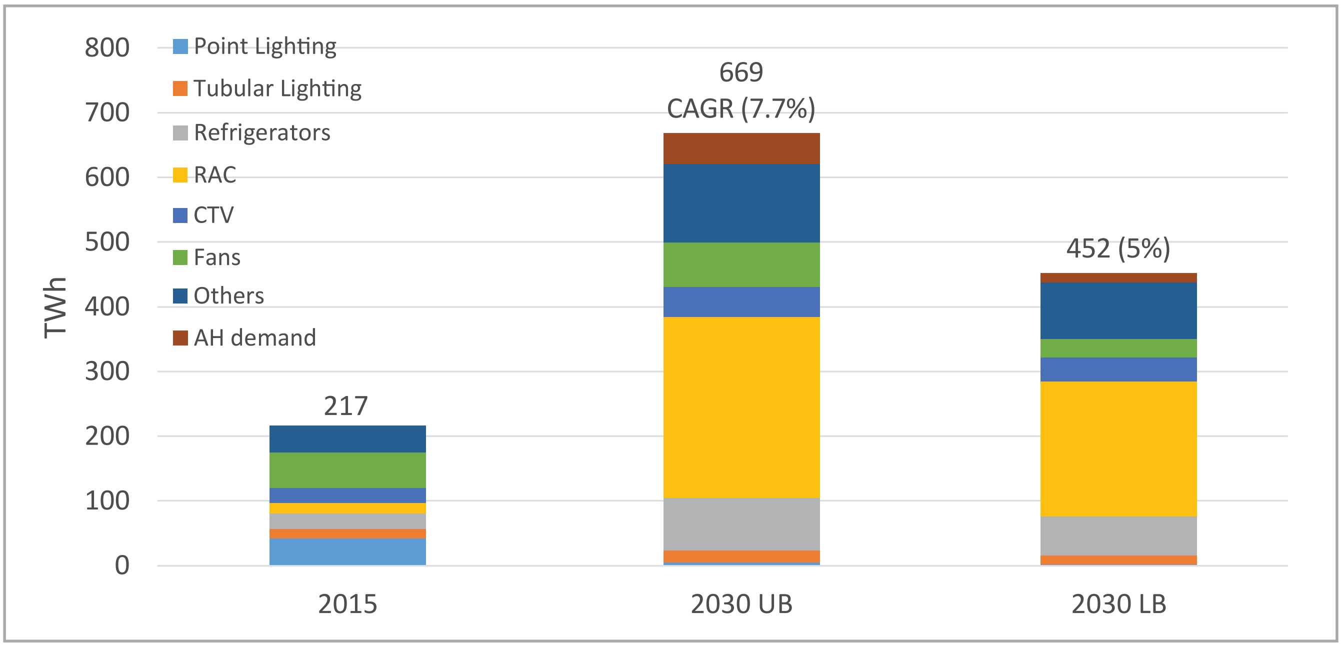
Annual Electricity demand per AH dwelling	**Houses in Phase I**		**Houses in Phase II**	
	2022	**2030**	**2022**	**2030**
Electricity (kWh) /HH/annum	500	700	500	600
EPI (kWh/sq. m/annum)*	12.50	17.5	12.5	15
*All India Residential EPI in 2015- 15.2 kWh/sq. m				

[25] The Integrated Energy Policy mentions a lifeline use of 1 kWh/per day for basic lighting, ventilation and charging. We extend this to 500 kWh annually (SPARC, 2016) and further add productive use of more sophisticated appliances and equipment in the future for these households. For benchmarking, all-India residential EPI of 15.2 kWh/sq. m in 2015 is used.

The aggregate electricity demand from AH units is obtained as 48 TWh and 14 TWh respectively in the UB and LB cases. This shows that even with full housing access by 2030, the additional electricity demand generated will be less than 5 percent of the aggregate electricity consumption in 2015, indicating that the big challenge lies not in the quantum of electricity demand is but creation of sustainable frameworks to ensure electricity access.

Figure 9 shows a consolidated snapshot of the electricity demand from 'organic' growth in residential appliances and the 'inorganic' component of AH.

Figure 9: Residential Electricity Demand



From 217 TWh in 2015, residential electricity demand may grow to between 452 (5.0 percent CAGR) and 669 (7.8 percent CAGR) TWh based on per capita income growth, appliance ownership, energy efficiency, and stock of households electrified. This will raise the average household consumption by 1.5-2.25 times the consumption in 2015 (787 kWh per annum). While energy efficiency of the appliance mix improves compared to base year in both LB and UB, the aspirational motives for comfort and convenience imply that future growth could turn out near historical growth rates in consumption if satisfactory outcomes in energy efficiency and conversation are not achieved.

Electric cooking

While cook-stoves form a part of residential consumption, they are treated separately owing to lack of historical precedent. With enhanced electricity access and emphasis on cutting down household drudgery, mortality and morbidity due to inefficient and polluting biomass cook-stoves in rural areas, electric cooking has emerged as an important option for the future. This also helps avoid imports of crude oil and natural gas for cooking and can serve as a viable second option in case of non-availability of LPG/ PNG, especially for rural households.

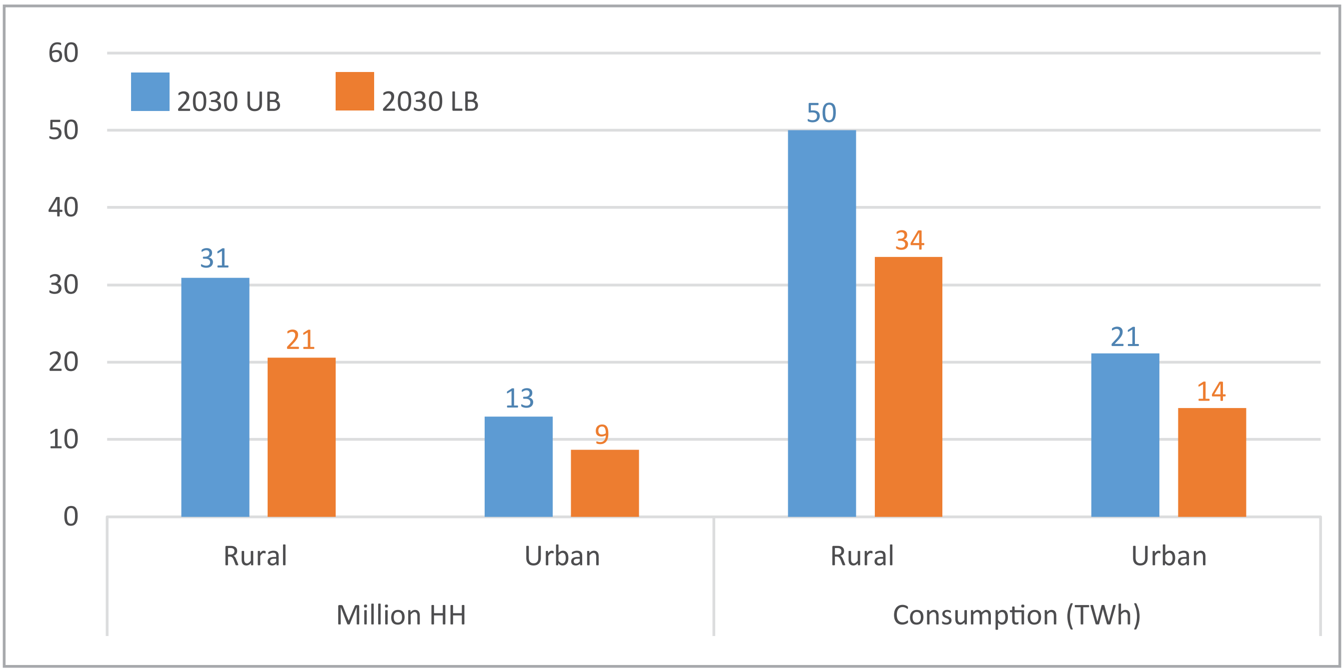
To arrive at this demand, an annual household consumption equivalent to 10 LPG cylinders of 15 kg is assumed, which is equivalent to 1371 kWh per annum of useful energy requirement per household[26]. For the upper bound,

[26] Based on a calorific of LPG as 47 tera-joule per kilo-tonne and 70 percent efficiency of LPG cook-stoves. Efficiency of electric cook-stoves is taken at 84 percent (Jain, Choudury, & Ganesan, 2015; Byravan, Ali, & al, 2017).

energy requirement equivalent to complete switching by 15 percent rural and 10 percent urban households is estimated. For the lower bound, two-thirds of this switching is envisaged to account for predominant use as a secondary rather than primary fuel for cooking.

Figure 10 shows the results obtained in the upper and lower bound cases for household penetration of electric cooking[27] and resultant electricity demand.

Figure 10: Electric cooking penetration and electricity consumption



Therefore, electric cooking may add another 48 to 72 TWh in electricity demand but bring with it significant benefits in health and productivity, especially in rural areas.

