Analysing and Projecting Indian Electricity Demand to 2030

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Executive Summary

Introduction

This paper conducts an analysis and projection of the Indian electricity demand to 2030 on the basis of three methodologies, which were then synthesized. Three macroeconomic scenarios were used, considering 6.80%, 7.50%, and 8.00% GDP growth, with higher growth scenarios having correspondingly higher shares of industry in the GDP. For each, a high and low energy-efficiency variant was developed.

Aggregate Findings

Grid electricity demand, without losses, captive power, or behind-the-meter generation, is projected to be between 2040–2857 TWh by 2030. The central estimate is between 2254–2533 TWh (7.50% GDP growth, high- and low-efficiency variants). The largest source of uncertainty, and the driver of the wide spread between the full range of estimates, comes from different GDP growth rates and levels of industrialization assumed in the macroeconomic scenarios. Between the high growth and moderate growth scenarios, the difference is 525–550 TWh by 2030. By contrast, within each macroeconomic scenario, different assumptions on electricity efficiency lead to differences of 267–292 TWh by 2030.

Sectoral Findings

Compared to historical trends, the analysis in this paper suggests that agriculture projections are significantly biased to the downside. Current estimates of agricultural demand are found to be likely to be inflated, possibly due to the classification of losses as agricultural consumption.Considering the large potential for end-use efficiency and loss reduction, the agricultural demand is projected at 238– 307 TWh, weighted towards the lower end (7.50% GDP, high- and low-efficiency variant).

Compared to historical trends, the analysis in this paper suggests that commercial and residential buildings projections are biased to the upside. Across the projection period, rising incomes are likely to drive faster growth in the buildings sector than observed historically. The upward bias is found to be larger for scenarios with faster GDP growth. Air conditioning is the fastest-growing end use, and reaches 21–23% of the total sectoral demand. The total demand from the buildings sector is estimated at 1134–1234 TWh by 2030 (7.50% GDP, high- and low-efficiency variant).

The industry projections in this paper are in line with historical trends, but subject to the large uncertainties around the rate and industrial structure of growth. Relative to the agricultural and buildings sector, the energy-savings potential of the industry is estimated to be less. Projections of captive-power dominated sectors suggest strong growth. Assuming that the share of captive generation stays at its current level, the total industry grid demand is 838–924 TWh. The total industry demand, including captive, is estimated at 1290–1338 TWh (7.50% GDP, high- and low- efficiency variant).

Given the lack of historical data, a scenario approach was used to model electric vehicle penetration. The total EV demand is estimated at 41–234T Wh, biased towards the lower side of this range, and is therefore not considered a game changer for electricity demand to 2030.

Implications for Policy

The large uncertainties around the macroeconomic scenario for India, significant energy-efficiency policies and potentials, and the emergence of new end uses pose a challenge to forecasters and policymakers. In official forecasts such as the Electric Power Survey, it would be desirable, over time, to develop a stronger scenario-based approach considering different macroeconomic outcomes; deepen, strengthen, and systematize the collection of end-use data; and deepen the use of end-use modelling with explicit representations of equipment stocks and efficiency assumptions.

Introduction, Scenario Framework, and Methodology

Introduction

Mid- and long-term demand forecasting is a key aspect of power-system planning. It is necessary when considering investments in new generation capacity and transmission and distribution infrastructure. Electricity-demand forecasting is also a crucial aspect of policy formulation and monitoring, for example, regarding energy-efficiency policies.

The history of energy and electricity demand forecasting, both in India and internationally, is rife with examples of significant forecast errors. It is thus crucial that i) electricity demand forecasting be given a greater focus in policymaking and business strategy, and ii) the use of electricity demand forecasts be carefully considered. Given the likely error margins, the development of sensitivity analyses, scenarios, and periodic evaluation of the actual outturn of drivers of electricity demand is crucial. As noted by Smil (2000):

> [A] new century will make little difference to our ability of making point forecasts: we will spend more time and money on playing the future game—but our predictions will continue to be wrong … acknowledging these realities is not the same as advocating a complete abstention from looking far ahead. There is a fundamental difference between decisions that are good only if a particular prediction turns out to be correct—and the ones that are good for a range of alternative futures: scenarios, rather than point forecasts, are thus much more valuable, both from heuristic and practical points of view .

In developing countries, there are additional issues that make demand forecasting particularly challenging. These include:

- Large-scale uncertainties over the development trajectory, such as the rate and structure of economic growth, industrialization, and urbanization.
- Large-scale economic distortions
- Incomplete markets, informalization, and consumption of non-commercial energy
- Lack of complete, coherent, and accurate data.

Table 1: Scenario framework

Item	Historical Period (2000–16)	Baseline Scenario (6.80%)	Strong Growth (7.50%)	High Growth (8.00%)
Real growth in GVA (% yoy)	7.09%[A)]	6.80%	7.50%	8.00%
Share of Agriculture in GVA (%)	15% [B)]	9%	9%	9%
Share of Industry in GVA (%)	31% C)	31%	33%	34%
Share of Services in GVA (%)	54%	60%	58%	57%
Electricity Intensity Improvements	n/a	• Baseline Variation • High Variation	• Baseline Variation • High Variation	• Baseline Variation • High Variation

Notes:
A) Between 2000–16, real GVA grew at 7.1% yoy, while the population grew at 1.5%. Thus GVA/capita grew at 5.6%. Between 2016–30, our scenario assumes a population growth of 1.2% yoy, and thus a GVA growth rate of 6.80% equates to a GVA/capita growth rate of 5.6% in the baseline, consistent with what is seen across the historical period.
B) Between 2000–16, the share of agriculture in GVA dropped from 28% to 15%. A further decline to 9% of GVA by 2030 is consistent with a continuation of this historical trend.
C) Consistent with the World Bank methodology, we include construction GVA in the industry sector. Between 2000–16, the share of industry in GVA rose marginally from 30.4% to 31.2%, with a peak of 32.5% in 2009. Given the industry sector's higher productivity growth, and the historical experience of high growth being tied to rapid industrialization (China, Vietnam, and South Korea), we assume that faster growth scenarios are associated with a rise in the share of industry in GVA.
Source: TERI analysis. Historical data based on CEA (various years) and RBI (2018)

In the light of these issues, forecasts should endeavour to provide a causal framework for making and tracking policy, by revealing the underlying drivers, uncertainties, and possible outcomes for energy and electricity demand. Contributing to this agenda is the objective of this study.

Scenario Framework

The study employs three macroeconomic scenarios, intended to consider the major drivers and sources of uncertainty in electricity demand. The scenarios are presented in Table 1. Each of these scenarios comes with a high energy-efficiency variant and baseline energy-efficiency variant. The assumptions related to energy efficiency are further specified in the sections presenting the results of the partial end-use analysis (Section 4).

Methodology

In view of the challenges associated with demand projection discussed earlier, we investigate and project demand from multiple angles:

- Econometric analysis and projection to establish a set of projections based on past trends (Section 2).
- A cross-country historical analysis, in order to assess the historical experience of countries having passed through the development phase that India is currently undergoing (Section 3).
- A partial end-use analysis, in order to probe the impacts of energy efficiency notably (Section 4).
- These three approaches are 'triangulated' to present a set of internally coherent final scenarios including energy-efficiency potentials (Section 5).

Econometric Analysis and Forecasting

Agricultural Sector

Basic Facts about Agricultural Electricity Demand

Table 2 and Figure 1 present some basic data about the agricultural-sector electricity demand. Agricultural electricity demand has grown rapidly, notably on the back of an increasing trend in electrical intensity. The share of agricultural electricity demand in the total final electricity demand has not declined commensurate to the sector's declining share in GVA (see the notes to Table 1). A number of potential drivers of agricultural electricity demand, such as the number of pumpsets and gross irrigated area, are also growing. Finally, as can be seen from Figure 1, agricultural electricity demand and intensity have followed a non-linear trajectory in recent years: their historical trajectory is better approximated by an exponential curve.

Table 2: Overview of agricultural electricity demand

	2002	2015	CAGR
Agricultural VA (Billion Rs 2011–12)	10312	16172	3.52%
Agricultural Electricity Demand (GWh)	84486	173185	5.68%
Share of Agricultural Demand in Total Final Electricity Demand, Including Captive (%)	21%	17%	-1.65%
Agricultural Electricity Intensity (kWh/1000 Rs 2011–12)	8	11	2.08%
Number of Pumpsets (Million)	14	20	3.07%
Gross Irrigated Area (kHa)	73055	95772*	2.49%

** 2013, not 2015*
Source: TERI, based on data from RBI (2018), CEA (various years), and MOSPI (2017)

Statistical Analysis of the Drivers of Agricultural Electricity Demand

In this section we present a brief statistical analysis of the drivers of electricity demand in the agricultural sector across the historical period. Table 3 presents the correlation coefficient (R2) between agricultural electricity demand and various drivers. It can be seen that the highest correlation is with the number of pumpsets energized (0.992), followed by the kWh/pumpset (0.990) and then the agricultural GVA (0.971).

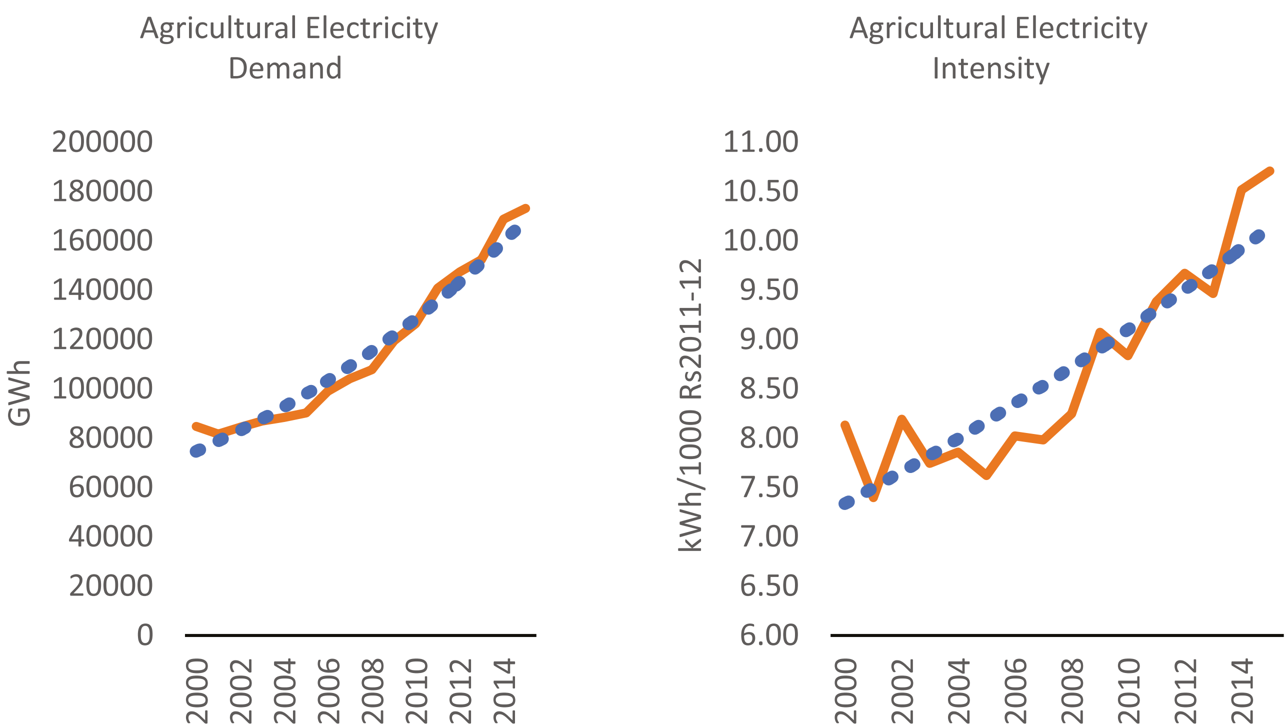


Figure 1: Trajectory of agricultural electricity demand and intensity, 2000–15
Source: TERI based on data from (RBI, 2018; CEA, Various Years)

Although the data series is short to reveal a secular trend in the annual rainfall, there appears to be only a weak correlation between the annual rainfall received on an all-India basis and agricultural electricity demand. This suggests that agricultural electricity demand forecasting may be amenable to a partial end-use analysis based on the pumpset stock and efficiency (see Section 4).

Table 3: Correlation coefficient for agricultural electricity demand and various drivers, 2000–16

	Agricultural Demand
Agricultural demand	1.000
Annual Rainfall	0.029
Agricultural GVA	0.974
Net Irrigated Area	0.885
Gross Irrigated Area	0.878
Number of Pumpsets	0.992
kWh/Pumpset/Year	0.990
Number of Pumpsets/Ha	0.870
Power Capacity of Pumpsets	0.831
Hours Per Pump Per Year	-0.353
Hours	-0.353

Source: TERI, based on data from RBI (2018), CEA (various years), MOSPI (2017), Kothawale and Rajeevan (2017)

Table 4 presents a decomposition analysis of the drivers of agricultural electricity demand for the period 2002 to 2013. Decomposition analysis is based on an identity between the drivers of energy demand and the energy demand itself, for example:

Energy demand = Population * GDP/Population * Energy/GDP

In this case, the equation is:

Agricultural electricity demand
= Gross Irrigated Area *Pumps/Gross Irrigated Area
* Electrical Consumption/Pumpset

A number of insights can be drawn from Table 4. Firstly, the growth in the gross irrigated area has contributed about 46% of the observed demand growth (31209 GWh). Secondly, the pumpset intensity of irrigation land (number of pumpsets/Ha) has risen somewhat across the period analysed, contributing to about 12% of the observed demand growth. Thirdly, the electrical intensity of the pumps themselves (kWh/pumpset/

Table 4: Decomposition analysis of the drivers of agricultural electricity demand

	Unit		2002	2013	Contribution to Agricultural Electricity Demand Growth, 2002–2013 (GWh)
Gross Irrigated Area	kHa	A	73055	95772	31209
Pumpset Intensity of Irrigation Land	Pumpsets/kHa	B	189	202	8065
Electrical intensity of Pumpsets	kWh/pumpset/year	C	6126	7877	28979
Derived Agricultural Demand	GWh	A*B*C for columns '2002' and '2013'. A+B+C for the remainder.	84492	152748	68253
Reported Agricultural Demand	GWh		84486	152744	68253
Residual	GWh		6	4	0

Note: For details on the logarithmic mean divisia index (LMDI) methodology used in the decomposition analysis, see Ang (2015). This table presents data for 2002–13, due to the unavailability of gross irrigated area data after 2013.
Source: TERI, based on data from RBI (2018), CEA (various years), and MOSPI (2017)

year) has grown significantly across the period analysed, contributing 42% to the observed demand growth. Given that, according to the Central Electricity Authority (CEA) data, pumping hours/pumpset/year have not changed significantly across the historical period, the key parameter driving the growth in kWh/pumpset/year has been the growing power capacity of the pumps themselves (kW). According to data reported by the CEA, the average power capacity of pumpsets has grown from 3.89 kW in 2002 to 4.86 kW in 2013, and 5.32 in 2015 (this aspect is discussed further in Box 3 in Section 4.2.1).

