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Electricity demand in South Asia – data gaps and pathways for research and modeling

Nihan Karali, Nikit Abhyankar, Shruti Deorah

Abstract

South Asia is one of the fastest growing regions - economically and energy-wise in the world. However, there are significant uncertainties in how the energy demand would grow given the rapidly rising incomes, urbanization, industrialization, access to energy, warming climate and technological change. The transition to clean energy in the region is a priority and is critical to limiting emissions in the region and increasing regional energy security. The power sector will play an important role in decarbonization of energy systems, lowering emissions in other sectors through electrification. However, as existing end uses are scaled up more and new end uses are electrified, the temporal and spatial patterns of electricity consumption could change. These changes have implications for the magnitude, shape, and timing of peak demand, which in turn affects the power sector's investments and operations, and ability to provide reliable power.

In this report, we outline key uncertainties in demand growth that South Asian countries would face in the near to medium term, along with summarizing insights from stakeholder consultations we held over the past 6 months.

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1. Introduction

South Asia is a region covering almost a quarter of the world's population, including some of the most densely populated nations such as India, Bangladesh, Sri Lanka, Nepal, and Bhutan. It is also the fastest-growing region in the world with energy demand projected to grow from ~900 MTOE in 2018 (~7% of world's energy demand) to ~1500 MTOE (~12% of world's energy demand) by 2030 and installed electric generation capacity from 400 GW in 2018 to 900 GW by 2030 with a significant capacity addition from renewables (SAARC, 2019; IEA, 2020). In terms of energy supply, the countries in the region are primarily dependent on fossil fuels, and greenhouse gasses (GHGs) generated through energy production represent 63% of regional emissions (World Bank, 2021). The transition to clean energy in the region is a priority and is critical to limiting emissions in the region and increasing regional energy security. With this goal in mind, multiple stakeholders in South Asia—including national governments, municipalities, states, and non-governmental corporations —are setting ambitious clean energy targets. India's power sector is on the cusp of transitioning from a system predominantly powered by thermal, nuclear, and hydro sources, to a grid with increasing penetration of renewable energy from sources such as solar and wind. India currently has about 95 GW of renewables-based capacity and is striving for 175 GW of installed renewable capacity by 2022 (Kahrl et al., 2021). Furthermore, Prime Minister Modi has announced an ambitious goal of 500 GW of non-fossil fuel capacity by 2030 (Kahrl et al., 2021). Similarly, Bangladesh and Sri Lanka have 40% and 70% renewable energy targets by 2041 and 2030, respectively. However, this transition will need to occur as demand for energy in emerging economies of South Asia escalates.

The power sector will play an important role in decarbonization of energy systems, lowering emissions in other sectors through direct electrification (for example transport and industry) and electricity-derived fuels such as green hydrogen (Abhyankar et al., 2021; Barron et al., 2018; Davis et al 2018; EPRI 2018).[1] However, as existing end uses are scaled up more and new end uses are electrified, the temporal and spatial patterns of electricity consumption may change. For example, the Indian government has announced $2.5 billion of subsidies in its most recent scheme on electric vehicles (EVs), with a focus on public buses, two and three wheelers. Space cooling demand is anticipated to increase significantly in the coming decades, as average temperatures in the region keep rising and affordable air conditioning systems become more available (IEA, 2018; Abhyankar et al., 2017a). Similarly, energy demand for accessing irrigation water is expected to increase due to climate change impacts, i.e., higher temperatures, prolonged droughts, and depleting water tables. Industrial electrification and green hydrogen use in the sector are also expected to ramp up in the region over the next couple of decades along with the decarbonization goals and efforts in this sector.

These changes have implications for the magnitude, shape, and timing of peak demand, which in turn affects the electric sector's investments and operations, and ability to provide reliable power. Peak electricity demand determines capacity needs and utilization in the power system and is linked to resource adequacy, reliability, and cost (Stoft 2002; Abhyankar et al, 2017a,b&c). This is particularly important in a decarbonized power system where load profile would determine the amount of storage and other flexible resources needed in the system. The region is also highly vulnerable to extreme weather events such as cyclones, flooding, drought,

[1] Green hydrogen is hydrogen that is generated entirely by renewable energy.

and heat waves which can further stress the electricity generation, transmission, and distribution infrastructures and capacities. Such considerations will become increasingly important as electricity demand surges across South Asia.

Most of the traditional long-term forecasting methods that are commonly used by utilities include institutional top down analysis that relies on historical trends and regression analysis, linking demand growth with economic, demographic, and other variable growths. These methods assume that demand and peak load are likely to be influenced by the same factors that have influenced its growth in the past. They lack technical details and data to proactively assess new loads and assess associated uncertainties. Historical EV loads or space cooling demand are not indicative for future EV loads or cooling demand, respectively. Space cooling systems, which were once a luxury household item to have, have become a necessity for healthy living with uncomfortable temperatures being the new normal. In addition, these methods are not typically able to account for uncertainties that may result from seasonal variations of demand (Colelli and de Cian 2020; Sun et al 2020).

With these challenges in mind, over the past 6 months, we conducted multiple stakeholder discussions and sessions with countries in the South Asia region to discuss and identify the key factors and variables that can drive the electricity demand and peak load in South Asia. The virtual meeting held with the Indian stakeholders on October 25, 2021, was attended by the officials from Niti Aayog, Central Electricity Authority (CEA), Central Electricity Regulatory Commission (CERC), National Institute of Wind Energy, National Institute of Bio Energy, and BSES Rajdhani. The virtual meeting held on November 2, 2021 with stakeholders from Bangladesh, was attended by the officials from the Power Grid Corporation of Bangladesh, Bangladesh Power Development Board, Dhaka Electricity Supply Company, Dhaka Power Distribution Company, USAID Bangladesh, Sustainable and Renewable Energy Development Authority, and Centre for Policy Dialogue. The virtual meeting held on November 30, 2021 for Nepal, was attended by the officials from the Nepal Electricity Authority and Ministry of Energy and Water Resources and Irrigation. In addition, we met with USAID Sri Lanka and Chemonics, who is implementing USAID's energy program in the country and has done extensive consultations with various stakeholders in the country.[2]

The objective of this report is to outline key uncertainties in demand growth that South Asian countries would face in the near to medium term, along with summarizing insights from stakeholder consultations. For this purpose, we first outline South Asia's growing demand and peak load; then discuss the need for new load and demand models to include all of the key additional factors required for more accurate forecasting with inputs from stakeholder discussions. Finally, we conclude the report with an emphasis on the need for systematic exploration of future electricity demand and load growth.

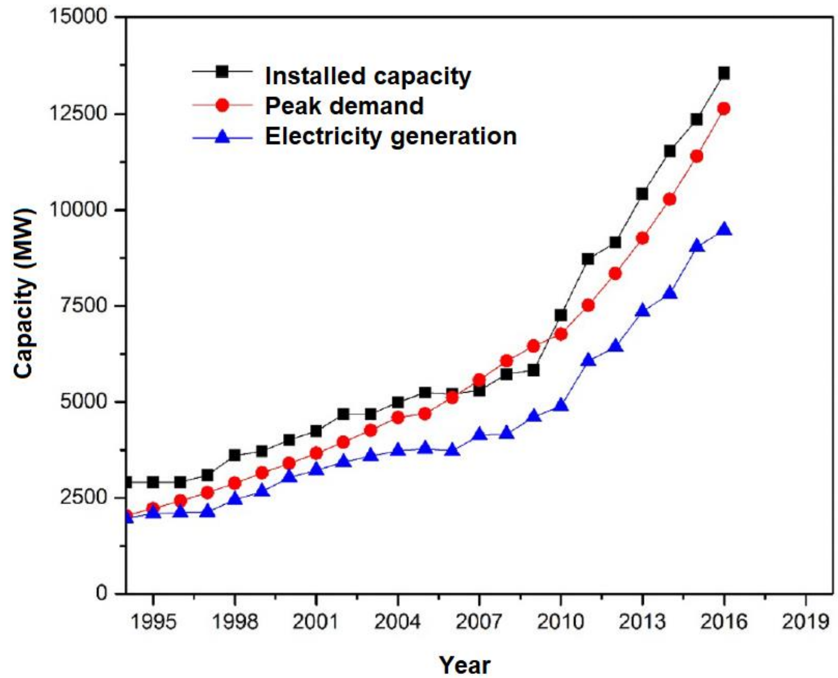
2. Composition of current demand and load

Energy demand and load curves in South Asia changed dramatically with rapid urbanization and industrialization and as access to energy increased and new technologies came into usage and existing ones further penetrated the market over the last decade. For example, Figure 1a summarizes the increasing trend of installed generation capacity, maximum demand, and peak

[2] See https://chemonics.com/region/asia for more details on Chemonics and its work on Asia.

generation of electricity in Bangladesh between 1994 and 2016. As seen, the installed capacity is just over the maximum demand, but the growth rate got steeper within the last decade.