Commercial buildings

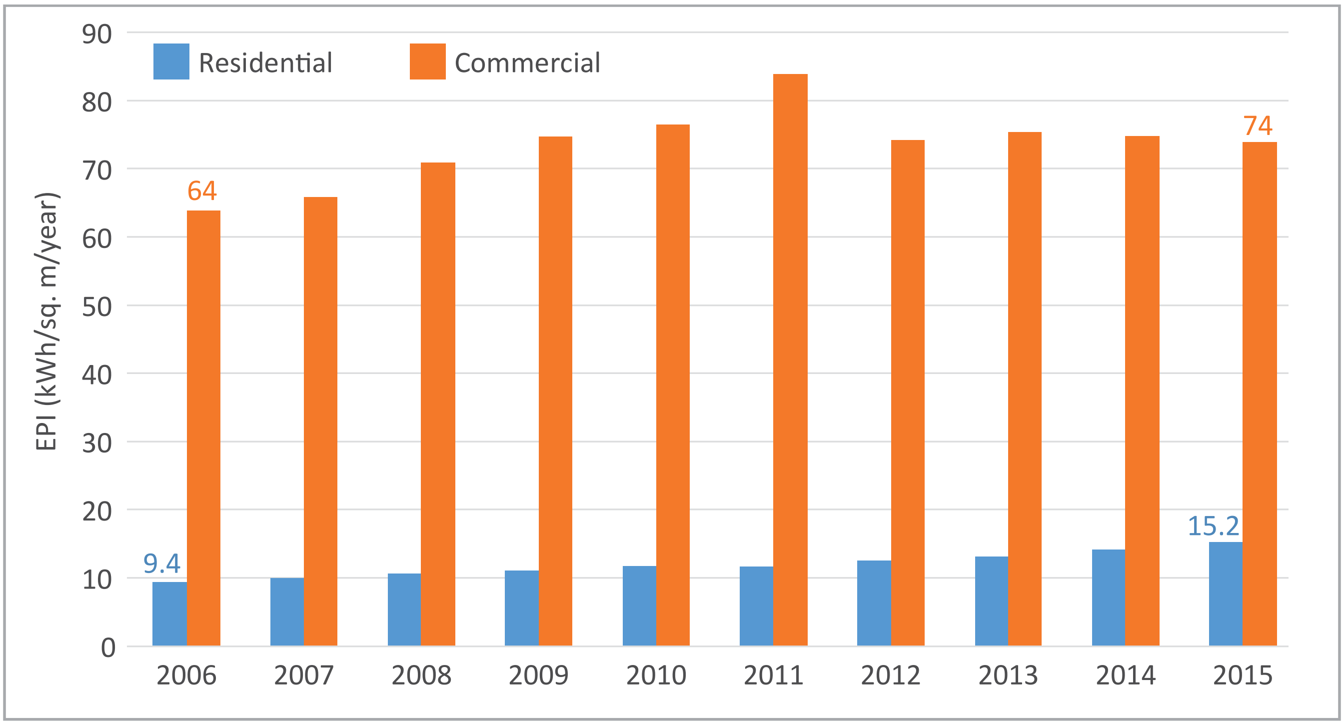
In contrast to its contribution in economic growth, the commercial sector in India consumes less than 10 percent electricity, owing to low energy intensity of its output. However, the sector has registered the highest growth in electricity consumption at nearly 10 percent CAGR since 2000 (Central Electricity Authority, 2017).

Compared to residential Built-up area, commercial sector has a much higher energy consumption per square foot, which boils down in large part to accessibility and difference in paying abilities between the two sectors, aside from the critical need of electricity to run commercial activity. Figure 10 shows how commercial electricity consumption per square foot was almost five times than that of households in 2015 (NITI Aayog, 2015; Central Electricity Authority, 2007-2016)[28].

[27] Equivalent to full switch-over to electric cooking. In practice, penetration may be higher with mixed use.

[28] It should be stressed that average EPIs of both residential and commercial buildings are still very low. Modern apartment complexes consume between 40-60 kWh/sq. m / annum and high-end fully air conditioned commercial buildings in India can consume up to 250-400 kWh/sq. m (The Weidt Group, 2011a).

Figure 11: Historical EPIs of Residential and Commercial Buildings



A significant reason for low EPIs of Indian buildings has been the lack of air-conditioning services compared to developed countries. But demand for HVAC has been growing rapidly as witnessed in the residential sector discussions. However, the density of AC coverage usage is much higher in the commercial sector, as evidenced in Figure 10. Despite this, our calculations show that average annual AC coverage in the commercial sector in India remains as low as 8.5 percent of the floor-space area[29], which explains the low EPI of Indian commercial buildings. Also, a sizeable number of Indian commercial buildings and built-up area, particularly in the retail trade and restaurant business is occupied by 'Own Account Enterprises'—commercial enterprises that are individually owned or run by family having no hired employees. These are invariably small-scale, numerous and characterised by lack of air-conditioning, which further keeps the average commercial EPIs low (Kumar, Deshmukh, Kamnath, & Manu, 2010).

Owing to the diversity of appliances employed in the commercial sector, its energy consumption is distributed across HVAC, lighting and other uses[30] (Planning Commission, 2014). Even within these categories, solutions from household level to much larger scale application are available, so service demands are projected on the basis of application to total floor-space area rather than as stock of appliances. In such a case, growth in commercial floor-space area and service-intensity combine to give the total service demand.

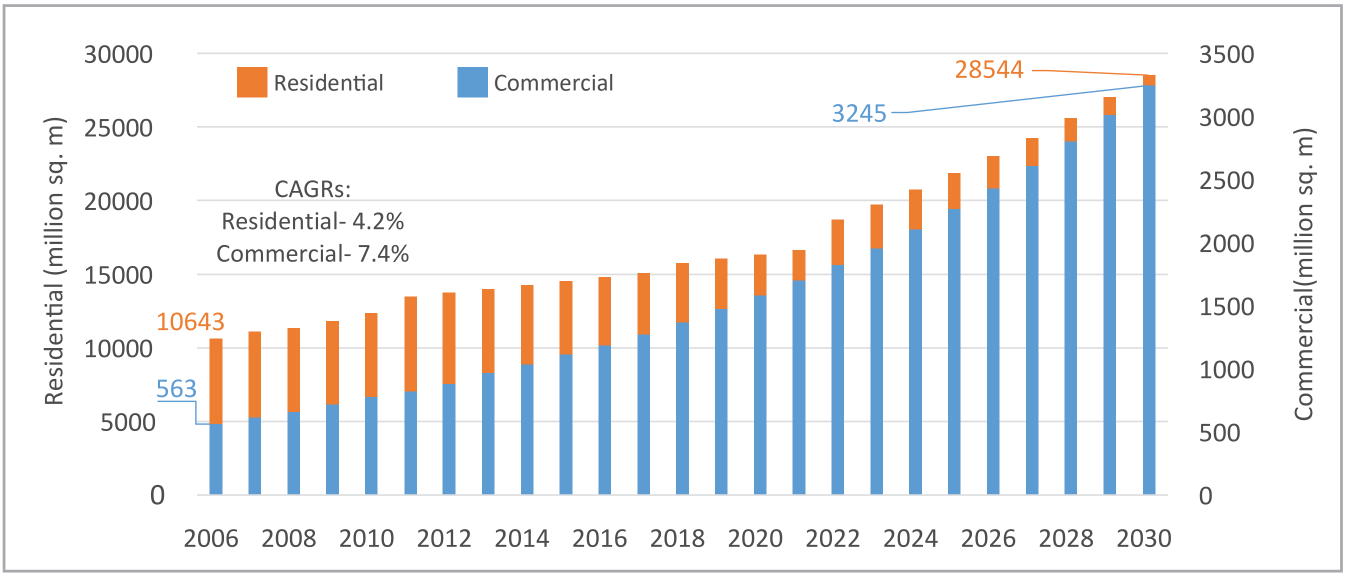
Figure 12 shows the historical and projected levels of residential and commercial floor-space area (at 7.5 percent GDP growth)[31]. In 2015, commercial sector built-up area is only 7.7 percent of the residential area. On account of higher future growth rates in commercial area, this ratio is projected to increase up to 12 percent by 2030 (Byravan, Ali, & al, 2017; NITI Aayog, 2015).

[29] Not all of the built-up area necessarily requires air conditioning (such as shafts, staircases, hallways, passages, rest-rooms, storage) in an air-conditioned building.

[30] These pertain to internal server loads, laptop, printers, and other sector-specific equipment.

[31] In the low GDP scenario, the respective CAGRs for residential and commercial sectors are 3.4 percent and 6.4 percent respectively.

Figure 12: Historical and Future floor-space area of Buildings



Further, the growth in service intensity between 2015 and 2030 is shown in Table 10. Service intensity in the base year is arrived at by converting the units of electricity consumed in useful service[32].

Table 10: Service Intensity across commercial sector applications

	2015	2030	CAGR
HVAC Coverage (%)	8.5%	22.5%	6.7%
Lighting (lumens/sq. m)	290	350	1.3%
Others	-	-	4.0%

For projections on energy efficiency and conservation, a differential penetration of high, medium and low efficiency technologies across the applications (9 technologies overall) and 19 ECBC related interventions is applied across the lower and upper bound scenarios.

Based on this, the commercial electricity demand derived is shown in Figure 12. The impact of air conditioning growth figures prominently as total electricity demand across applications grows from 82 TWh in 2015 to 247 TWh by 2030 in the LB (7.6 percent CAGR) and 348 TWh in the UB (10.1 percent CAGR).

[32] In case of ACs, this pertains to the standard area covered per ton of air-conditioners, calibrated with end- use consumption based on weighted average wattage and EERs of representative technologies. For lighting, this is based on lumens/watt for LCD and LED lighting technology mix. The share of electricity consumed by respective end-use applications is 55 percent, 25 percent and 20 percent for HVAC, lighting and others in 2012 (Planning Commission, 2014). This is forward projected to 2015 based on assumed growth in appliance mix and service intensity till 2030. CAGR of others till 2030 is taken as an intermediate value between HVAC and lighting intensity growth such that the electricity demand obtained in 2015 is balanced with officially reported values.