This analysis suggests some key parameters that will be picked up again in the partial end-use analysis in Section 4.

Econometric Projections of Agricultural Electricity Demand

In this section, we conduct simple econometric projections of electricity demand, taking as the independent variable the agricultural GVA, as projected in each scenario presented in Table 1. Several issues should be noted:

- While the analysis presented in Table 3 highlighted the high correlation between agricultural electricity demand and other drivers such as the number of pumpsets and electrical intensity of pumpset use, we conduct an initial round of econometric projections based on the agricultural GVA, in order to establish a baseline understanding of the implications of continuation of the current trends. Further analysis on a partial end-use basis is conducted in Section 4.
- The projections presented in this section have not been adjusted for energy efficiency. This is done in the partial end-use projections in Section 4 and the synthesis in Section 5.
- The projections presented are for final agricultural electricity demand, not grid-based electricity demand (relevant in the case of future solarization of agricultural load).

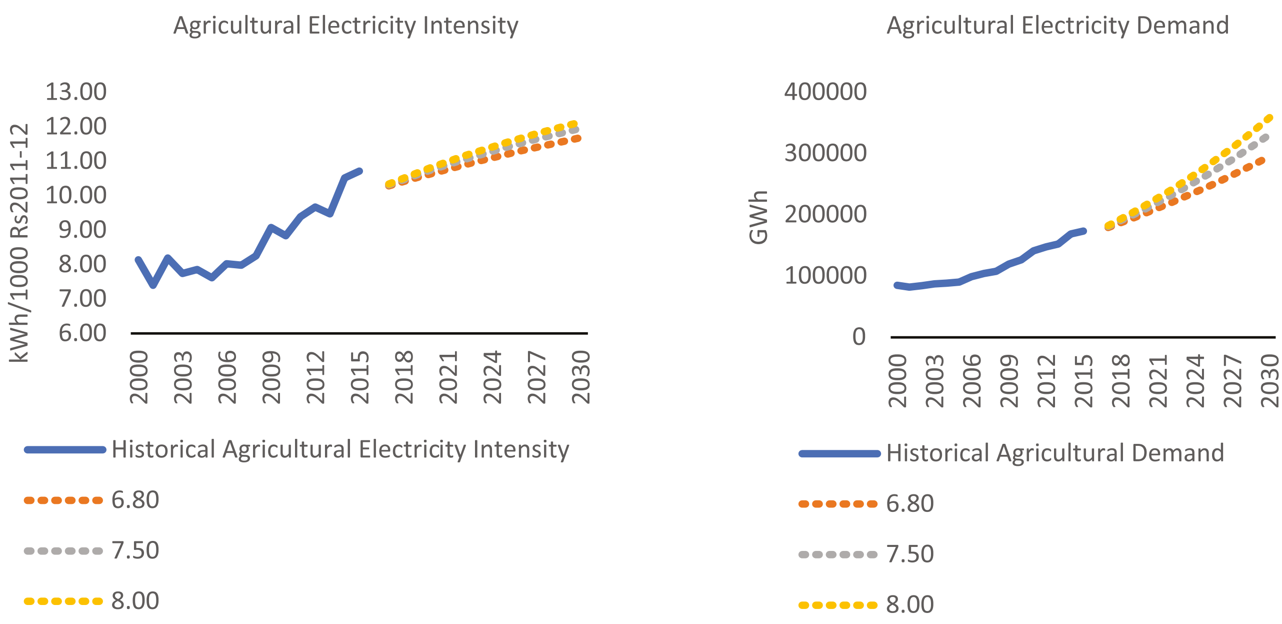


Figure 2: Trajectory of agricultural electrical intensity and agricultural electricity demand—econometric projections without efficiency adjustments, 2015–30

Source: TERI

Figure 2 and Table 5 present the key results. A number of observations can be drawn. Firstly, the assumption of a linear functional form, rather than an exponential functional form, explains the slowdown in the growth rate of agricultural electricity demand and agricultural electrical intensity in the projection period, when compared with the historical period. Mathematically, it is not possible to determine which is the more appropriate functional form between a linear (R2 = 0.92) and exponential functional form (R2 = 0.96).

Figure 2: Trajectory of agricultural electrical intensity and agricultural electricity demand—econometric projections without efficiency adjustments, 2015–30

Industrial Sector

Basic Facts about Industrial Energy Demand

Table 6 and Figure 3 present some basic data about industrial electricity demand in India. Industrial electricity demand has grown at 7.22% yoy during 2001–15, slower than the growth of industrial VA, indicating an elasticity of industrial electricity demand to VA of less than 1. This is due to the declining electricity intensity of the industrial sector. After the Global Financial Crisis (2008), industrial electricity intensity has seen an erratic trend (see Figure 3); this is further investigated below. The share of grid electricity in industry demand has fluctuated by a few percentage points across the period 2001–15, starting at 67.3%, rising to 71.4% during the boom years prior to the Global Financial Crisis, and falling back to 67.5% in 2015.

Figure 3 shows an erratic trend in the electrical intensity of the industrial sector since the Global Financial Crisis in 2008–09, spiking significantly up to 2013, and then declining sharply up to 2015 (see Figure 3). We can try and investigate the drivers behind this phenomenon using the available data.

Analysis of Recent Trends in Electricity Efficiency

The starting hypothesis is that the erratic trend in the electricity intensity of the industrial sector seen in Figure 3 is due to the economic shocks seen since 2009, to wit: the Global Financial Crisis and its aftermath, the slowdown in growth and investment under the last years of the UPA government, and the persistent 'twin balance sheet' problem impeding industrial credit, investment, and growth.

In order to investigate this, we conduct a decomposition analysis of the drivers of industrial electricity demand,

Table 5: Agricultural electrical intensity and agricultural electricity demand—econometric projections without efficiency adjustments

		Historical	
Agriculture Electricity Demand, 2000 (GWh)	84729		
CAGR of Demand, 2000–15 (% yoy)	4.9%		
CAGR of Electrical Intensity, 2000–15 (%)	1.8%		
Elasticity of Demand to Sector VA, 2000–2015 (ratio)	1.6		
	6.80% SCENARIO	**7.50% SCENARIO**	**8.00% SCENARIO**
Agriculture Electricity Demand, 2015 (GWh)	173185	173185	173185
Agriculture Electricity Demand, 2030 (GWh)	295377	331207	358723
CAGR of Demand, 2015–30 (% yoy)	3.6%	4.4%	5.0%
CAGR of Electrical Intensity, 2015–30 (%)	0.6%	0.7%	0.8%
Elasticity of Demand to Sector VA, 2015–2030 (ratio)	1.2	1.2	1.2

Source: TERI.

similar to the one conducted for the agricultural sector in 2.1.2, Table 4. This decomposition analysis incorporates a structural parameter, namely, the share of electricity-intensive sectors within the industrial sector. If, for example, structural change led to the declining share of iron and steel production within the overall industry GVA, this would contribute to a decline in electricity intensity, given that iron and steel is more electricity-intensive than the industrial sector in aggregate. The formula underlying this analysis is as follows:

Industry electricity demand

= Industry GVA * Share of Energy-Intensive Sectors in Industry GVA

*Electricity Intensity of Energy- Intensive Sectors+Industry GVA

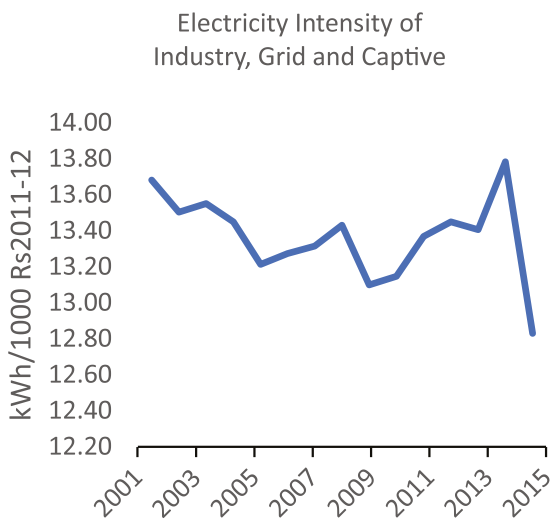
*Share of Non-Energy Intensive Sectors*Electricity Intensity of Non

-Energy Intensive Sectors

Table 6: Overview of industrial electricity demand

	2001	2015	CAGR
Industrial VA (Billion Rs 2011–12)	11658	33011	7.72%
Industrial Electricity Demand, Grid and Captive (GWh)	159507	423523	7.22%
Of Which Grid (GWh)	107296	285696	7.25%
Of Which Captive (GWh)	52211	137827	7.18%
Share of Industrial Electricity Demand in Total Final Electricity Demand, Including Captive (%)	42.57%	42.30%	-0.05%
Industrial Electricity Intensity, Grid and Captive (kWh/1000 Rs2011-12)	13.68	12.83	-0.46%

Note: Here the base year is 2001 due to the unavailability of industrial captive demand in 2000 in our data set.
Source: TERI, based on data from CEA (various years) and RBI (2018)



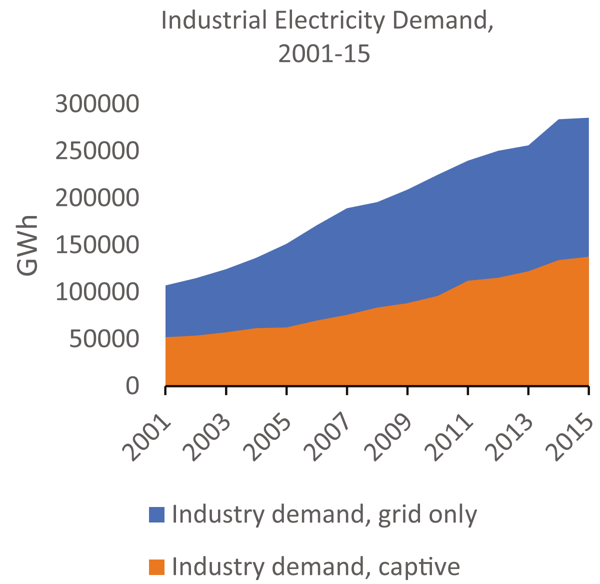


Figure 3: Trajectory of electricity intensity and industrial electricity demand, 2001–15
Source: TERI, based on data from CEA (various years) and RBI (2018)

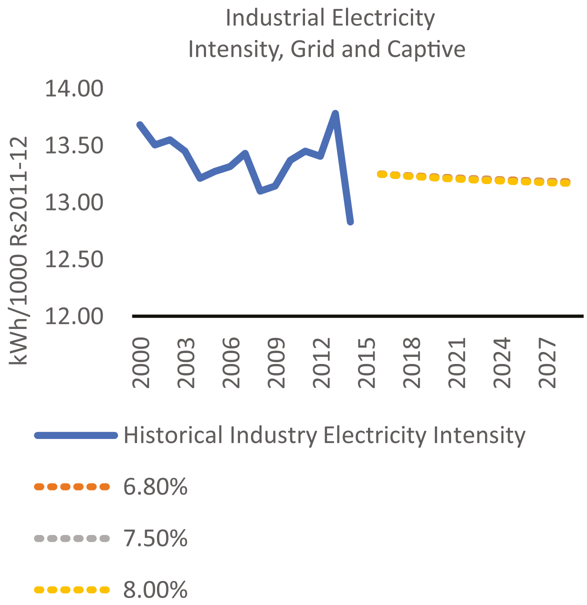
Table 7 presents the results. The decline in the GVA share of energy-intensive sectors between 2009 and 2015 has contributed to a reduction in electricity demand equivalent to about 9% of the observed change in demand, compared to a counterfactual observation in which their share in the industry GVA had remained constant at the 2009 levels. At the same time, the increasing electricity intensity of these sectors has contributed to an increase in electricity demand equivalent to about 19% of the observed change in demand. Both these observations are consistent with a situation in which the slowdown in economic activity resulting from the post-2009 shocks impacted the level of output from these large, cyclical sectors, leading to the decline in their share of industry GVA. At the same time, reduced output would lead to reduced capacity-utilization rates at production plants, which would in turn contribute to the increase in the electricity-intensity of the sectors.

The decline in electricity intensity in 2015 is driven notably by a decline in the electricity intensity of the energy-intensive sectors, as their output and capacity utilization picks up with the recovery seen in 2015 (the energy-intensive sectors grew 8% yoy in 2015, as against 2% in the preceding four years). The available data is, therefore,

Table 7: Decomposition analysis of the drivers of industrial electricity demand growth, 2009–15

	Industry GVA Growth	Share of Energy-Intensive Sectors in GVA	Share of Non- Energy-Intensive Sectors in GVA	Electro-intensity of Energy-Intensive Sectors	Electro-Intensity of Non-Energy-Intensive Sectors	Change in Industry Demand	Residual[A)]
	A	B	C	D	E	A+B+C+D+E	
2009–2015 (GWh)	120287	-10889	6179	23648	-15812	123413	0.040%
2009–2015 (%)	97%	-9%	5%	-19%	-13%	100%	

Note: Energy-intensive sectors are: iron and steel; chemicals and petrochemicals; non-ferrous metals; non-metalic minerals; pulp, paper, and print. A) Residual = derived change in demand from the decomposition equation (A+B+C+D+E)/observed changed in demand in historical data.
Source: TERI, based on data from IEA (2018) and RBI (2018)



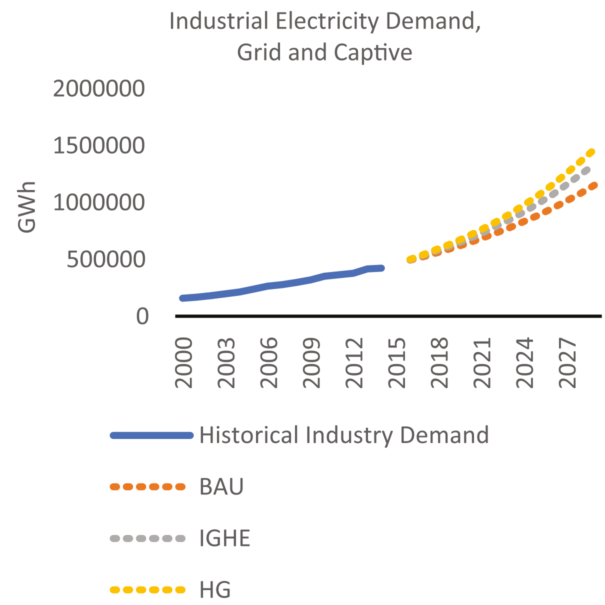


Figure 4: Trajectory of industrial electrical intensity and agricultural electricity demand—econometric projections without efficiency adjustments, 2015–30

Source: TERI

sufficient for us to conclude that the erratic trajectory of industrial electricity intensity from 2009 onwards, spiking and then declining sharply, is due to the effects of the economic shocks on the composition of industrial output and the capacity utilization of the sector. It can be expected that as economic growth picks up, the share of energy-intensive sectors in industrial output would recover along with their capacity-utilization rate. We also investigate long-term historical trends in industrial-sector electricity intensity in Section 3.