Bangladesh's electricity demand in 2018-19 equaled nearly 62 TWh (Nicholas and Ahmed, 2020). Domestic (i.e., residential) and commercial sectors had just over 60% of the electricity demand, which was followed by the industry sector (~35%) (Figure 1b).



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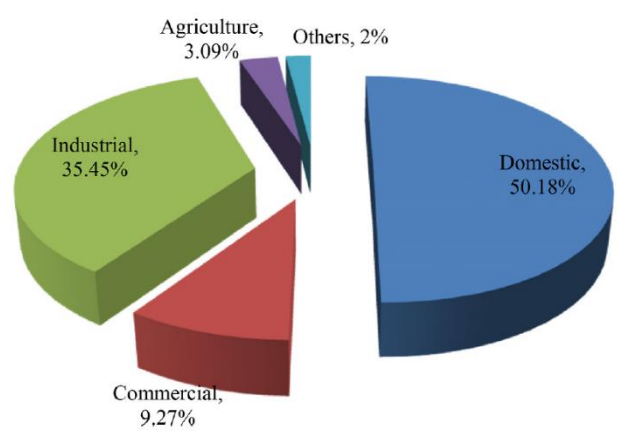

(b)

Figure 1. (a) Evolution of installed capacity, peak, and the share of the installed capacity used for electricity generation in Bangladesh between 1995 and 2018; (b) Sectorwise electric energy consumption for the fiscal year 2016–17.

Source: Das et al. (2020)

Similarly, Figure 2 shows the average hourly load in Delhi between 2010 and 2019. Over the course of the last decade, overall annual electricity demand (average load) increased significantly (in a range of 50-60%); however, as in Bangladesh's case, the evolution of peak demand was much steeper, particularly in the summer months. Also, because of the increasing residential space cooling usage, the peak load in Delhi has shifted from summer afternoons to summer early morning.

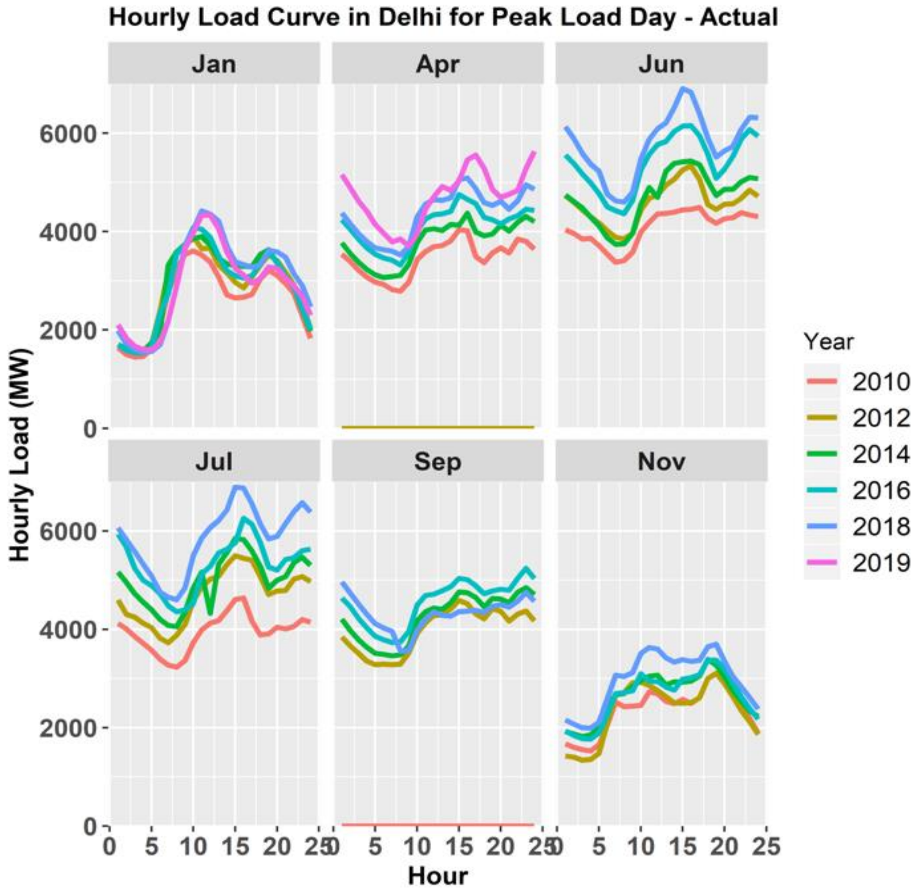

Figure 2. Evolution of hourly load curve in Delhi between 2010 and 2020.

Source: Abhyankar et al. (2021)

Figure 3 shows a previous LBNL analysis presenting the disaggregation of hourly demand at sector-level with an example of the Karnataka state in India in 2019. As seen, the region peaks both in the mornings and evenings. The overall pattern of current load aligns with the aggregated load pattern of the residential sector, driven mostly by electrical appliances, particularly space cooling. The same analysis indicated that cooling demand from all sectors contributed almost 25% of the peak demand in summer and about 15% in winter in 2019 (Figure 4). These results are based on a ~2% penetration rate of mini-split air conditioner (AC) ownership[3]. Similarly, Abhyankar et al. (2017a) analyzed the hourly electricity demand differences between summer and winter in Delhi, which is mostly driven by larger space cooling demand during summer months (Figure 5). In addition, the agriculture sector also has a significant contribution to the energy demand and peak load. In 2019, the agriculture sector

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[3] Mini-split air conditioners allow you to control the temperatures in individual rooms or spaces. These systems have two main components -- an outdoor unit (compressor/condenser) and an indoor unit (evaporator).

contributed 23%-27% of the peak load of the state of Karnataka. The drop-in demand from 6:00 to 22:00 hrs represents the power cut off to this sector to use solar hours and leverage low solar prices. Several other states in India (e.g., Maharashtra, and Gujarat) have also shifted a major part of the agricultural load to solar hours (over 6 GW total in 2020) (Abhyankar et al., 2021). This is possible as many states have separated distribution feeders for agricultural consumers from other feeders.