Figure 13: Commercial Electricity Demand

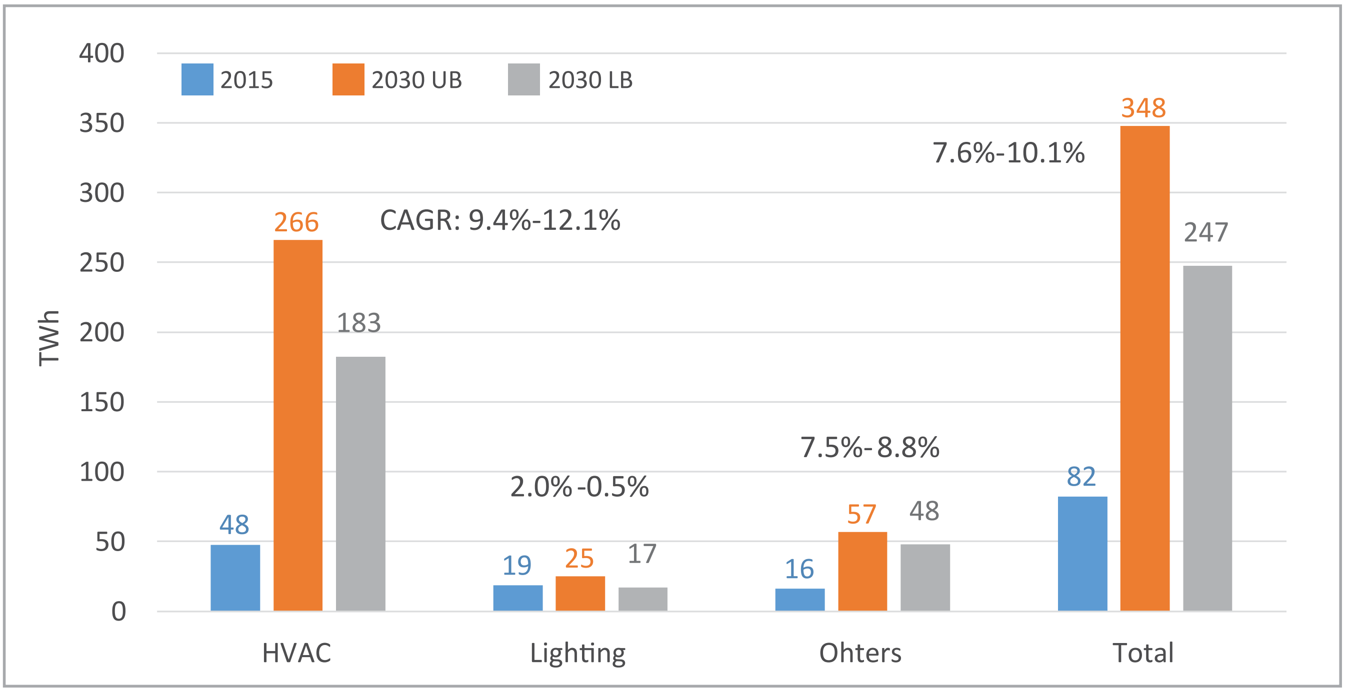


Table 11: HVAC consumption in Buildings

Electricity demand (TWh)	2015	2030 UB	2030 LB
Residential HVAC	25	280	209
Commercial HVAC	48	266	183
Total HVAC	72	546	392
HVAC: Total buildings demand	25%	54%	56%

In general, HVAC growth emerges as a mega-trend across residential and commercial buildings as evidenced in Table 11. From a quarter of total buildings' demand in 2015, the share of HVAC is likely to more than double by 2030, with CAGRs of 12 and 14 percent respectively across the LB and UB scenarios. This calls for aggressive interventions in this space, particularly as average AC Energy Efficiency Ratios (EERs) in India lag much farther behind those in the developed world. Making inverter based star-rated ACs cost competitive with their non-inverter counterparts through direct government interventions and easy low-cost finance schemes can help foster energy efficiency in this space.

Industry

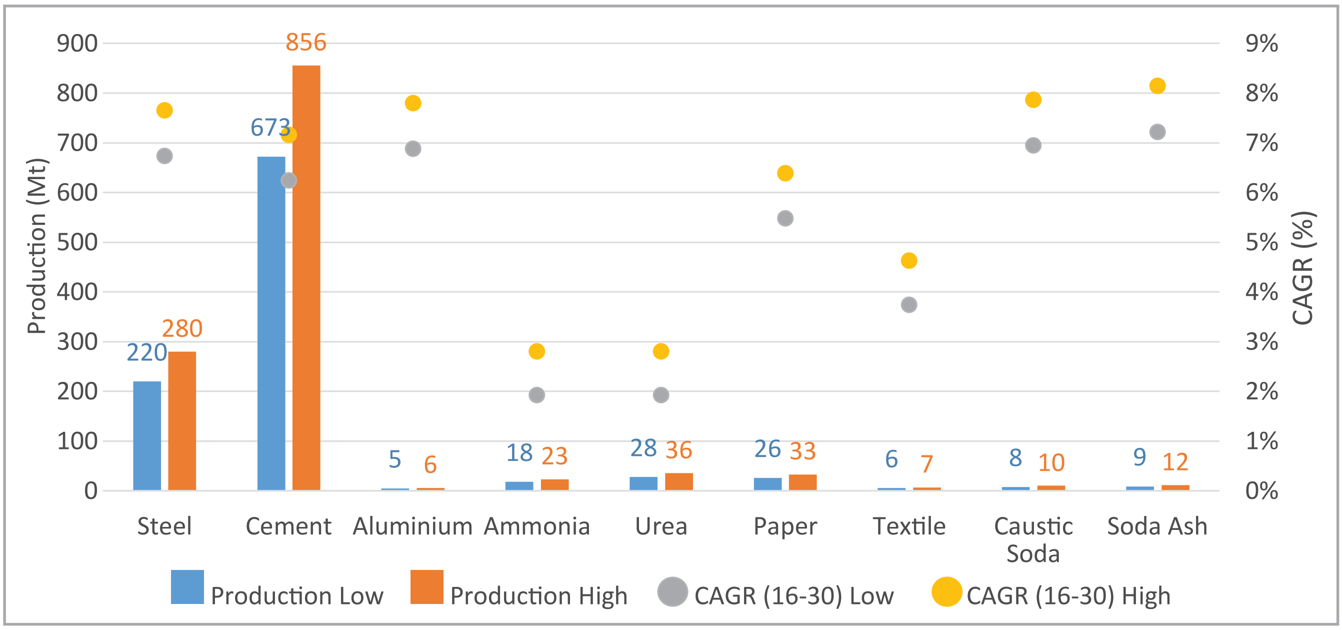
While the industrial sector is the largest consumer of grid power, it also has substantial and growing captive generation (Central Electricity Authority, 2007-2016). While efforts to enhance industrial production and employment have been consistent since the 1950s, the largest scheme for enhancing energy efficiency in the industrial sector has been the PAT, for which the specific energy consumption (SEC) targets for individual designated consumers (DCs) across eight energy intensive sectors –Iron and steel, cement, aluminium, fertilisers, textiles, pulp and paper, chlor-alkali, and thermal power plants— were first given in 2012[33].

[33] The first cycle of PAT included 478 DCs and came to an end in 2014-15. The second PAT includes three new sectors- railways, refineries and Discoms, and energy saving targets have been notified for 621 DCs (Bureau of Energy Efficiency, 2016).

Based on the PAT classification, the analysis for industry sector attempts to account for process-wise production and SECs for the PAT sectors[34]. In total, 26 processes are modelled across the seven PAT sectors, with fuel-wise SECs (electricity, individual fossil fuel and waste/ renewable energy). For future projections of electricity/energy saving, sector/process-wise energy saving interventions, and raw material, fuel and process switching interventions were considered. Of the total industrial electricity consumption (grid and captive) reported by the CEA, electricity consumption from the remaining sectors is obtained as a residual 'non-PAT' consumption category, which mainly includes secondary and small-scale manufacturing industries' consumption of electricity.

The key driver for electricity consumption in the industrial sector in the model is the economic activity represented by production across individual PAT sectors as shown in Figure 13. Production of all sectors is taken to vary proportionately across different growth scenarios. This is a simplifying assumption since specific sectors are also impacted by particular policies growth drivers, all of which need not necessarily move in the same direction.

Figure 14: Industrial Production in high and low industrial growth scenarios (2030)



Sources: Indiastat.com, ministry, consulting and industry associations' reports, and other scenario modelling studies mentioned for Table 7.

For the non-PAT sectors, the growth of their value-added in production is taken as a proxy for physical production, owing to the diversity of production which cannot be neatly categorised across all sectors on a weight or volume basis. Therefore, the overall industrial sector growth scenarios are used to project their economic activity by 2030.

Each industrial process modelled is associated with its own SEC and underlying fuel mix. The decision to model any process as a separate category is taken if the technologies and raw materials, and therefore energy requirements involved in distinct processes are substantially different. The penetration of high-efficiency technologies and processes as modelled in high and low-efficiency scenarios across the PAT sectors are presented in Table 12.

[34] This is barring PAT targets on efficiency improvement for thermal power plants, which is an electricity supply issue.

Table 12: Industrial Process shares across high and low efficiency scenarios (2030)

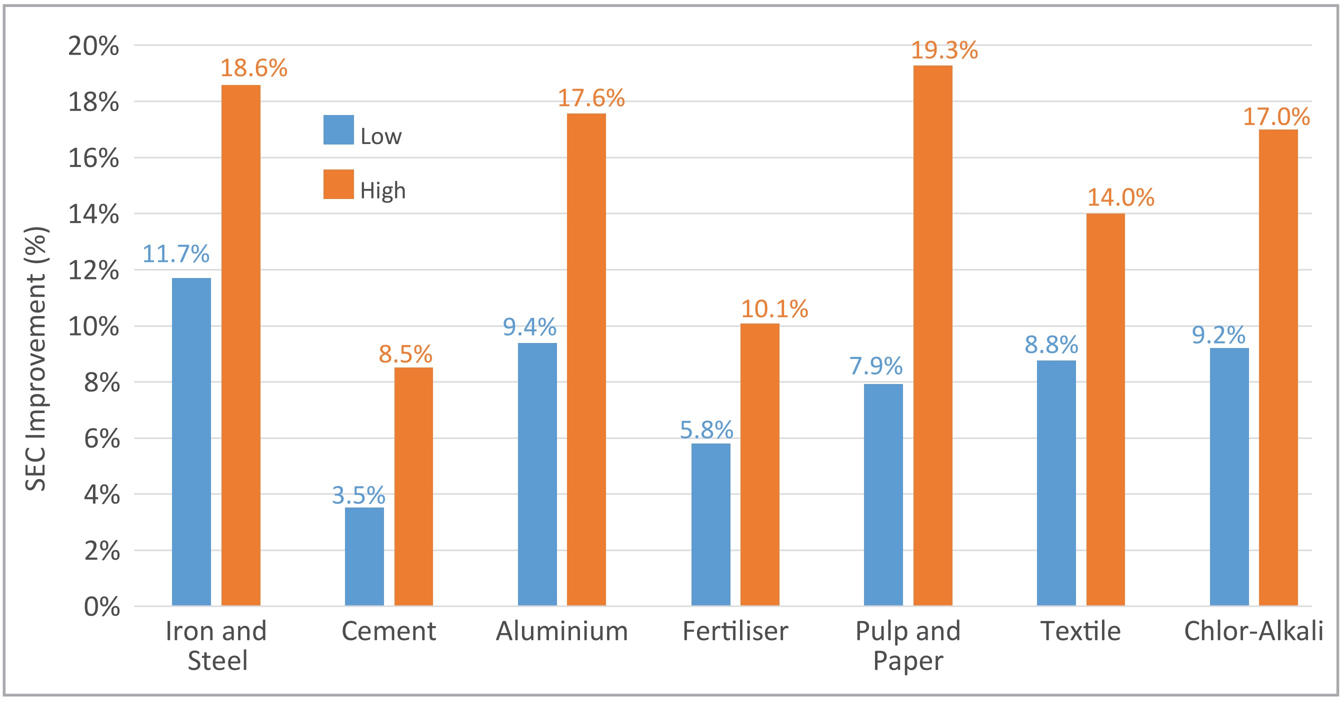
Industry	Process	High Efficiency	Low Efficiency
Iron & Steel	BF-BOF	36%	22%
	Coal DRI-EAF	25%	15%
	Gas DRI-EAF	12%	12%
	COREX-BOF	12%	14%
	Scrap-based EAF/IF	15%	37%
Cement	OPC	20%	8%
	PPC	70%	80%
	PSC	10%	12%
Aluminium	Pre-baked	75%	60%
	Soderberg	5%	0%
	Scrap-based	20%	40%
Pulp & Paper	Integrated Kraft (Wood/bamboo/agro waste)	57%	35%
	RCF based (includes market pulp)	43%	65%
Fertilisers (Urea and Ammonia)	Natural Gas-based	80%	100%
	Naptha-based	10%	0%
	Fuel Oil- based	10%	0%
Textile	Integrated Textile Production	100%	100%
Caustic Soda	Mercury Cell	0%	0%
	Membrane Cell	95%	80%
	ODC	5%	20%
Soda Ash	Solvay	35%	0%
	Modified Solvay	25%	30%
	Akzo Dry Lime	40%	70%