Econometric Projections of Industrial Electricity Demand

Figure 4 contains the baseline econometric projections for industrial electricity demand and intensity to 2030. As with the agricultural projections presented in Section 2.1.3, no adjustments have been made for energy efficiency, beyond the baseline efficiency improvements seen in Figure 4. These adjustments will be made subsequent to the end-use analysis in Section 4.

Table 8 displays the numerical results in more detail. Grid and captive power are projected to more than double, to 1154–1471 TWh by 2030. Assuming that the share of grid demand remains at its long-term historical average, grid demand from the industrial sector is projected to grow to 797–1016 TWh by 2030. The projections demonstrate the importance of the structural assumption related to the share of industry in GVA.

Services Sector

Basic Facts about Services Sector Electricity Demand

Table 9 presents some basic facts about the services sector electricity demand. Services was the fastest-growing economic sector at 8.87% yoy in the historical period assessed, leading to its climbing share in the total GVA. Services electricity demand grew faster than GVA, driven by the somewhat rising electricity intensity of the services sector between the start year and end year of the data (the trend is actually downward sloping when all intervening years are considered). The trend for services sector electricity intensity has been erratic, albeit around a fairly small band; the drivers of this erratic trajectory are not clear (Figure 5).

Table 10 and Figure 6 present the results of the econometric projection for the services sector. The projections are based on the driver of services sector

Table 8: Industrial electrical intensity and industrial electricity demand—econometric projections without efficiency adjustments

		Historical	
Industrial Electricity Demand, Grid and Captive, 2001 (GWh)		159507	
CAGR of Demand, 2001–15 (% YOY)		7.22%	
CAGR of Electrical Intensity, 2000–15 (%)		-0.46%	
Elasticity of Demand to Sector VA, 2000–15 (Ratio)		0.95	
	6.80% Scenario	**7.50% Scenario**	**8.00% Scenario**
Industrial Electricity Demand, 2015 (GWh)	423523	423523	423523
Industrial Electricity Demand, 2030 (GWh)	1153916	1338250	1470894
of which grid demand (GWh) A)	796897	924199	1015804
CAGR of Demand, 2015–30 (% yoy)	6.91%	7.97%	8.65%
CAGR of Electrical Intensity, 2015–30 (%)	0.18%	0.18%	0.17%
Elasticity of Demand to Sector VA, 2015–30 (Ratio)	1.02	1.02	1.02

Note: A) Assuming that the share of grid electricity in industrial demand remains at its long-term average.
Source: TERI

Table 9: Basic facts about services sector electricity demand

	2000	2015	CAGR
Services GVA (Billion Rs 2011–12)	15583	55722	8.87%
Services Electricity Demand (GWh)	40406	149012	9.09%
Share of Services in Total Final Electricity Demand, Including Industry Captive Demand (%)	12.19%*	14.88%	1.34%
Services Electricity Intensity, Grid and Captive (kWh/1000 Rs2011-12)	2.59	2.67	0.21%

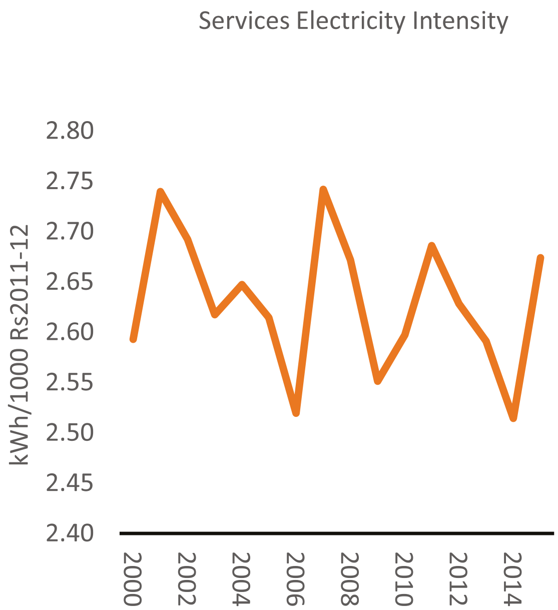
**2001, not 2000*
Source: TERI, based on data from CEA (Various Years) and RBI (2018)

value added, which is strongly correlated across the historical period with the services sector electricity demand (R2 = 0.99). By 2030, the services sector could account for around 436–486 TWh of electricity demand. The projections assume a continuing modest decline of electrical intensity in the sector, consistent with the trend seen in the historical period (abstracting away from the swings observed around this trend). As can be seen, there is not a substantial difference in the level of 2030 services sector demand between the scenarios, as the low electrical intensity of the sector means that the demand is less sensitive to the different macroeconomic scenarios for the growth of GVA.

Residential Sector

Basic Facts about the Residential Sector

Table 11 and Figure 7 present some basic facts about



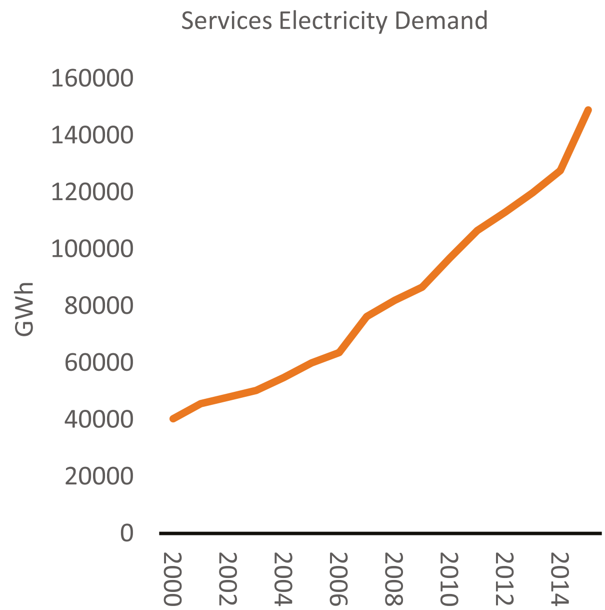


Figure 5: Trajectory for service sector electricity intensity and electricity demand, 2000–15
Source: TERI, based on data from CEA (various years) and RBI (2018

Table 10: Services electrical intensity and services electricity demand—econometric projections without efficiency adjustments

	6.80% Scenario	7.50% Scenario	8.00% Scenario
Services Electricity Demand, 2015 (GWH)	149012	149012	149012
Services Electricity Demand, 2030 (GWH)	436298	463334	485856
CAGR of Demand, 2015–30 (% yoy)	7.42%	7.86%	8.20%
CAGR of Electrical Intensity, 2015–30 (%)	-0.20%	-0.20%	-0.20%
Elasticity of Demand to Sector VA, 2015–30 (Ratio)	0.98	0.98	0.98

Source: TERI

residential electricity sector demand. Demand from this sector has grown the second-fastest after the services sector. Per capita residential sector demand remains very low, however, at just 31% of China's level and 11% of the EU's. The residential sector has exhibited a rising trend of electricity intensity, albeit with a somewhat erratic trend (see Figure 7). In the following Section 3, we will investigate the historical experience of other countries to see whether one can expect a rising trend of residential sector electricity intensity. Finally, one can see that the residential sector electricity demand is highly correlated with both GVA/capita and household demand expenditure. In the econometric projections that follow, we use as the driver GVA/capita, due to the challenges of projecting household-consumption/savings rates in the simple macroeconomic framework we used in this study to develop our scenarios.

Econometric Projections

Table 12 and Figure 8 present the results for the initial round of econometric projections. As with those presented for the other sector, here no adjustments have been made to take into account energy-efficiency improvements. The residential electricity demand is

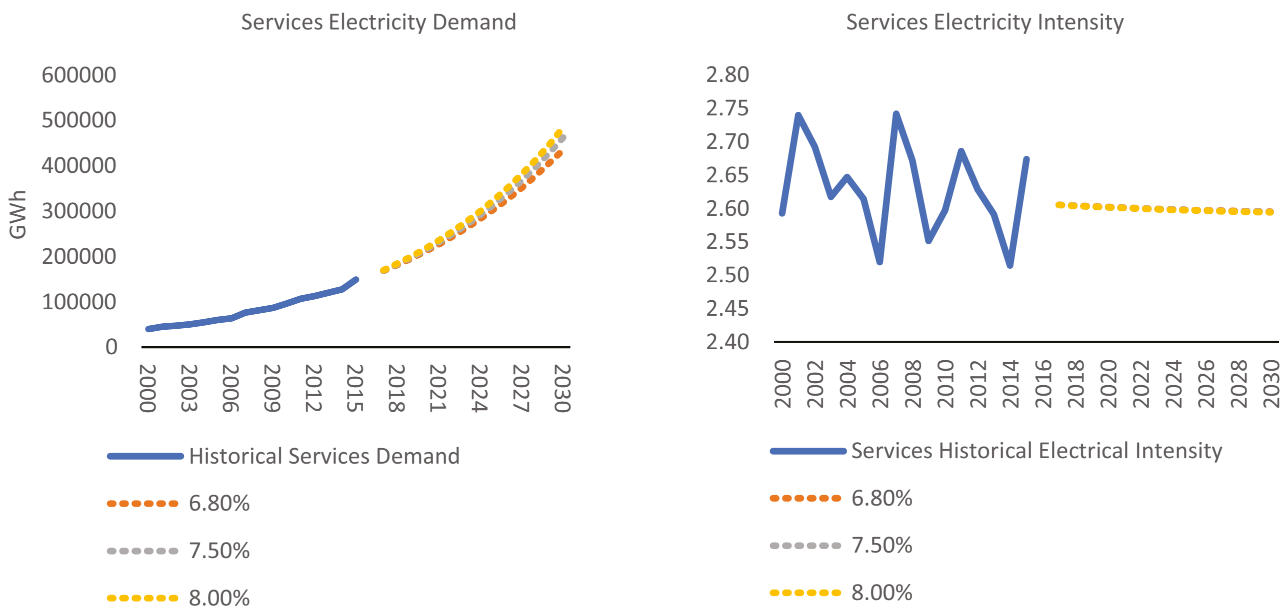


Figure 6: Trajectory for services electricity intensity and electricity demand without efficiency adjustments, 2015–30
Source: TERI

projected to reach 646–758 TWh in 2030, growing roughly at the same rate of growth as that of the overall economy (elasticity of consumption to GVA 1.01). A key question is whether the upwards kink in residential electricity intensity shown in Figure 7 is structural: the least squares regression used in the projection assumes a more moderate curve of electricity-intensity growth (compare the historical with the projected intensity curves in Figure 8). This issue is investigated in more detail in the chapters that follow.

Table 11: Some basic facts about the residential sector electricity demand

	2000	2015	CAGR
Residential Electricity Demand (GWh)	75629	238876	7.97%
Residential Electricity Demand/Capita (kWh)	73	186	6.38%
GVA/Capita (Rs 2011–12)	36305	81662	5.55%
R2 of Residential Electricity Demand to GVA/capita	0.991		
R2 of Residential Electricity Demand to Household Consumption Expenditure	0.960		
Electricity Intensity of the Residential Sector (kWh/1000 Rs 2011–12)*	2.02	2.28	0.79%

**Defined as residential electricity demand/total economy wide GVA*
Source: TERI, based on data from CEA (various years) and RBI (2018)

Summary of This Section

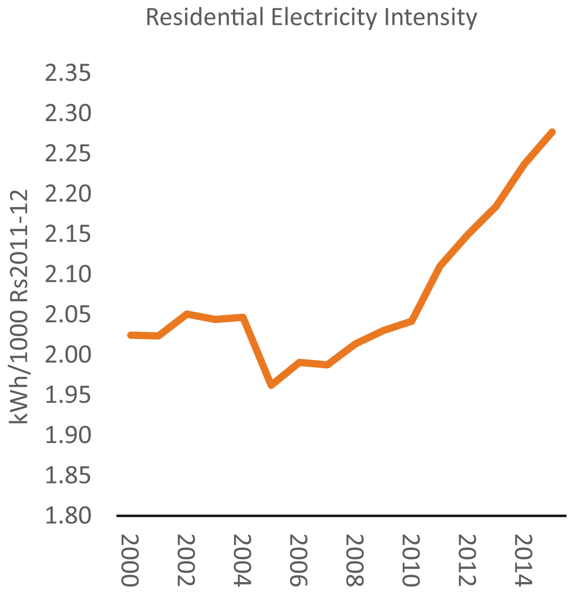
Aggregation of Results

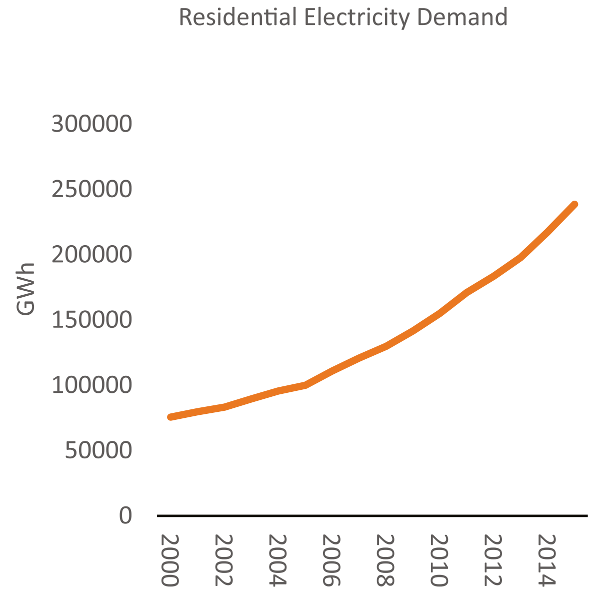
In this section, we conducted an initial investigation into the historical trends and drivers of electricity demand in India. In addition, an initial set of econometric projections has been conducted, using the set of macroeconomic scenarios defined in Table 1. The results of these projections are gathered in Table 13.