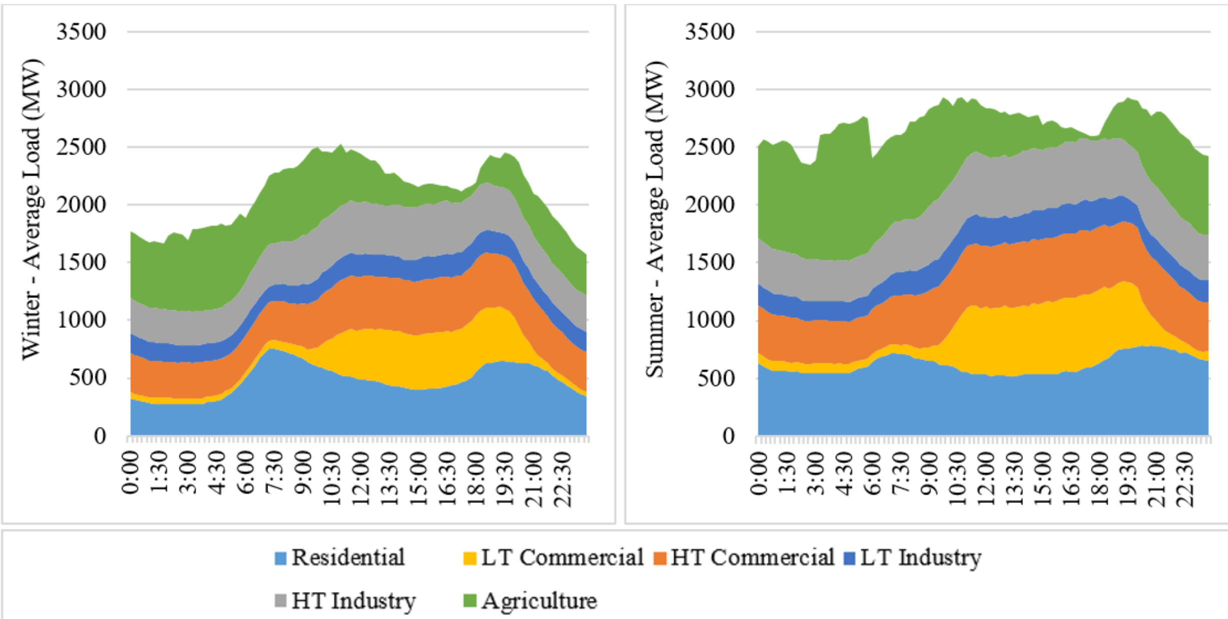


Figure 3. Average seasonal load curves in the state of Karnataka in India.

Note: Please note that January is the representative month for winter month and April is the representative month for summer in this study. Source: Karali et al. (2020)

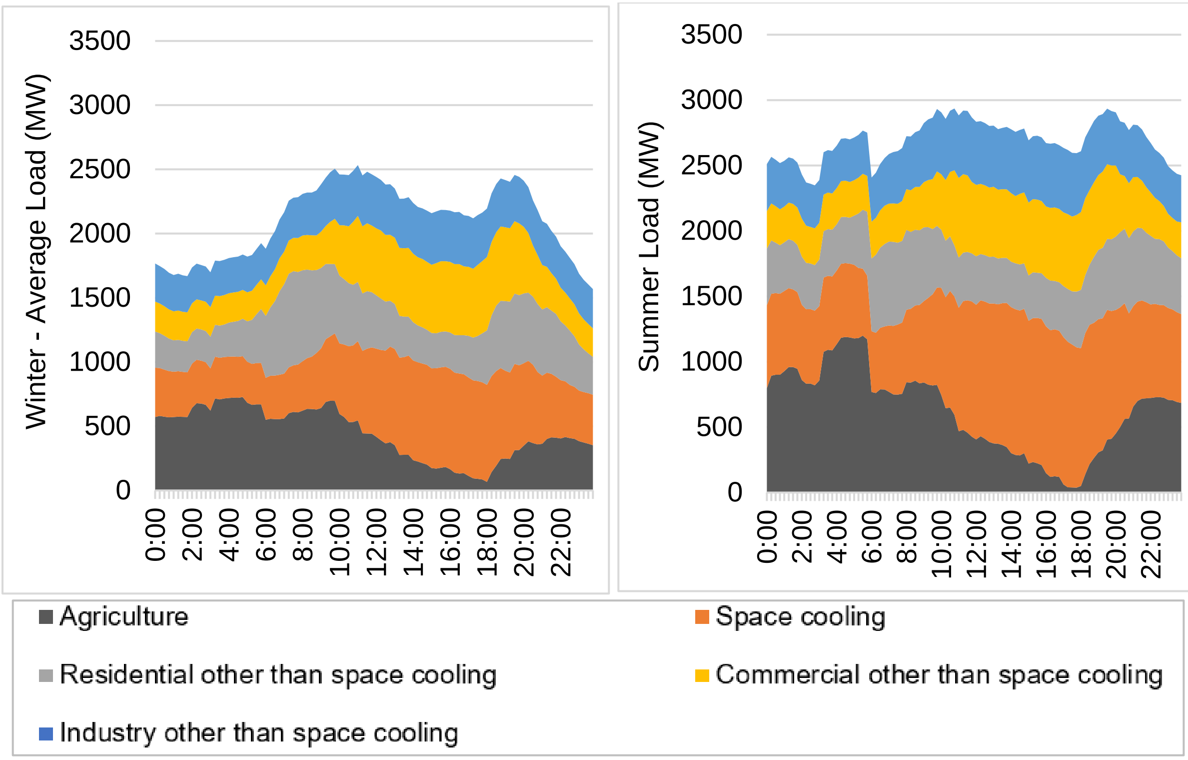


Figure 4. Share of agriculture and space cooling on average winter and summer loads in the state of Karnataka, compared to other residential, commercial and industrial loads.

Source: Karali et al. (2020)

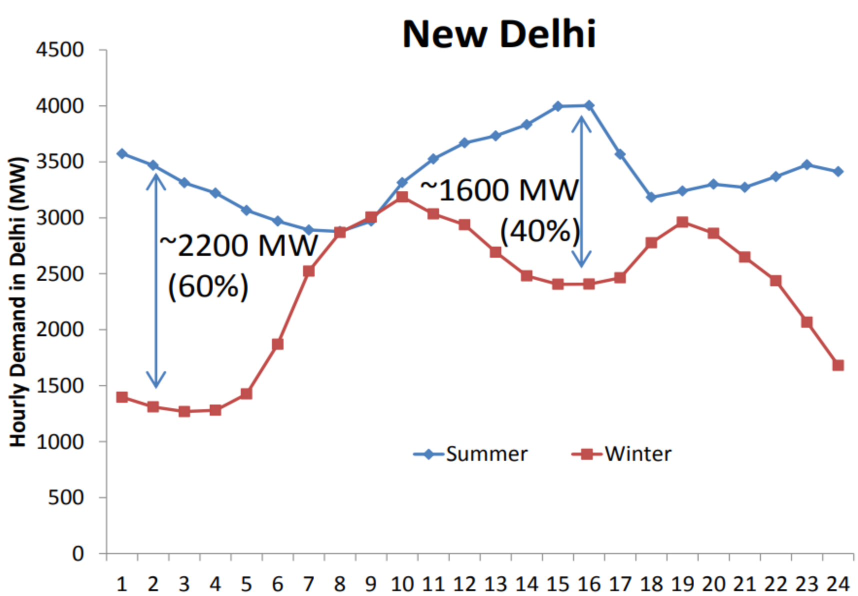


Figure 5. Load Curves on a Summer and Winter Day (Average) in New Delhi.

Source: Abhyankar et al. (2017a)

3. Implication of new and additional loads on the grid

The region's need for power is expected to grow substantially over the coming decades (Abhyankar et al., 2021; Ichord, 2020). For instance, India's peak load is expected to grow from 180 GW in 2020 to 340 GW in 2030, while the total energy demand (bus-bar) increases from 1,357 TWh to 2,363 TWh per year over the same period (CEA, 2017). Similarly, net electricity demand of Bangladesh by 2041 has been forecasted to grow to 61 GW to achieve their development goals (Ichord, 2020).

None of these projections consider the potential impact of electrification of new end-uses such as electric vehicles (including not just passenger vehicles but buses, medium and heavy duty vehicles, and rail) and industrial electrification strategies and increased penetration of existing end-uses with the impact of climate change such as increased space cooling and irrigation needs. As discussed earlier, increased adoption of these electrified technologies can lead to a substantial growth in electricity demand by midcentury, a growth doubling or tripling the current projections. In this section, we discuss the potential implication of some key end-uses (coupled with climate change impacts) on the growing demand.