For non-PAT sectors, which consumed 47 percent of total industrial electricity consumption in 2015, conservative efficiency improvements of 5-10 percent are considered, since they offer limited energy saving potential due to scale economics, front costs and financing constraints. To arrive at the industrial electricity demand, energy efficiency potential along with specific share of electricity in total SECs across the processes are used with process shares (Table 13) and industrial production (Figure 13).

Prevailing circumstances in each PAT sector are accounted for. For example, India's cement industry is among the most efficient in the world, next only to Japan on account of scale of production and technological advances, but in no less measure due to high share (over four-fifths) of blended (Portland Pozzolana and Portland Slag) cements in the mix that require less limestone and energy in production (Krishnan, Vunnam, Sunder, & al, A Study of Energy Efficiency in the Indian Cement Industry, 2012). Similarly, India's natural gas based fertiliser production is highly efficient with low scope for future efficiency improvement, which is not the case with naptha or fuel-oil based production (Bhushan, 2010). On the other hand, the iron and steel industry with its heavy reliance on blast oxidation furnace based production has significant room to shift towards smelting technologies (COREX or FINEX) or gas-based Direct Reduced Iron (DRI), apart from utilising much higher level of scrap in production. Such alternatives in steel offer high energy saving potential, in significant cases due to electrical switching, in combination with other technologies such as continuous casting, variable frequency drives, waste heat recovery systems, etc.

(Krishnan, Vunnam, Sunder, & al, A Study of Energy Efficiency in the Indian Iron and Steel Industry, 2013). Figure 15 shows the weighted average efficiency improvements considered across various PAT sectors in the high and low efficiency cases.

Figure 15: Efficiency Improvements across PAT sectors in the Low and High Efficiency cases

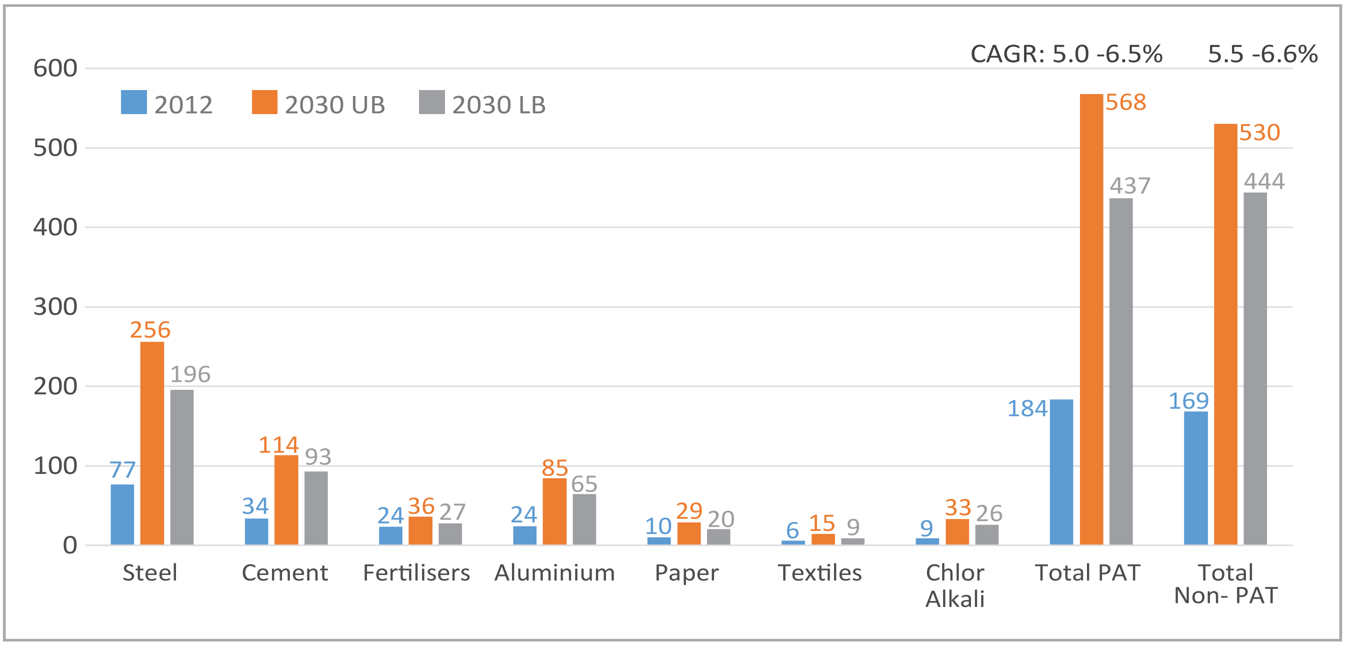


The SEC improvements arrived at in Figure 14 consider the baseline improvements mandated by that PAT scheme and the gap between current domestic and best available technology SECs.

For the low efficiency scenario, the SEC reductions mandated by PAT are assumed to be carried forward through 2030 at a decreasing rate, since price of efficiency varies inversely with its penetration as low hanging fruits are exhausted. The SEC improvements in the high-efficiency scenario are predicated on 50-100 percent achievement of SECs of the best available technologies available or likely to be adopted in future for commercial deployment (Byravan, Ali, & al, 2017). The variance in achievement levels across sectors is borne out of differential levels of technological sophistication and policy thrust in different PAT sectors as discussed above.

The total industrial demand so obtained is shown in Figure 16. The base year for this analysis (as for residential electricity consumption) is 2012 and is forward projected to 2015 based on SEC improvements corresponding to the sector actuals.

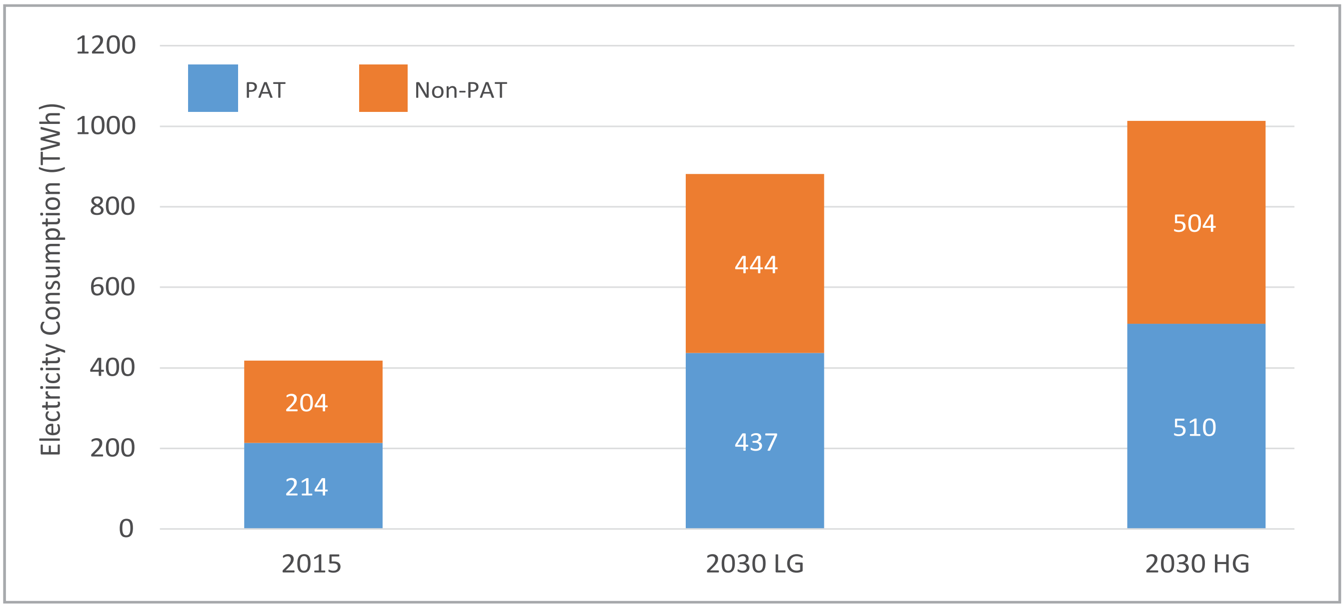
Figure 16: Industrial electricity demand



Total industrial consumption thus grows from 418 TWh in 2015 to 881 TWh (5.1 percent CAGR) in the LB case to 1098 TWh in the UB case (6.6 percent CAGR). Steel, cement and aluminium remain dominant consumers within the PAT sectors, which also offer greatest potential for absolute energy savings. The growth rates indicate that the sector will remain the dominant consumer of electricity in the foreseeable future especially with high emphasis on manufacturing.