Outstanding Questions

The preceding analysis raised a number of outstanding questions, including:

- Given the number, interactions, and complexity of the drivers of agricultural electricity demand, what could be their potential evolution in the coming years, and how would this impact our projections?





Source: TERI, based on data from CEA (various years) and RBI (2018)

Table 12: Residential electrical intensity and residential electricity demand—econometric projections without efficiency adjustments

	6.80% Scenario	7.50% Scenario	8.00% Scenario
Residential Electricity Demand, 2015 (GWh)	238876	238876	238876
Residential Electricity Demand, 2030 (GWh)	646184	709724	758520
CAGR of Demand, 2015–30 (% yoy)	6.86%	7.53%	8.01%
CAGR of Electrical Intensity, 2015–30 (%)	0.07%	0.08%	0.09%
Elasticity of Demand to Sector VA, 2015–30 (Ratio)	1.01	1.01	1.01

Source: TERI

- Are the kinks seen in the trajectories for the electricity intensity of the residential and industrial sectors cyclical or structural? What is the likely evolution of these sectoral intensities, independent of additional efficiency policies?
- What could be the impact of additional efficiency policies?
- Given the short timeframe for the historical analysis and India's position as a low-income, fast-growing country, what is the potential for non-linearities that would not be captured in the historical data?

The following Sections 3 and 4 address these questions.

Cross-Country Historical Analysis

Introduction, Approach, and Data

A low-income, fast-growing country provides few internal benchmarks for what electricity demand may look like in 2030. For this reason, we now turn to cross-country comparison. In this section, we analyse the historical experience of Asian countries since 1970, in terms of the growth in electricity demand in the industrial, services, and residential sectors. The agricultural sector is left aside because India's heavy reliance on pumped irrigation is dependent on locally specific factors. The analysis is based on the Global Energy and CO2 data set of Enerdata

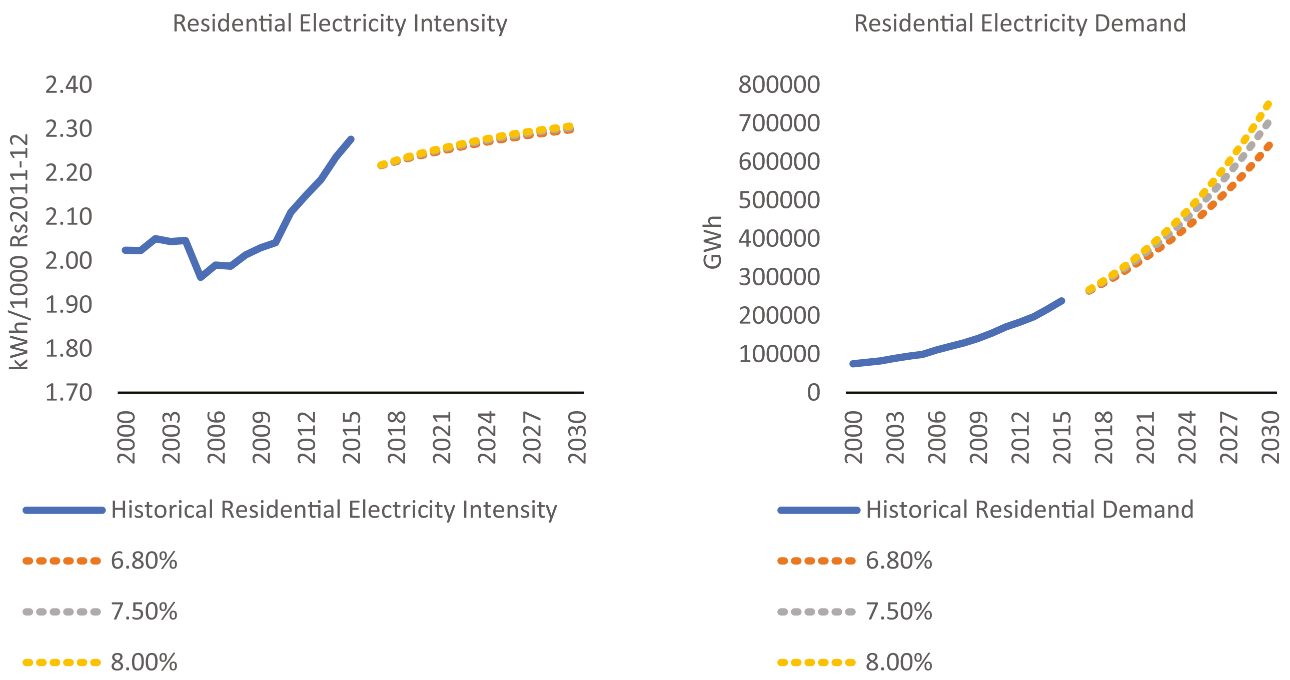


Figure 8: Trajectory for residential electricity intensity and residential electricity demand without efficiency adjustments, 2015–30
Source: TERI

(2018). We analyse the relationship between sectoral drivers of the final electricity demand for the industrial, services, and residential sectors—namely, industry VA, services VA, and the total GVA/capita—for a set of 18 Asian countries, since 1970. Table 14 gives an overview of the extent of the data set.

We use constant purchasing power exchange rates for all monetary units (constant USD 2015 purchasing power parity [PPP]), as this best approximates an internationally comparable estimate of the volume of goods and services produced. As noted by Samuelson (2014):

> Market exchange rates, on the other hand, have no necessary relationship to the 'real' value of an economy's GDP—that is, how much it will buy locally. The PPP approach ensures that if two economies have the same physical outputs, they will have the same GDP, whereas market exchange rates provide no such assurance […] it is this real GDP that should drive energy demand.

In this section, we compare the Indian historical data and projections conducted in Section 2 with the historical data set for Asian countries since 1970. To do so, for the India-specific historical and projected data derived in Section 2, monetary values in Rs 2011–12 are converted into USD 2015 PPP using GDP deflators and PPP conversion factors from the IMF and the OECD, respectively.

We normalize the independent and dependent driver on a per capita basis, so industrial value added is expressed as industrial value added per capita and industrial electricity demand as industrial electricity demand per capita. This allows us to easily compare countries with vastly different population sizes, and hence different-sized economies. Box 1 provides a description of how to read the graphs on which the analysis of this chapter is based.

The general approach is to represent the entire data set in grey, as well as the line of best fit and its R2 in red. The historical data for India is presented in orange, and the projections derived from the econometric analysis in Section 2 are presented in green.

The general objective of the approach is twofold:

- To analyse the projections conducted in Section 2 in the context of what has occurred in other countries as a test of their plausibility.

Table 13: Overview of results of the initial round of econometric projections

	Unit	2015	2030		
			6.80% Scenario	7.50% Scenario	8.00% Scenario
Agricultural Demand	TWh	173	295	331	359
Share of Agricultural in Total Final Demand	%	18%	12%	12%	12%
Industry Demand, Grid and Captive	TWh	424	1154	1338	1471
of which grid	TWh	286	797	924	1016
Share of Industry in Total Final Demand	%	43%	46%	47%	48%
Services Demand	TWh	149	436	463	486
Share of Services in Total Final Demand	%	15%	17%	16%	16%
Residential Demand	TWh	239	646	710	759
Share of Residential in Total Final Demand	%	24%	26%	25%	25%
Total Final Demand, Including Industry Captive	TWh	985	2532	2843	3074
Total Final Demand, Grid Only	TWh	863	2175	2428	2619
CAGR of Total Final Demand, Including Captive (2001–15 for the Historical Period)	%	7.3%	6.5%	7.3%	7.9%
Elasticity of Total Final Demand Growth to GVA Growth, Including Captive (2001–2015 for the Historical Period)	Ratio	1.00	0.96	0.98	1.00

Source: TERI

Table 14: Overview of the cross-country electricity demand data set

Sector	Industry Sector		Services Sector		Residential Sector	
Independent Variable and Dependent Variable	Industrial VA	Industrial Electricity Demand	Services VA	Services Electricity Demand	GVA/Capita	Residential Electricity Demand
Number of Data Pairs*	698		658		660	

** A data pair means that data for both the independent variable and the dependent variable is present in a given year.*
Source: TERI

Box 1: How to Read the Graphs in this Chapter

Figure 9 represents China's industrial electricity demand from 1978 to 2016. It can be read as follows:

- Horizontal (x-axis): industrial VA/capita on a log scale (base 2), in thousand USD 2015 at PPP rates (kUSD2015 PPP/capita). For the services and residential sectors, the corresponding values are services sector VA/capita and total VA/capita, respectively.
- Vertical (y-axis): industrial electricity demand per capita, in kWh, log scale (base 2). This is obtained by dividing the total final electricity demand of the industrial sector by the population.
- Time: The data is from 1978–2016. Each dot represents the values of the aforementioned indicators for a given year. Reading the graph from left to right, therefore, allows one to chart the development trajectory of China's industrial sector. The data set used in this section ranges from 1970 to 2016 (2017 for some countries), although the completeness of data across this timescale varies between countries.
- Log scale: We use a log scale of base 2 for both box axes, which allows us to easily visually compare countries or time periods with very different values, and get a clear overview of a large dataset.
- Sectoral intensities: In addition to the graph below, which shows sectoral demand per capita on the vertical axis, we also present a set of graphs showing the sectoral intensities expressed as kWh/kUSD2015 PPP of sectoral VA. For the residential sector, the entire economy's output is used as the denominator (total GVA).
- Geographical scope: We have taken as our data set the economies of Asia since 1970, for a couple of reasons. Firstly, these countries are likely to have similar socio-economic and climactic conditions. Secondly, these countries, particularly viewed across time, span a large range of the developmental trajectory (for example, China's GVA/capita has grown from 730 USD2015 PPP in 1978 to 15600 USD2015 PPP/capita in 2016, an increase of 2147%).

It can be seen that in Figure 9, in 1998 China's industrial VA was 1.80 kUSD2015 PPP/capita and its industry electricity demand was 469.52 kWh/capita. In 2016, this had grown to 7.06 kUSD2015 PPP/capita and 2515.84 kWh/capita of the sectoral electricity demand.

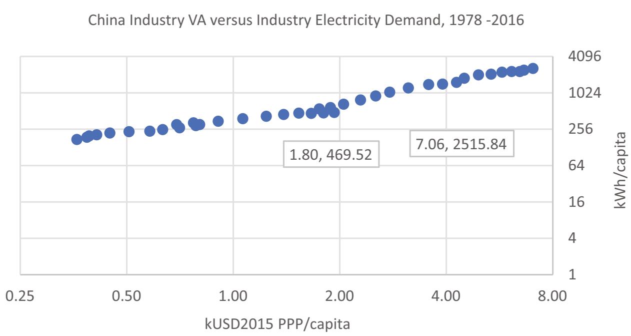


Figure 9: Sample graph, China's industry VA versus industrial electricity demand per capita, 1978–2016
Source: TERI, based on data from Enerdata (2018)

- Through the comparison with other countries, gain further insights into the drivers and specificities of India's electricity demand.
- To gain insights from the experience of other countries in order to develop another strand of evidence as to how India's electricity demand may evolve as it proceeds on its development trajectory.

Results

Industrial Sector

Figure 10 presents the results for the industrial sector. Several observations can be made with regard to the data. Firstly, there is a robust R2 between the independent (industrial VA) and dependent variable (industrial electricity demand), even across a large panel of countries and development conditions, and a long span of time. Secondly, the R2 for electricity intensity of the industrial sector is weaker. Thirdly, there is a weak trend of increasing electrical intensity of the industrial sector, up to a level of about 6–7 kUSD2015 PPP/capita of industrial VA, before intensities tend to plateau and decline somewhat (see Panel B). Fourthly, currently, India is broadly in the middle of the distribution of the data set in terms of industrial demand/capita and industrial electricity intensity, when compared to countries at comparable levels of per capita sectoral GVAs. At 186 kWh/kUSD2015 PPP, India's electricity intensity is less than that of what we might term the countries of the East Asian Model (notably China, South Korea, Japan, and Vietnam) at comparable stages in the development pathways, at which point these countries had a sectoral intensity >325 kWh/kUSD2015 PPP. But it is higher than that of what we might term countries of the South East Asian Model (for example, Thailand, Indonesia, Laos, and Sri Lanka) at similar levels of sectoral output/capita (<150 kWh/kUSD2015 PPP). Fifthly, the projections to 2030 fit reasonably well with historical experience. They imply a continuation of India's pathway in the 'South East Asian' model of lower electrical intensity (see Panel B), albeit by no means towards the bottom of what has been seen historically.

To the extent that India may desire faster industrial growth; higher infrastructure investment; and higher shares of infrastructure-related, more electro-intensive sectors ('Make in India' style industrialization), the trajectory envisaged in the projections to 2030 appear to imply more continuity than transformation.