Space cooling:

ACs unit energy consumption is significantly higher than any other electrical household appliances (Abhyankar et al., 2017b). People respond to uncomfortably hot climate conditions by adopting cooling devices that contribute to maintaining thermal comfort at home, and warmer temperatures might lead people to allocate more time to indoor activities. According to Randazzo et al. (2020), households on average spend 35%–42% more on electricity when they adopt air conditioning. These results are based on the analysis of conditions in eight temperate, industrialized countries (Australia, Canada, France, Japan, the Netherlands, Spain, Sweden, and Switzerland). Therefore, in a changing climate, space cooling becomes an energy service of growing significance in two key respects. Cooling demand typically jumps during a heatwave, placing greater demands on the power system, the reliability of which can be further undermined by hot equipment increasing the risk of outages. In some places, such as the United States, space cooling can represent more than 70% of peak residential electricity demand during extremely hot days (IEA, 2018).

South Asia is home to some of the hottest and the most humid countries around the world (Figure 6). Despite already having high cooling needs, relatively small proportions of the large and growing populations in the region currently own ACs. For example, in 2016 and 2018 AC household penetrations were only 5% in India and 10% in Sri Lanka, respectively (Abhyankar et al., 2017a; RM, 2018). It is expected that cooling demand would grow significantly over the coming decades with increasing temperatures and as affordable ACs and access to electricity rise.

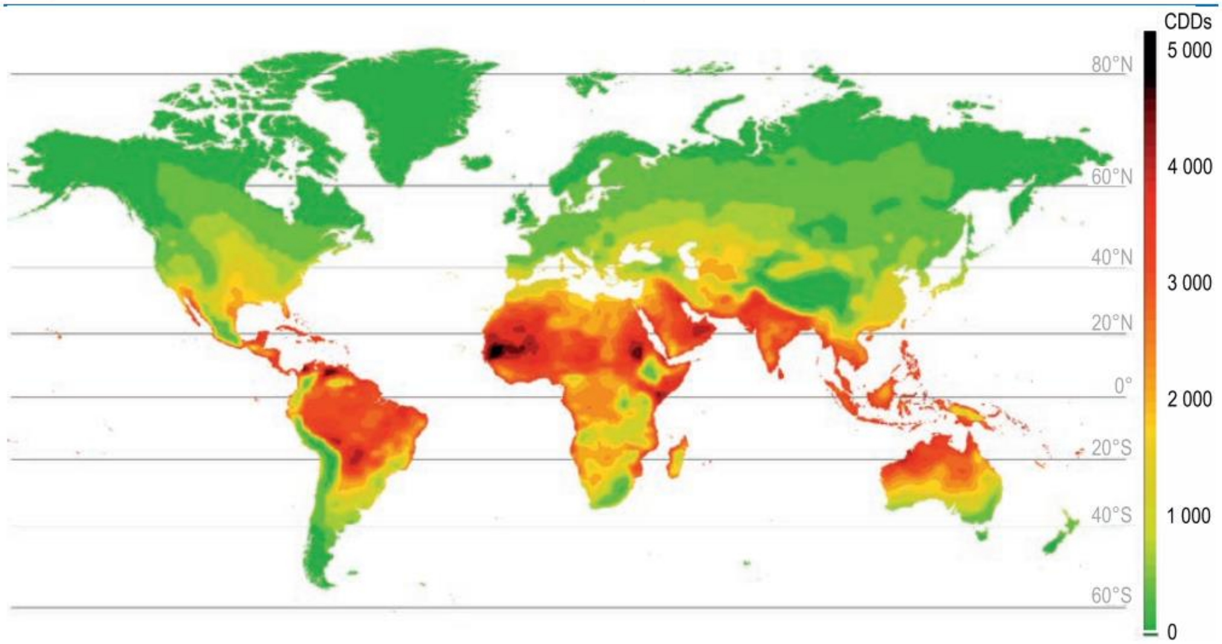


Figure 6. Increase in cooling degree days (CDDs) across the world, 2016-50.

Source: IEA (2018)

For example, many assessments of future electricity demand in India already project large increases in electricity consumption from adoption of air conditioning technologies in the buildings sector over the next two decades (Abhyankar et al., 2017a; IEA, 2018; Barbar et al., 2021). Figure 7 shows the magnitude of projected growth of AC penetration in India compared to other major economies. According to IEA (2018), India's demand for cooling equipment could grow to more than 15-fold by 2050, a rate surpassing any other economy, and the share of space cooling in peak electricity load could jump from just 10% today to 45% in 2050, a share more than any other economy (Figure 7 and 8). Similarly, Abhyankar et al. (2017a) project that air conditioning systems are on track to contribute 140 gigawatts (GW) (~30%) to peak demand in 2030 in large Indian cities such as Delhi. Other South Asian countries are expected to follow similar trends.

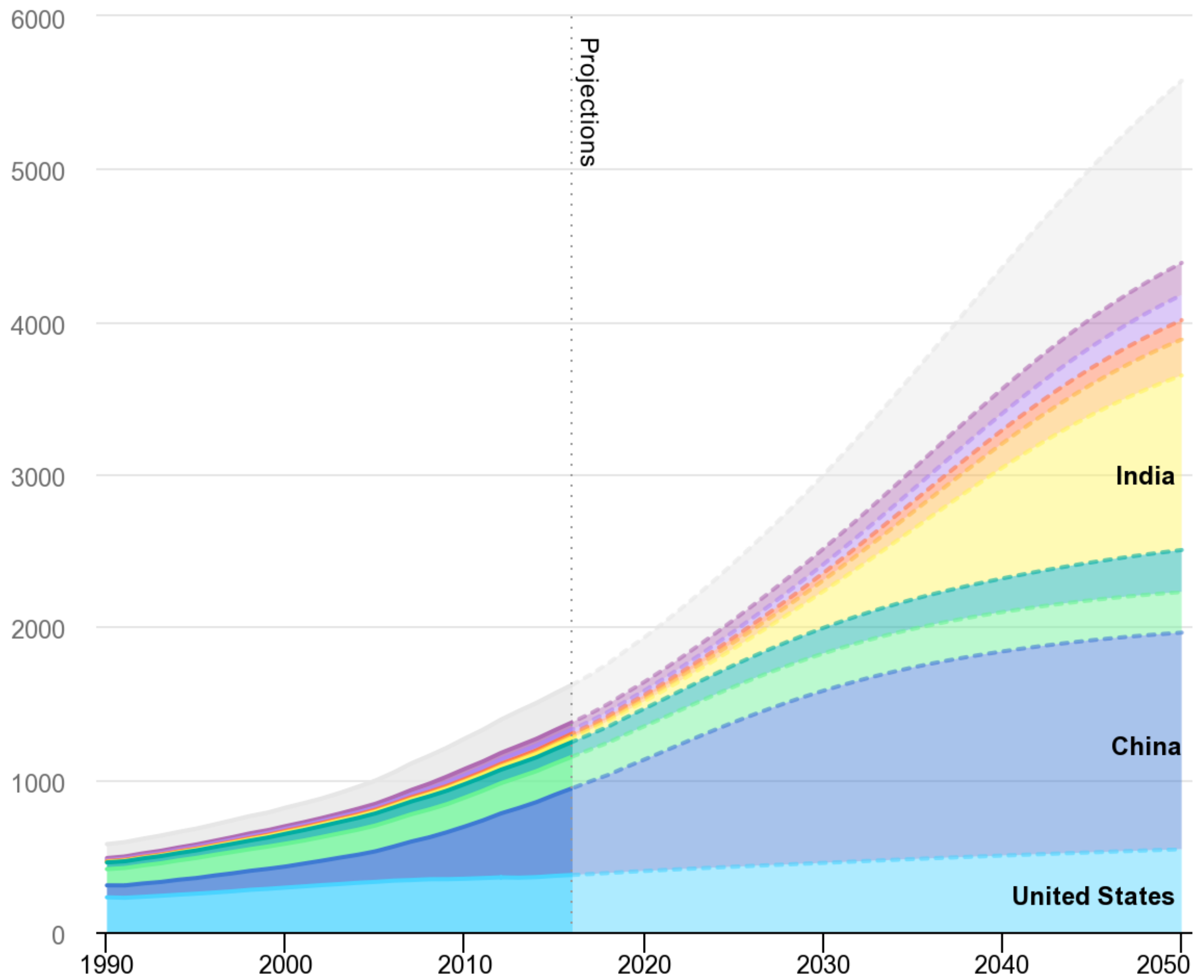
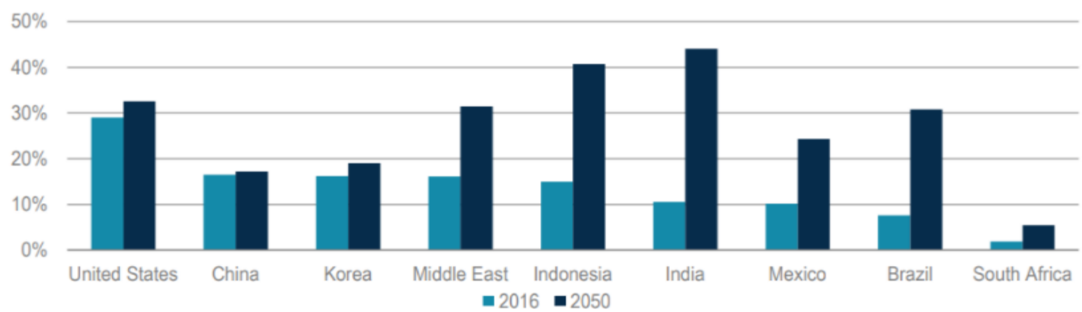