This is reflected in Figure 17 which shows the electricity demand for PAT and non-PAT sectors under high growth (HG) and low growth (LG) scenarios for domestic manufacturing.

Figure 17: Impact of high manufacturing growth on industrial electricity demand



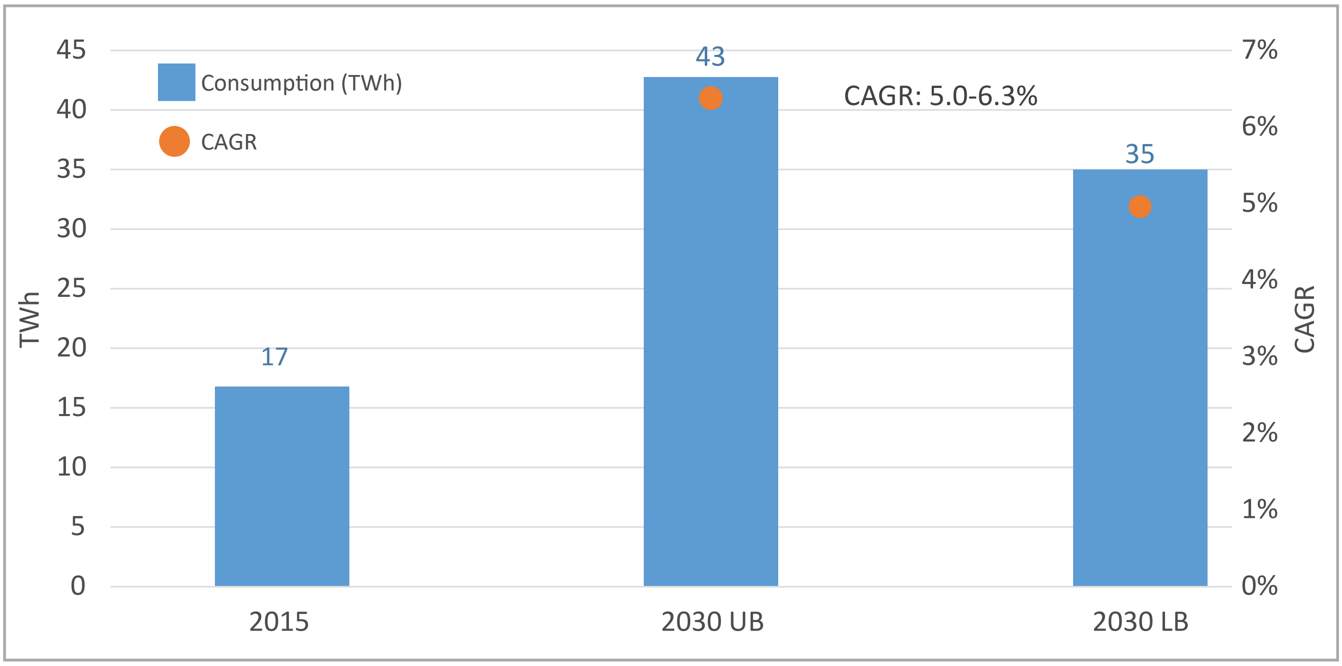
From Figure 17, it can be estimated that the difference in electricity demand is 15 percent higher in a high manufacturing scenario when the levels of energy efficiency are held constant (at high level in this case) in both scenarios. For the benefits associated with a robust manufacturing base, this growth in electricity consumption should be facilitated.

Railways

As of 2015, the Indian Railways had achieved an electrification of 40 percent of its 66,030 rail-route kilo-meters (RRkm) (Ministry of Railways, 2016). While the gross RRkms have been growing at less than 0.4 percent CAGR, their electrification has grown over 4 percent over the past fifteen years, resulting in an electricity consumption growth of nearly 5 percent (Central Electricity Authority, 2007-2016; Central Organization for Railway Electrification, 2018). By 2021, the government has planned to electrify 24,400 RRkms, which would drastically improve the electrification rate to 77 percent (Press Trust of India, 2016).

In accordance with the above, the high and low electrification (and therefore electricity demand cases) are constructed with annual specific consumption improvements of 1.5 percent and 3.5 percent annually based on the historical and potential rates for improvement of traction-based consumption, which has historically contributed 85-90 percent of electricity demand for railways. The levels of electrification in the high and low cases are 90 percent and 75 percent respectively by 2030. The resulting electricity demand obtained is shown in Figure 18.

Figure 18: Electricity demand from Railways



From the above, it can be ascertained that the impact of ongoing electrification drive in the railways will have only a slight impact on electricity demand (8 TWh). However, this can bring in significant efficiency and import substitution benefits via replacement of the old diesel-based locomotives.

Electric Vehicles

The push towards electrification of road mobility started with the National Electricity Mobility Mission Plan (NEMMP) in 2012, which targeted to achieve a certain (albeit) small penetration of battery and hybrid EVs in the sales mix by 2020. The rationale for EVs is provided in terms of reduction of local air and noise pollution and dependence on imported oil. However, owing to a number of factors, most notably the low driving range, top speed, acceleration, high front costs (especially due to battery) and lack of adequate charging infrastructure, the annual two and four wheeler EV sales are a fraction of daily aggregate sales in these categories.

More recently, there has been a renewed thrust on EVs, with targets of all vehicular sales by 2030 to be EVs. While this ambition seems to have been tempered at the policy level, many vehicular manufacturers have taken the cue and announced plans to significantly expand EV production capacity. Accordingly, two scenarios for EVs stock–-ambitious penetration of EVs (100 percent) and modest achievement of 33 percent EV sales by 2030— are considered for estimating electricity demand[35].

Further, the electricity demand is obtained for urban (intra-city) passenger transport demand only due to range anxiety, relationship of costs with battery sizing, low speed over longer distances, and ability to support only limited loads unsuitable for heavy duty freight operation.

The EV sales so obtained from 2017 in the UB and LB scenarios are shown in Table 13.

Table 13: Future sales of EVs (Cumulative 2017-30)

	% Total Sales		Million Numbers	
	2030 UB	2030 LB	2030 UB	2030 LB
(Private) Cars	20%	60%	14.1	42.2
Taxis	25%	65%	2.6	6.8
Buses	25%	65%	0.9	2.3
2W	20%	60%	65.9	197.8
3W	33%	65%	12.6	24.7
Total/ Wtd. Avg.	21%	61%	96	274

Based on this, the category-wise electricity demand obtained is shown in Figure 19. The intermediate steps and considerations in estimating electricity demand from the EV stock, annual vehicular kilometres and mileage are available in a detailed publication by the author that highlights specific issues with regard to grid compatibility with the EV stock and charging ecosystem in the future (Ali & Tongia, Electrifying Mobility in India, 2018).

[35] Cases on battery efficiency (electricity lost during charging) or mileage (km per kWh of charge) improvements are not examined for owing to future uncertainties in battery technology evolution and prices, and relatively small absolute electricity saving potential as later analysis shows.

Figure 19: Vehicular Category-wise Electricity Demand by EVs in 2030

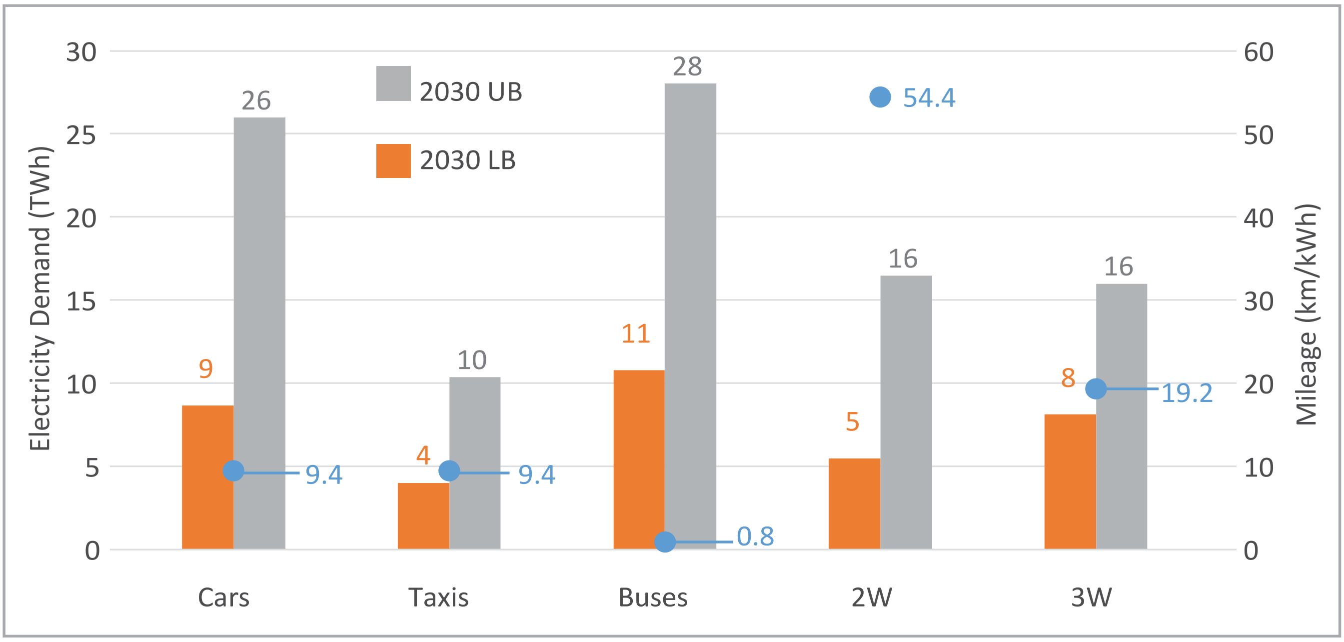


Figure 19 shows how aggregate electricity demand from EVs may range from 37 to 97 TWh in the LB and UB scenarios of electricity demand. Buses and private four-wheelers are the largest consuming categories accounting for over half of this demand. However, even with 100 percent EV sales by 2030, electricity demand of less than 100 TWh is timid- only 10 percent of the total electricity consumption in 2015. However, meeting the instantaneous load of several EVs plugging in simultaneously will likely be the major hurdle for supply planning, especially due to locational and time-sensitive nature of this demand.