Figure 10: Industry VA versus industry electricity demand (A) and industry electricity intensity (B)

Services Sector

Figure 11 presents the results for the services sector. Again, one sees a robust R2 between services value added and services electricity demand across our data set (0.9049). The R2 between services VA/capita and services electro-intensity is less, but still explains 43% of the variance seen between these two variables across our large data set of countries. It can also be seen that a 'quasi Kuznets curve' between services VA/cap and services electro-intensity is present (see Panel B), is more marked for the services sector as compared to the industrial sector, and occurs somewhat later in the development trajectory, peaking at around 16 kUSD2015 PPP/capita (for comparison, India is currently at 3.45 kUSD2015 PPP/cap). Finally, one can see that our projections imply that the Indian services sector continues to be highly electro-efficient when compared to its peers at comparable levels of development (see Panel B). For example, across the projection period India's services VA/cap is projected

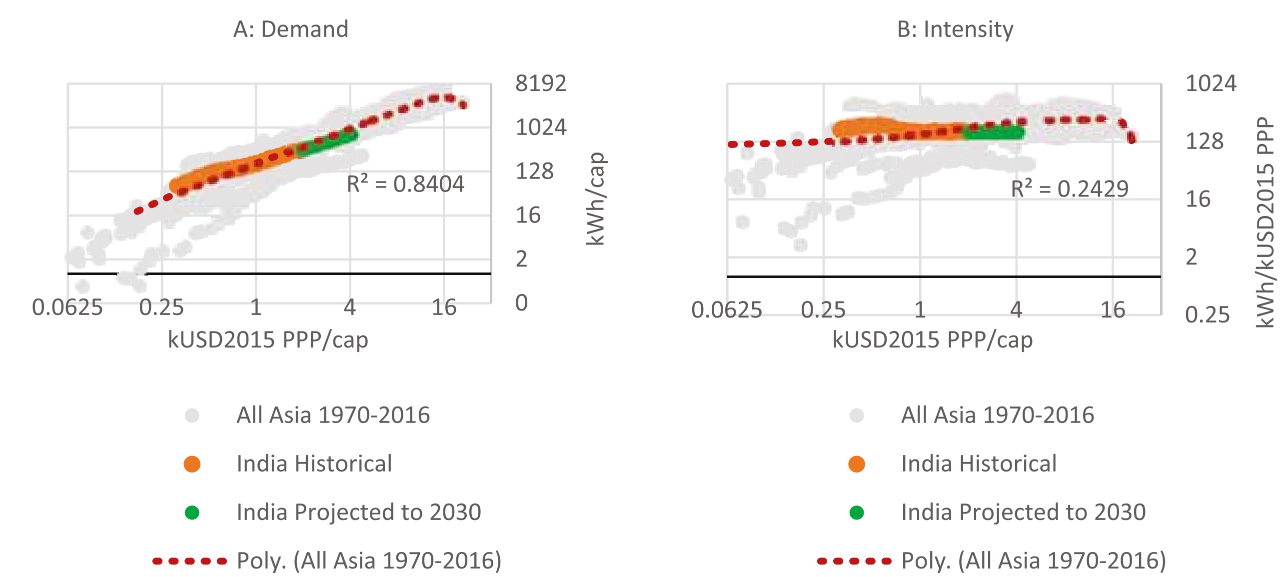


Figure 10: Industry VA versus industry electricity demand (A) and industry electricity intensity (B)
N.B. Under 'India Projected to 2030', only the 6.80% scenario presented in Section 2 is shown.
Source: TERI analysis and projections, based on data from Enerdata (2018)

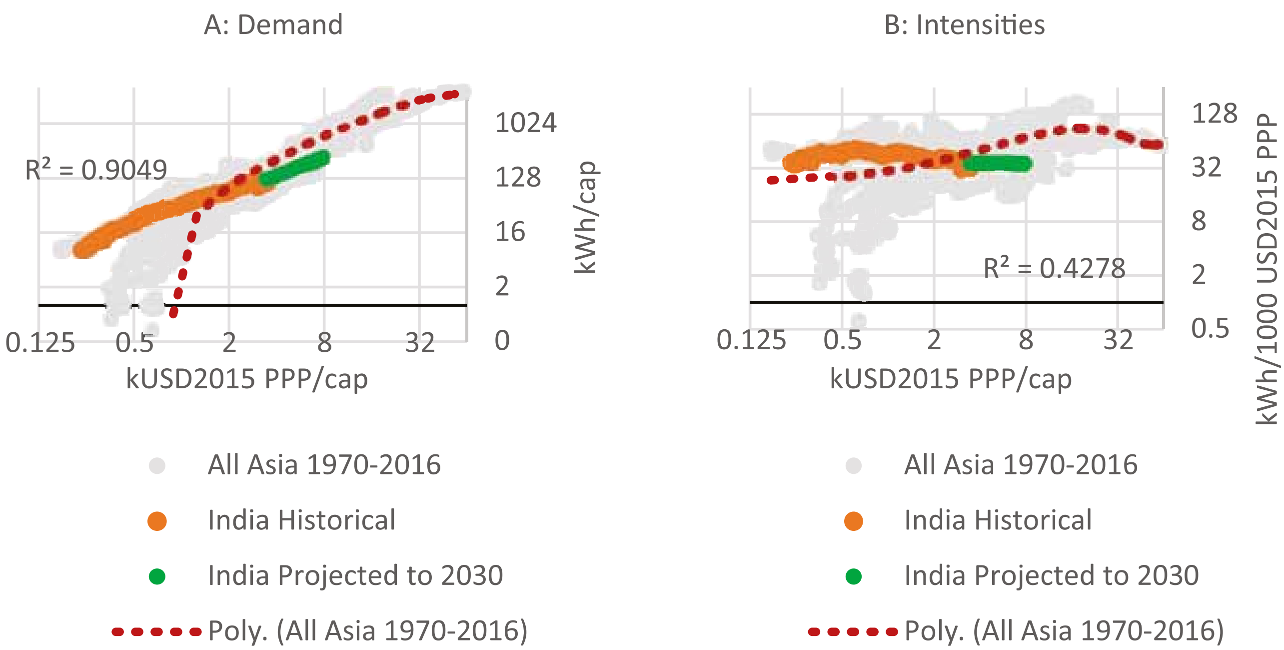


Figure 11: Services VA versus services electricity demand (A) and services electricity intensity (B)
N.B. Under 'India Projected to 2030', only the 6.80% scenario presented in Section 2 is shown.
*Source: TERI analysis and projections, based on data from Enerdata (2018) *

to rise from 3.3 to 7.8 kUSD2015 PPP: this is comparable with what Thailand achieved in the last 20 years, during which its services electricity intensity rose from about 53 kWh/kUSD2015 PPP to about 100 kWh/kUSD2015 PPP. India's currently stands at 32.8 kWh/kUSD2015 PPP.

Further investigation of the driving factors behind the peak in services electro-intensity is required before one could assess whether India's projected trajectory in Panel B is reasonable. One can hypothesize a number of countervailing forces as countries become more developed. Firstly, the shift to high VA service sectors would tend to depress intensities by raising the denominator. Secondly, however, there could be an increasing marginal propensity to consume electricity, as countries urbanize and as incomes increase. Thirdly, it is possible that structural changes are occurring in the economy and energy sectors which increase the electricity demand (decline in the relative price of electricity-consuming goods, digitization and connectivity, urbanization and formalization). By way of a digression, we provide a brief

Box 2: A Digression: Are Economies Becoming More Electro-intensive Over Time?

Nordhaus's seminal paper noted that the real cost of lighting services has declined by thousands of orders of magnitude since the beginning of the industrial age (Nordhouse, 1996). Likewise, the real cost of electricity-consuming goods continues to decline rapidly in the present age, while the trends of digitization and connectivity increase the importance of electricity as an input for many economic processes. Thus, electricity has increased its share in the global final energy demand from 10.7% in 1980 to 18.4% in 2016.

In order to investigate whether there is an increasing marginal propensity to consume electricity over time, we conduct the following analysis. Figure 12 plots sectoral income on the horizontal axis (in kUSD2015 PPP/cap) and sectoral electricity demand on the vertical axis (kWh/cap). The data set is the same as is used earlier, namely, all Asian countries since 1970. The data set is broken up into three parts, for which lines of best fit and their attendant R2 are presented:

- Observations before 1985 (red)
- Observations between 1985 and 2000 (purple)
- Observations since 2000 (green)

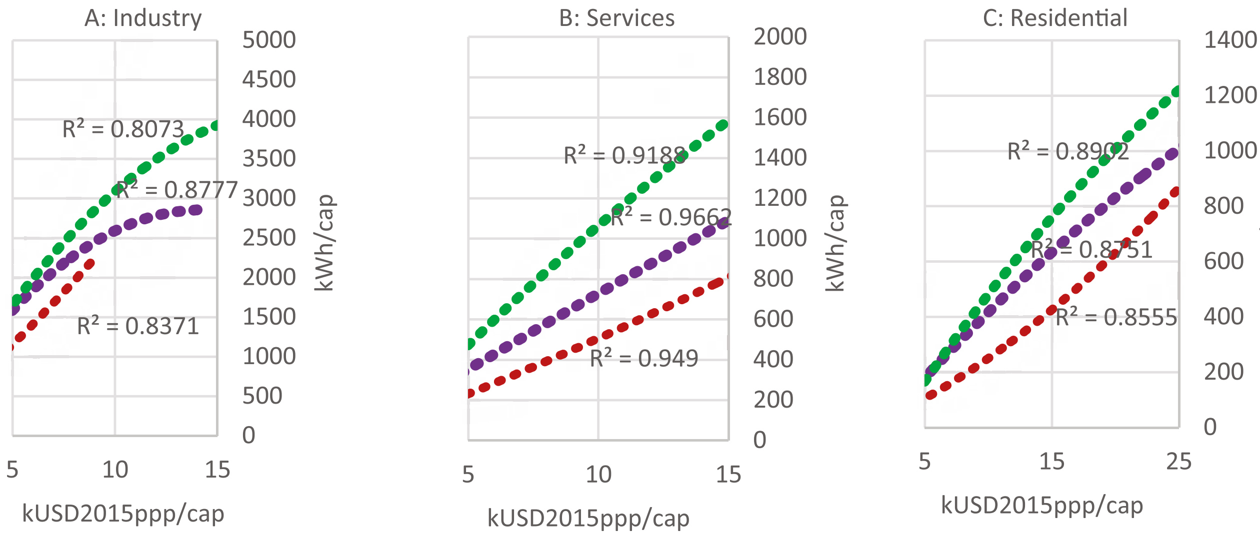


Figure 12: Are economies becoming more electro-intensive?
Source: TERI analysis, based on data from Enerdata (2018)

investigation of the last hypothesis in the Box 2.

The aforementioned analysis suggests that economies have indeed become more electro-intensive over time. For example, an economy producing about 10 kUSD2015 PPP industrial VA/cap would have been expected to consume about 2600 kWh/capita in the industrial sector in 1990, and about 3000 kWh/capita in 2010. Of course, the data set would have to be expanded and tested with more robust econometrics to provide stronger support to the hypothesis. But the presence of the effect across all three sectors provides a fairly strong initial evidence to confirm the intuition that economies are indeed becoming more electro-intensive over time with the declining relative costs of electricity-consuming goods and the increasing importance of digitization, connectivity, and information processing to modern economic processes.

Residential Sector

Figure 13 presents the results for the residential sector. As with the other sectors, the R2 is robust across the data set for demand per capita as a function of GVA/capita. The R2 for sectoral intensity as a function of GVA/capita is weak, explaining only 23% of the variation seen in these variables. India's recent trajectory is seen to be very much in line with the experience of other countries. As with the services and industrial sectors, there is a weak 'quasi Kuznets curve' in the intensity data, peaking at a level of GVA/capita of around 28 kUSD2015 PPP. In the projections, India's sectoral electricity intensity would be towards the lower half of what is seen in the data set, but only moderately so.

Conclusion to This Section

What shall we make of the preceding data? Overall, a number of conclusions come to the fore.

- Firstly, the econometric models developed and used to make the projections in Section 2 give results that are quite consistent with the observed historical development trajectories of India's peers. This can give further support to the use of these models.
- Secondly, India is approaching a development level where other countries have tended to see somewhat of an increase in their sectoral electricity intensities (notably in the services sector and, to a lesser extent, the industrial and residential sectors). However, the correlation between sectoral intensities and sectoral income per capita is not particularly strong and there is a wide diversity of circumstances seen in the data for sectoral electricity intensities.
- Overall, the trajectories implied by the projections in Section 2 and compared to the cross-country historical data in this section would imply more continuity than transition in India's macroeconomy. A macroeconomic transition towards faster, more industrialized, and more urbanized growth would, in all probability, lead to an increase in sectoral intensities, particularly in the industrial sector.

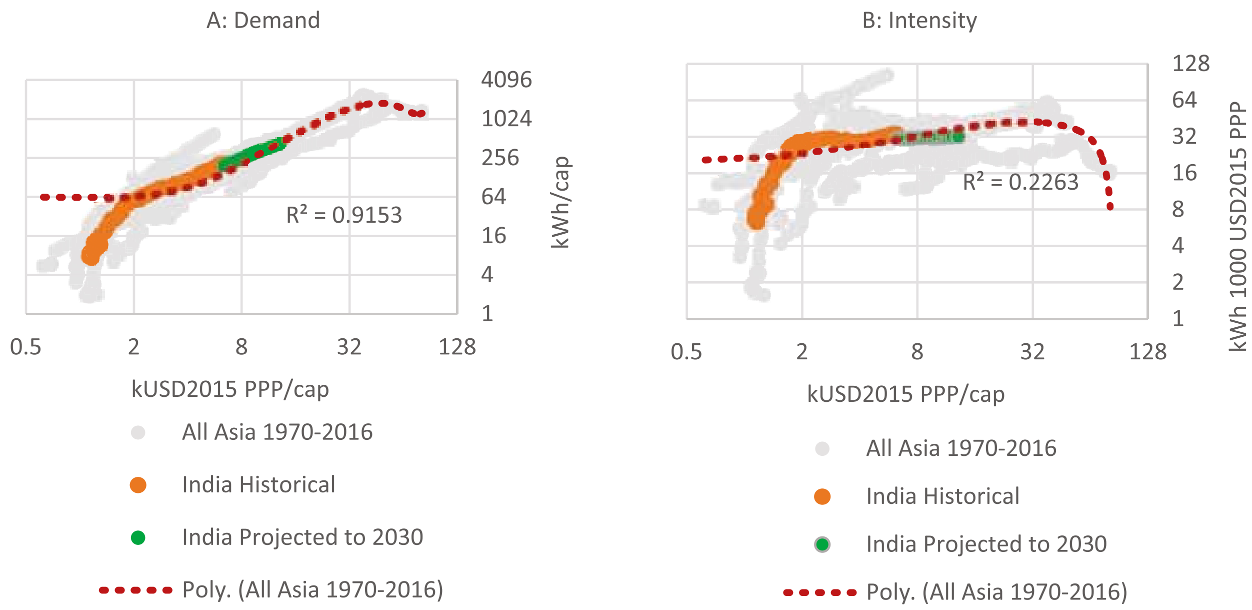


Figure 13: ervices VA versus services electricity demand (A) and services electricity intensity (B)
Source: TERI, based on data from Enerdata (2018)

- The services sector is one sector where India's trajectory stands out more from its peers. India is, and is projected to continue to be, significantly less electro-intensive than its peers. Further investigation of why this should be so is required. Is it because of the importance of high value-added subsectors in India's service sector value added (larger denominator)? Anecdotally, there doesn't seem to be enough evidence to support this: high-productivity subsectors like business and financial services made up 21% of China's service sector, versus 24% of India's in 2010. Yet India's service sector electricity intensity was 35% less than China's in the same year, in PPP terms. On the other hand, between 2010 and 2015, high-productivity sectors increased their share of the Indian services sector from 24% in 2010 to 33% in 2015, while at the same time service sector electricity intensity declined by 27%. To what extent are these two phenomena related? Can they be expected to continue in the future? Answers to these questions would require further analysis at the subsector level, for which data is lacking.