Figure 7. Global air conditioner stock (in million units), 1990-2050.

Source: IEA (2018)



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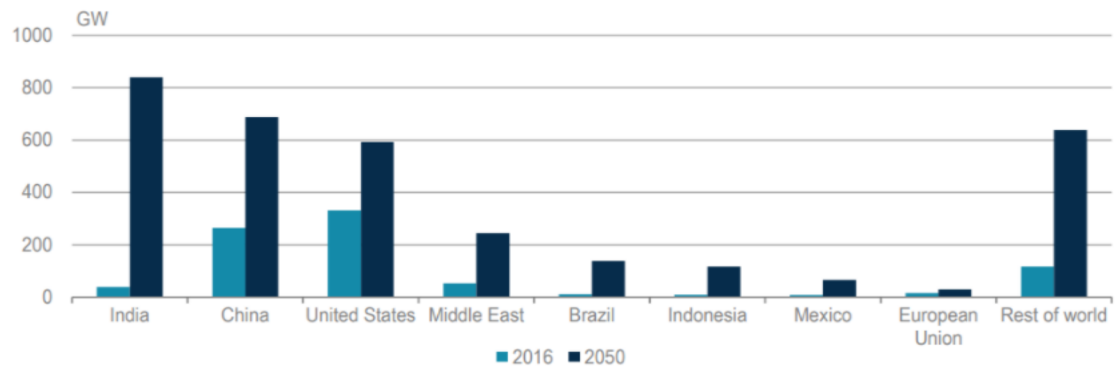

(b)

Figure 8. (a) Share of space cooling in peak electricity load by country/region; (b) Power generation capacity required for cooling by country/region.

Source: IEA (2018)

<u>Electric vehicles:</u>

Large-scale deployment of EVs is another factor that is expected to significantly impact the power system in South Asia as EVs become increasingly cost- and range-competitive with traditional passenger vehicle technologies. See Figure 9 for decreasing battery prices within the last decade. Battery prices have decreased about 80% compared with a decade ago and are expected to decrease more due to intense competition and improved processes to reduce production costs.

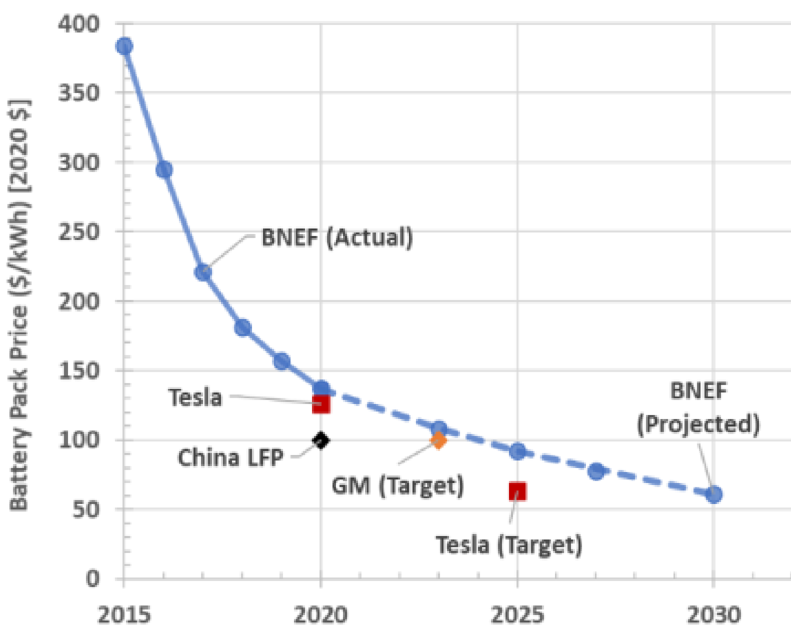

Figure 9. Global average battery pack price over years.

Source: Abhyankar et al. (2021)

India has already laid out ambitious vehicle electrification plans in the National Electric Mobility Mission Plan (NEMMP) 2020, and Phase II of the Faster Adoption and Manufacturing of Electric

Vehicles (FAME) scheme.[4] Recently, India's Minister for Road Transport Nitin Gadkari announced that India is aiming to have 80% of 2W/3W sales, 70% of commercial vehicle sales and 30% of passenger vehicle sales to be electric by 2030. However, these targets are yet to be notified as official Government of India (GoI) policy.[5] Bangladesh is drafting an auto industry policy with a target of >15% of vehicles to be powered by environmentally friendly electricity in 2030.[6] Nepal has EV adoption targets of 25% and 90% of all private vehicles by 2025 and 2030, respectively and Sri Lanka plans to ban private fossil fuel vehicles by 2040.[7]

Some of the transportation electrification plans also include medium- and heavy-duty vehicles, buses, and rails. Transit buses are already beginning to electrify in India, and some estimates show nearly full adoption of electric buses by 2050 (Khandekar et al., 2018). Some studies discussed impact from electrification in these sectors (Khandekar et al., 2018). An LBNL study focused on the electrification of Indian heavy-duty trucks shows that total cost of ownership (TCO) for electric trucks is less than diesel counterparts in India for the over 12-ton category . This study discussed that electric trucks have much better motor-to-wheels efficiency which results in significant fuel savings over long distances, common in medium and long-haul trucking. The same study concluded that payback is within 2.5-3 years for the over 12-ton category.

Soon, the anticipated growth in EVs will have a significant impact on utility peak demand in the long run. For example, BNEF projects that passenger EV sales will be over 30% of the total vehicle sales by 2030, absent any additional policy support. LBNL shows that the given the dropping battery costs, with the right policy framework, passenger EV sales could reach 100% of total vehicle sales and electric truck sales could reach 80% of total truck sales by 2030 (LBNL's study on deep decarbonization of the Indian economy, forthcoming publication). Such aggressive EV sales penetrations would also be critical for achieving the rapid GHG emission reductions and achieving air quality benefits. The results show that the additional electricity demand from all electric vehicles could reach 209 TWh by 2030 (8% of the native electricity demand) and 1,190 TWh by 2050 (15% of the total native electricity demand) (Figure 11).