Others

The electricity consumption in the 'Others' category includes public lighting, public water works and 'miscellaneous' consumption as reported by the CEA. The year-on-year growth rates in these components have been much more volatile compared to other sectors (Table 15), which may indicate either low reliability of data or statistical adjustments in reporting (or both).

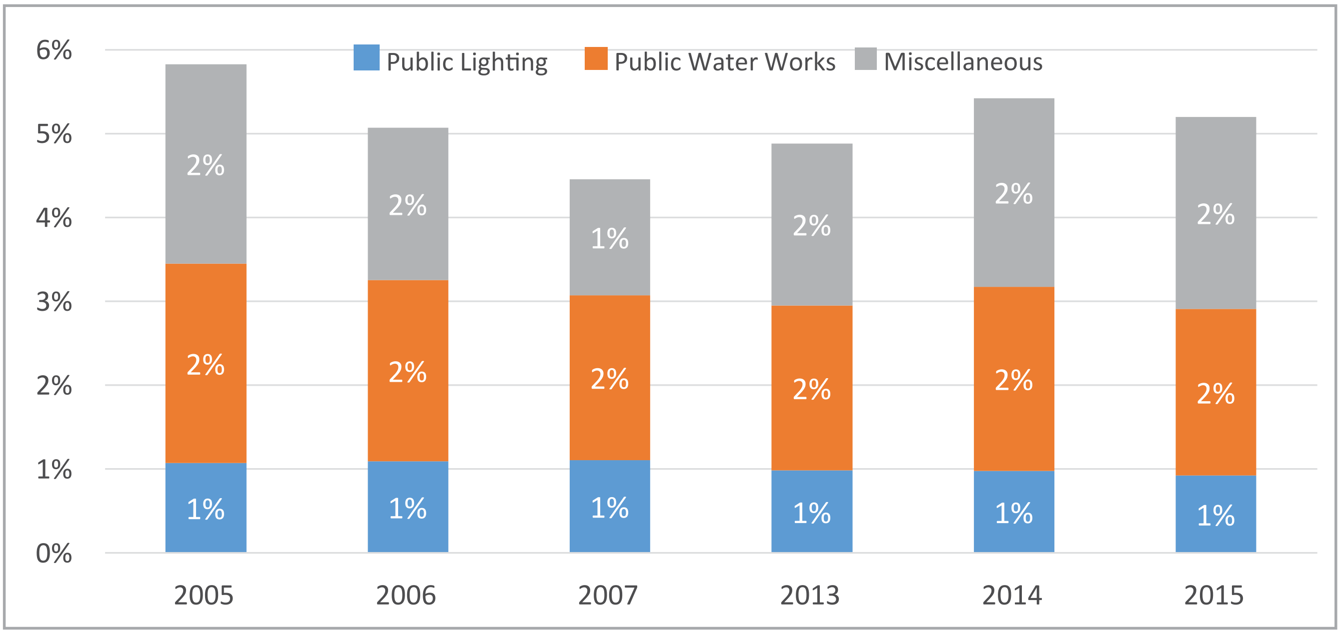
Table 14: Historical yearly electricity consumption CAGRs in the Other sector

Yearly Growth Rates	Public Lighting	Public Water Works	Miscellaneous	Total
2006	13%	1%	-16%	11%
2007	13%	1%	-16%	11%
2014	6%	18%	24%	6%
2015	2%	-2%	10%	9%

Source: CEA General Reviews

Over the past decade the sector has grown at 4.6 percent per annum and had an average share of about 5 percent in total electricity consumption (Figure 20). In 2015, the sector accounted for 49 TWh of electricity demand

Figure 20: Historical share of Others in rural electricity consumption



Since the granularity in consumption with respect to technology application against end-use demands is difficult to estimate (owing to sketchy data on these categories), urbanisation is taken as a key driver for future growth such that the share in total electricity consumption is maintained at 5 percent. Further to this, an additional electricity saving of 10 percent is applied in the high-efficiency case. The resultant electricity demand obtained by 2030 is 115 TWh (5.8 percent CAGR) in the UB case and 104 TWh (5.1 percent CAGR) in the LB case. Here again, the quantum of supply is not the main challenge, but the ability of urban infrastructure to keep pace with the growing demand.

Conclusion and discussion

The aggregation of the sector-wise analysis to total end-use electricity demand is shown in Figure 21, which shows aggregate electricity demand growing from 949 TWh in 2015 to anywhere between 2074 TWh (5.4 percent CAGR) and 2785 (7.4 percent CAGR)—the two extreme scenarios. The key demand sectors— industry, residential, commercial and agriculture—continue to be significant contributors to electricity demand growth, whilst also offering the highest potential for energy efficiency. The new (sub) sectors analysed for this study, namely affordable housing, electric cooking and EVs, together account for less than 10 percent of the new demand by 2030, across scenarios.

Figure 21: Sector-wise national electricity demand in UB and LB Scenarios

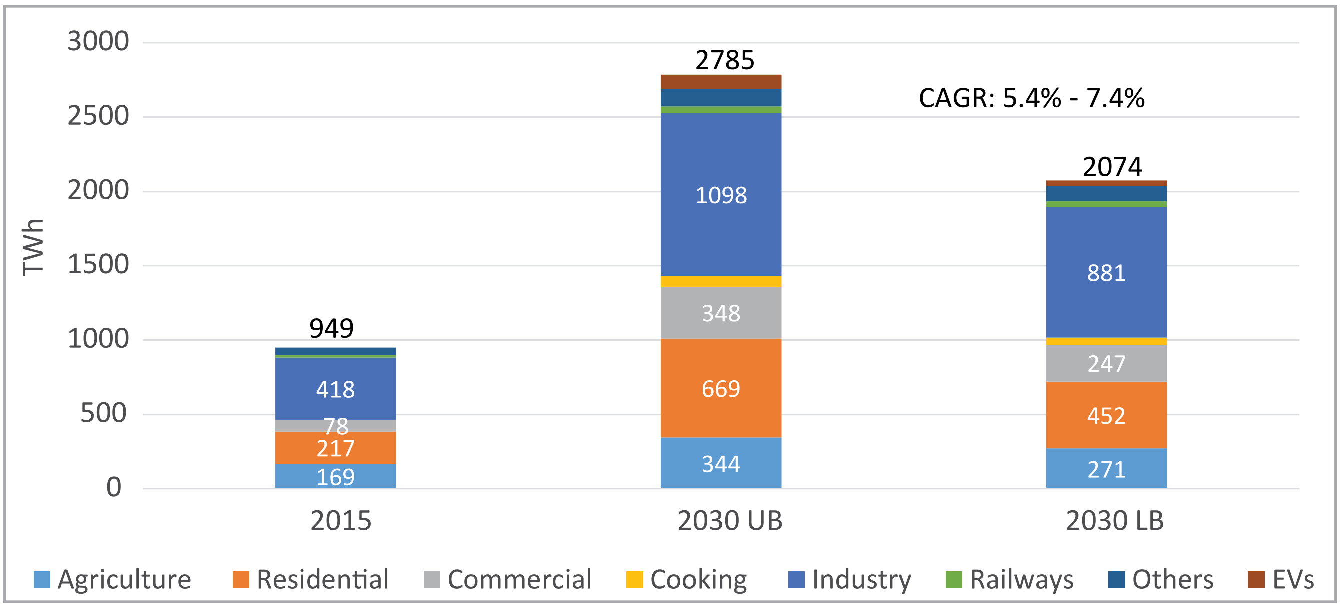
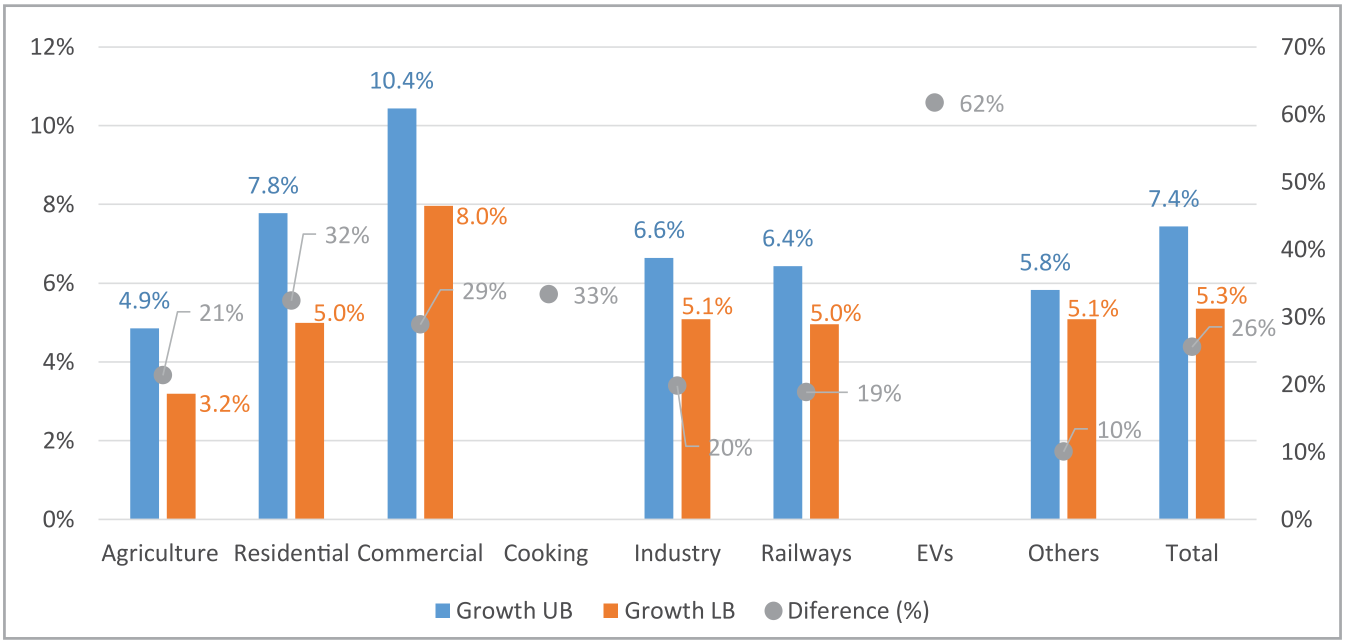


Figure 22 shows the sector-wise electricity demand growth and percentage difference in the levels of demand (with respect to the UB). Commercial sector is the big mover, partly on account of low consumption base, but largely owing to the surging HVAC demand, matching (or even surpassing in some cases) agricultural demand by 2030[36]. The new demand from affordable housing (subsumed in Figure 20 within the residential demand), electric cooking and EVs shows high volatility across the cases on account of uncertainty in service demands and technologies, driven largely by dedicated policy allocations and enabling infrastructure.