Partial End-Use Analysis

Introduction

In this section we gather another strand of evidence regarding the trajectory for Indian electricity demand growth. The end-use or partial end-use methodology is often used in energy demand forecasting. Compared to the econometric methodology, it has a number of advantages: notably, through partial end-use methodologies the forecaster can consider the impacts of technology change and efficiency policies. Partial end-use methodology also has a number of disadvantages. It is highly data-intensive, which is particularly challenging in a developing country like India. It is especially challenging to establish a statistically robust link between a macroeconomic scenario and the dependent variable—namely, the development of the stock of energy-consuming equipment—when historical data for stock development is based on infrequent sample surveys and patchy industry data (for example, annual sales).

Agricultural Sector

Analysis and Projection of Drivers

Table 3 showed the correlations coefficients of the various drivers of agricultural electricity demand. The growth of gross irrigated area, number of pumpsets, and intensity of pumpset use are found to be statistically significant drivers. In this section we construct a projection of these drivers, in order to then project, firstly, a baseline scenario for agricultural electricity demand; and secondly, a high-efficiency scenario.

- Net and gross irrigated area: Across the historical period 2002–13, the gross sown area has grown by 1.9% yoy, almost solely through the growth of the area under two annual crops growing at 1.9% yoy (the net sown area has increased by only 0.04% yoy). The net irrigated area has grown by 2% yoy, taking the net irrigated area to 48% of the net sown area. On the other hand, the area irrigated more than once per year has grown by 2.2% yoy (gross irrigated area). Thus, the transition to two annual, irrigated crops has been a major driver of the increase in the irrigation demand across the period. Given that only 48% of India's gross sown area is irrigated, and irrigation brings significant benefits in terms of productivity and resilience (Economic Review, 2018), we can assume that there is still a significant unmet demand for irrigation services. In the baseline scenario we, therefore, assume that the gross irrigated area grows in line with its historical rate, from 95,772 kHa in 2014 to 120,424 kHa in 2030. The share of gross sown area which is irrigated thus grows by 6 percentage points, to 54% by 2030.
- Pumpsets per Ha of gross irrigated area: The number of pumpsets per Ha of gross irrigated area has grown by about 0.6% yoy. We assume that this trend will continue to 2030.
- Total number of pumpsets: The product of the two variables above gives the total number of pumpsets across the projection period. The number of pumpsets grows from 19.4 million in 2013 to 26.7 million in 2030.
- Pumpset power capacity and annual hours of use: We assume in the baseline scenario that the average kW of power capacity of pumpsets continues to grow in line with the historical trend at 0.5% yoy to reach 6.3 kW by 2030. We assume that the hours of pumping per year do not change, in line with the historical trend in the CEA data. Therefore, the increased electrical consumption of the pumps is due to their increased power rating. Given that the current popular pump models range between 3.7 kW and 5.6 kW (Shakti Foundation, 2012), an all-India average, as reported by the CEA, of 5.32 kW for the entire pumpset stock in 2015 may appear on the higher side (see Box 3 for a discussion). But in the absence of better data, we take the data as reported by the CEA for the average power rating of pumpsets as given.

Box 3: Investigating Agricultural Demand Data

A number of concerns have been raised about the quality of agricultural electricity demand data, given the absence of more robust metering in the sector (Dharmadhikary, et al., 2018). It is possible that losses, or rural residential sector demand, are being reported as agricultural demand. The question is how to investigate this hypothesis. The decomposition analysis of the growth in agricultural demand (see Table 4 in Section 2.1.2) showed that about 46% of agricultural growth could be attributed to the growth of the gross irrigated area. Let us assume that this data is sound. A further 42% of agricultural electricity demand growth was attributed to the growth in the reported average power capacity of pumps, from 3.89 kW to 5.32 kW.

The question is whether this is a plausible trend. Several observations can be made in this regard. Firstly, the average power capacity as reported by the CEA is a derived indicator, not directly observed: derived from the number of pumpsets, GWh of agricultural demand, and estimated annual hours of pumping. Secondly, the reported average power capacity of the pumpset stock varies considerably year-on-year in the historical data. Such large annual variations are implausible, given that the indicator represents the average of a large and slowly changing stock. Thirdly, with some assumptions about the life cycle of pumpsets, one can calculate what the average power capacity of new pumps would need to be in order to shift the average power capacity of the stock according to the reported values. For this purpose, let us suppose an operating life of seven years. Table 15 presents the results of the analysis.

Table 15: Investigating reported power rating of pumpsets

	2005	2008	2011	2012	2014
Reported stock average in that year (kW)	3.78	4.40	6.15		5.53
Implied average power capacity of new sales in the past 3 years, assuming a 7-year life cycle (kW)	3.77	4.44	6.26		5.49
Weighted average power capacity in pumpset market, based on market survey*				4.60	

** From Shakti Foundation (2012)*
Source: TERI, based on data from CEA (various years)

Shakti Foundation (2012) reports on the market segmentation of pumps by power rating, the weighted average whereof comes to 4.60 kW in the study's publication year of 2012. According to our analysis, raising the average power capacity of the pumpset stock to 5.53 kW, as reported for 2014, would require an average of 5.49 kW of all new sales in the preceding three years. Clearly, this does not quite stack up with the available market survey data for 2012. Moreover, the data for 2011, with a reported stock average of 6.15 kW, is clearly an aberration, rising from 5.35 kW the previous year. Hypothetically, for this to hold true, all sales in 2010 would have had to have a power capacity of 10.18 kW to raise the stock average accordingly, whereas Shakti Foundation (2012) reports the market share of the most powerful pump (11.2 kW) at 6% in 2012. Clearly, this is not plausible. As a thought experiment, imagine that the stock of pumps in 2012 had an average power capacity which is the same as the weighted average capacity of new pumps in the market this year, as reported by Shakti Foundation (2012). Taking this number as the stock average, and holding the number of pumps and hours pumped as reported, would give an agricultural electricity demand about 27% less than the reported value.

The evidence is, therefore, on the side of those who raise questions about the accuracy of the agricultural data. In the absence of an alternative, we go with the available data. If any possible gaps between reported demand and actual on-the-ground demand are due to losses, this may bias downwards the future projections of agricultural demand, assuming that these losses can be controlled in the future.

These parameters give us the variables required to make a baseline projection. An important assumption we make is that the growth rate of gross irrigated area is linear, and does not compound annually. The historical trend of gross irrigated area fits a linear curve better than an exponential one. In addition, one may argue that the transition to two biennial irrigated cropping was a one-off event in certain northern states, and that the future growth of gross irrigated area may be driven more by the slower expansion of irrigation to the previously unirrigated land.

Below, we detail the assumptions in the high-efficiency scenario.

- Total number of pumpsets: as per the baseline scenario above.
- Efficiency of pumpsets: There is known to be significant efficiency potential in the agricultural pump sector, in the order of 20% or more with the best available technology (Impact Energy and TERI, 2017). Drip irrigation and water efficiency could further reduce pumping requirement. However, the countervailing impact of groundwater decline would also impact the efficiency scenario. We construct a stock model of pumpsets, assuming a pumpset lifetime of seven years. In the moderate scenario, we assume that power capacities of new pumps can be kept at 10% below the baseline level, reaching 5.7 kW by 2030 instead of 6.3 kW. In the high-efficiency scenario, power capacities are kept 20% below the baseline scenario, reaching 5.06 kW. This represents an absolute decline of around 5% against today's level, whereas the moderate scenario assumes an increase of around 7% against today's level. Efficiency improvements are applied only to future vintages of pumps, although by 2030 a full replacement cycle occurs.

Table 16: Baseline assumptions in the end-use agricultural projection

	Gross Irrigated Area (kHa)	Of Which, Area Irrigated More than Once (kHa)	Number of Pumpsets Per Ha Gross Irrigated Area (#)	Total Number of Pumpsets (Million)	Average Power Capacity of Pumpsets (kW)
Yoy Growth Rate Historical	1.7%	2.2%	0.6%	2.9%	1.9%
2013 Value	95772	27672	202	19.39	4.86
Assumed Yoy Future Growth Rate	1.4%	1.6%	0.5%	1.9%	1.6%
2030 Value	120424	36508	222	26.72	6.33

Source: TERI, based on CEA (various years) and MOSPI (2017)

Results

Table 17 presents the results of the different scenarios. The 6.80% End-Use Projection (no efficiency improvements) develops a projection based on a bottom-up analysis of drivers outlined above, without taking into account technical efficiency. Its 2030 outcome is marginally lower than the 6.80% Econometric Projection presented in Section 2.1.3 (7.2% less). The driver for this is the slower growth of the gross irrigated area, which is assumed to be linear rather than compounding. The two efficiency scenarios are lower still, with 2030 projections that are 18.6% and 25.1% lower than the econometric projection of Section 2. Thus, purely technical efficiencies could be assumed to yield reductions of power demand of around 11–19%. This is without making assumptions on the impact of water efficiency. It also makes no assumptions about the solarization of agricultural load: the projections here are of demand.

Conclusion to This Section

This section has analysed the drivers of electricity demand in the agricultural sector and developed an end-use projection. The central conclusions are as follows:

- One of the main drivers of agricultural electricity demand growth has been the growth in the gross irrigated area, mostly through the shift to two annual irrigated crops. Assuming that the gross irrigated area grows linearly in the future leads to a lower projection than the econometric projection, even without assuming technical-efficiency improvements.
- The second major driver of demand growth has been found to be the growth in the power capacity of pumps. A number of questions have been raised about the quality of agricultural electricity demand data. The examination conducted of the pumpset power capacity data suggests that these issues are real (see

Table 17: Results of the end-use modelling

	6.80% Econometric Scenario	6.80% End-Use Scenario (No Efficiency Improvements)	6.80% End-Use Scenario (Moderate-Efficiency Scenario)	6.80% End-Use Scenario (High- Efficiency Scenario)
Demand in 2030 (GWh)	295377	274100	240436	221367
Sectoral Intensity in 2030 (kWh/1000 Rs 2011–12)	11.68	10.84	9.51	8.73

Source: TERI analysis and modelling

also the corroborating analysis of Dharmadhikary et al., 2018). If pumpset power capacities are indeed overstated, it would imply that agricultural electricity demand is likewise inflated. If this is so, it may give a reason to think that agricultural demand will not grow as strong in the future as it has been reported to have done in the past. We, therefore, consider that agricultural demand projections are biased to the downside, assuming that the losses reported as demand are controlled.

- Our analysis suggests that there is a significant technical-energy-saving potential in the agricultural sector, in the order of 55–75 TWh. Savings potential from water-efficient irrigation and losses reduction (assuming that some reported demand is actually losses) would be higher still.

Services Sector

Analysis and Projection of Drivers

End-use projections for the services sector are driven by projections for floor space in the services sector, and the respective electrical intensities of that floor space for both AC and non-AC buildings. The projections are as follows:

- Service-sector floor space: Commercial floor space is assumed to be a function of service sector VA per capita, with an elasticity of slightly more than 1, as per what can be gleaned from Indian historical data. Projections thus range from 2.9–3.2 billion m2 by 2030 in our different macroeconomic scenarios.
- Air-conditioned floor space: We assume a rise in the share of air-conditioned floor space in the total stock from roughly 40% today to 54%, 56%, and 58%, respectively, in our three macroeconomic scenarios by 2030. These projections imply that by 2030 between 67% and 73% of incremental service-sector floor space is air-conditioned.
- Electricity intensity: We assume a starting Energy Performance Index (EPI) of 210 kWh/m2/year in AC buildings and 55 kWh/m2/year in non-AC buildings. These are weighted averages of all commercial floor space across different subsectors.
- Efficiency scenario: For AC buildings, we assume a reduction rate in the high-efficiency scenario of 3%/year for new builds through a combination of appliance efficiencies and envelope efficiencies. In the other scenarios, we assume the efficiency of the AC building new build declines by 1%/year. Efficiencies improve at 0.5%/year for the stock of non-AC buildings across all scenarios. The residual sectors—namely, public lighting, public water, and 'other'—are estimated econometrically, and no assumptions are made regarding their efficiency improvements. It should be noted that because the projections are based on an EPI, which combines activity level (intensity of consumption of energy-consuming devices per m2) and electrical intensity (electricity consumption per appliance), it is possible for an EPI reducing at 3%/year for new buildings to imply a faster rate of equipment intensity improvement, somewhat offset by an increase in the activity level. For example, if a new floors pace is lit by three light points instead of two in a floor space of the same size, and the electrical intensity of the light bulbs improves by 50%, then the EPI will only have improved by 25%, not 50%. In view of the likely increase in service-sector activity levels, assuming a 3%/year reduction in the EPI is aggressive.

Results

Table 18 presents the results of the analysis. Several things are worthy of note. Firstly, the end-use methodology, assuming moderate efficiency improvements, results in higher projections than the econometric methodology, by around 8.5–11.8% in 2030. This would put India on a trajectory more similar to its international peers', with service sector electrical intensities rising somewhat as sectoral output reaches a level of 8 kUSD2015 PPP/capita (see Figure 11). Secondly, the high-efficiency scenario results in total savings of about 6.7–7.6% by 2030, allowing the end-use projection to track the lower-intensity econometric projection.