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[4] See https://heavyindustries.gov.in/writereaddata/Content/NEMMP2020.pdf for details of National Electric Mobility Mission Plan (NEMMP) 2020 - Department of Heavy Industry (DHI) and https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1778962 for details of Phase II of the Faster Adoption and Manufacturing of Electric Vehicles (FAME) scheme.

[5] See https://auto.hindustantimes.com/auto/news/govt-plans-30-ev-sales-penetration-for-private-cars-by-2030-nitin-gadkari-41633688941964.html for details.

[6] See https://moind.gov.bd/sites/default/files/files/moind.portal.gov.bd/notices/d17e0566_13cb_486d_b77e_2d4063d09426/Automobile%20Industry%20Development%20Policy,%202020%20Draft.pdf for details of Automobile Industry Development Policy, 2020 (Draft).

[7] See https://www.mofe.gov.np/downloadfile/E-mobility%20Assmnt%20NDC%202020_1623998131.pdf for details of Assessment of Electric Mobility Targets for Nepal's 2020 Nationally Determined Contributions (NDC) (March 2021) and https://www.straitstimes.com/asia/south-asia/sri-lanka-to-scrap-state-owned-fossil-fuel-vehicles-by-2025 for details of Sri Lanka's electric vehicle plans.

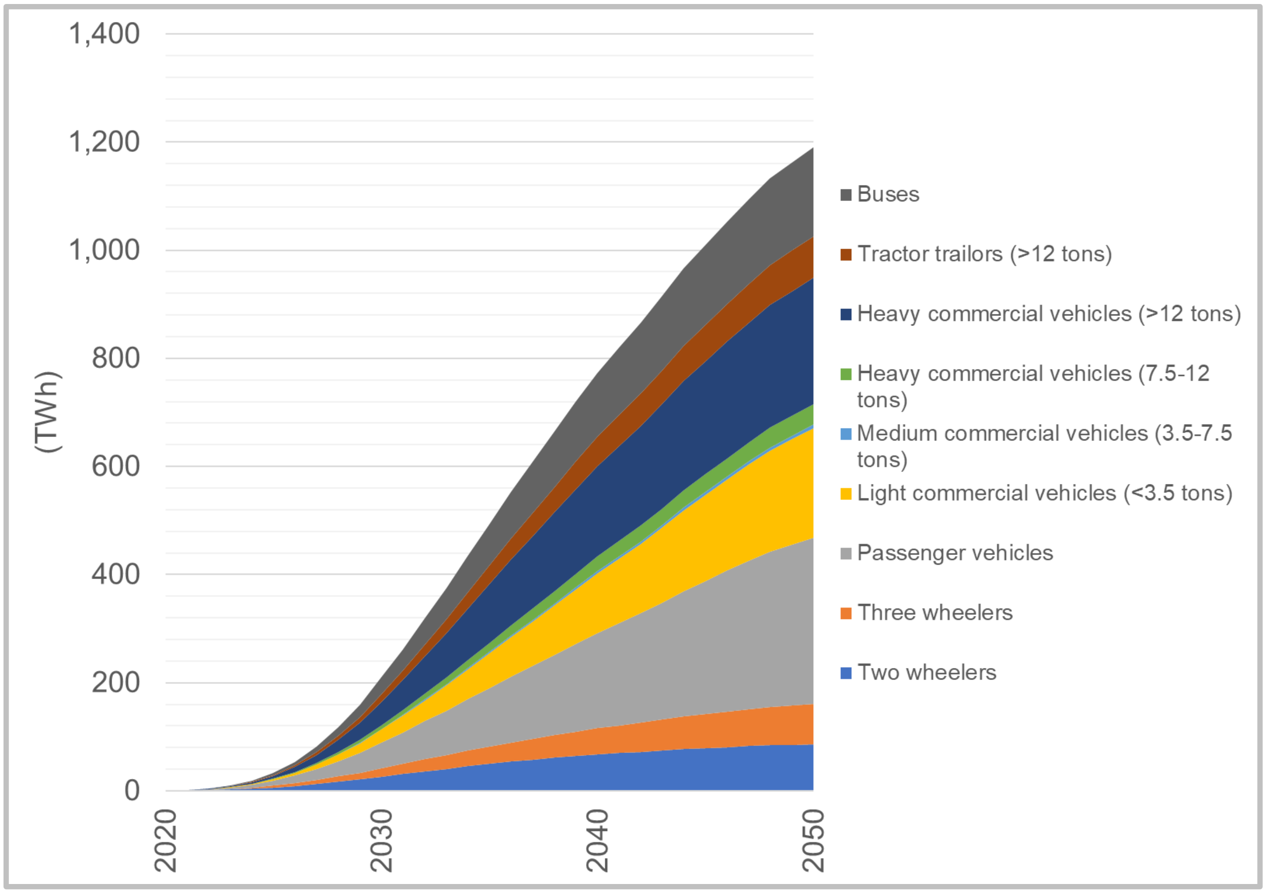

Figure 10. Electricity demand of transport sector electrification for a near zero emissions by 2050 scenario

Source: LBNL's study on deep decarbonization of the Indian economy (forthcoming publication)

Earlier studies show that a poorly managed EV charging, particularly on the fleet level for commercial vehicles, could boost the demand to coincide with the typical system-level peak period, which adds load when the system is most stressed and could result in overloading of distribution and transmission networks (Borlaug et al., 2021). However, charging loads can be flexible and shifted through managed charging to hours of the day where the demand is the lowest and RE generation is at its peak (see Figure 12 as an example). Smart and managed EV charging can be a useful means to better align and balance a power supply that is increasingly diverse, decentralized, renewable and intermittent with flexible demand. Indeed, recent studies show that with the right charging strategy, electrification of fleets does not require major investments in the electric grid substations (Barbar et al., 2021; Liimatainen, 2021; Mareev et al., 2018; Nykvist and Olsson, 2021).

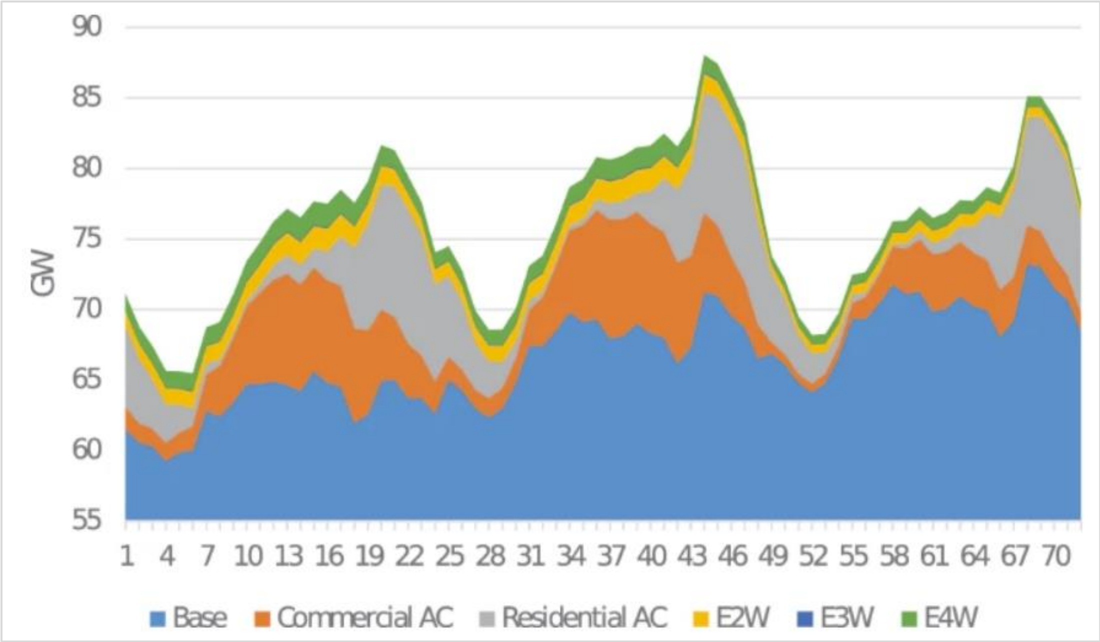

Figure 11. 2030 load profile for southern India across three days in summer.