Figure 22: Sector-wise electricity demand growth



[36] Consumption from irrigation pump-sets was more than twice the size of commercial consumption in 2015.

Finally, the key results of the nine scenarios described in the methodology section earlier are presented in Table 16. Under each growth scenario, the labels 'low', 'mid', and 'high' correspond to levels of electricity demand, which is inversely related to energy efficiency in that scenario. Between 2000 and 2015, electricity demand grew by 6.9 percent CAGR yielding an elasticity of 0.95. By 2030, there is a chance that higher efficiency can reduce the elasticity by almost 20 percent, signalling a decoupling between electricity demand and economic growth. The achievement on future goals related to electrification (households, cooking and mobility) and enhancing domestic production yields higher per capita consumption of electricity, which is likely to double between by 2030 compared to 2015.

Table 15: Aggregate electricity demand under various cases

GDP CAGR by 2030 →		6.5%			7%			7.5%		
	2015	**LB**	**Mid**	**High**	**Low**	**Mid**	**High**	**Low**	**Mid**	**High**
Electricity Demand (TWh)	949	2075	2251	2587	2156	2338	2665	2253	2432	2785
Growth (CAGR)	-	5.4%	5.9%	6.9%	5.6%	6.2%	7.1%	5.9%	6.5%	7.4%
Elasticity	0.95	0.82	0.91	1.06	0.80	0.89	1.02	0.79	0.86	0.99
Per Capita Consumption (kWh)	724	1358	1473	1693	1411	1531	1745	1475	1592	1823

The distinction between prescriptive 'scenario-building' exercises and the 'cases' of electricity demand explored in this study is owing to the objective of finding plausible bounds to electricity growth in future as an input to supply planning. The advantage of bottom-up analyses of separate components of demand allows for flexibility in generating and analysing prescriptive scenarios to develop roadmaps for sectoral strategies, as well as the electricity sector as a whole.

The analysis points to the policy prescription of stimulating 'good' demand (related to access and imported fuel substitution, and manufacturing and job growth) and curbing 'bad demand' (related to inefficient and profligate consumption). The concentration of newer and more complex loads in urban areas, and the added variability of use (ACs in hot weather and EVs charging cycles) indicate that while India's electricity capacity expansion plans may be sufficient to cover electricity demand growth, peak loads and local distribution capacity issues may be drastically exacerbated. This not only calls for measures to enhance energy efficiency at central and state level, but greater coordination between the load generators and electricity suppliers.

References

Institut für Energie - und Umweltforschung Heidelberg GmbH , The Energy and Resources Institute, Sustainable Europe Research Institute, Wuppertal Institute, GIZ –Deutsche Gesellschaft für Internationale Zusammenarbeit. (2013). India's Future Needs for Resources. Deutsche Gesellschaft fürl Internationale Zusammenarbeit.

Abhyankar, N., & Gopal, A. et al. (2017). Techno-Economic Assessment of Deep Electrification of Passenger Vehicles in India. Berkley, California: LBNL.

Ali, M. S. (2015, Apr 07). Energy Efficient Irrigation Pumping: 96 GWh of power can be saved. Retrieved from Sustainability Next: http://sustainabilitynext.in/cstep/energy-efficient-irrigation-pumping-96-gwh-of-power-can-be-saved/

Ali, M. S. (2015, June 15). The Path to Light: A case for LEDs. Bengaluru. Retrieved from Business World SmartCities: http://ngil.cstep.in/uploads/default/files/pressroom/stuff/CSTEP_The_Path_to_Light_Oped_2015.pdf

Ali, M. S., & Tongia, R. (2018). Electrifying Mobility in India. New Delhi: Brookings India.

Ali, S., Goyal, N., & Srinivasan, S. (2017). Sustainable Energy Access for All: Building Sustainability into Universal Energy Access. In D. Bhattacharya, & A. O. Llanos, Southern Perspectives on the Post-2015 International Development Agenda. New York: Routledge.

Bhattacharjee, K. (2015). Make in India: A Step Towards Development. Indian Association for Management Development. Lucknow.

Bhattacharya , D. (2011). Emerging trends in global aluminium industry. 6th International Conference on Aluminium - INCAL 2011. Aluminium Association of India.

Bhushan, C. (2010). Challenge of the New Balance. New Delhi: Centre for Science and Enviornment.
Building Technologies Office. (n.d.). Appliance and Equipment Standards Rulemakings and Notices . Washington D.C.: U.S. Department of Energy.

Bureau of Energy Efficiency. (2016). PAT Scheme: Update and Evolution. New Delhi: Ministry of Power. Retrieved from BEE India.

Bureau of Energy Efficiency. (2017). Energy Conservation Building Code 2017. New Delhi: Ministry of Power.

Byravan, S., Ali, S., & al, e. (2017). Quality of life for all: A sustainable development framework for India's climate policy reduces greenhouse gas emissions. Energy for Sustainable Development, 48-58.

Central Electricity Authority. (2007-2016). All India Electricity Statistics. New Delhi: Ministry of Power.
Central Electricity Authority. (2012- 2018). Load Generation and Balance Report. New Delhi: Ministry of Power.

Central Electricity Authority. (2017). 19th Electric Power Survey. New Delhi: Government of India.

Central Electricity Authority. (2017). Growth in Electricity Sector in India from 1947- 2017. New Delhi: Ministry of Power.

Central Organization for Railway Electrification. (2018, 04 01). State-wise Electrification. Retrieved from http://www.core.indianrailways.gov.in/view_section.jsp?lang=0&id=0,295,331,561

Institut für Energie - und Umweltforschung Heidelberg GmbH , The Energy and Resources Institute, Sustainable Europe Research Institute, Wuppertal Institute, GIZ –Deutsche Gesellschaft für Internationale Zusammenarbeit. (2013). India's Future Needs for Resources. Deutsche Gesellschaft fürI Internationale Zusammenarbeit.

Abhyankar, N., & Gopal, A. e. (2017). Techno-Economic Assessment of Deep Electrification of Passenger Vehicles in India. Berkley, California: LBNL.

Ali, M. S. (2015, Apr 07). Energy Efficient Irrigation Pumping: 96 GWh of power can be saved. Retrieved from Sustainability Next: http://sustainabilitynext.in/cstep/energy-efficient-irrigation-pumping-96-gwh-of-power-can-be-saved/

Ali, M. S. (2015, June 15). The Path to Light: A case for LEDs. Bengaluru. Retrieved from Business World SmartCities: http://ngil.cstep.in/uploads/default/files/pressroom/stuff/CSTEP_The_Path_to_Light_Oped_2015.pdf

Ali, M. S., & Tongia, R. (2018). Electrifying Mobility in India. New Delhi: Brookings India.

Ali, S., Goyal, N., & Srinivasan, S. (2017). Sustainable Energy Access for All: Building Sustainability into Universal Energy Access. In D. Bhattacharya, & A. O. Llanos, Southern Perspectives on the Post-2015 International Development Agenda. New York: Routledge.

Bhattacharjee, K. (2015). Make in India: A Step Towards Development. Indian Association for Management Development. Lucknow.

Bhattacharya , D. (2011). Emerging trends in global aluminium industry. 6th International Conference on Aluminium - INCAL 2011. Aluminium Association of India.

Bhushan, C. (2010). Challenge of the New Balance. New Delhi: Centre for Science and Enviornment.
Building Technologies Office. (n.d.). Appliance and Equipment Standards Rulemakings and Notices . Washington D.C.: U.S. Department of Energy.

Bureau of Energy Efficiency. (2016). PAT Scheme: Update and Evolution. New Delhi: Ministry of Power. Retrieved from BEE India.

Bureau of Energy Efficiency. (2017). Energy Conservation Building Code 2017. New Delhi: Ministry of Power.

Byravan, S., Ali, S., & al, e. (2017). Quality of life for all: A sustainable development framework for India's climate policy reduces greenhouse gas emissions. Energy for Sustainable Development, 48-58.

Central Electricity Authority. (2007-2016). All India Electricity Statistics. New Delhi: Ministry of Power.
Central Electricity Authority. (2012- 2018). Load Generation and Balance Report. New Delhi: Ministry of Power.

Central Electricity Authority. (2017). 19th Electric Power Survey. New Delhi: Government of India.

Central Electricity Authority. (2017). Growth in Electricity Sector in India from 1947- 2017. New Delhi: Ministry of Power.

Central Organization for Railway Electrification. (2018, 04 01). State-wise Electrification. Retrieved from http://www.core.indianrailways.gov.in/view_section.jsp?lang=0&id=0,295,331,561

Central Statistics Office. (2011). Housing Stock 2001-2011 . New Delhi: Ministry of Statistics and Programme Implementation.

Central Statistics Office. (2014-17). Energy Statistics 2014-2017. New Delhi: Ministry of Statistics and Programme Implentation.

Chaturvedi, V., & Sharma, M. (2013). Modelling Long-Term HFC Emissions from India's Residential Air Conditioning. New Delhi.

Chaturvedi, V., Nagar Koti, P., & R, C. A. (2018). Sustainable Development, Uncertainities, and India's Climate Policy . New Delhi: Council on Energy, Environment and Water .

Dalberg Global Development Advisors. (2013). India Cookstoves and Fuels Market Assessment. Global Alliance for Clean Cookstoves.

Department of Agriculture and Cooperation. (2013). State of Indian Agriculture 2012-2013. New Delhi: Ministry of Agriculture.

Department of Agriculture, Cooperation & Farmers Welfare. (2017). Annual Report 2016-17. New Delhi: Ministry of Agriculture & Farmers Welfare.

Dubash, N. K., Khosla, R., Rao, N. D., & al, e. (2015). Informing India's Energy and Climate Debate: Policy Lessons from Modelling Studies. New Delhi: Centre for Policy Research.