Cooling demand grows by 9–11% per year across the projection period, several percentage points faster than

Table 18: Services electricity demand in 2030—econometric versus end-use methodologies

Macro Scenario and Methodology	Efficiency Scenario	2030 Services Demand (GWh)	Of Which Estimated Cooling Demand (GWh)	2030 Service Sector Electricity Intensity (kWh/1000 Rs 2011–12)
6.80% End Use	Moderate	487794	106450	2.90
6.80% End Use	High	455144	95022	2.71
6.80% Econometric	n.a	449377	n.a.	2.67
7.50% End Use	Moderate	524677	133162	2.94
7.50% End Use	High	485111	117335	2.72
7.50% Econometric	n.a	477375	n.a.	2.67
8.00% End Use	Moderate	559807	144838	2.99
8.00% End Use	High	517531	127927	2.76
8.00% Econometric	n.a	500697	n.a.	2.67

Source: TERI analysis

the total services electricity demand. Cooling demand grows disproportionately faster in high GDP growth scenarios, because of the more rapid shift to AC buildings in the new floor space. By 2030, it reaches around 21–26% of the total service-sector demand, depending on the macroeconomic and efficiency scenario. A high-efficiency scenario would see savings in the order of 10–12% on the cooling demand.

Conclusions to This Section

We draw the following conclusions from the aforementioned analysis:

- The analysis provides another strand of evidence that econometric projections based on recent (15 year) historical data may somewhat understate the potential service sector electricity demand in 2030.
- The results suggest that the sector intensity may be somewhat higher than implied by the econometric projection by 2030, if the rise in sectoral intensities seen in other countries is reproduced in India.
- The cooling demand is expected to grow faster than the rest of the sector's demand, and may reach in the order of 21–26% of the sector's demand by 2030.
- There is a significant energy-savings potential in the sector, estimated at around 32–42 TWh.

Residential Sector

Analysis and Projection of Drivers

The projections developed in this section are based on a stock model of major electricity-consuming appliances in the residential sector. Lighting demand, and demand from appliances not represented in the stock model, are estimated as a residual and projected econometrically. The historical household penetration rate of appliances is calculated based on various years of the National Sample Survey (NSSO). The model is calibrated so that it can reproduce the observed electricity demand of the sector within a reasonable error margin. Calibrating the model is a real challenge given the five-yearly regularity of the NSSO, the lack of time-series data on appliance stocks as a function of income, and the general paucity of end-use demand data in the residential sector. For example, estimates of the share of lighting in residential electricity demand vary between 37% and 21% (Prayas, 2016). Constructing an end-use model for the residential sector is, thus, more art than science: it should be used more to get an idea of energy-savings potential and the possible structure of demand, and projections of the level of residential demand should be compared with those of other sources and methodologies. In Box 4, we explore one of the challenges of calibrating an end-use model for the residential sector.

Box 4: How Much Cooling Can One Lakh of Rupees Buy?

A typical approach to end-use modelling is to examine sample surveys in order to understand the penetration of energy-consuming equipment as a function of household-consumption expenditure classes. One, then, makes a projection for the evolution of household-consumption expenditure classes in constant rupees across the projection period, and assumes that the equipment penetration holds per expenditure class as per the historical data of the survey. For example, if expenditure class 'x' is seen to have a penetration rate of air-conditioning units in the sample survey of 'y', then a projection of the number of households in expenditure class 'x' in t+1 suffices to derive a projection of air-conditioning units, assuming that 'y' stays constant.

The problem emerges, however, if relative prices between energy-consuming and non-energy-consuming consumption goods are changing significantly. In this case, the assumption that 'y' stays constant may not hold true, because a given level of 'x' may be able to purchase more or less energy services, depending on the movement of relative prices. Let us examine this point in a little more detail, using data from India's Wholesale Price Index (WPI). In Figure 15, we plot the ratio between the WPI-All Commodities Index and a Residential Cooling Price Index that we derive by combining the price indices for air conditioners and domestic electricity prices (with respective weights of 2/3 and 1/3). As can be seen, by the end of the period 2005–17, the relative price of cooling was about 30% lower than the WPI-All Commodities Index. In other words, a domestic salary, whose real value is kept constant relative to the WPI-All Commodities Index, would still be able to purchase 30% more cooling services in 2017 than in 2005. Such relationships between relative prices can be captured in econometric models, but are more difficult to capture in end-use models, in the absence of sufficient time series of incomes, sectoral value added, and equipment penetrations.

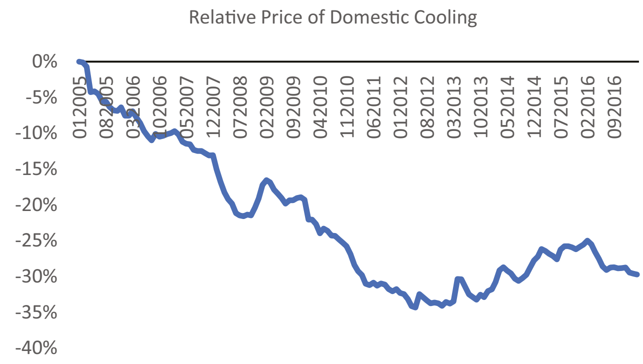


Figure 15: How Much Cooling Can One Lakh Rupees Buy?
Source: TERI, based on data from OEA (2018)

Table 19 presents the equipment penetrations projected in the different macro-scenarios. Air-conditioning units are projected to grow fastest, with a CAGR in the order of 16–18%. This is higher than the current sales rate seen over the last few years in the order of 14%/year. This is because the 's-curve' used to model AC penetration per household sees an increasing slope at the income levels India is likely to achieve by the 2020s. Other large domestic appliances like geysers, refrigerators, and washing machines also see strong stock growth, in the order of 6–10% per year. Our stock projections compare favourably with other projections in the literature, giving some degree of confidence to the exercise (Abhyankar, et al., 2017 ; Planning Commission, 2014).

In terms of efficiency, we assume, in the moderate-efficiency scenario, that equipment efficiencies improve at slightly more than 1% per year. In the high-efficiency scenario, we assume that this increases to 3.0% per year. Generally speaking, equipment lifetimes are assumed to be seven years, and efficiency improvements are modelled on the basis of a stock model. For smaller appliances like mobile phones and laptops, a stock model is not used; rather, efficiency improvements are made for the stock as a whole over time. Lighting is estimated as a residual, and projected econometrically as a residual. No efficiency assumptions are made for lighting, beyond what is implied in the econometric equations.

Results

The results from the residential sector end-use modelling are presented in Table 20. Several points are worthy of

Table 19: Equipment penetrations in the residential sector by 2030, BAU scenario (million)

Scenario	Item	AC	Fans	Fridge	Geyser	TV	Laptop	Mobile Phone	Washing Machine
6.80%	Million Units	70	486	173	139	285	184	530	33
	Stock Growth Rate (% yoy)	16%	3%	6%	7%	3%	8%	3%	8%
	Penetration Per Household	21%	146%	52%	42%	86%	55%	159%	10%
7.50%	Million Units	89	577	202	158	353	216	722	39
	Stock Growth Rate (% yoy)	18%	4%	7%	8%	4%	10%	6%	9%
	Penetration Per Household	26%	171%	60%	47%	105%	64%	214%	12%
8.00%	Million Units	106	609	217	170	375	235	780	43
	Stock Growth Rate (% yoy)	19%	4%	7%	9%	5%	10%	6%	10%
	Penetration Per Household	32%	183%	65%	51%	113%	70%	234%	13%

Source: TERI analysis and modelling

note. Firstly, the end-use model produced results quite similar to the econometric model, albeit with a delta of -4 to + 3%. The end-use model produced higher results than the econometric model for higher GDP growth scenarios, suggesting that it may be reflecting some non-linearities in households' propensity to consume electricity-consuming goods with rising incomes. Secondly, the high-efficiency scenarios showed efficiency potentials in the order of 10–11% savings versus the moderate-efficiency scenarios (55–75 TWh, depending on the macro-scenario in question). The largest efficiency savings were to be found in the air-conditioning sector, in the order of 18% (20–32 TWh).

Conclusion to This Section<Level C>

We can draw the following conclusions to this section:

- Despite the challenges of calibrating an end-use model, the projections derived fit reasonably well with the projections from the econometric methodology.
- By 2030, cooling is, by some margin, the fastest-growing end use, and accounts for around 19–22% of the residential electricity demand, depending on the macro-scenario.
- The savings potential of the sector is estimated to be in the order of 55–75 TWh.

Industrial Sector

Analysis and Projection of Drivers

End-use modelling of the industrial sector is a challenge due to the structure of electricity demand. According to the IEA statistics, around 42% of the industrial electricity

Table 20: Residential sector electricity demand in 2030 according to different modelling approaches and efficiency assumptions

Macro-scenario	Modelling Approach	Efficiency Scenario	2030 Residential Demand (GWh)	Of Which Cooling (GWh)	Sector Intensity (kwh/1000 RS 2011–12)
6.80%	End Use	Moderate	619561	118930	2.21
	End Use	High	564132	97942	2.01
	Econometric	n.a.	646184	n.a.	2.30
7.50%	End Use	Moderate	716891	149009	2.33
	End Use	High	649517	122200	2.11
	Econometric	n.a.	709724		2.31
8.00%	End Use	Moderate	783341	176142	2.38
	End Use	High	707610	144015	2.15
	Econometric	n.a.	758520	n.a.	2.31

Source: TERI analysis and modelling

demand was recorded as 'non-specified (industry)'. We can explore this problem by looking, as best as we are able to, at the sectoral electrical intensity of different industrial subsectors, comparing, in this case, India and China. We use the harmonized cross-country KLEMS databases to derive sectoral value-added outputs for industrial subsectors (RBI, 2018; RIETI, 2015). We use the IEA's electricity demand data which breaks up the final industrial electricity demand, including captive power, into different industrial subsectors (IEA, 2018). Sectoral electrical intensity is derived by dividing sectoral electricity demand by sectoral value added. Sectors are matched using comparative tables of the relative classification codes. It can be seen that India is far more electro-intensive in the 'non-specified' sector as compared to China. Secondly, China is far more electro-intensive in certain sectors than India, notably metals, non-metallic minerals, and chemicals and petrochemicals. The extent of this divergence does not seem plausible, given that these sectors are large, electro-intensive, cost-sensitive, trade-exposed sectors, in which one would expect to see convergence of efficiencies for such a key production factor as energy. The solution to the puzzle appears to lie in the fact that a significant share of India's industrial electricity demand is classified in the 'non-specified' sector, artificially raising the electro-intensity of this sector and lowering the electro-intensity of other sectors.

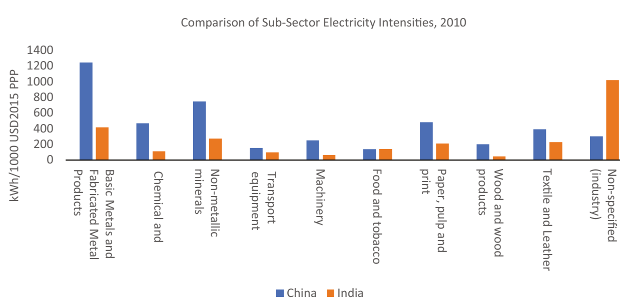


Figure 16: Electrical intensity of industrial subsectors
Source: TERI, based on data from RBI (2018), RIETI (2015), and IEA (2018)

This makes a comprehensive end-use model of the industrial sector difficult to build. We can do so only for a few large sectors in which physical outputs and electricity demand are (more or less) well-known. For want of data, the remaining industrial electricity demand must be projected as a residual using the econometric approach based on residual industrial value added. To add further complexity, the sectors amenable to an end-use approach in industry also tend to be those dominated by captive power. Thus, end-use modelling may be able to tell us about the potential future size of the captive power market, but not so much about the grid demand in the industrial sector.

The approach is as follows:

- Projections of sectoral valued added: The industrial value-added projections developed in Section 2 are further broken down to individual subsectors by assuming that individual subsectors' shares do not change significantly in the future. We have 15 years of details, subsectoral value added, from the KLEMS database (RBI, 2018). From this, it can be seen that large industrial subsectors' share in industry value added has not changed significantly, nor do we see any clearly identifiable structural trend in their shares.

- Correlations of subsectoral value added to physical sectoral outputs: Historical data since 2000 of physical sectoral outputs was gathered and correlated with the historical value added. For example, for the iron and steel sector, this involved correlating the physical output of crude steel with the value added of the basic metals sector. Adjusted R2 for the iron and steel, aluminium, cement, and refineries and petrochemicals sectors were 0.91, 0.92, 0.92, and 0.91, respectively.
- Projections of physical output: From these econometric relationships, physical outputs of major electricity-consuming industrial sectors were projected to 2030, using the same three macroeconomic scenarios that we have been using throughout this paper.
- Electricity intensity of physical output: The sectoral electricity performance index (EPI) was derived from the existing data and industry consultations. Multiplying physical output with this EPI gives us the electricity demand of the sectors modelled using the end-use approach. As mentioned earlier, all other sectors are modelled as a residual.

The growth rate for the output of these products is in the order of 6–9% per year, which is consistent with the rate of industrial GVA growth in the different scenarios. However, it is plausible that some of India's future industrial GVA growth would be from higher value addition within sectors and a shift to higher value-added sectors. However, given the low infrastructure stock and the role of urbanization in driving growth, the physical output of these sectors is likely to closely track industrial value addition at least for the coming decade.

India's large-scale industrial sectors are understood to be close to the world's best available technology. For this reason, we assume that most of the incremental energy-savings potential is in the MSME sectors, which are not amenable to end-use modelling. Rather, scenario-based assumptions regarding the rate of improvement achievable in these sectors are used, based on TERI's experience with the MSME energy-savings projects.

Results

The results are presented in Table 22. The end-use results match the econometric results fairly closely, which is not surprising given that such a large share of the industrial sector must be modelled as a residual, using the same econometric approach. Nonetheless, the results give us confidence that there would be a significant demand, in the order of 300–400 TWh, from sectors which have historically been dominated by captive power. We find a moderate efficiency potential in the order of 28–35 TWh in the sector, due to the fact that the major sectors are already close to the best available global technology, and smaller end uses such as industrial motors are also close to the world standard. For example, Abhyankar et al. (2017) find savings in the order of 20 TWh in industrial motors in an aggressive policy scenario.