Source: Barbar et al. (2021)

<u>Industrial load:</u>

Thermal energy, especially for heat, represents two thirds of all energy demand in the industrial sector globally. In India, industrial electricity demand represents about 40% of the total electricity demand (IEA, 2021). Energy for high-temperature heat requirements of heavy industries are one of the major focuses of climate change mitigation efforts. There are significant innovation efforts and opportunities to decarbonize the industrial sector by shifting heat production away from carbon-intensive fossil fuels with the help of electrification and electrolysis based green hydrogen. Therefore, increased use of electricity in industry is likely to happen in the medium to long term along with ambitious climate change targets set out by the South Asia countries. In India, there is already interest in electrification of low-temperature heat in industries such as secondary steel production, petrochemicals and aluminum production, and using electrolysis to produce hydrogen for replacing fossil fuel use in the iron and steel and cement industries and as a feedstock in the petrochemical industry {Ask Priyanka for reference}. The industrial processes can be redesigned so that they use low-cost intermittent renewable energy to provide the required heat. The heat can also be localized only where needed (Roelofsen et al., 2020). However, the penetration could be slower due to economics and availability of new technologies.

Completely electrifying the industrial sector would require significant new electricity generation, even when electric technologies provide improved energy efficiency. The same LBNL analysis that we refer previously for electric vehicles load projects that the additional electricity demand from the industry sector due to greater electrification and green hydrogen production could reach about 745 TWh by 2050, respectively, under the near zero emission scenario (Figure 13) (LBNL's study on deep decarbonization of the Indian economy, forthcoming publication).

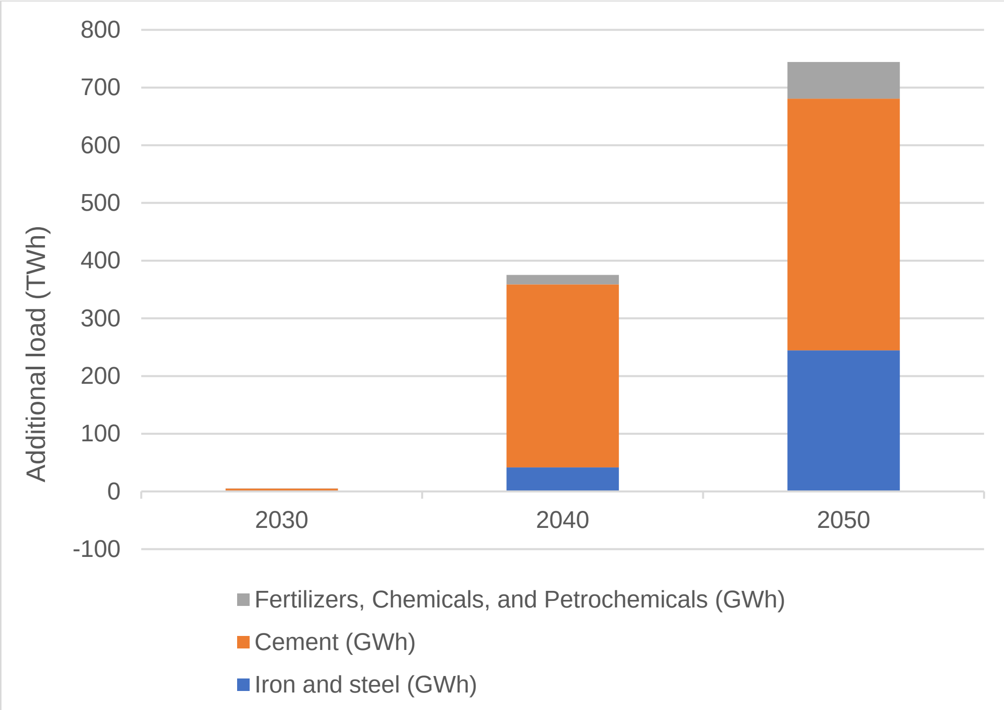

Figure 12. Additional load from heavy industries between 2030 and 2050 in India under a near zero emissions scenario

Source: LBNL's study on deep decarbonization of the Indian economy (forthcoming publication)

Agricultural load:

Energy demand for accessing irrigation water has increased in recent years due to higher temperatures, prolonged droughts, depleting water tables, and provision of heavily subsidized power to South Asian farmers. In 2019, the agriculture sector had about 18% (~214 TWh) of India's electricity consumption. Agriculture in India is significantly dependent on irrigation, and with only ~30% of the agricultural land irrigated, the agricultural energy use (mainly groundwater pumping) is expected to increase significantly in the future (IEA, 2021). India has undertaken an aggressive program to deploy almost 2 million solar pumps by 2022.[8] Up to 2018, roughly 180 000 had been deployed. In addition to pumping, cold chain storage to keep products fresh and high quality in high temperatures can also increase electricity demand.

Other loads:

There are other technologies that are likely to contribute in small amounts to sectoral electrification. For example, electric resistance space and water heaters might increase a small amount as electricity becomes more available, affordable, and environmentally attractive compared to fossil fuels (Karali et al., 2020; IEA, 2021). Electric cooking equipment, as a clean cooking alternative, is also likely to contribute to electrification (World Bank, 2020).

[8] See https://www.pv-magazine.com/2021/06/14/upscaling-pv-powered-irrigation-in-india/ for more details.

4. Need for new load/demand forecasting and stakeholder inputs

Considerable uncertainty exists about the penetration of technologies, temperature profiles, seasonal variations of demand, consumer responses to demand response strategies, and incentives to adopt low-carbon technologies. Future demand and load forecasting would need to adjust and incorporate the changing consumption profiles of electrification. With these considerations in mind, we discussed the following electricity demand and load questions with the key stakeholder profile from South Asia.

- What will be the most important load growth drivers in the future?

While stakeholders mention many factors, particular importance has been given to space cooling demand and air conditioner usage, electric vehicle ownership and charging, and growing agricultural energy demand. The region's vulnerability to extreme temperatures, heat waves, and drought and the expected impact on space cooling and agriculture’s irrigation demand has been emphasized. Decarbonization targets and links to future penetration of electric vehicle ownership and charging infrastructure have been clearly defined. Stakeholders also reported an expected growth of industrial load, particularly in heavy industries such as iron and steel and fertilizer sectors.

- What are the factors that are incorporated into load forecasting processes?

Figure 13 summarizes the factors ranked by the stakeholders based on importance in current load forecasting. These factors cover a wider range, but they are indicative. Stakeholders identified economic growth and coincidence factors as the main drivers of current load forecasting methods (over 75% of respondents) while there are efforts to incorporate new electrical connections such as transport electrification and electric vehicle charging (about 60% of the respondents). However, there is not much effort to include drivers of end-use level demand and temporal (seasonal/hourly) variation of load. Individual factors that can significantly shape the future load curve such as the impact of climate change on cooling load, appliance ownership and energy efficiency standards, sectoral demand response strategies, and penetration of DERs has not been identified as the key factors of current forecasting methods.