IIT Kanpur. (2010, 01 27). Water Requirement of Different Crops. Retrieved 09 2017, 30, from http://agropedia.iitk.ac.in/content/water-requirement-different-crops

Indiastat.com. (n.d.). Total Number of Registered Motor Vehicles in India (1951, 1956 and 1959 to 2015). Retrieved August 2017, 17, from https://www.indiastat.com/transport/30/vehicles/289/registeredvehicles/16443/stats.aspx

International Energy Agency. (2015). India Energy Outlook: World Energy Outlook Special Report. New Delhi: International Energy Agency.
Jain, A., Choudury, P., & Ganesan, K. (2015). Clean, Affordable and Sustainable Cooking Energy for India. New Delhi: Council on Energy, Enviornment and Water.

JNNURM Mission Directorate. (2012). Guidelines for Affordable Housing in Partnership. New Delhi: Ministry of Housing and Urban Poverty Alleviation.

Josey, A., M, M., & Shantanu, D. (2017). The Price of Plenty: Insights from 'surplus' power in Indian States. Pune: Prayas Energy Group.

Krishnan, S. S., Vunnam, V., Sunder, P. S., & al, e. (2012). A Study of Energy Efficiency in the Indian Cement Industry. Bangalore: Center for Study of Science, Technology and Policy.

Krishnan, S. S., Vunnam, V., Sunder, P. S., & al, e. (2013). A Study of Energy Efficiency in the Indian Iron and Steel Industry. Bangalore: Center for Study of Science, Technology and Policy.

Kulkarni, H. D. (2013). Pulp and paper industry raw material scenario - ITC plantation a case study. Quarterly Journal of Indian Pulp and Paper Technical Association, 79-89.

Kumar, S. K., Deshmukh, A., Kamnath, M., & Manu, S. (2010). Total Commercial Floor-space Estimates for India. Delhi: Burea of Energy Efficiency.

Live Mint. (2015, March 24). Ending India's housing squeeze. Retrieved from https://www.livemint.com/Opinion/jEOmDiEumjrma7rTMdB6pN/Ending-Indias-housing-squeeze.html

Ministry of Coal. (2017). Provisional Coal Statistics 2016-17. Kolkata: Coal Controller's Organisation.

Ministry of Environment, Forests and Climate Change, GoI. (2015). India's Intended Nationally Determined Contribution. New Delhi: MoEFCC.

Ministry of Railways. (2016). Route Track Electrification Yearbook. New Delhi: Ministry of Railways.

Ministry of Road Transport and Highways. (2013-2015). Road Transport Year Book. New Delhi: National Data Sharing and Accessibility Policy.

National Buildings Organisation. (2015). Slums in India: A Statistical Compendium. New Delhi: Ministry of Housing and Urban Poverty Alleviation.

NITI Aayog. (2015). India Energy Security Scenarios 2047: Demand Sector. New Delhi: NITI Aayog, Government of India.

NITI Aayog. (2015). User Guide for 2047 Energy Calculator: Agriculture Sector. Delhi: NITI Aayog.

Parikh, K. S., & Parish, J. K. (2016). Realizing potential savings of energy and emissions from efficient household appliances in India. Energy Policy, 102-111.

Phadke, A., Abhyankar, N., & Shah, N. (2014). Avoiding 100 New Power Plants by Increasing Efficiency of Room Air Conditioners in India: Opportunities and Challenges. Berkeley: Ernest Orlando Lawrence Berkeley National Laboratory.

Planning Commission. (2014). Data-book for use of Deputy Chairman. New Delhi: Planning Commision, Government of India.

Planning Commission. (2014). The Final Report of the Expert Group on Low Carbon Strategies for Inclusive Growth. New Delhi: Planning Commission, Government of India.

PPPAU NITI Aayog. (2017). Micro-Irrigation through Public Private Partnership: "From Source to Roots". New delhi: NITI Aayog.

Press Trust of India. (2016, 11 02). Railways to almost double electrified track length to reduce carbon emission. Retrieved from http://www.infracircle.in/railways-almost-double-electrified-track-length-reduce-carbon-emission/

Pricewaterhouse Coopers. (2012). Emerging opportunities and challenges: India Energy Congress 2012. New Delhi: Pricewaterhouse Coopers.

Rawal, R., Vaidya, P., Seth, S., & al, e. (2012). Energy Code Enforcement for Beginners: A Tiered Approach to Energy Code in India. Washington DC: American Council for an Energy-Efficient Economy.

Saha, D., & Muro, M. (2016). Growth, carbon, and Trump: States are "decoupling" economic growth from emissions growth. Washington D.C.: Brookings Institution .

Saxena, A. K., Gopal, I., Ramanathan, K., & al, e. (2017). Transitions in Indian Electricity Sector 2017- 2030. New Delhi: The Energy and Resources Institute.

Sehgal, A., & Tongia, R. (2016). Coal Requirement in 2020: A Bottom-up Analysis. Brookings India Research Paper No. 072016-2, New Delhi.

Shah, S. (2012). Institutional Reform for Water Use Efficiency in Agriculture. New Delhi: Council for Energy, Enviornment and Water.

Shukla, P R; Garg, A; Dholakia H H. (2015). Energy-Emissions: Trends and Polciy Landscape in India. New Delhi: Allied Publishers.

SPARC. (2016). Energy Justice for the Urban Poor. Delhi.

The Weidt Group. (2011a). Energy Analysis Report for Tier Development for Partial Compliance with ECBC - Phase 1. New Delhi: Shakti Sustainable Energy Foundation.

The Weidt Group. (2011b). Stepped Bundle Development for ECBC Measures – Phase 2. New Delhi: Shakti Sustainable Energy Foundation.

The Weidt Group. (2012). Buildings Data Report for CNC DSM Programs. New Delhi: Shakti Sustainable Energy Foundation.

Uehara, Masashi; Tahara, Kengo; et al. (2017). Medium-Term Forecast of Asian Economies (2017-30). Tokyo: Japanese Center for Economic Research.

UN Department of Economic and Social Affairs. (2017). 2017 Revision of World Population Prospects. New York: United Nations.

Appendix: Key results from past studies

Various past studies have used different approaches towards different ends (energy policy, electricity planning, greenhouse gas mitigation and climate policy, etc.) to obtain electricity demand and supply projections. This section highlights some recent work to place the results of this analysis in the larger context of existing knowledge. Table 17 shows the pertinent results for electricity growth from these studies. While this study estimates end-use demand that includes industrial captive consumption, some projections are only reported at gross generation[37] or net generation (bus-bar demand)[38] level.

Table 16: Key results from recent studies on the electricity sector

	Metric$	Base year TWh#	Years to 2030	2030 TWh	CAGR
Sustainable Development Uncertainties and Climate Policy (CEEW 2018)~	Gross generation	1105	15	2671	6.06%
	Gross generation	1105		3350	7.67%
Transitions in Indian Electricity Sector (TERI 2017)	Bus-bar demand/ Net generation	1115	14	3175	7.76%
Draft National Energy Policy (NITI 2017)^	End-use demand (incl. captive)	804	18	2104	5.49%
		804		2244	5.87%
19th Electric Power Survey (CEA 2017)*	End-use demand	921	13	2078	6.46%
India Energy Outlook (IEA 2015)	End-use demand	897	17	2241	5.53%
Energy Emissions Trends and Policy Landscape (Shukkla et al 2015)~	Gross generation	923	18	2821	6.41%
		923		3383	7.49%
Quality of Life for All (CSTEP 2015)	End-use demand (incl. captive)	745	18	2822	7.68%
		745		3343	8.70%
Expert Group on Low Carbon Inclusive Growth (Planning Commission 2014)~	Gross generation	923	18	3370	7.46%
		923		3465	7.63%

$ Reporting is for grid-based demand and generation unless explicitly mentioned to include captive.
 # Base year refers to the nearest year to the study release that is presented in the tables, graphs and/or narrative.
~ Gross Generation taken from official CEA numbers.
^ 2030 Values interpolated between 2022 and 2040.
** Base year value is the 19th EPS estimated demand for 2017. 2030 value extrapolated using 2022 to 2027 CAGRs.*

From Table 16, while the range of demand (or generation) growth obtained from isolated electricity demand projections to wider scenario-based studies varies between 5.5- 8.7 percent[39], it is useful to note that more recent studies studying electricity demand, particularly NITI's Draft NEP and CEA's 19th EPS, obtain considerably lower growth rates for future demands than studies conducted earlier (with the exception of TERI's and IEA's projections)[40]. This appears to be a correction from previous projections on electricity demand that appeared to

[37] Gross generation= End- use demand +T&D losses+ Auxiliary/own consumption.
[38] Electricity Demand at bus-bars= Net Generation= End-use demand+ T&D losses.
[39] The 8.7 percent demand growth in CSTEP (2015) is obtained in a scenario of high manufacturing and air-conditioning demand growth, unrestricted irrigation pumping growth, with emphasis on service provision rather than energy efficiency or fuel/material substitution. These are employed to an economically viable degree (no loss in output per unit spent on energy) in the Sustainable scenario which yields 7.7 percent demand growth.
[40] In general, we should expect the growth rates of end-use demand to be higher than generation requirement owing to falling T&D losses over time.

be a correction from previous projections on electricity demand that appeared to have over-estimated demand under some implicit driving notion of aspirational per capita consumption of electricity (for example, Planning Commission's Low Carbon Inclusive Growth report, CEA's previous EPS, and CSTEP's Quality of Life for All report), a fact highlighted by various observers of the Indian electricity planning process (Josey, M, & Shantanu, 2017).

This study incorporates the learning from past experience and reflects the ongoing process of decoupling of electricity demand from growth, whilst accounting for substitution of electricity for other fuels as a means to achieve an overall more energy efficient and cleaner system[41]. Consequently, while the study projects various cases of electricity demand from 5.4 to 7.4 percent CAGR, the mid-value for the study (at 7 percent GDP growth and medium efficiency) corresponds to a CAGR of 6.2 percent (see Table 16).

[41] In certain cases, electricity (grid and non –grid) is directly replaced by on-site cleaner equivalent sources such as solar irrigation pumps and waste heat recovery systems.

QUALITY.

INDEPENDENCE.

IMPACT.