Table 21: Physical output of major electricity-consuming goods

Macro-scenario		Primary Aluminium Production (1000 Tons)	Crude Steel Production (1000 Tons)	Hydraulic Cement Production (1000 Tons)	Production of Petroleum Products (1000 Tons)
	2355	89026	300000	231866	
6.80%		5756	249864	804006	639620
7.50%	2030	6679	289938	932955	742204
8.00%		7343	318775	1025746	816023

Source: Historical data from World Steel Association (2018), USGS (various years), and PPAC (2018)

Table 22: Industry sector electricity demand in 2030 according to different methodologies and efficient assumptions

	Modelling Approach	Efficiency Scenario	Electro-Intensive, End-Use Modelled Sectors (TWh)	Other Sectors (TWH)	Total Industry (TWh)
6.50%	End Use	Moderate	318	821	1140
	End Use	High	302	809	1112
	Econometric	n.a.	n.a.	n.a.	1154
7.50%	End Use	Moderate	369	951	1321
	End Use	High	351	937	1288
	Econometric	n.a.	n.a.	n.a.	1338
8.00%	End Use	Moderate	406	1045	1451
	End Use	High	386	1029	1415
	Econometric	n.a.	n.a.	n.a.	1471

Source: TERI analysis and modelling

Conclusions to This Section

Overall, a number of conclusions can be drawn from the preceding analysis:

- Firstly, the end-use modelling has provided validation for the econometric modelling, with results being reasonably comparable.
- Secondly, the exception here is the agricultural sector, where a number of questions can be raised about the quality of agricultural electricity demand data. It seems probable that this uncertainty would bias the future trajectory of the agricultural sector to the downside.
- The end-use analysis for the residential and commercial sectors has tended to produce higher results than the econometric methodology, potentially reflecting the increasing elasticity of electricity demand as incomes increase. The balance of evidence suggests that projections in these sectors are biased to the upside.
- In total, we find a demand savings potential in the order of 170–230 TWh by 2030, which is comparable to other estimates in the literature. The largest sectors for these savings are the residential and agricultural sectors, which is again consistent with what one sees in the literature on electricity-saving potentials (Abhyankar, et al., 2017).

Transport

In this section we model scenarios for future electricity demand from the transport sector, consisting of both railway traction and the electrification of freight and passenger road transport. The latter has been the subject of much discussion and debate, with significantly different projections being found in the literature. Given the emergent nature of the transport-sector transition, and its dependence on the policy-driven development of infrastructure and commercial innovation of new business models, it is difficult to conduct any projections on an econometric or strictly empirical basis. Rather, a scenario-based analysis is appropriate, providing a range of estimates for potential outcomes and clearly showing the influence of different variables on the projections.

Electrification of Road Transport

Scenario Framework and Assumptions

The macroeconomic scenario framework remains the same as in the preceding sections, with three different macroeconomic scenarios being considered, with GVA growth at 6.80%, 7.50%, and 8.0%, respectively. These different scenarios drive the growth of passenger kilometres (PKM) and ton kilometres (TKM) in the passenger- and freight-transport segments respectively.

Higher growth scenarios are associated with faster growth of PKM and TKM. The macro-scenarios also drive the growth of the vehicle fleet in the various segments of passenger and freight transport. To 2030, we do not assume any major disruptions in vehicle ownership or usage patterns through the evolution of trends like shared mobility or dematerialization: doing so would require another report.

We make different assumptions for the share of electric vehicles in new sales by 2030, in the different segments of passenger and road transport. Several principles determine these assumptions. Firstly, we assume that penetration rates of EVs would be higher in high-growth scenarios, as higher incomes would be more amenable to overcoming the higher upfront cost of EVs, and higher investment rates would imply a faster growth of new capital stock and, generally speaking, faster rates of innovation. Notably, in the high-growth scenario, we assume a quite transformational level of EV penetration. **While it can be questioned as to whether the conditions are in place for the realization of such a transformation, it is nonetheless instructive to explore such a scenario.**

Secondly, we assume that smaller-scale segments of the passenger- and freight-transport sectors would have higher penetrations of EVs. This is because smaller vehicles require smaller batteries and tend to cover fewer kilometres, all other things being equal. This lower battery size lowers the upfront incremental cost of the vehicle versus a comparable internal-combustion-engine vehicle. Since India is a highly cost-sensitive environment, with budgeting constraints and higher discount rates, upfront costs will be a crucial determinant. Moreover, smaller vehicles may require less bespoke charging infrastructure development than larger vehicles, which is always an important consideration in a country where the public provision of infrastructure is still a concern. Likewise, we assume that only the light-duty freight vehicle (LDCV) segment would be amenable to electrification.

Thirdly, we assume that shared segments of the mobility sector (buses, taxis, and three-wheelers) would be more amenable to electrification than the private segments (private four-wheelers). Shared segments tend to have higher utilization rates, allowing incremental capital costs to be paid off faster against higher annual fuel savings. They may also face lower budget constraints, have greater access to capital, and lower discount rates. It may also be easier to address the charging infrastructure challenge for shared segments than for the private sector, although this hypothesis requires a deeper analysis based on India's urban environments.

Table 23 displays the key assumptions for the different scenarios. It should be noted that when referring to the share of EVs in sales in the various segments, we mean the share of EVs in new sales in that year, not the share of EVs in the vehicle stock in that year.

Results

The results are presented in Table 24. The total electricity demand from the road-transport sector is between 41 and 118 TWh in 2030, in the different scenarios. The largest segments for demand are the bus and LDCV segments. This is due to the assumption that such segments would show a comparable or higher penetration of EVs compared to segments such as the four-wheelers. In addition, the bus and LDCV vehicle segments have a higher electro-intensity per km and higher utilization rates (km/year), compared to the four-wheeler segment. The combination of these factors explains the higher electricity demand coming from the bus and LDCV segments, compared to the four-wheeler segment.

Overall, the results give the sense that the electrification of road transport seems unlikely, according to the scenario assumptions that we have taken here, to be a game changer in terms of the aggregate electricity demand on the 2030 time horizon. On the other hand, the charging profile and role of vehicle-to-grid (V2G) interactions may play an important role in terms of grid stabilization and renewables integration. That is a topic for another report.

Rail-Transport Demand

Approach and Results

The rail-traction segment is modelled econometrically,

Table 23: Scenario assumptions for transport electrification

Macro-scenario	Year	Item	Unit	Value
	2015	Road Passenger Kilometres	Billion PKM	7771
		Freight Ton Kilometres	Billion TKM	1330
6.80%	2030	Road Passenger Kilometres	Billion PKM	20597
		Freight Ton Kilometres	Billion TKM	3814
		Share of EVs in Four-Wheeler Sales	%	5%
		Share of EVs in Two- and Three-Wheeler Sales	%	20%
		Share of EVs in Bus Sales	%	10%
		Share of EVs in Light Duty Freight Vehicles	%	5%
7.50%	2030	Road Passenger Kilometres	Billion PKM	22794
		Freight Ton Kilometres	Billion TKM	4447
		Share of EVs in Four-Wheeler Sales	%	10%
		Share of EVs in Two- and Three-Wheeler Sales	%	25%
		Share of EVs in Bus Sales	%	15%
		Share of EVs in Light Duty Freight Vehicles	%	10%
8.00%	2030	Road Passenger Kilometres	Billion PKM	24481
		Freight Ton Kilometres	Billion TKM	4903
		Share of EVs in Four-Wheeler Sales	%	20%
		Share of EVs in Two- and Three-Wheeler Sales	%	45%
		Share of EVs in Bus Sales	%	40%
		Share of EVs in Light Duty Freight Vehicles	%	40%

Source: TERI

based on regressions on the total GVA. The results are presented in Table 25. As can be seen, the projections cluster around 40–46 TWh. Thus, the railway-traction demand is still relatively small compared to the aggregate electricity demand and uncertainties are pretty tightly constrained.

Conclusion: Recommendations for Policymakers and Scenario Synthesis

Recommendations for Policymakers

The preceding analysis and projections lead to a number of conclusions and recommendations that can be considered by policymakers engaged in different aspects of electricity system planning, regulation, and policy. These insights are both of a quantitative and qualitative nature, and apply both to the practice of electricity demand forecasting, as well as its use in policy determination and evaluation.

Qualitative Insights into Future Electricity Demand

- Unsurprisingly for a fast-growing, industrializing, and urbanizing economy, by far the largest source of uncertainty for future electricity demand is related to India's macroeconomic scenario. The rate and sectoral structure of economic growth are found to have significant impacts on the projected levels of electricity demand. The industrial electricity demand is determined to a significant degree by the share of industry in the future GDP. Pent-up demand for

Table 24: Road transport electricity demand in 2030 (GWh)

Macro-scenario	Item	Value (GWH)
6.80%	Four-Wheeler EV Demand	7626
	Two- and Three-Wheeler EV Demand	11152
	Bus EV Demand	12630
	LDCV EV Demand	9726
	Total Road Transport Demand	41134
7.50%	Four-Wheeler EV Demand	17166
	Two- and Three-Wheeler EV Demand	15704
	Bus EV Demand	21360
	LDCV EV Demand	23243
	Total Road Transport Demand	77474
8.00%	Four-Wheeler EV Demand	37290
	Two- and Three-Wheeler EV Demand	30697
	Bus EV Demand	61929
	LDCV EV Demand	103932
	Total Road Transport Demand	233848

Source: TERI

Table 25: Railway-traction demand in 2030

Macro-scenario		Transport Traction Demand (GWh)
	2015	16594
6.80%	2030	39785
7.50%		43270
8.00%		45947

materials related to urbanization, such as steel and cement, suggests that there is scope for continued growth of captive power, to the extent that these sectors depend on captive power today and the reliability and cost-effectiveness of grid power does not improve for industrial sectors.

- A cross-country comparison and insights from end-use modelling suggest that there is uncertainty on the upside for future forecasts for residential and commercial electricity demand. In the next 10–15 years, India will pass through levels of income within which other countries have seen an upswing in the electrical intensity of these sectors. This is likely to occur in India as well, as the relative inflation-adjusted prices of major electricity-consuming goods continue to fall and electricity increases its importance for the modern economy.
- The analysis suggests that projections are biased to the downside for agricultural electricity demand. There is considerable uncertainty in agricultural demand statistics, and it appears highly unlikely that these are robust. If losses are being 'hidden' as agricultural demand, then a future scenario of reduced losses would imply significant future savings against a scenario of artificially inflated growing agricultural demand.
- Uncertainties in the transport sector electricity demand from road-transport electrification are likely to be limited on the time frame of 2030. Even scenarios with substantially different assumptions on PKM, TKM, and EV penetration in all segments do not show significant electricity demand, in the context of total demand, coming from electrified road transport.

Policy Recommendations for Forecasting and Data Management

- The preceding analysis has shown that there is considerable uncertainty coming from the macroeconomic scenario of the country (in the order of 25% by 2030 between a moderate- and high-growth scenario). India's planning and forecasting framework, notably the periodic Electric Power Surveys, should evolve into a framework that includes different assumptions about the macroeconomic scenario, at the very least. Forecasts are only useful as 'if-then statements'. Omitting the 'if' part of the forecast, that is, an explicit, scenario-based representation of its drivers, renders the forecast much less useful for policymakers and planners at all levels.

- Data quality matters to the reliability of forecasts. This is seen most clearly in the agricultural sector, but other sectors face similar issues, for example, the huge share of 'unspecified demand' in the industrial sector. Data quality issues can be divided into several different areas, such as improving the quality of electricity statistics themselves, notably at the state level; better integration between economic and electricity-sector statistics; and progressive development of sectoral sample surveys to improve the available end-use data.
- Data and forecast quality are not purely academic concerns: The current demand-and-supply imbalance in the electricity sector, giving rise to the situation of non-performing assets, shows the real financial and economic consequences of forecast errors, and more importantly, errors in the use of forecasts in commercial decisions and policy planning. Investing in improving forecast frameworks, capacities, and data, and the use of forecasts in policymaking and investments will have positive returns.

Scenario Synthesis

In this section, we provide a series of tables which present a final synthesis of the preceding analysis and a set of coherent scenarios for electricity demand to 2030. The principles for deriving these tables are as follows:

- Scenarios: The three tables represent GVA growth of 6.80%, 7.50%, and 8.00% per year to 2030. For each, a high- and low-efficiency variation is presented, based on the end-use modelling conducted earlier. Due to space constraints, only the total grid demand is presented. Likewise, sectoral demand is presented only in high-efficiency variation (high ef), whereas only the total grid electricity demand is presented under the BAU efficiency variation (BAU ef).
- Agriculture: For the agricultural sector we assume that the projections are biased to the downside, for the reasons discussed earlier. If the current level of agricultural demand hides significant losses, this assumption of a downward bias in future projections would be consistent with these losses being controlled.
- Service sector and residential sector: We assume that for these sectors, projections are biased to the upside, based on the evidence of the end-use modelling and the cross-country historical experience. Thus, we follow the end-use projections for these sectors in deriving our synthesis.
- Industrial sector: In the industrial sector we don't find evidence of a structural bias to the upside or the downside. We, thus, use the econometric projections, but integrate the estimated electricity savings from the end-use modelling in the high-efficiency variant.

Table 26: 6.80% GVA growth scenario, results

	BAU EF	HIGH EF	HIGH EF	HIGH EF	HIGH EF	HIGH EF	HIGH EF
	Total Grid Demand	Total Grid Demand	Of Which Agriculture	Of Which Industry	Of Which Residential and Commercial	Of Which Road Transport	Of Which Rail
Year	TWh	TWh	TWh	TWh	TWh	TWh	TWh
2001	322	322	82	107	125	0	8
2015	863	863	173	286	388	0	17
2021	1280	1229	192	408	602	4	24
2027	1895	1726	210	595	865	23	33
2030	2307	2040	217	723	1019	41	40

Table 27: 7.50% GVA growth scenario, results

	BAU EF	HIGH EF	HIGH EF	HIGH EF	HIGH EF	HIGH EF	HIGH EF
	Total Grid Demand	Total Grid Demand	Of Which Agriculture	Of Which Industry	Of Which Residential and Commercial	Of Which Road Transport	Of Which Rail
Year	TWh	TWh	TWh	TWh	TWh	TWh	TWh
2001	322	322	82	107	125	0	8
2015	863	863	173	286	388	0	17
2021	1330	1265	198	430	612	6	24
2027	2046	1859	225	672	926	42	35
2030	2533	2254	238	838	1135	77	43

Table 28: 8.00% GVA growth scenario, results

	BAU EF	HIGH EF	HIGH EF	HIGH EF	HIGH EF	HIGH EF	HIGH EF
	Total Grid Demand	Total Grid Demand	Of Which Agriculture	Of Which Industry	Of Which Residential and Commercial	Of Which Road Transport	Of Which Rail
Year	TWh	TWh	TWh	TWh	TWh	TWh	TWh
2001	322	322	82	107	125	0	8
2015	863	863	173	286	388	0	17
2021	1387	1319	203	446	628	10	25
2027	2303	2108	237	725	983	126	37
2030	2973	2680	254	922	1225	234	46

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