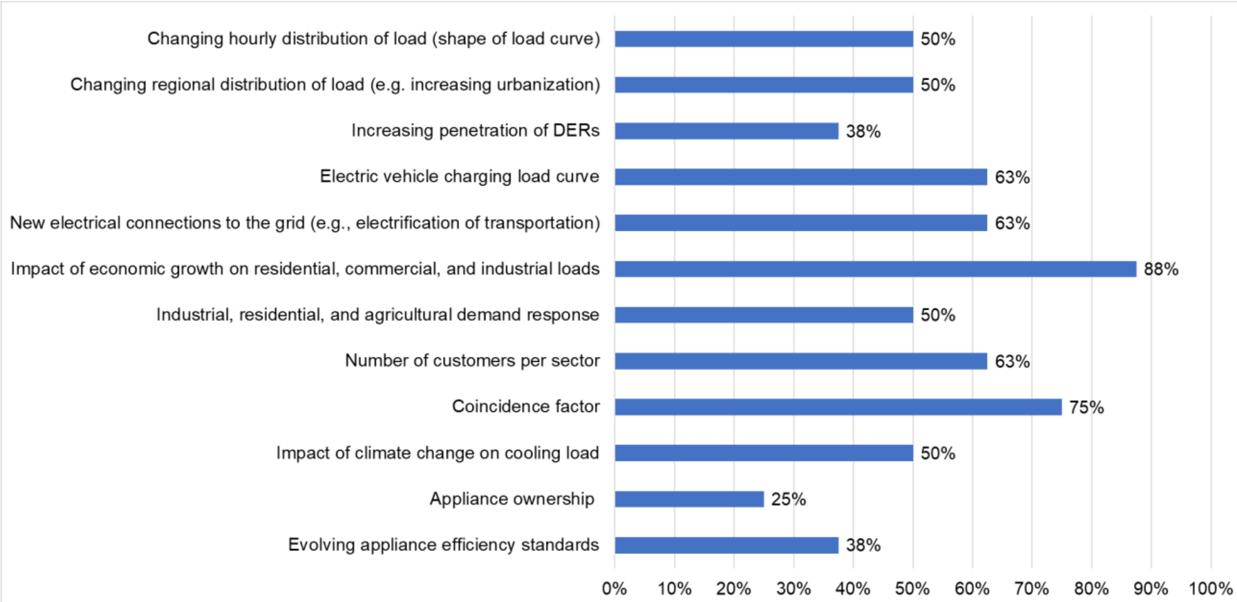

Figure 13. Percentages of stakeholders who considered the listed factors as important in load and demand forecasting

Current energy demand and load forecasting methods used by utilities are not able to incorporate all the factors discussed in this report and emphasized by the stakeholders.

In what ways, the existing load forecasts could be improved to integrate potential climate change impacts, renewable energy transition, and electrification and decarbonization goals; and how they be redesigned to better account for uncertainties in load are key questions to answer. The most effective strategy is to perform detailed end-use analysis to understand the potential load impact of each factor presented in Figure 13 and any relations and synergies among them. Here, we highlight five critical areas that we believe could have a meaningful impact on more accurate demand and load forecasting.

<u>New electrical loads on the grid:</u>

- Electrification of transportation - There is an expected huge role of electrification in the transport sector for decarbonization across the world, including South Asia. Any load forecasting needs to include a detailed modeling that can capture increasing electric vehicle ownership and charging load profiles. This modeling should also be capable of accounting for potential heterogeneity and uncertainty across different consumers and transport segments, e.g., charging patterns that can vary by driver type, day type, and charging location.

- Decarbonization of industry sector - industrial load shape information in the literature to date is limited, and there is likely considerable variation across different processes. However, decarbonization of industry sectors has been identified as a key area to stay under 2 Celsius degree by midcentury and there are increasing efforts to electrify low-temperature heat requirements and use green hydrogen for high-temperature heat requirements. It is critical to have capabilities and detailed understanding of new trends and technologies to account for the changing structure of industry sector load in demand forecasting.

- Agriculture sector energy demand - Agricultural load has already been increased as a result of climate change related events (e.g., rising average temperature, heat waves, and drought). Many climate models estimate the increasing frequency of these events in South Asia in the following decades. These events have the ability to drive sudden peaks of demand and also stress the system infrastructure. Any load forecasting model needs to link the agriculture demand with climate model weather forecasts. The newest technological advancements in climate change modeling and long-term weather forecasting include high-resolution spatial projections based on downscaling techniques. These downscaling techniques aim to improve the geographic and temporal resolution of specific weather projections, including air temperature, wind speed, solar radiation, precipitation, snowpack, and hydrology for specific geographic regions (Abatzoglou et al., 2018).

Impact of climate change on cooling load:

- Deploying higher efficiency end-use equipment to lower electricity consumption is an effective way of lowering demand at peak hours. Continuous updating of energy efficiency programs such as MEPS (Minimum Energy Performance Standards) have proven to be effective to increase the adoption of higher efficiency air conditioning systems (Abhyankar et al., 2017a; Karali et al., 2020b). In addition, designing demand response strategies that could effectively lower the AC use coincidence factor at peak demand could also be helpful (Karali et al., 2020a). Similar to electric vehicles, detailed end-use stock turnover models can show the potential impact of updated MEPS and demand response strategies on electricity demand and load curve. These models can also be informed by climate models and residential appliance use surveys to capture the link between increasing temperature and AC ownership and usage. AC equipment load shapes are generally based on hourly temperature profiles as in renewable resource profiles. These profiles should be synchronized to ensure the same weather-related variables are used.

Geographical clustered adoption:

Based on geographical conditions, regional and hourly distribution of load can be different. Load curve profiles and drivers of the peak would be different in urban and rural areas. That could require upgrades in infrastructure and result in demand projections with local peaks at different times than the full system peak.

Demand response:

Demand response can be used as one of the strategies to improve the balance between demand and supply of electricity, especially in systems that rely heavily on intermittent energy renewable resources (Karali et al. 2020a; Shah et al., 2015; Anjo et al., 2018). A significant proportion of electrical loads are flexible that can be shifted or shed based on energy balancing requirements. Demand flexibility can be sourced from the existing residential, commercial and industrial sectors or from the future electrified transport, where electric car batteries may contribute significant storage capacity. EV charging—in particular, residential EV charging—can be considered a flexible load, meaning that the timing and rate of charging can be changed without a significant cost to the customer (i.e., load shifting) (Daina et al., 2017).

South Asia countries, particularly India use TOU retail rates as the key industrial DR strategy. However, Industrial load shifting may be limited by technical constraints, process requirements and availability of unutilized plant or machine capacity in some heavy industries while for others (e.g., fertilizer and paper production) it can be a suitable demand response strategy. For processes with very high utilization rates – as they are found in energy-intensive industries (e.g., iron and steel and cement sectors) – load shedding can be implemented. Similarly, Anjo et al. (2018) argues that industrial processes such as cement production and air separation allow for flexibility of demand for processes other than cooling because of the number of daily time-slices and the daily load profiles. Gils (2014) discusses that steel, pulp and paper, and cement industries have the largest shares in the overall load reduction potential from demand responses (9%, 7%, and 6% of total load reduction, respectively).

Agricultural pumping cannot offer shimmy service but they can offer shift service, as already practiced by several utilities in India. In their analysis, Karali et al. (2020a) found that agricultural load shifting could offer ~1,000 MW of demand response potential in Karnataka state of India.

5. Conclusion

Questions about the evolution of electricity and peak demand and load profiles become increasingly important as power systems start to decarbonize across the South Asia economies. Changes in seasonal and hourly electricity demand patterns from electrification of end uses such as transportation and industry will profoundly shape electric sector planning decisions going forward. In addition to new electrical loads, demand uncertainties due to increased use of space cooling, increased appliance ownership, increased per capita consumption with GDP growth, increasing penetration of distributed resources, demand response, etc., need to be incorporated into demand forecasting practices to ensure the grid can meet the load reliably. We consult several key stakeholders in the sector across the region to seek their perspectives on these drivers.

This analysis is only a first step towards systematically exploring electricity demand and load growth for future electrified and decarbonized systems, and the discussion highlights opportunities for future research, modeling and analysis. It is worth mentioning that much of this report is based on work carried in the Indian context due to data availability, and therefore cannot simply be extrapolated to other South Asian countries. There is a clear need for greater data, research, and analysis to better understand sector specific electricity demand growth and potential load shape impacts that are specific to the environmental, economic, political and social context of each country in the south Asian region.

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